CCME

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GUIDANCE DOCUMENT FOR THE BENEFICIAL USE OF MUNICIPAL BIOSOLIDS, MUNICIPAL SLUDGE AND TREATED SEPTAGE

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OVERVIEW

This 'Guidance Document for the Beneficial Use of Municipal Biosolids, Municipal Sludge and Treated Septage' was developed by the Canadian Council of Ministers of the Environment (CCME) Biosolids Task Group (BTG) in support of the Canada-wide Approach for the Management of Wastewater Biosolids (the Approach). This guidance document outlines the *beneficial use* and sound management of *municipal biosolids, municipal sludge* and *treated septage* and contains information to assist Canadian regulators and generators to manage these three categories of *wastewater residuals* in an environmentally beneficial and sustainable manner.

The framework for managing *wastewater residuals* varies among federal, provincial, territorial and municipal jurisdictions in Canada. This guidance document outlines best management practices and guidelines for *beneficial use* of *wastewater residuals* regardless of the jurisdiction under which they are regulated.

Beneficial use options include combustion to capture energy contained in *municipal biosolids, municipal sludge* and *treated septage* (generating heat and power) and land application to utilize the nutrients and *organic matter* contained in *municipal biosolids* and *treated septage*. *Beneficial use* options must adhere to jurisdictional standards, requirements or guidelines.

Combustion and its derivative processes present opportunities for the *beneficial use* of *wastewater residuals*. Combustion capitalizes on the heat and energetic value of the *wastewater residuals* and provides a *beneficial use* opportunity, provided that it is accomplished in a manner that results in a positive energy balance, incorporates ash recovery and minimizes greenhouse gas emissions. When combusted, *wastewater residuals* can offset the use of fossil fuels for heating or electrical power generation.

Some municipal wastewater treatment facilities use *municipal sludge* as a feedstock for the microbial and extracellular enzymatic production of methane (notably anaerobic digestion), which can then be used to produce energy. The process stabilizes the resultant *municipal biosolids*, which are usually of high quality and may be land applied.

Opportunities for land application of *municipal biosolids* and *treated septage* include forestry, land reclamation and agriculture. Another opportunity includes incorporating *municipal biosolids* and *treated septage* as a feedstock in the production of compost or top-soil. When land applied, *municipal biosolids* and *treated septage* can serve as a source of non-fossil fuel derived *organic matter* and nutrients to promote plant establishment and growth, enhance soil fertility and structure and provide opportunities for carbon sequestration.

Regardless of the utilization opportunity chosen, there are potential benefits and adverse impacts. The level of treatment and the quality of the *wastewater residuals* directly impacts the number of management considerations associated with their use, particularly in land application. The design and operation of a wastewater treatment facility will affect whether the final material is *municipal biosolids* or *municipal sludge*. Unless specifically designed and operated to produce material that meets jurisdictional standards, requirements or guidelines for *municipal biosolids*, material from wastewater treatment facilities is considered *municipal sludge*. This guidance document includes specific management considerations to minimize the potential for adverse impacts associated with land application of *municipal biosolids* and *treated septage*.

The challenges of *beneficial use* become less complex when utilizing *municipal biosolids* or *treated septage* originating from an effective and properly managed treatment process. Implementation of source control programs protects the quality of the *wastewater residuals*. Some wastewater treatment processes may further improve the quality of the *wastewater residuals* and broaden the options available for *beneficial use*.

Jurisdictions should consider adopting a continuous improvement philosophy and remain up-to-date with respect to *wastewater residuals* research. The consideration of new information, emerging technologies and greenhouse gas implications in the decision-making process should ensure a robust selection of appropriate technology and opportunities for *beneficial use*. Ongoing research and technology development lead to changes in management practices, and can result in changes to the *beneficial use* options available.

Beneficial use programs should minimize risks to the environment and human health through the use of regulatory standards, requirements or guidelines and the implementation of best management practices pertaining to *wastewater residuals* quality, environmental factors, operational logistics, social responsibilities and economic considerations. *Beneficial use* programs capitalize on the inherent value of nutrients, *organic matter* and energy contained in *wastewater residuals*.

This guidance document was written at a level which assumes a degree of professional understanding of *wastewater residuals*, soils, nutrient and trace element management, and nutrient/carbon cycling in general. Background reading and references are provided throughout the document to assist the reader in locating the additional information they need to prepare for the beneficial management of *wastewater residuals*. It is strongly recommended that those responsible for preparing and implementing a plan for *beneficial use* of a residual be familiar with current and emerging research, scientific literature, and technology. Ongoing education and research allows for the implementation of *beneficial use* options that suit individual environments, governance structures, and situations.

PREFACE

The Canadian Council of Ministers of the Environment (CCME) is the primary minister-led intergovernmental forum for collective action on environmental issues of national and international concern. The 14 member governments work as partners in developing nationally consistent environmental standards and practices.

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ABBREVIATIONS

General Abbreviations

As – arsenic
BEAM – Biosolids Emissions Assessment Model
BNQ – Bureau de normalisation du Québec
BTG – Biosolids Task Group
Ca – calcium
CCME – Canadian Council of Ministers of the Environment
Cd – cadmium
CEC – cation exchange capacity
CEPA – Canadian Environmental Protection Act
CFIA – Canadian Food Inspection Agency
Co – cobalt
CO_2 – carbon dioxide
Cr – chromium
Cu – copper
CRD – Capital Regional District
DNA – deoxyribonucleic acid
EDC – endocrine disrupting chemical
Fe – iron
Hg – mercury
IPCC – Intergovernmental Panel on Climate Change
K - potassium
Mo – molybdenum
N – nitrogen
N_2O – nitrous oxide
NBP – National Biosolids Partnership
NH_3 – ammonia
Ni – nickel
NIST – National Institute of Standards and Technology
P – phosphorus
PAH– polycyclic aromatic hydrocarbons
Pb – lead
PCB – polychlorinated biphenyls
PPCP – pharmaceutical and personal care products
S – sulphur

Se – selenium
TKN – Total Kjeldahl Nitrogen
USEPA – United States Environmental Protection Agency
VAR – vector attraction reduction
WEF – Water Environment Federation
Zn – zinc

Unit Abbreviations

% – percent
°C – degrees Celsius
dt – dry tonnes
kJ/kg – kilojoules per kilogram
µg/Rm^3 – micrograms per reference cubic metre
mg/kg – milligrams per kilogram
MLD – megalitres per day
Pg I-TEQ/m^3 – picogram International Toxicity Equivalent per cubic metre
ppm – parts per million
wt – wet tonnes

DOCUMENT ORGANISATION

To facilitate its use, this guidance document has been divided into five parts as follows:

Part 1: Introduction

Part 1 introduces the intent and purpose of this guidance document and the work that has been completed in developing a *Canada-wide Approach for the Management of Wastewater Biosolids*. Part 1 also provides an overview of the current production and management of *municipal biosolids*, *municipal sludge* and *treated septage* in Canada.

Part 2: Land Application

Part 2 provides guidance on the beneficial management of *municipal biosolids* and *treated septage* through land application. Information provided includes the properties of *municipal biosolids* and *treated septage* that allow for *beneficial use*, mechanisms of controlling quality through source control and treatment, and management considerations.

Part 3: Combustion

Part 3 presents information on the beneficial management of *wastewater residuals* through combustion including the minimum achievement criteria in order for combustion to be considered a *beneficial use*. Management considerations relating to logistics and handling, site suitability, atmospheric emissions, heat value and ash management are provided.

Part 4: Regulatory Frameworks, Best Management Practices, Research and Technology Development

Part 4 includes information on the development of legislative frameworks, best management practices for identifying and evaluating management options and ongoing research and technology development for both the land application and combustion of *wastewater residuls.*

Part 5: References and Further Reading

References, literature cited in the document and recommendations for further reading are presented in Part 5.

PART 1: INTRODUCTION

1.1 Guidance Document Intent and Purpose

The *Canadian Council of Ministers of the Environment* (*CCME*) promotes *beneficial use* and sound management of *municipal biosolids, municipal sludge* and *treated septage* managed in accordance with the Canada-wide Approach for the Management of Wastewater Biosolids (the Approach).

The best management practices and guidelines contained herein will assist regulators and generators in beneficially managing *wastewater residuals* according to the *beneficial use* policy statement and supporting principles developed by *CCME*; which can be found in the Approach and in Appendix 1.

This guidance document identifies and provides rationale for various factors that jurisdictions can consider when designing a *beneficial use* management program. It is not intended as a technical reference manual. *Wastewater residual* generators must comply with the standards, requirements or guidelines of their own jurisdictions and any applicable federal requirements.

Terminology, numerical quality criteria and mechanisms of implementing a *wastewater residuals* management program differ across Canada. The Glossary lists the terminology used in this guidance document which is also discussed in Section 1.1.1. Numerical quality criteria and certain mechanisms of implementation are not provided in the guidance document relative to land application while some key baseline numerical criteria are provided for combustion.

Information Highlight
Best management practices for land application

This Guidance Document contains best management practices for land application of *municipal biosolids* and *treated septage* and numerical criteria for combustion of *wastewater residuals.* Numerical criteria were omitted for land application due to site specific environmental and soil conditions.

1.1.1 Terminology

The definitions of *municipal biosolids, municipal sludge* and *treated septage* vary across Canada. Some jurisdictions use the term *municipal biosolids* while other jurisdictions use *municipal biosolids* to refer to *municipal sludge* which has been treated to meet specific provincially legislated criteria. Differing terminology provides challenges when discussing *wastewater residuals* management in a Canada-wide context.

For the purpose of this guidance document, the terms *municipal biosolids, municipal sludge* and *treated septage* are used as defined by *CCME,* these definitions are provided in the Glossary.

Glossary terms which have specific meaning in the context of the guidance document are italicized within the text of the document, except where self-evident, to remind readers that they are defined within the document.

For ease of readability the term '*wastewater residuals*' is used throughout the document to refer to *municipal biosolids, municipal sludge* and *treated septage* collectively.

1.1.2 Scope of the Document

The guidance document applies to the *beneficial use* of:

- *municipal biosolids*
- *municipal sludge* and
- *treated septage* produced in Canada from municipal/domestic wastewater treatment.

This guidance document does not apply to:

- solids resulting from industrial wastewater treatment processes or
- compost - compost production, quality and sampling criteria are detailed in *CCME's* Guidelines for Compost Quality, 2005.

This guidance document does not apply to the management of *wastewater residuals* in a manner not considered beneficial as defined in the Approach. For example disposal of *wastewater residuals* in landfills is not considered a *beneficial use*.

The document does not cover methanization in detail, though it may be part of a *beneficial use* program. Literature about methanization/anaerobic digestion of *wastewater residuals* in general is accessible from other sources.

With intention, this guidance document pertains only to technologies and management methods that are well defined and practiced in Canada. There are many innovative technologies being introduced throughout the world that may have some future application in *wastewater residuals* management, particularly in the arena of combustion. This document acknowledges these innovative technologies (see Section 4.4) however the purpose of this document is to provide guidance with respect to those technologies which are currently in full scale operation in Canada for management of *wastewater residuals***.** As a result guidance for technologies such as *gasification* and pyrolysis for *municipal biosolids* are not included here, as these are captured in section 4.4.2 that addresses innovation.

1.1.3 Background

In 2009 the Canadian Council of Ministers of the Environment endorsed The *Canada-wide Strategy for the Management of Municipal Wastewater Effluent* (the Strategy). The Strategy sets out a harmonized framework to manage discharges from more than 3,500 wastewater facilities in Canada. The Strategy provides an agreed-upon path forward for achieving regulatory clarity in managing municipal wastewater effluent across the country. Performance standards contained in the Strategy are intended to increase protection for human health and the environment across Canada.

The quantity of municipal biosolids produced is expected to increase as new and upgraded wastewater facilities are constructed as a result of implementation of the Strategy. Anticipating this, CCME, in consultation with interested and affected parties, developed the Approach to allow municipalities and biosolids generators to manage *municipal biosolids* under a framework which instils public confidence and protects the environment and human health.

In Canada, production, transport, use (including *beneficial use*) and disposal of *wastewater residuals* are regulated on a provincial/territorial basis. Although there are federal pieces of legislation (*Fertilizers Act*, the *Canadian Environmental Protection Act*) that apply to aspects of the *wastewater residuals* life cycle, there is no comprehensive legislation for *wastewater residuals* management. As a result the opportunities, conditions, and considerations for the use of *wastewater residuals*, and the terminology used, vary across the country.

1.1.3.1 Initiatives on Wastewater and *Municipal Biosolids*

The following initiatives were undertaken by *BTG* to support the development and jurisdictional use of the Approach and guidance document.

- The Biosolids Emissions Assessment Model (*BEAM*) and supporting User Guide (CCME, 2010). The *BEAM* is an open-source Microsoft Excel-based tool designed to calculate the greenhouse gas emissions associated with various common *municipal biosolids* treatment and management processes currently in use in Canada. The *BEAM* can be used to: estimate the greenhouse gas emissions from a *municipal biosolids* management program; compare emissions from different *municipal biosolids* management options; estimate the impacts on greenhouse gas emissions resulting from changes in a *municipal biosolids* management program; and, highlight the factors that have the greatest impact on increasing or reducing greenhouse gas emissions associated with *municipal biosolids* management.

- A Review of the Current Canadian Legislative Framework for Wastewater Biosolids which applies to aspects of *wastewater residuals* management (CCME, 2010).

- A literature review and field survey of *emerging substances of concern* (ESOCs) in Canadian *municipal biosolids* including their concentration and the effects of treatment processes (CCME, 2010). This project was designed to: review the state of the knowledge with respect to *municipal biosolids* science and research; identify, inventory and quantify ESOCs that may be present in Canadian *municipal biosolids* through collection of *municipal biosolids* samples across Canada; determine the effects of *wastewater residuals* treatment on reducing ESOCs; identify those ESOCs that that may pose a risk to the environment if land applied; and, recommend best management practices and future research for ESOCs.

Information Highlight

There is no beneficial use hierarchy in this document

CCME notes within the Approach and guidance document that there is no intention to rank beneficial uses. This may differ from jurisdictional policy, which may identify a preference or hierarchy with respect to beneficial options. However, more information is devoted to land application than to combustion in this document. This is indicative of the vast body of knowledge which has been developed to accurately reflect the diversity of land application uses that are available, and the diversity of challenges inherent in each beneficial use land application option.

While there are diverse combustion methods, there is some degree of unification of challenges and requirements within combustion, as the environmental consequences and required outcomes of any combustion system are unified: Emissions, Heat, Power and Ash.

1.2 Production

Natural human metabolic processes result in the production and excretion of wastes. Septic systems and sewage systems capture wastewater from households and protect public health by ensuring that it does not negatively impact the environment. Septic systems serve approximately 25% of the population in Canada (Environment Canada, 2010). Septic systems separate the solid and liquid fraction of wastewater. The solids settle in the septic tank and the liquid is typically distributed into the ground. When the *septage* is removed from the tank it may be transported to storage and/or treatment facilities. Typically in smaller, rural communities the *septage* is placed in a lagoon and may be treated to reduce *pathogens* and *vector* attraction. As discussed in Section 1.1.2, this document applies to *treated septage*. *Septage* may be treated independently or transported to a wastewater treatment facility. In some cases, *septage* is received and treated with the influent from the municipal sewage system and in others the facility has a separate *septage* receiving facility.

Municipal sewage collection and wastewater treatment facilities serve the remaining 75% of the Canadian population (Environment Canada, 2010). In the 3,000 municipalities across Canada there are approximately 4,000 wastewater treatment facilities (UN-HABITAT, 2008). The level of wastewater treatment at these facilities varies from simple processes such as screening and discharge of effluents to advanced (tertiary) treatment.

The extent of wastewater treatment is determined by a range of factors including:

- population density and economics
- environmental sensitivities
- variety of influent inputs (i.e. domestic, industrial, institutional, commercial)
- regulatory requirements, and
- the fate of the effluent and *municipal biosolids* or *sludge* (*beneficial use* or disposal).

The level of wastewater treatment implemented by municipalities varies between Canadian jurisdictions. The products of centralised wastewater treatment are treated liquid effluent as well as *municipal biosolids* or *municipal sludge*. The extent of wastewater treatment influences the quantity and quality of the *wastewater residuals* produced and the resulting management options that may be considered. The relationship between *wastewater residuals* quality and use is discussed in Section 2.3.2.

Table 1: Summary of currently used solids stream unit processes.

Solids Management Step	Unit Processes	
Thickening	• gravity • dissolved air flotation • centrifuge	• gravity belt thickener • rotary drum
Biological Stabilization	• anaerobic digestion	• aerobic digestion
Dewatering	• centrifuge • screw press • rotary press • belt filter press	• solar drying • lagoon/reed bed • geotextile/bags • vacuum assisted drying beds
Drying/Additional Treatment	• high temperature drying • alkaline *stabilization*	• composting
Utilization and Disposal	• land application • combustion	• landfill disposal
Energy/Resource Recovery	• landfill gas utilization • incinerator heat recovery • ash recovery/utilization	• heat and power • biogas • struvite phosphorus recovery

1.3 Treatment Options to Facilitate Beneficial Use

The quantity and quality of *wastewater residuals* intended for *beneficial use* is predicated on influent quality, which can be managed by source control programs, and the extent and type of wastewater treatment. Improving the quality of *wastewater residuals* offers flexibility in end use options. In land application programs, improved quality may enable increased application rates or extend the lifetime of an application site. For combustion programs, which concentrate many constituents in ash, lower influent concentrations may result in greater opportunities to utilize ash as a product or soil amendment.

A number of parameters charaterize the quality of *wastewater residuals*, including trace elements/heavy metals, trace *organics*, *pathogens*, and odour, Some of these parameters come from anthropogenic sources and are managed through wastewater treatment, while source control initiatives may aid in reducing other parameters. Reduction or the potential elimination of the input of trace elements/heavy metals, *organic* pollutants, and *ESOCs* into the wastewater stream may reduce or eliminate their presence in *wastewater residuals*.

Wastewater source control and treatment processes, and their impacts on the quality of *municipal biosolids* and *treated septage* are discussed in Sections 1.3.1 and 1.3.2. Sewer use bylaws are discussed in Section 4.1.1 as a component of regulatory frameworks.

Information Highlight

Higher quality wastewater residuals = more management options

Source control initiatives and wastewater treatment influence *wastewater residuals* quality. Source control initiatives can reduce the concentration of trace elements and other contaminants entering the wastewater treatment plant; wastewater treatment reduces *pathogen* concentrations. The lower the concentration of trace elements, contaminants and *pathogens* the greater are the number of beneficial management options for the *wastewater residuals* and, as there is less risk associated with their use, fewer management considerations are required to ensure health and environmental protection.

Non beneficial use (i.e. disposal) of *wastewater residuals* may reduce the incentive to decrease the concentration of trace elements, contaminants and *pathogens* through the use of source control initiatives and effective treatment. Beneficial use supports the incentive to produce high-quality *wastewater residuals* with negligible trace element, contaminant and *pathogen* concentrations, which minimizes the risks to the environment.

1.3.1 Source Control Initiatives

Source control programs restrict the materials/substances that can be discharged to the sewer system. Municipalities implement source control programs to:

- ensure wastewater treatment facilities function properly
- protect the health and safety of wastewater treatment facility operators and
- improve the quality of effluent discharged and *municipal biosolids* and *treated septage* produced.

A source control program may include several mechanisms to prevent or restrict materials/substances from entering the treatment plant:

- sewer use bylaws
- provincial/territorial regulation
- waste discharge permits
- industry-specific codes of practice
- bans on substances determined to be toxic under the *Canadian Environmental Protection Act 1999* (CEPA, 1999)
- public education/outreach initiatives
- self-monitoring, audit sampling and site inspections
- enforcement and penalties
- mail-outs and newspaper advertisements
- industry workshops and
- user fees.

Typically, jurisdictions implement source control initiatives to reduce regulated constituents. In *municipal biosolids* and *treated septage*, these constituents are primarily trace elements regulated by federal, provincial or territorial standards, regulations or guidelines. *CCME* developed a model sewer use bylaw (CCME, 2009) for use by communities of all sizes and with a variety of wastewater inputs.

Jurisdictions can determine the effectiveness of source control initiatives by evaluating *municipal biosolids* and *treated septage* quality data and drawing linkages between changes in *municipal biosolids* and *treated septage* quality and the implementation of specific source control initiatives. An example of an effective source control initiative is the implementation of the Canada-wide Standard on Mercury for Dental Amalgam Waste (CCME, 2001). Dental amalgams contain mercury and can contribute to up to 90% of the mercury loading in municipal wastewater.

Some jurisdictions have observed greater than 50% decreases in mercury concentration in *municipal biosolids* and *treated septage* within 1 to 2 years of implementing mandatory dental amalgam separation. This trend is typical of jurisdictions implementing dental amalgam separation source control initiatives (SYLVIS, 2007).

Effectiveness of source control initiatives varies between jurisdictions. A survey of jurisdictions was conducted, requesting information on the relative effectiveness of various source control initiatives (SYLVIS, 2007). In general, the jurisdictions rated the implementation and enforcement of sewer use bylaws to be the most effective mechanism for source control. Jurisdictions also rated face-to-face meetings with industrial partners as a highly effective source control tool; explaining the downstream consequences of unacceptable or clandestine industrial discharges was effective in improving compliance with bylaws, permits and other source control mechanisms.

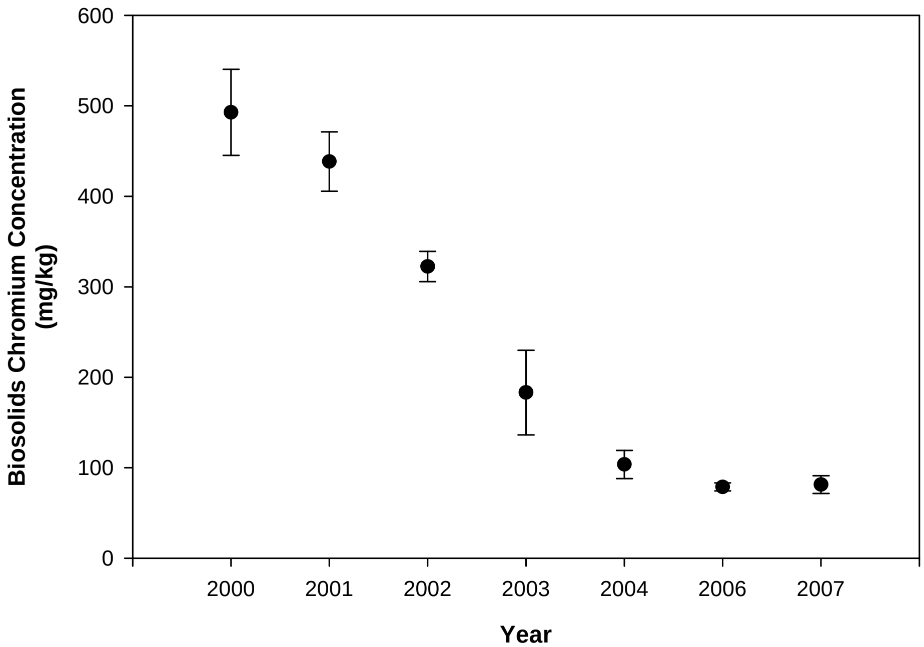
Recent field sampling undertaken in Canada has identified that the quantities of metals in biosolids and septage are no longer significantly different, indicating that most metal in biosolids likely originates from domestic wastewater (CCME, 2010).

Case Study: Capital Regional District, British Columbia

The Capital Regional District (CRD) established a Regional Source Control Program to augment their sewer use bylaw. Several industry-specific Codes of Practice have been developed by the CRD, with the objective of improving the quality of industrial wastewater discharges into the municipal wastewater collection system. One Code of Practice targets the dental industry and requires the installation of dental amalgam separators in dental offices. Dental amalgam is a major source of mercury in wastewater and can account for up to 90% of mercury loading to wastewater. Since implementation of the Dental Amalgam Separation Code of Practice in 2001, the CRD has observed a continual decline in *municipal biosolids* mercury concentrations from their Saanich Peninsula Wastewater Treatment Plant (Morrison Hershfield, 2010).

Other industry-specific source control initiatives have proven to be effective. The implementation of best management practices for the management of wastes generated by the automotive repair industry contributed to the reduction of chromium concentrations as demonstrated in Figure 1. Substantial reductions in regulated trace element concentrations improve *municipal biosolids* quality which can enable land application or even increase application rates and extend the lifetime of the site due to reduced trace element loading rates. The quality of ash from the combustion of residuals may be improved with a higher likelihood of beneficial ash utilization. The data presented in Figure 1 are from *municipal biosolids* from the Gold Bar Wastewater Treatment Plant in Edmonton, Alberta (SYLVIS, 2007).

Figure 1: Decreasing chromium concentrations (dry weight basis) in *municipal biosolids* generated by the City of Edmonton following implementation of best management guidelines for the management of wastes in the automotive repair industry (SYLVIS, 2007).



Along with inorganic trace elements/heavy metals, several other groups of compounds may be present in *wastewater residuals* in trace amounts. These compounds include legacy *organic* contaminants and *ESOCs*. These constituents usually originate from waste released from homes and businesses into the sewer system. Items that we produce, use and consume enter the wastewater treatment system directly through human waste products or indirectly through cleaning and washing activities. Legacy *organic* contaminants refers to substances whose use has been banned or severely restricted by government agencies for many years and due to chemical stability and slow rate of decomposition, they persist in the environment for a long period of time after restrictions are put in place and their decrease is gradual (Axys Analytical Services, 2011). Legacy *organic* contaminants are compounds such as dioxins and furans, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs). *ESOCs* include:

- pharmaceuticals and personal care products
- flame retardants including polybrominated diphenyl ethers and hexabromocyclododecane and
- endocrine disrupting compounds including nonylphenol and linear alkylbenzene sulfonate.

The concentrations of *ESOCs* and legacy *organic* contaminants are usually very low in wastewater influent (CCME, 2010). As a result, treatment facilities do not regularly test for either legacy contaminants or *ESOCs*.

As *ESOCs* are identified and risks evaluated, regulations and policies are amended accordingly. At present, source control and treatment initiatives are not generally in place for these groups of compounds, with the exception of pharmaceuticals, where some jurisdictions have developed pharmaceutical take-back programs. Take-back programs allow (unused and expired) pharmaceuticals to be returned to the location of purchase for proper disposal thus reducing the disposal of products containing these constituents to the wastewater collection system.

Some forms of wastewater treatment and *wastewater residuals* may reduce *ESOCs* while other forms of wastewater treatement may not impact *ESOCs* or result in an increase in concentration. A 2010 study of Canadian biosolids treatment processes concluded that biological treatment processes are more efficient in reducing the concentration of *ESOCs* than non-biological processes. Of the biological treatment processes, treatment through aerobic composting was more effective in reducing the concentration of *ESOCs* than mesophilic anaerobic digestion; autothermal aerobic digestion was less effective than mesophilic anaerobic digestion (Hydromantis et al., 2010).

Societal practices impact the quality of the *wastewater residuals* and in turn the options that are available for *beneficial use*. Source control initiatives aid in promoting producer/consumer responsibility to protect the quality of *wastewater residuals*.

1.3.2 Stabilization Processes

The main products of wastewater treatment processes are treated wastewater effluent (liquid) and *municipal sludge* (solids). *Municipal sludge* consists of settled primary wastewater solids and natural occurring microorganisms that assist the treatment of wastewater. Some wastewater treatment processes further treat the *municipal sludge* to meet *municipal biosolids* criteria. Processes such as liming or composting can also treat *municipal sludge* to meet *municipal biosolids* criteria. Treated sludge which meets the *municipal biosolids* criteria is of sufficient quality to minimize potential adverse impacts to the environment, and with specific considerations, enable *beneficial use*. *Septage* removed from septic tanks can also be treated to meet *municipal biosolids* quality. *Stabilization* may also improve handling and odour characteristics which may benefit combustion systems.

In producing *municipal biosolids* and *treated septage* for *beneficial use*, treatment processes relate to *stabilization* of the *organic matter* resulting in:

- reduced volatile *organic* compounds and therefore a reduction in the associated odour potential
- decreased or eliminated pathogen concentration and

- reduced attraction of potential *vectors* to the *municipal biosolids* and *treated septage* (*vector* attraction reduction).

The United States National Biosolids Partnership's (NBP) National Manual of Good Practice for Biosolids provides the following five considerations in evaluating *stabilization* processes (NBP, 2006):

- **sizing of the process system**

  Stabilization processes must achieve the required *wastewater residuals* quality under all likely operational conditions. For example, a digester must be capable of maintaining its prescribed mean residence time through prolonged periods of peak flow, in order to ensure *stabilization* through the digestion process. This may require design accommodations for future consideration of co-digestion with other *organic* materials.

- **downstream Goals**

  A successful *stabilization* system should achieve a specific design outcome, and does not necessarily aim to optimize the *stabilization* system itself. For example, optimizing a digester beyond the required parameters may instigate challenges downstream in dewatering. It is the process outcome which is key, rather than optimization of any single component of the treatment process.

- **combining *Stabilization* Processes**

  The combination of processes can result in a better product. For example, while drying can meet specific *pathogen* reduction goals the addition of digestion prior to drying may reduce odour and volatile *organic* content, an outcome which drying alone cannot achieve. Adding digestion or alkaline *stabilization* prior to composting may reduce odour during the composting process.

- **end use**

  Knowledge of end use opportunities for *municipal biosolids* and *treated septage* is beneficial when selecting a *stabilization* process. Certain processes, such as digestion and thermal drying, generate products that are stable for longer periods of time than products generated by alkaline *stabilization*. Increased stability may be desired for the specific use option and should be considered with respect to the associated cost increase and requirement for large process volumes.

- **limitations**

  Each treatment process has a purpose and limitation in managing solids. The capabilities of a particular process, in the context of treatment and end use, must not be overestimated. For example, dryers may be used to stabilize *municipal sludge* (reduce *pathogen* and *vector* attraction); it rarely manages volatile *organics*, and thus does not typically manage odour.

The Sections below provide an overview of the following *stabilization* processes:

- Digestion
    - anaerobic digestion and methanization
    - aerobic
- alkaline *stabilization*
- dewatering, including air and thermal drying and
- composting.

1.3.2.1 Digestion

Digestion is a biochemical process in which rapid decomposition of wastewater solids is undertaken through uptake and modification of the solids by specific groups of bacteria, or by catalysis of extracellular enzymatic or chemical processes. The bacterial families involved are dependent upon the digestion environment provided, with particular emphasis on the presence or absence of oxygen as a determinant.

Anaerobic Digestion

Anaerobic digestion occurs in the absence of oxygen. The absence of oxygen promotes specific bacterial families and a preferential fermentation process over respiration. The basic concept of anaerobic digestion contains three key stages:

- **stage one**: conversion of *organics* including cellulose, lignin, lipids, proteins and simple sugars to carbon dioxide (CO_2), alcohol, soluble fatty acids, and ammoniacal compounds.

- **stage two**: conversion of the products of stage one to low molecular weight *organic* acids, principally acetic acid and propionic acid, as well as hydrogen and CO_2.

- **stage three**: conversion of hydrogen and CO_2 to methane by methanogenic bacteria; conversion of acetic acid to methane and bicarbonate by acetogenic bacteria. (WEF, 1987).

Typically, digesters are cylindrical tanks with sloping bottoms and domed or flat roofs that can be implemented as low-rate digesters, high-rate digesters, or two-stage digesters (in-series). There is a myriad of process control points in anaerobic digestion, which impact product quality, or degree of *stabilization*. If digestion is too complete, dewatering the remaining *organics* can be challenging. Thus there is a balance between *stabilization* and end use considerations.

An important consideration and value to anaerobic digestion is the evolution of methane as a co-product. The methane produced in stage three of digestion is collected, at which point it can be neutralized to CO_2 through flaring, or purified and used to produce energy. This energy is often used within the wastewater treatment facility or excess energy can be supplied back to the provincial or territorial power grid.

Aerobic Digestion

Aerobic digestion occurs in the presence of oxygen and is similar to suspended growth extended aeration (NBP, 2006). The digestion typically stabilizes waste-activated solids, and operates on the principle of oxidation of *organics*. Aerobic digestion also acts as a conditioning step for further *stabilization* or processing. Conditions similar to those used to maintain activated *municipal sludge* are required.

Aerobic digestion is typically considered to have high energy requirements, although improvements in technologies (fine bubble diffusion, thermophilic operation) have increased energy efficiency (NBP, 2006). Similar to anaerobic digestion, a broad spectrum of *stabilization* endpoints must be balanced with the product characteristics. A key dissimilarity is the lack of methane generation, which requires a fermentative process. Aerobic digestion is a valuable stabilization process for reduction of volatile *organic* compounds, *vector* attraction and pathogen concentrations. Typically sludge that is destined for combustion or energy recovery is not digested.

1.3.2.2 Alkaline Stabilization

The process of *stabilization* using alkaline chemicals operates on a simple principle: raising the pH of the residual to 12 or higher, with adequate mixing and an appropriate contact time to ensure that microorganisms are either inactivated or destroyed (NBP, 2006). Combining high pH with high temperature reduces production of odorous gases due to microbial activity, which will remain suppressed with a pH greater than 10. However, the same high temperature/high pH conditions produce other volatile, odorous gases (ammonia and trimethylamine among them).

Alkaline additives traditionally used include hydrated lime ($Ca(OH)_2$) and quicklime (CaO), although variations with liquid lime and alternative chemicals such as cement kiln dust, lime kiln dust, Portland cement, potassium hydroxide or fly ash are also used. All additives have unique behavioural attributes, with common outcomes of *vector* attraction reduction and *pathogen* reduction through an acknowledged time-pH process. Alkaline *stabilization* will alter nitrogen forms in the *wastewater residuals*, reducing ammonia (through volatilization). Alkaline *stabilization* will result in slightly increased volumes of *wastewater residuals* requiring management due to the addition of the alkaline chemical. With respect to *beneficial use*, the increase in pH due to the alkaline addition influences the solubility of minerals and nutrients both in the *municipal biosolids* and in the soil to which it is applied. This influence may be positive or negative on plant growth, depending on the agronomic circumstances.

1.3.2.3 Dewatering and Drying

The purpose of dewatering and drying is the mechano-physical increase in solids content, changing the form of the *wastewater residuals* from slurry to a semi-solid. Dewatering and drying results in a significantly reduced volume and the solidification changes the handling characteristics of the *wastewater residuals*, with dewatered or dried *wastewater residuals* considered to be more easily transported and managed than slurries. Dewatering can also change the nutrient availability (generally making them less available) which is a consideration in land application programs. These processes have significant impacts upon combustion systems, where solids content is a key determinant of the combustion energy balance within a *wastewater residuals* system.

Dewatering is the action of removing water through mechanical processes, generally either pressing (belt press) or spinning (centrifuge). Belt presses have a tendency to result in lower solids content than dewatering by centrifuge; however, the higher solids content obtained through centrifuges may also be accompanied by increased odour potential, as *municipal biosolids* may be sheared through the centrifugal action, releasing odour molecules from the biosolids matrix (Adams, 2004). Dewatering does not result in further *stabilization* of *wastewater residuals*.

Drying is the physical process of moisture reduction through evaporation of water. Drying can either be completed passively or actively through the use of thermal drying systems. While passive drying is capable of some additional *stabilization*, in the absence of pre-drying *stabilization* steps, it is unlikely to provide a level of *stabilization* required to satisfy regulatory authorities due to the relatively short drying (summer) season in Canada and low temperatures as compared to thermal drying systems.

Thermal drying systems operate with a myriad of configurations, including:

- rotary drum dryers
- radiant heat augmentation static pile systems
- flash dryers, and
- paddle, hollow flight, disk or other horizontal vessel dryers.

Thermal drying generally produces a granular product that is greater than 90% solids, and is likened in consistency and form to granular fertilizers (Tchobanoglous et al., 2003). Drying *wastewater residuals* further improves the transportability of the product. Depending on the quality, dried *municipal biosolids* can be used as a fertilizer or a feedstock in combustion. Several pelletized *municipal biosolids* are commercially sold as fertilizers in Canada and the United States.

Air drying of stabilized *municipal biosolids* is suitable in the semi-arid regions of Canada, or in regions with a pronounced drought period. Air drying is generally undertaken in rapid drying beds overlaying sand. Drying may be augmented with the use of a mechanical turning apparatus (auger) or installation of a greenhouse-like cover (Tchobanoglous et al., 2003).

1.3.2.4 Composting

Composting is a popular *stabilization* method that produces a *wastewater residuals*-based soil conditioner. Composting provides an environment for microbiological growth, and the controlled and managed decomposition of *organics*. Composting produces a stable product high in *organic matter* which can be used as a soil amendment. To a lesser extent, compost can provide a source of nutrients; however, nutrient concentrations in compost are generally lower due to their consumption by microbes in the composting process.

Similar to other treatment processes, composting facilities can adopt a number of configurations. Composting can be conducted in open air, in-vessel or under synthetic covers. The systems can be static, or dynamic, where the compost is turned/agitated to redistribute moisture, re-establish porosity and introduce oxygen into the system. Oxygen can also be mechanically introduced into the system using blowers to either force air into the compost (positive aeration) or draw air through the system (negative aeration). Odour can be managed by passing process air through a biofilter or using other odour management technologies (e.g. ozone oxidation/dilution).

Further information is provided in the Guidelines for Compost Quality (CCME, 2005).

1.3.2.5 Nutrient Recovery

Nutrient recovery, through precipitation or other emerging technologies is a term used to refer to the recovery of nutrients directly from the *wastewater* stream.

An example of a nutrient recovery system is one that selectively precipitates struvite (ammonium magnesium phosphate) crystals. The result is a crystalline precipitate, the most common of which contains approximately 13% phosphorus, 6% nitrogen, and 10% magnesium (Britton et al., 2005). The precipitate can be pelletized and used as fertilizer.

The selective removal of key elements through nutrient recovery will influence *municipal biosolids* quality through the shifting and possible optimization of *municipal biosolids* nutrient ratios. Carefully planned nutrient recovery will allow the *municipal biosolids* to be used in a wider array of agronomic applications where specific nutrient ratios are required, while producing a valuable third product (struvite) from the wastewater stream.

1.4 Management Practices

A variety of management options for *wastewater residuals* are in use in Canada. These management options, and the number of associated considerations, are predicated on the quality and quantity of the *wastewater residuals*. Knowledge of *wastewater residuals* production and opportunities for use aids *wastewater residuals* generators and/or regulators in selecting a *beneficial use* option.

Beneficial uses capitalize on the intrinsic value of *organic matter*, nutrients, or energy content of *wastewater residuals*. Disposal of *wastewater residuals* is becoming less accepted due to landfill tipping fees, reduced landfill availability, and the understanding that disposal does not capitalize on the resources contained in the *wastewater residuals*.

Table 2 lists the *wastewater residuals* management options currently in use in Canada and provides general examples. Not all of the management options provided in Table 2 are considered beneficial.

Table 2: Summary of *wastewater residuals* management options in use in Canada.

Management Option[a]	Examples
Forestry	• applications to juvenile or mature forest stands • reforestation following harvest or site disturbance • establishment of biomass crops including poplar and coppice willow systems
Mine reclamation	• application to aggregate, mineral and coal mines • reclamation of overburden stockpiles, waste rock dumps and tailings
Agriculture	• applications to crop and range land • biomass cropping systems with grasses and non-food crops
Disturbed land improvement	• application to landfills to augment the topsoil component of the closure system or mitigate fugitive methane emissions • brownfield reclamation, marginal agricultural land, roadside reclamation • application to disturbed areas to promote vegetation establishment for habitat creation and aesthetic enhancement
Value added product development	• utilization of *wastewater residuals* as a feedstock in composting, soil fabrication or commercial fertilizer production
Energy capture as a *beneficial use*	• combustion of *wastewater residuals* with energy recovery
Cement manufacture[1]	• use of *wastewater residuals* as a combustion feedstock in kilns, with associated ash utilized in cement manufacture
Disposal through combustion	• combustion without energy capture and/or without recovery of a significant portion of the ash and/or with significant N_2O emissions (GHGs)
Landfill disposal	• disposal of *wastewater residuals* to landfill with or without landfill gas recovery/utilization

[a] The table provides a summary of **residuals** management options in current use in Canada or readily available which include both *beneficial use* and disposal. Options not considered *beneficial use* include landfill disposal and disposal through combustion that does not meet the minimum *CCME* criteria from this guidance document.

The type of *beneficial use* management option selected, land application or combustion, is predicated on a variety of factors which are discussed in Section 4.2. One of these factors is the quality of the *wastewater residuals*; a factor which is strongly affected by society. Items that are

[1] Cement manufacture can be considered a form of combustion, and as such, would need to meet the basic requirements of combustion, including net positive energy balance, ash utilization, and GHG emissions criteria to be considered beneficial use.

produced, used and consumed can enter the wastewater treatment system directly through human waste products or indirectly through cleaning and washing activities.

The following sections describe in detail the considerations in determining the development of a land application (Part 2) or combustion (Part 3) *beneficial use* program.

Focus on Beneficial Use

This Guidance Document applies to the beneficial use of municipal biosolids, municipal sludge and treated septage. The dewatered biosolids shown are the product of lime stabilization (light colour) and

PART 2: LAND APPLICATION

Municipal biosolids and *treated septage* can be applied to land as a fertilizer or soil conditioner. *Beneficial use* through land application is based on the nutrient content and *organic matter* of the *municipal biosolids* and *treated septage* which promote vegetation establishment and growth, and enhance soil structure. *CCME* does not support the land application of untreated *septage*.

The following sections provide a discussion of the properties of the *wastewater residuals* that enable *beneficial use* (Section 2.1.1 and 2.1.2) and sustainable land application opportunities (Section 2.2).

2.1 Properties of Wastewater Residuals that Enable Beneficial Use

Municipal biosolids and *treated septage* can be used in many applications depending on management objectives and the quality of the residual. Benefits associated with land application include:

- promoting plant establishment and growth (Sopper, 1993; Henry et al,. 1993)
- improving soil quality, development and structure (Haering et al., 2000; Basta, 2000)
- resource recovery, particularly of nutrients cycled through the agro-ecosystem (Haering et al., 2000; Basta, 2000).

In addition to nutrients and *organic matter*, there are numerous ancillary benefits to land application of *municipal biosolids* and *treated septage*:

- erosion protection due to improved soil quality and corresponding vegetation response
- improved nutrient cycling
- habitat creation through vegetation establishment and
- improved visual quality through reclamation/vegetation of degraded areas (Henry et al., 1993; Cole et al., 1986, Bledsoe, 1981).

Land application benefits depend on proper management of the *municipal biosolids* and *treated septage*. Proper management infers the consideration of quality, mineralization rates, application rates, timing and location of application. Additional information and management considerations in developing a land application program are provided in Section 2.3, 2.4, 2.5 and 2.6. Inappropriate management could lead to detrimental environmental effects through leaching of nutrients due to application of nutrients above the crop nutritional demands or other unforeseen effects. Limitations on land application are provided in Section 2.7.

2.1.1 Nutrients

Municipal biosolids and *treated septage* contain macro and micronutrients required for plant growth and can be land applied for their fertilizer value (Table 3). The *organic matter* in *municipal biosolids* and *treated septage* may serve to mitigate undesirable leaching of some nutrients while providing nutrient mineralization over time.

Mineralization is the conversion of *organic* compounds in the soil to their inorganic (mineral) ionic forms which are more readily available to plants in the soil solution. Mineralization is an important soil process as it provides nitrogen, phosphorus, sulphur and other nutrients in a form that can be taken up by plants. Factors influencing mineralization rates include: pH, moisture, aeration and temperature (Brady and Weil, 2004).

The release of plant available nutrients from *wastewater residuals* is related to:

- local environmental conditions
- the concentration of nutrients in *wastewater residuals*
- the properties of nutrients (*organic* or inorganic forms) and
- the extent to which the *wastewater residuals* have been stabilized, or if they are in liquid or dewatered form.

Municipal biosolids and *treated septage* undergo *stabilization* during treatment which promotes the development of organo-nutrient complexes through ingestion resulting in the development of biological mass (Bitton, 1994). This results in prolonged release of several nutrients dependent on the mineralization rates of *organic* nutrients (Henry et al., 2000), and improved moisture retention as compared to fertilization with untreated animal manure or traditional chemical fertilizers (Oberle and Keeney, 1993). For example, the nitrogen mineralization rate (release of plant available nitrogen) is inversely related to the stability of the residual; manures were observed to have the highest mineralization rate, followed by *municipal biosolids* and composts (Cowley et al., 1999).

Table 3: Essential plant macro- and micronutrients present in *wastewater residuals*.

Macronutrients	Micronutrients	
• nitrogen (N) • phosphorus (P) • potassium (K) • sulphur (S) • calcium (Ca) • magnesium (Mg)	• boron (B) • copper (Cu) • iron (Fe) • chlorine (Cl) • manganese (Mn)	• molybdenum (Mo) • zinc (Zn)

Municipal biosolids and *treated septage* can be land applied for fertilization purposes to provide nitrogen and phosphorus and to improve soil structure. *Municipal biosolids* and *treated septage* also contain micronutrients, providing a soil amendment with plant nutrients, though not necessarily in the required ratios, or in plant available forms. The concentration of nitrogen and phosphorus in the *municipal biosolids* and *treated septage* is dependent on the influent quality and the treatment process. A summary of the nitrogen and phosphorus concentrations in Canadian *municipal biosolids* is provided in Table 4. A discussion of individual plant macronutrients is provided below.

The land application of *municipal biosolids* often draws comparisons with the land application of raw or composted manures (e.g. Spicer, 2002 and Hébert, 2011). Comparisons between *municipal biosolids* and several manures generally note that these amendments comprise similarly broad ranges of nitrogen (1-10.8% dry weight), phosphate (from 0.7%-7.5% dry weight), *organic matter* and most trace elements (Hébert, 2011). The greatest disparities between *municipal biosolids* and manure have been observed in microbiological content, with untreated manures carrying levels of *E.coli* and *Salmonella* several orders of magnitude higher than treated *municipal biosolids*, and in bulk density, where *municipal biosolids* are generally more compact through dewatering techniques than manures. Both materials offer advantages through *organic matter* content and soil conditioning when land applied.

However, *municipal biosolids* and livestock manure differ in the mineralization rate of the *organic* fraction and it is suggested that mineralization rates in livestock manure are higher than in *municipal biosolids* (Morvan et al., 1997; Henry et al., 2000; Cogger et al., 2001; Barbarick and Ippolito, 2007). Within the variety of *municipal biosolids* produced in Canada (aerobic, anaerobic, digested, liquid, dewatered, pelletized, etc.), there will be variation in mineralization rates which will be further influenced by natural climatic and soil conditions. Timing of mineralization has implications for agronomic planning. An optimal mineralization rate will release nitrogen at the same rate as crop uptake. High mineralization rates may release nitrogen faster than the crop is able to take it up, resulting in leaching losses. These losses will occur if mineralization is combined with enough rainfall or meltwater to achieve soil water movement completely through the rooting depth and into the vadose zone. A slow mineralization rate equates to a sustained release of nutrients over time, but if the release is too slow, the crop may lack sufficient available nutrients. It may also contribute to nitrogen leaching if favourable weather conditions extend mineralization beyond the growing season (Haynes et al., 2009), and are again combined with significant water movement through the soil profile, just as with the use of *organic* fertilizer such as livestock manure and compost.

(a) Nitrogen

Nitrogen content and availability in *wastewater residuals* can vary greatly depending on the source of the residual and the treatment process. Forms of nitrogen present in *wastewater residuals* include *organic* nitrogen (i.e., nitrogen bound in *organic* molecules such as proteins), nitrate (NO_3^-), nitrite (NO_2^-), and ammonia (NH_3). With the exception of aerobically digested *municipal biosolids* and *municipal sludge*, the concentration of nitrate and nitrite is insignificant in most *wastewater residuals* and the *organic* nitrogen is the predominant form in most *wastewater residuals*, especially in dry *wastewater residuals* (Henry et al., 2000). Determining the mineralization rates of *organic* nitrogen from the *wastewater residuals* is therefore important in estimating the nitrogen availability to plants (Henry et al., 2000).

The inorganic nitrogen (i.e. NH_3, NO_3 and NH_4) is available for plant uptake when the *municipal biosolids* and *treated septage* are land applied. The inorganic nitrogen that is available to the plants is the total inorganic nitrogen in the *municipal biosolids* or *treated septage* minus any lost to other aspects of the nitrogen cycle through volatilisation, immobilisation or leaching (Prasad and Power, 1997).

Organic nitrogen contained in the *municipal biosolids* and *treated septage* is not directly available to plants. When *municipal biosolids* and *treated septage* are applied to land a fraction of the *organic* nitrogen will mineralize (i.e., be transformed to available inorganic forms by microorganisms in the soil) in the year of application (Prasad and Power, 1997). The amount of nitrogen available to the crop in the first year is the sum of the inorganic nitrogen plus the mineralized *organic* nitrogen.

When designing a site specific nutrient management plan the following factors need to be taken into consideration:

- mineralization rate of the *municipal biosolids*
- volatilization rate of ammonium N
- Nitrate N concentration in the *municipal biosolids*
- crop type and
- soil fertility level (Haynes et al., 2009).

These will then help determine the appropriate application rate to meet the nutritional requirement of the crop. Mineralization rates for several provinces and areas of Canada are available in peer-reviewed literature to provide guidelines for practitioners.

Nitrogen transformations are important as they affect plant growth and vigour as well as microbial activity. Factors affecting nitrogen transformation when *wastewater residuals* are land applied are soil moisture, temperature, porosity, microbial activity and aeration (Gilmoure et al., 2003; Tisdale et al., 1985; Wang et al., 2003).

Nitrogen is one of the most important nutrients for plant growth. Most soils in Canada benefit from the addition of nitrogen to ensure optimum growth of agricultural crops. Amending soils with *municipal biosolids* and *treated septage* may represent a complementary source of N and consequently contribute to reductions in the use of conventional nitrogen fertilizers.

Land application rates for *municipal biosolids* and *treated septage* are often based on nitrogen although this varies across Canada. Application rates are calculated with consideration given to:

- the agronomic nitrogen requirement of the intended vegetation
- the nitrogen concentration in the *municipal biosolids* or *treated septage*
- the nitrogen mineralization rate (which may be calculated, estimated from literature, or based on a conservative rule of thumb)
- the loss of nitrogen before vegetation uptake (due to land application practices for example)
- the nitrogen available from other sources (chemical fertilizers for example).

Agronomic application rates should mitigate the potential for adverse environmental impacts through nitrogen leaching. Furthermore, application rates should not result in over-application of phosphorus or other constituents that may impact sensitive ecosystems. Additional information on application rates is provided in Section 2.5.5. A summary of nitrogen and phosphorus concentrations for different treatment processes used at Canadian wastewater treatment facilities is provided in Table 4**.**

Table 4: Indicative nitrogen and phosphorus concentrations (total solids, dry weight basis) for different treatment processes used at Canadian wastewater treatment facilities.

Treatment Type and Location	Nutrient concentrations[a]			Units
	TKN	Ammonia (as N)	Total P	
Biological – aerobic (compost), Prince Albert, Saskatchewan	44,000	7,320	14,300	mg/kg
Physical – thermal drying (heat dried pellets), Smiths Falls, Ontario	32,600	1,890	18,900	mg/kg
Physical – geotextile bag dewatering (*septage*), Eganville, Ontario	45,300	2,050	32,500	mg/kg
Physical – filter press dewatering, Saguenay, Québec	59,500	5,060	17,700	mg/kg
Physical - chemical (alkaline *stabilization*), Halifax, Nova Scotia	12,100	1,280	5,180	mg/kg
Biological – aerobic (compost), Moncton, New Brunswick	19,300	953	5,130	mg/kg
Biological – aerobic (compost from *septage*), Gatineau Valley, Québec	17,100	540	4,120	mg/kg

[a] Data provided by Hydromantis Inc et al., 2010.

(b) Phosphorus

Phosphorus is a macronutrient that is present in *wastewater residuals* in *organic* and inorganic (phosphate) forms. Inorganic phosphorus is often predominant in *wastewater residuals* (Macguire et al., 2000; Soon and Bates, 1982). *Organic* phosphorus must undergo mineralization in the soil before plant assimilation.

When considering biological treatment, phosphorus "availability" often does not change during the wastewater treatment process. Approximately 50% to 80% of the total phosphorus applied to land is available to plants in the first year (Australia Environmental Protection Authority, 2009). In contrast to biological treatment, chemical treatment by which alum or ferric chloride is added to the wastewater to precipitate the dissolved/soluble phosphorus reduces the "availability" of phosphorus compared to the raw wastewater. In general, phosphorus availability in *municipal biosolids* as affected by the treatment processes can range as follows: biological P removal > treatments with no addition of aluminium, iron salts, or lime (i.e. mainly Ca) > treatments with addition of aluminium, iron salts or lime, or heat dried biosolids (Haynes et al., 2009). Phosphorus bound in these aluminum or iron complexes is not readily available to plants (< 25% compared to triple superphosphate (O'Connor et al., 2004).

Information Highlight
Plant-available phosphorus

While it is easy to understand that some phosphorus is available to plants, while other forms of phosphorus are not, the development of an analytical tool to effectively assess the quantity of 'plant-available phosphorus' has been remarkably difficult to develop. This is because phosphorus is potentially available to plants as solution phosphorus (also known as orthophosphate), but also as labile phosphorus, which can either be organically bound, or weakly adsorbed to soil particles. Due to the analytical challenge of determining what phosphorus is actually available to a plant, the term 'available phosphorus' is often used when discussing an analytical technique used to estimate the quantity of phosphorus that is in solution and weakly absorbed to soil or organic particles.

Phosphorus in traditional agricultural fertilizer is obtained from rock phosphate. It is estimated that existing rock phosphate reserves could be exhausted within the next 50 to 100 years (Cordell, 2009) which could result in a global phosphorus shortage. The land application of *wastewater residuals* may offset the need for traditional phosphorus fertilizers due to the phosphorus contained in *wastewater residuals* in a context of depletion of phosphorus sources (Soil Association, 2010).

(c) Potassium

Potassium forms are soluble in wastewater and remain in the liquid stream; therefore, potassium is not typically found in *wastewater residuals* in high concentrations, and the rations K/N or K/P are much lower than with farm manures. In the USA an average potassium content of 0.4% based on 192 biosolids samples has been reported (Epstein, 2003). As such *municipal biosolids* generally could be considered as a negligible source of potassium in crop production systems, thus some crops may require additional potassium fertilization.

(d) Calcium

Most *wastewater residuals* contain substantial concentrations of calcium, approximately 2.1-3.9%, similar to the content in animal manures (Hue, 1995; Haynes et al., 2009). In the USA, an average calcium content of 5% based on 193 *municipal biosolids* samples has been reported (Epstein, 2003). When lime is added to *wastewater residuals* during the *stabilization* process, e.g. 30% of lime to the dry matter (European Commission, 2001), the calcium content in residuals is increased. Applying *wastewater residuals* at agronomic nitrogen-based rates may supply a significant amount of calcium to correct calcium deficiencies or improve the soil pH where applicable.

(e) Sulphur

Most *wastewater residuals* contain substantial concentrations of sulphur which promotes plant growth, development and seed formation (Sullivan et al., 2001; Zhao et al., 1999). In *wastewater residuals*, sulphur exists in available and slow-release forms resulting from the oxidation of sulphides, and decomposition of *organic matter* respectively. When *wastewater residuals* are applied at agronomic nitrogen-based rates the sulphur demand of the crops is also typically met (Mullins and Mitchell, 1995).

2.1.2 Organic Matter

Organic matter is material derived from plants or animals. In this Section, *organic matter* is discussed specific to the land application of *wastewater residuals*; the heat value associated with *organic matter* is discussed in Section 3.1.

Wastewater residuals typically contain significant concentrations of *organic matter*. Land application of *municipal biosolids* and *treated septage* enhances the *organic matter* content of the soil resulting in improved physical, chemical and biological properties including increased water holding and cation exchange capacity (CEC) and maintenance of soil microbes (Sopper, 1993).

CEC refers to the ability of soil to hold cation nutrients. The addition of *organic matter* to the soil enhances CEC, resulting in a potential increase in the retention of cationic plant nutrients that are added to the soil. Nutrient addition plays a larger role in intensively farmed systems, as a replacement for *organic matter* which is degraded through annual cultivation or grazing.

Organic matter and nutrient loss from productive soils is a major issue of concern in the agricultural sector, with large declines observed over the past 20 years (Schipper et al., 2007). Additional *organic matter* also increases microbial activity in the soil by providing soil microbes with both a short and long-term nutrient source (British Columbia Ministry of Environment/SYLVIS, 2008).

2.1.2.1 Soil Structure

Land application of *municipal biosolids* and *treated septage* improves soil structure through the addition of *organic matter*. Benefits of *organic matter* addition to soil structure include:

- aggregation of soil particles
- reduction in soil bulk density
- increased aeration and root penetration and
- mitigation of erosion (Wallace et al., 2009).

The addition of *organic matter* results in increased soil aggregation (Wallace et al., 2009). Aggregation refers to sand, silt and clay amassing together to form larger soil particles. Larger soil particles are beneficial as they increase the pore space in the soil. Pore spaces provide areas for water and air resulting in increased water infiltration and holding capacity and improved soil aeration (Brady and Weil, 2001).

Soil aggregation also reduces the bulk density of the soil and mitigates loss of soil particles through erosion by wind or water. Low soil density facilitates vegetation establishment by allowing plant roots to penetrate down the soil profile. Aggregated soils are less susceptible to erosion by water or wind as the large-soil particles resist movement (British Columbia Ministry of Environment/SYLVIS, 2008). Additional information on land application site suitability with regard to soil properties is included in Section 2.4.

2.2 Land Application – Areas of Beneficial Use Opportunities

In terms of land application, *beneficial use* opportunities for *municipal biosolids* and *treated septage* can be divided into four general areas: agriculture, forestry, reclamation and fabricated growing medium or topsoil. Each of these areas of *beneficial use* is described below.

2.2.1 Agriculture

Wastewater residuals worldwide are managed extensively through agriculture. A study conducted with the support of the European Commission indicated that agricultural application of *municipal biosolids* is preferable, both environmentally and economically, compared with disposal through landfilling or combustion (Hébert, 2008).

Application of *municipal biosolids* and *treated septage* to agricultural land is a common practice in Canada and has been ongoing for many decades. *Municipal biosolids* and *treated septage* are used in some provinces in Canada to fertilize agricultural land to grow crops such as forage and grain crops, biomass crops, fruits and vegetables. More stringent controls are in place when using *wastewater residuals* to fertilize crops for human consumption and animal consumption compared to biomass generation for energy production. Local guidelines/regulations should be consulted for more information on specific limits.

In agricultural applications, *municipal biosolids* and *treated septage* are applied to land as a source of nutrients and *organic matter*, maintaining crop productivity while protecting the surrounding environment is a challenge for agricultural land owners. Agricultural soils in Canada become depleted in nutrients and *organic matter* as crops assimilate nutrients which are then removed from the site. This results in nutrient deficiencies. Tillage and removal of crop residues results in a loss of *organic matter* leading to poor soil structure, less water and nutrient holding capacity, and increased susceptibility to erosion (Prasad and Power, 1997).

Case Study: Halifax Regional Municipality, Nova Scotia

Municipal biosolids generated by the Halifax Regional Municipality are treated by the N-Viro™ process, a patented alkaline stabilization process that produces Class A *municipal biosolids* using a second residual stream (cement kiln dust) for alkalinity. Since 2008, 100% of the *municipal biosolids* produced have been beneficially used to fertilize sod and agricultural crops (corn, soybeans, cereals and forages). The combination of anaerobic digestion with resultant gas used to heat the facility, *stabilization* using a recycled product, and land application of the *municipal biosolids* results in a net GHG sequestration effect as calculated by the Biosolids Emissions Assessment Model (CCME, 2010). Feedback to N-Viro from sod farms indicates that soil amendment with *municipal biosolids* has resulted in improved germination and growth of the sod. Improved crop quality and yield in agricultural applications has also been reported, primarily due to the increase in soil pH and nutrient concentrations associated with the addition of biosolids.

Prior to receiving *municipal biosolids* end users are required to have a nutrient management plan in place which includes an N-Viro™ plan. A public education program is currently being developed to educate the public and the users about the program, best management practices and regulatory requirements.

Amending soil with *wastewater residuals* has been proven to be a viable solution for land owners as agricultural applications of *wastewater residuals* result in soil nutrient and *organic matter* replenishment and increased water holding capacity which can increase crop yields (Cogger et al., 2001; Haynes and Naidu, 1998; Olness et al., 1998).

Best management practices should be implemented when applying *municipal biosolids* and *treated septage* to agricultural land to protect crop, soil and water quality and human health. Considerations include environmental and human health protection, contributions to or mitigation of climate change through greenhouse gas emission or carbon sequestration and the application of the precautionary principle (refer to “Information highlight: application of the precautionary principle”). Considerations in agricultural application programs are discussed in Section 2.3, 2.4, 2.5 and 2.6.1.

Information Highlight

Application of the Precautionary Principle

The precautionary principle was initially proclaimed in the Rio Declaration (1992) during the United Nations Conference on Environment and Development. Since the Rio Declaration the precautionary principle has been used by many governments.

The Canadian Environmental Protection Act (CEPA, 1999) sets out several guiding principles in the preamble and embodies them in the administrative duties of the Canadian Government. Key among them include the precautionary principle, where the government's actions to protect the environment and health are guided by the precautionary principle, which states that "where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

Since then, some municipal governments, organizations and even interested members of the public evolved various versions of a precautionary approach. As a result of the differing interpretations, the precautionary principle is often misunderstood (Hébert, 2011).

In this guidance document, the precautionary principle was considered and used as a guiding principle at a global scale (e.g., minimizing greenhouse gas emissions), and at a local scale (e.g., consideration of characteristics and quality of biosolids applied to soil, separation distances to prevent potential leaching of nutrient to water, and waiting periods prior to harvesting crops or grazing animals on land where biosolids were applied to minimize risks to human and animal health).

In accordance with the principle, policy makers can make discretionary decisions in situations where there is sufficient scientific evidence to support that the possibility of harm from taking a particular course or making a certain decision is low even if there are some gaps in the scientific knowledge on the matter.

The principle implies that there is a social responsibility to protect the public from exposure to serious or irreversible harm, when scientific investigation has found a plausible risk. These protections should only be relaxed if further scientific findings emerge that provide sound evidence that no serious or irreversible harm will result.

2.2.2 Forestry

Forest fertilization with *municipal biosolids* encourages tree growth and increases yields while enhancing understory vegetation to improve wildlife habitats (Henry et al., 1993; 1994; Pion and Hebert, 2010). Forest productivity in Canada is often nutrient limited. Fertilizing forest soils with *wastewater residuals* results in enhanced soil fertility and water holding capacity, decreased erosion and pH buffering which can increase tree growth (Henry and Cole, 1994).

The demand for fibre and wood products results in a need to improve forest productivity. Forest fertilization may occur on different types of forested land including existing forests, plantation forests or energy crops (woody biomass). Growing woody biomass crops is a relatively new practice in Canada. Woody biomass crops are grown to produce fibre for pulp and paper products or for burning as a source of energy. *Municipal biosolids* and *treated septage* are used to increase the yield of woody biomass crops.

Other forestland values such as recreation, landscape aesthetic considerations, other non-traditional uses, wildlife considerations, biodiversity and possible historical or religious significance should be considered.

A discussion of the considerations associated with *municipal biosolids* and *treated septage* applications to forested land is provided in Sections 2.3, 2.4, 2.5 and 2.6.2.

Case Study: City of Prince George, British Columbia

The City of Prince George operates the Lansdowne Wastewater Treatment Plant which produces anaerobically digested, mechanically dewatered *municipal biosolids*. Since 1998, the City of Prince George's *municipal biosolids* beneficial use program has included agricultural and silvicultural applications. Silvicultural applications include fertilization of natural forests and biomass plantations and reclamation of roads in crown land tenures and privately owned woodlots. *Municipal biosolids* fertilization is of significant interest in the forest industry, as the slow nutrient release results in a fertilization response that can last in excess of 5 years, versus chemical fertilizer responses which can be as brief as 2-3 years (Cole *et al.,* 1986). *Municipal biosolids* application to forest stands is timed to provide the maximum growth benefit: prior to canopy closure, after thinning, and 5-10 years prior to harvest (Cole *et al.,* 1986). *Municipal biosolids* reclamation of temporary roads and landings within forests can return these degraded areas to the productive land base immediately, resulting in a larger productive growing area and, consequently, a greater cutting allowance. While the Prince George system has not been assessed for GHGs, the combination of anaerobic digestion with gas utilization and land application make it a likely candidate to be a net carbon sequestration system.

2.2.3 Reclamation

Municipal biosolids have been used in Canada to reclaim mines (mineral, aggregate and coal), roads and landings (forestry), disturbed sites (transportation corridors for rail, vehicles, pipelines and hydro), create wetlands, provide final cover for landfills, and remediate landslides and erosion channels. These sites typically have disturbed soils which lack adequate moisture holding abilities, *organic matter*, microorganisms, and nutrients (Antoniadis et al., 2006). Adding *municipal biosolids* or *treated septage* to these sites can assist in the development of productive soil through the addition of nutrients and biologically active *organic matter* where previously there has been a shortage of these key soil formation elements.

The goal of reclaiming disturbed land is to improve the soil quality so that it can support a self-sustaining community of plants and animals. Reclamation often accelerates succession processes by adding a significant amount of nutrients, *organic matter* and microbes to depleted soils. Reclamation is required to facilitate succession processes which enhance soil development and increase biodiversity.

Depending on the reclamation objectives, grasses, trees or shrubs may be planted into reclaimed soils. Intensive reclamation may result in a diverse forest cover whereas minimal reclamation may result in a grassland cover. The reclamation objectives should be finalized prior to application of the *municipal biosolids* or *treated septage*. In addition to furthering reclamation objectives, land application of *municipal biosolids* and *treated septage* can serve to sequester carbon in the soil. Research conducted on mine sites in the United States showed that repeated application of *municipal biosolids* to degraded soils increases the carbon sequestration in the soil beyond conventional fertilization practices (Tian et al., 2009).

Additional information on the use of *municipal biosolids* and *treated septage* in reclamation is included in Sections 2.3, 2.4, 2.5 and 2.6.3.

Case Study: Lehigh Materials – Sechelt, British Columbia

The Lehigh Materials mine, one of the largest aggregate mines in Canada, is located immediately adjacent to the community of Sechelt, British Columbia. Locally generated *municipal biosolids* have been used for over 10 years at the mine to return organic matter and nutrients to depleted mine soils. The primary goals of the reclamation program are to mitigate the disturbance caused by mining activities and to improve visual aesthetics of the mine from town by establishing vegetation on previously barren sites. *Municipal biosolids* are used to improve the soil quality in order to establish poplar plantations, native vegetation and wetlands on the site. Mine reclamation provides a sustainable management option for the local *municipal biosolids* producers, and the community is very supportive of the successful program. In 2010 the mine was recognized for achievements in mine reclamation through receipt of the prestigious British Columbia Jake McDonald Mine Reclamation Award.

2.2.4 Use of Fabricated Growing Media (Topsoil)

Incorporating *municipal biosolids* and *treated septage* into a fabricated growing media, or soil product is similar to land application. A fabricated growing media is created by combining a mineral feedstock, a carbon feedstock and a nutrient rich *organic* feedstock. The formulation of the growing media changes depending on the end use. Fabricated growing media are used in reclamation, landscaping, slope stabilization, gardening, agriculture, leachate treatment and landfill closures. Fabricated growing media have excellent water holding capacity, are cost effective, and can be designed for specific applications.

In addition to using *wastewater residuals* in fabricated growing media, *municipal biosolids* and *treated septage* may be used as a feedstock in compost. More information on *wastewater residuals* use in compost may be found in *CCME* Guidelines for Compost Quality (CCME, 2005).

Additional details on management considerations regarding fabricated growing media are included in Sections 2.3, 2.4, 2.5 and 2.6.4.

Case Study: City of Abbotsford, British Columbia

The City of Abbotsford and the District of Mission own and operate the Joint Abbotsford Mission Environmental Systems Wastewater Treatment Plant (JAMES Plant). One of the beneficial *municipal biosolids* management options that the City of Abbotsford has implemented is the production of fabricated topsoil. As a feedstock in soil manufacture, the dewatered *municipal biosolids* produced by the JAMES plant provide a source of nutrients and organic matter. The topsoil produced by the City of Abbotsford is marketed and retailed under the trade name Val-E-Gro™. The successful program resulted in a sale of 2,464 cubic yards of Val-E-Gro™ in 2009. The topsoil and the *municipal biosolids* used to produce it meet the British Columbia regulatory standards for *municipal biosolids* growing medium and Class A *municipal biosolids* respectively (City of Abbotsford, 2010).

2.3 Management Consideration #1: Characteristics and Quality

As discussed in this section and Section 1.3.2, *wastewater residuals* quality is contingent on influent characteristics and the type of treatment process used. The quality of the *municipal biosolids* and *treated septage* must be determined prior to selecting an application management option. The regulated parameters used as a measure of quality of *municipal biosolids* and *treated septage* intended for land application will vary based on:

- the *beneficial use* opportunity, for example jurisdictional quality criteria for topsoil fabrication may differ from criteria for forest land application and
- the regulatory framework of the applicable jurisdiction.

Several of the parameters that are used for measuring *wastewater residuals* quality in Canada are discussed in Section 2.3.1.

Determination of *wastewater residuals* quality is completed through sample collection and analysis. The key consideration in measuring *wastewater residuals* quality is the collection of representative samples that accurately reflect the residual to be beneficially used. The extent to which a sample and the associated data accurately represent the residual under consideration is influenced by:

- the frequency of sampling and the extent to which the monitoring program captures changes in *wastewater residuals* quality
- consistency in processing, i.e., addressing the fluctuations in the quality of the final product
- the type of sample (e.g., grab samples versus composite samples), sample number and size relative to the total volume of the residual
- the timing of sample collection
- quality assurance procedures and
- analytical methods and techniques, including detection limits, reproducibility, quality assurance and quality control.

References and additional information on the determination of *wastewater residuals* quality are provided in Appendix 3.

2.3.1 Parameters Used to Measure Quality

The following sections provide detail regarding parameters used to define *wastewater residuals* quality.

2.3.1.1 <u>Inorganic Trace Elements/Heavy metals</u>

Many trace elements/heavy metals are vital for the growth and development of plants and animals. Trace elements are naturally present in the environment, and in some cases natural trace element concentrations in soils may be higher than regulated limits. Trace elements are also found in *wastewater residuals*. Trace element concentrations in *wastewater residuals* depend on the inputs to the wastewater stream. Rural and urban jurisdictions have different inputs to the wastewater stream thus the trace element concentrations in *wastewater residuals* will differ.

Table 5 below provides a comparison of trace element concentrations in manures, *municipal sludge* and *septage* (Perron and Hébert, 2007). In general, *municipal biosolids* contain trace element concentrations that are higher than beef cattle manure and comparable to poultry manures (Perron and Hébert, 2007). In most cases mean concentrations of trace elements in manures and *municipal biosolids* are less than the maximum trace element concentrations provided in the BNQ National Standard of Canada for Soil Amendments (Alkaline or Dried Municipal Biosolids).

A large proportion of trace elements in *municipal biosolids* and manures are bound to *organic matter* or metal oxides and are insoluble when applied to land, preventing their movement to water courses (Antoniadis et al., 2006). Trace elements may accumulate in soil upon repeated applications of *wastewater residuals* due to their immobility. Best management practices implemented in conjunction with regulations ensure that trace elements are within the allowable limits in the product, and do not accumulate to concentrations that negatively impact the environment in the long term (Perron and Hebert, 2008).

Table 5: A comparison of trace element concentrations in manures, *municipal sludge* and septage.

Fertilizer type	**Trace Element Concentration (mg/kg)[b]**										
	As	**Cd**	**Co**	**Cr**	**Cu**	**Hg**	**Mo**	**Ni**	**Pb**	**Se**	**Zn**
Pig Manure	1	0.5	2.9	8.6	839	0.02	4.1	11	2.5	1.9	1,475
Cattle Manure	0.6	0.2	1.9	6.9	36	0.02	2.2	5.6	1.4	0.4	156
Poultry Manure	9	0.4	4	4.7	192	0.1	5	12	2	1.3	399
Dewatered *Municipal sludge*	3.8	1.3	6.5	33	402	0.7	5.4	25	28	1.8	398
Municipal sludge Ponds	7.2	3.3	10.5	55	680	1.2	9.6	36	61	2.5	689
Septage	4.3	1.7	8.3	21	246	0.7	5.7	18	34	1.3	418
CAN/BNQ Standards[a]	41	15	150	1,000	1,500	4	20	180	300	25	1,850

[a] The BNQ National Standard of Canada (Soil Amendments – Alkaline or Dried *municipal biosolids*) maximum trace element concentrations.

[b] This table was adapted from Perron and Hébert, 2007.

Certain inorganic trace elements, if present in *wastewater residuals* at elevated concentrations and applied improperly (e.g., higher application rates), can lead to health and environmental concerns. Adverse effects of trace element accumulation are abnormal or stunted growth in plants and bio-accumulation in plants that are then consumed by livestock or humans. Typically, the 11 trace elements of concern in *wastewater residuals* are:

- arsenic (As)
- cadmium (Cd)
- chromium (Cr)

- cobalt (Co)
- copper (Cu)
- lead (Pb)
- mercury (Hg)
- molybdenum (Mo)
- nickel (Ni)
- selenium (Se) and
- zinc (Zn).

A significant amount of research has been completed on these trace elements in *wastewater residuals*, and on their effects on the environment and human health following land application (WEAO, 2010). Most jurisdictions have regulations which include limits for trace element concentrations in the *municipal biosolids* and *treated septage* that are to be applied to land and limits for trace element concentrations in the soil. These are often similar to regulatory limits for the trace elements in chemical fertilizers or other soil amendments.

Trace elements are not degradable and can accumulate in animal and plant tissues and in the soil. Trace element mobility is variable and is affected by the trace element and soil properties. When *wastewater residuals* are applied to land, the trace elements in the *wastewater residuals* are adsorbed to *organic matter* and soil surfaces. Most trace elements strongly adsorb to soil particles and remain relatively immobile in the soil surface with limited migration through the soil profile. When the *organic matter* and soil surfaces adsorption sites are at capacity, trace element availabilities to plants may increase. Soil conditions can influence trace element speciation and plant uptake.

Soil pH is the most important factor affecting trace element availability. Most of the 11 trace elements increase in availability at lower (acidic) pH. The exceptions to this are molybdenum and selenium which become more available at higher pH (Antoniadas et al., 2006). The pH should always be monitored in the soil and residual applications to acidic soil should be undertaken with caution.

Organic matter also affects trace element availability. *Organic matter* has a high CEC; as such it binds trace elements thus making them less available for plant uptake. Complex interactions between trace elements also affect availability. Elemental interactions that take place in the soil increase and/or decrease trace element availability depending on the trace element.

Plant uptake and human health impacts of trace elements in *wastewater residuals* have been studied extensively. Regulations and guidelines on *wastewater residuals* quality and ongoing research provide knowledge and tools for continuous improvement and allow for considerations of *beneficial use* options.

As trace elements can accumulate in soils, it is important to monitor their concentrations in the soil before and/or after application of *municipal biosolids* and *treated septage*. Trace element inputs to *wastewater residuals* may be managed through source control programs as discussed in Section 1.3.1. Trace elements which may originate from other sources such as chemical fertilizers or pesticides should also be considered.

2.3.1.2 Nutrients and Organic Matter

Wastewater residuals may be high in nutrients and/or *organic matter*. The beneficial attributes of nutrients and *organic matter* are discussed in Sections 2.1.1 and 2.1.2, respectively.

Land application of *municipal biosolids* and *treated septage* provides the opportunity to improve soil structure and fertility in soils with low concentrations of nitrogen, phosphorus and *organic matter*. As with farm manures, the application rate of *municipal biosolids* and *treated septage* should be calculated to meet the nutrient requirements of the crop without supplying excess nutrients. In addition, the mineralization rate of *organic* nitrogen in *wastewater residuals* should be taken into consideration in order to ensure that sufficient amount of nitrogen will be made available to crops/plants. The application rate of *municipal biosolids* and *treated septage* is typically calculated based on the nitrogen requirements of the crop. In general, when the *wastewater residuals* cannot supply a sufficient amount of a given nutrient, for example N, at the recommended rate, other potential sources of this nutrient should be recommended in the nutrient management plan. A nitrogen-based application rate will typically provide a greater supply of phosphorus than is required by the crops due to the relative ratio of nitrogen and phosphorus found in the *municipal biosolids* and *treated septage*. Monitoring of the phosphorus concentration in the soil, *municipal biosolids* and *treated septage* is recommended to prevent or mitigate excess phosphorus application. When the P site index or the degree of P saturation is high, the application rate should be based on available P rather than the potential available nitrogen; as such, a complementary source of N may be required to meet crop N requirements.

Agronomic application rates mitigate nutrient leaching and protect water resources, by taking into consideration the nutrient loading and other quality parameters including best management practices. If *municipal biosolids* and *treated septage* applications exceed agronomic rates recommended in the nutrient management plan there is the potential for nutrient losses to the environment movement and adverse impact to water resources. In addition to agronomic application rates, management measures such as *buffers* serve to protect water resources.

2.3.1.3 Pathogens

Wastewater residuals can contain a variety of *pathogens* including bacteria, viruses, parasites and fungi which may be harmful to animal and human health. Wastewater treatment often includes processes to reduce *pathogen* concentrations. *Pathogen* reduction during *wastewater* *residuals* treatment may be achieved, for example, by maintaining the material at a certain pH or temperature for a given time, using chemical disinfectants, or by desiccation (drying of *municipal biosolids* (Apedaile, 2001; Brooks et al, 2004).

In addition to achieving *pathogen* reduction during the treatment process, natural processes such as: heat, sunlight, drying, unfavourable pH and predation by native soil microorganisms that are present in land application programs may further reduce *pathogens*.

Escherichia coli (E. coli), *Salmonella* and fecal coliform concentrations in the *wastewater residuals* are often used as an indicator of the degree of pathogen reduction attained during the treatment process. Some *pathogens* are subject to federal/provincial/territorial standards, requirements or guidelines which provide maximum *pathogen* or *pathogen* indicator concentrations for land application programs. Respecting waiting periods prior to harvesting crops or grazing animals is another method of reducing *pathogen* associated risks.

2.3.1.4 Vector Attraction Reduction and Odour

Another measure of *wastewater residuals* quality is *vector* attraction reduction (VAR) and odour. *Vector* attraction reduction refers to stabilizing the *wastewater residuals* such that odours are minimized and the *wastewater residuals* are less attractive to *vectors* such as rodents, insects or other organisms capable of transmitting *pathogens*.

Wastewater residuals that have not been treated in a VAR process are likely to be associated with foul odours and *vectors*. Most provincial/territorial regulations specify the minimal acceptable level of VAR in *wastewater residuals* which are to be managed beneficially. If these specifications are met, the likelihood of disease spread is very low (Apedaile, 2001; Brooks et al, 2004).

Odours in *wastewater residuals* are caused by sulphur and ammonia compounds or by-products of microbial activity. In general, *wastewater residuals* which have undergone a higher degree of treatment will emit fewer odours and will be considered higher quality.

Methods to achieve VAR include:

- reducing the attractiveness of the *municipal biosolids* to *vectors*, by biological processes or specific chemical and physical conditioning (New Zealand Water and Wastes Association, 2003). These include reducing the moisture content of the residual, reducing the *organic matter* content by aerobic or anaerobic digestion, adding lime, heating or composting; or

- removing access to the *municipal biosolids* from *vectors*, usually by direct injection or incorporation of the *municipal biosolids* into soil shortly following application (New Zealand Water and Wastes Association, 2003).

VAR requirements for *wastewater residuals* should be met after or concurrent with *pathogen* reduction.

2.3.1.5 Emerging Substances of Concern

Emerging substances of concern (ESOC) in *wastewater residuals* have recently become a focus of related research in Canada and internationally. *ESOCs* include endocrine-disrupting chemicals (EDCs), hormones and pharmaceuticals and personal care products (PPCPs). Some of these compounds may occur naturally in the environment, however, the majority are from anthropogenic sources. Source control initiatives can help to reduce the volume of anthropogenic *ESOC* inputs to *wastewater residuals*. Refer to Section 1.3.1 for information on source control initiatives.

Most *ESOCs* are found in very low concentrations (measured in the nanogram per gram; 1.0×10^{-9} grams/gram) in *wastewater residuals*. A caveat to the detection of *ESOCs* in *municipal biosolids* is that detection does not necessarily imply a risk to human health and the environment. Detection and quantification of *ESOCs* in *municipal biosolids* serves as an initial step in determining the risks that these compounds might pose. Research has shown that some *ESOCs* degrade rapidly in soils, or solubilise in water and do not partition to biosolids or end up in soils (Smith, 2009).

Research investigating the persistence, environmental fate and human and animal health effects of these compounds is ongoing and risk assessments have generally not been completed for specific *ESOCs* in *municipal biosolids*. Research undertaken by McCarthy et al. (2009) noted that ecotoxicology testing using both plant and earthworm bioassays did not detect any significant negative impacts on growth or reproduction of either test group, and these results were in agreement with a similar study by Chassé et al. (2006) for other biota. Ecotoxicological assays of *municipal biosolids* do not target any single substance, but rather use biota to assess the toxicology of the residuals in their entirety. Minimizing concentrations of *ESOCs* through source control improves *wastewater residuals* quality. In developing the Approach *CCME* undertook a study on the concentration of ESOCs in Canadian *municipal biosolids* and how the concentrations were affected by the treatment process (CCME, 2010).

2.3.1.6 Chlorinated/Brominated Organics

Research was conducted on chlorinated and brominated *organics* in *wastewater residuals* in the past and is ongoing. Research focuses on the effects of chlorinated and brominated *organics* on human health and the environment. Chlorinated *organics* include dioxins, furans, polychlorinated biphenyls (PCBs) and polychlorinated phenols that are often used as disinfectants, dyes and pesticides (CCME, 2010). Some jurisdictions in Canada have standards, requirements or guidelines to restrict the levels of chlorinated *organics* in biosolids intended for land application; information on Canadian and international standards are listed in Appendix 2.

Brominated compounds include polybrominated diphenyl ethers (PBDEs) which are added to plastics, textiles, appliances and electrical equipment as flame retardants. Release of these materials from household products allows PBDEs to enter household dust and be released to the wastewater treatment process (through household cleaning for example) where they typically partition into the solid fraction.

Source control initiatives may help reduce the volume of anthropogenic PBDE entering the wastewater treatment process. Refer to Section 1.3.1 for information on source control initiatives.

PBDES were detected in *municipal biosolids* from Canada and other countries around the world. A literature review stated that (CCME 2006):

- concentrations of the PBDE isomers are substantially lower in the solids streams prior to secondary treatment (e.g. primary sludge), and more concentrated in the solids streams following secondary treatment (i.e., return activated sludge, and dewater secondary or mixed sludge)

- anaerobic digestion may result in a reduction of decabromo DPE, but concentrations of lower brominated congeners may increase

- there is insufficient information to determine if other *municipal biosolids* treatment processes can result in reduction of PBDEs

- no reduction efficiency data for the PBDEs or other brominated flame retardants in *municipal biosolids* treatment processes were observed in the literature.

Canada took steps to reduce the concentration of PBDEs in the environment. PBDEs are not manufactured in Canada but may be imported as commercial mixtures. In 2006 Environment Canada and Health Canada published a Risk Management Strategy for PBDE, the final version was published Canada Gazette, Part II on August 28, 2010. Risk management tools include the voluntary phase out of export of DecaBDE to Canada. Three large producers of DecaBDE have agreed to phase out export of DecaBDE into Canada (Environment Canada, 2011).

A study completed on 14 dairy farms in Québec where *municipal biosolids* were applied for an average of 11 years showed that there was a higher PBDE concentration in milk produced from cows on those farms as compared to control farms, however, the variability of exposure to dust among the different farm buildings was not quantified and may influence the results. Nevertheless the study found that the PBDE concentration was only 7 parts per trillion and was 3 to 7 times lower than average concentrations in US and Europe dairy products and concluded that based on the "results, current knowledge and available data, the application of *municipal biosolids* under Québec regulations would have no significant impact on PBDE exposure for consumers of dairy products produced in Québec" (Hébert et al, 2011).

2.3.1.7 Foreign Matter

Foreign matter is present in *wastewater residuals* in varying concentrations depending on the inputs to the wastewater stream and the treatment process. Foreign matter refers to plastics, glass, large or sharp debris. Most foreign matter is removed from *municipal biosolids* and *treated septage* during the treatment process, however, all foreign matter may not be removed. If present in the *wastewater residuals*, foreign matter may damage equipment and cause harm to workers due to sharp edges which can cause skin abrasions. Foreign matter is unsightly and is not suitable for *municipal biosolids* and *treated septage* that are to be land applied. Most provincial/territorial regulations in Canada impose a size and quantity limit on foreign matter. Refer to applicable regulations for foreign matter requirements in *wastewater residuals*.

One of the most widely used methods to remove foreign matter from *wastewater residuals* is screening. Many different types of screening technologies are available in Canada. *Wastewater residuals* free of visible foreign matter are of preferred quality.

2.3 Influence of Quality Considerations on Beneficial Use Opportunities

Wastewater residuals must be treated to reduce *pathogen* concentration and *vector* attraction (i.e., must meet the criteria for *treated septage* or *municipal biosolids*) prior to land application; treatment is not required for combustion of *wastewater residuals* or before sending it to a composting plant to transform it into *municipal biosolids.*

Furthermore, the quality of *municipal biosolids* and *treated septage* influences risk potential and the number and extent of management considerations. Although *treated septage*, *municipal sludge* and *municipal biosolids* can all be beneficially used either through land application (*treated septage* and *municipal biosolids*) or combustion (*all* w*astewater residuals*), the level of potential risk and therefore the number of management considerations decreases as the *wastewater residuals* quality increases.

Management considerations are designed to ensure the same level of health and environmental protection irrespective of the quality of the *municipal biosolids* and *treated septage*. *Municipal biosolids* and *treated septage* with a lower quality have a greater potential for risk to human health and the environment if land applied and are therefore subject to a greater number of considerations than those with higher quality.

Many Canadian jurisdictions specify different classes of *municipal biosolids*. An example is Class A and Class B *municipal biosolids* for *pathogen* reduction level, where Class A *municipal biosolids* are subject to more stringent process and quality criteria than Class B *municipal biosolids*; consequently Class A *municipal biosolids* are subject to less stringent management considerations.

The quality of the *wastewater residuals* will also influence recommendations for worker health and safety precautions. A Workplace Hazardous Materials Information System (WHMIS) is administered by Health Canada (September 2010). Additional information on worker health specifically relating to Class B *municipal biosolids* has been prepared by the US National Institute of Worker Health and Safety (July, 2002).

2.4 Management Consideration #2: Environment

There are benefits associated with the land application of *municipal biosolids* and *treated septage* and there is also potential for adverse impacts. Protection of the environment is paramount in any *beneficial use* program and includes protecting water and soil resources to ensure sustainable agriculture: protection of livestock and food sources. Considerations for environmental protection include:

- water resources
- *buffer* strips
- leaching potential
- neighbouring land uses
- climate and season of application
- soil properties of the intended application area
- current and future land use, including food, forage and feed crops and livestock production.

Considerations are discussed in further detail in Sections 2.4.1 to 2.4.5. Environmental factors should be considered when evaluating a site for application of *municipal biosolids* or *treated septage*.

Completion of a land application plan (LAP) or a nutrient management plan (NMP) serves to identify and provide criteria for environmental and human health protection. In some jurisdictions LAPs or NMPs are required by regulation. Additional information on LAPs and NMPs is provided in Part 4.

2.4.1 Water Resources

Land application of *municipal biosolids* or *treated septage* must be completed in a manner that is protective of surface and groundwater resources. Key considerations in establishing a land application area include:

- depth to groundwater with consideration given to seasonal variations
- proximity to wells, and surface water
- tile drainage
- primary direction of surface drainage
- flood potential.

When designing a nutrient management plan adhering to best management practices outlined above, the agronomic application rates should be based on the nutrient requirements of the crop, and taking into consideration strategies that reduce the potential for nutrient leaching to water resources (including nutrient mineralization rates). Application methods, cropping practices and *buffers* between the application areas and water resources further mitigate the impacts of nutrient loss to the environment. For additional information please refer to the references provided in Appendix 2.

There will be jurisdiction-specific cases where a complete hydrogeological assessment may be required to protect groundwater in sensitive areas. Care should be taken in selecting management areas in known areas of hydrologic sensitivity.

2.4.2 Flora and Fauna

Municipal biosolids and *treated septage* are typically applied to intensively managed areas with non-native vegetation such as in agricultural land and some land reclamation programs. However, *municipal biosolids* can also be applied to natural, undisturbed areas such as native forests.

Consideration should be given to the presence of sensitive species. This includes protection of habitat, nesting areas and sensitive vegetation from application activities.

Reclamation activities with *municipal biosolids* and *treated septage* often involve the creation of wildlife habitat through increased vegetation establishment and growth.

2.4.3 Climate and Season of Application

The timing of *municipal biosolids* or *treated septage* application should be considered in relation to the period of maximum benefit for soil development and/or vegetation uptake to mitigate the potential for leaching.

Considerations include:

- precipitation (rain or snow)
- season of application
- soil moisture and
- mineralization rates.

Precipitation increases the potential for macropore flow (movement of water through pores in the soil) through previously dry and cracked soil and surface run-off during heavy rainfall or snowmelt. Application of *municipal biosolids* or *treated septage* during heavy rainfall or on top of snow increases the risk of nutrient movement/leaching.

The rate of nutrient uptake by plants and climatic conditions vary seasonally. Leaching of nutrients can occur during periods of plant dormancy and heavy precipitation.

2.4.4 Soil Properties

The physical and chemical characteristics of the soil should be determined prior to application of *municipal biosolids* and *treated septage*. Characteristics for consideration include:

- trace elements
- macro and micronutrients
- moisture
- *organic matter*
- pH
- electrical conductivity
- cation exchange capacity
- sodium absorption ratio
- texture

- bulk density
- porosity.

Knowledge of the physical and chemical properties of the soil provides information on how the *municipal biosolids* or *treated septage* can be best applied for nutrient addition, soil development or pH modification. Application of *municipal biosolids* or *treated septage* may be restricted by high background trace element concentrations or sufficient nutrient concentrations in the soil or precautions warranted due to the pH of the *municipal biosolids*, *treated septage* or soil.

Soil texture is an important consideration in estimating the potential for movement of constituents in the *municipal biosolids* and *treated septage* once applied. Knowledge of the soil texture (slow versus high infiltration rates) and climatic conditions can be used to make informed decisions regarding how to mitigate potential movement of the *municipal biosolids* and *treated septage* through the soil profile.

The moisture of the soil is a consideration from both environmental and operational perspectives. The use of application equipment can cause compaction of wet soils leading to reduced infiltration, ponding of water on the soil surface, and anaerobic conditions. Operationally, soil with a high moisture concentration can restrict site access.

2.4.5 Current and Future Land Use

Municipal biosolids or *treated septage* must be applied in a manner that benefits the current land use through fertilization or soil development without comprising future land use objectives. For additional environmental protection, some jurisdictions have maximum loadings for trace elements to soils and/or maximum soil trace elements concentrations that, if reached, prohibit further land application.

2.5 Management Consideration #3: Operations

In addition to quality and environmental considerations, there are considerations associated with the practical implementation of a land application program for *municipal biosolids* and *treated septage*. This Section provides operational considerations with respect to logistics and handling in land application and combustion programs including:

- transportation
- area delineation
- stockpiling and storage
- odour
- application rates

- incorporation.

Careful, proactive operational planning positively affects the success of the *wastewater residuals* management program. Improper planning and implementation can result in social, environmental and economic challenges.

2.5.1 Transportation

One of the single largest logistical considerations and operational costs is transportation. Transportation costs are influenced by the transportation distance, type, volume of *wastewater residuals* to be transported and opportunities for synergies with the transport of other materials (for example backhauling another material may reduce trucking costs).

Transportation methods include road transportation (trucking), rail, barge or pipeline. The selection of a transportation method is based on the transportation distance, location of the wastewater treatment plant in relation to the *beneficial use* area, availability of local services (i.e., proximity to a rail spur), seasonal access variations (i.e., winter road conditions), and the volume of *wastewater residuals* to be transported. Road transportation is the most common *wastewater residuals* transportation method used in Canada.

The volume of *wastewater residuals* to be transported is determined partially by their water content. Dewatering to increase the solids content of *wastewater residuals,* results in a decreased volume of *wastewater residuals* to be managed. The costs associated with dewatering the *wastewater residuals* should be considered against the costs associated with transporting an increased volume of *wastewater residuals* if dewatering is not used. In regard to land application, liquid or slurried *wastewater residuals* provide additional water to the soil which may be beneficial in arid regions. However, dewatered *wastewater residuals* are typically easier to transport and store as the increased solids content reduces the possibility of spillage and facilitates stockpiling. Additional information on the management of liquid versus dewatered *wastewater residuals* is provided in the British Columbia *Land Application Guidelines for the Organic Matter Recycling Regulation and the Soil Amendment Code of Practice - Best Management Practices* (BC Ministry of Environment/SYLVIS, 2008).

When transporting *wastewater residuals*, it is vital to comply with applicable safety and regulatory policies. Considerations include transportation requirements such as containment/covering, weight restrictions, spill prevention measures and designated transportation hours. To comply with road and vehicle weight restrictions, knowledge of the bulk density of *wastewater residuals* is required to calculate the volume of*wastewater residuals* that can be safely transported, and the number of vehicles required. Another component of *wastewater residuals* transportation is spill prevention. A spill prevention plan should be put into effect before commencing *wastewater residuals* transportation and all drivers should be aware of the spill prevention plan. Spill prevention plans may include information on *wastewater residuals* quality, and procedures for containment, clean-up procedures (site, equipment, trucks etc.) and notification in the event of a spill. A spill kit should be on board each transport vehicle and the cleanup protocol should be effectively communicated.

Logistics of *wastewater residuals* delivery can be determined according to site and recipient operator hours, daylight and avoidance of peak traffic hours. If the delivery site is near residences, it is important to plan for deliveries such that truck traffic noise and dust is minimized. Where *municipal biosolids* or *treated septage* will be applied for several days or weeks near a populated area, the local community should be informed of the plan to transport *wastewater residuals* and efforts should be made to avoid affecting the community. In such instance, a public awareness program should be implemented so that the public has the opportunity to consult on the *wastewater residuals* transportation plan and the *wastewater residuals* management plan in general. Transport vehicles should be kept clean at all times to avoid transferring the *wastewater residuals* onto road ways and other unintended areas.

2.5.2 Area Delineation

Area delineation is an important consideration in planning for the operational management of *wastewater residuals*. Area delineation refers to the designation of residual application areas, stockpile areas, *buffers* and *setbacks*. Maps should be produced showing the location of sensitive areas (water resources for example), areas designated for land application and stockpiling, and *buffer* distances and *setbacks* separating the application and stockpile areas from the sensitive areas. These areas should be physically and clearly marked on the site (using stakes for example) to ensure that applications occur as planned. Transport delivery drivers should be informed of stockpile areas and site procedures. Signage, providing a contact name and phone number for further information, should be posted and it should designate where the stockpiling and/or application is to occur.

2.5.3 Stockpiling and Storage

In some land application programs stockpiling is done to develop an inventory of *wastewater residuals* for land application. Stockpiling is a short-term, interim activity prior to land application and should not be used as a long-term management method.

Considerations for *wastewater residuals* storage are:

- *wastewater residuals* form and quantity which relates to the potential for runoff, leaching, and fugitive or point source emissions
- *wastewater residuals* quality including odour and *vector* attraction potential
- proposed length of time for storage of the *wastewater residuals* and the effects of seasonal climate variations
- spontaneous combustibility
- public access to the site

- site specific factors such as topography, soil characteristics, presence of flora and fauna, current and neighbouring land use.

Stockpiling must be completed in a manner that prevents the movement of *wastewater residuals* outside of the stockpile area. The characteristics of *wastewater residuals* local climate and legislation influence containment requirements. A contained vessel such as a lined lagoon or sealed, leak-proof tank may be required for liquid *wastewater residuals* while berms and an impermeable surface may serve to contain dewatered *wastewater residuals*. Covering the stockpile may be required in areas with significant precipitation (rain or snow) to prevent the ingress of water and the egress of *wastewater residuals*. In addition, materials may be combustible under certain conditions, undergo self-heating and spontaneous combustion (e.g., from heat generated during microbial decomposition). Management plans should be developed to prevent this occurrence and contingency plans should be put in place to respond appropriately. Refer to provincial/territorial/federal standards, requirements or guidelines for stockpiling and storage restrictions.

When selecting a location for stockpiling *wastewater residuals*, site characteristics and sensitive features such as surface water and wells (groundwater) must be considered for environmental protection. A contingency plan must also be developed to identify actions to be taken in the event of a spill to avoid adverse effects.

2.5.4 Odour

As discussed in Section 2.3.1.4, odours can be mitigated but may not be entirely removed from *wastewater residuals*. Different forms of *wastewater residuals* exhibit different levels of odour potential. When research participants in a Québec study (Groeneveld and Hébert, 2007) were asked to compare the smell of *wastewater residuals* to the smell of manure the following were observed:

- compost had low odour; the odour was less than the odour associated with dairy cattle manure

- dried, lagoon stabilized (for greater than or equal to 4 years) and lime treated *municipal biosolids* had an odour similar to dairy cattle manure

- *municipal biosolids* from biological treatment had a more offensive odour than dairy manure but was less offensive than pig manure

- *municipal biosolids* from anaerobic digestion which were then mechanically dewatered with a high speed centrifuge had a more offensive odour than pig manure (Rupke, 2005).

It is important that site operations be managed to minimize odours. Odours are an important issue with regard to public perception and are typically considered to be a nuisance concern rather than a health or an environment related concern.

Considerations in managing odours in land application programs include:

- prevailing wind direction and velocity
- proximity to receptors (e.g. nearby residents)
- *wastewater residuals* quality
- application techniques
- covering of *wastewater residuals* and
- air quality control due to potential fire hazard – dust or pellets through drying processes (Rupke, 2005).

An odour management plan should be implemented specific to the land application project. The odour management plan should include a communications plan and contact person, operating procedures, risk management policies, and information on the characteristics and quality of the *wastewater residuals*.

2.5.5 Application and Application Rate Calibration

Application rates are typically expressed in dry tonnes of *municipal biosolids* or *treated septage* per hectare to account for fluctuations in moisture content. To determine the dry weight of *municipal biosolids* and *treated septage*, the wet weight is multiplied by the solids content.

For example, if the *municipal biosolids* and *treated septage* are 15% solids and there are 2,000 tonnes of *municipal biosolids* and *treated septage* (on a wet weight basis) there are 300 dry tonnes of *municipal biosolids* and *treated septage* (0.15 * 2,000 wet tonnes = 300 dry tonnes).

Application rates should be calculated based on the nutrient requirements of the crop and the concentration of nutrients provided by the *wastewater residuals*. For nutrients that exist in *organic* form (e.g., nitrogen) the mineralization rate should also be accounted when application rates are determined. Additional considerations include the addition of trace elements to the soil and fertility of the soil where the *municipal biosolids* and *treated septage* is to be applied.

Predicted trace element soil concentrations after application should be calculated to protect soil quality and ensure compliance with local regulations. Applications may be prohibited if the soil trace element concentration is close to and/or predicted to exceed maximum allowable soil trace elements concentrations which are prescribed in most jurisdictions. These parameters should be included in the nutrient management or land application plan.

For example the British Columbia *Land Application Guidelines for the Organic Matter Recycling Regulation and the Soil Amendment Code of Practice*: *Best Management Practices* provides additional information on calculating application rates. Provincial/territorial regulations or site-specific regulatory mechanisms such as permits may impose a maximum application rate.

Once the *municipal biosolids* and *treated septage* application rate has been determined, application may commence. Applications should be undertaken such that a uniform application is achieved and all areas within the application area receive equal amounts of *municipal biosolids* and *treated septage*. Areas within the application area boundary should not be missed, and *municipal biosolids* and *treated septage* should not be double applied in any area. This requires familiarity with the application equipment. The width of the spread of the application equipment should be known and consistency (uniform spread patterns, discharge rates, speed, spreader revolutions etc.) should be maintained. For sub-surface injection, the nozzle pressure should be consistent to achieve a uniform application rate. The *Alberta Guidelines for the Application of Municipal Wastewater Sludge to Agricultural Lands* contains detailed instructions on equipment calibration for land application.

The topography of the application area must be considered to minimize the environmental risks while optimizing the operational success. Steep slopes encourage movement and provide challenges for application equipment. Low lying areas surrounded by sloped areas may serve to mitigate migration; however, this may promote redistribution of *municipal biosolids* constituents to low lying areas and ponding of surface water during precipitation events.

2.5.6 Incorporation

Incorporation refers to introducing the *municipal biosolids* and *treated septage* into the soil rather than leaving the *municipal biosolids* and *treated septage* on the soil surface. Incorporation may be accomplished through tillage, deep row burial or injection into the soil. Incorporation often occurs after the *municipal biosolids* and *treated septage* have been applied to land. If incorporation is practiced, very little of the residual should be visible on the soil surface once incorporation is complete.

Whether incorporation is required depends on the land use, quality of the *municipal biosolids* and *treated septage* and applicable standards, requirements or guidelines. Incorporation may be beneficial for agricultural applications but not feasible in forestry applications to mature stands. Incorporation is typically recommended for *municipal biosolids* and *treated septage* which are more odorous or has higher *pathogen* concentrations. Advantages of incorporation are that it minimizes *vector* attraction and odour, provides access to soil microorganisms which enhances biological reactions, and reduces the potential for nutrient loss through volatilization, wind movement or runoff. Disadvantages of incorporation are that it is not suitable for areas which are already vegetated (mature forest stands for example), movement or loss of nutrients if the incorporation depth is deeper than the rooting zone, and placement of nutrients closer to the groundwater table (although incorporation mitigates surface movement and protects surface water) and it costs more than other application methods.

Provincial/territorial standards, requirements or guidelines may impose minimum time frames in which *municipal biosolids* and *treated septage* must be incorporated and minimum incorporation depths.

2.6 Special Considerations Relating to a Specific Use Opportunity

In addition to management considerations identified in Sections 2.3, 2.4 and 2.5, there are special considerations that are identified as "use specific" considerations. These considerations are specific to the proposed *beneficial use* option: agriculture, forestry, reclamation and fabricated growing media (topsoil).

2.6.1 Agriculture

Beneficial use of *municipal biosolids* and *treated septage* in agriculture is complex, due to the unique requirements of the wide array of crop types and land application techniques that occur Canada-wide. Important agricultural considerations are:

- agronomic (for crops)
- food safety and animal health.

The following subsections deal with each of these concepts individually.

(a) Agronomic Considerations

An agrologist, biologist or other qualified person who has knowledge of agriculture and of *municipal biosolids* and *treated septage* plays an important role in land application programs. Such qualified persons can determine application rates and identify the measures that must be taken to minimize the risks to human, animal and environmental health. Most aspects of the preceding sections regarding management considerations and environmental considerations are components of a land application project or program that require the skills of a qualified professional in the planning and supervision stages.

Most agricultural applications are based on the nutrient requirements of the crop, mineralization rates of the nutrients or the soil conditioning properties afforded by the *municipal biosolids* and *treated septage*. Once optimum nutrient (or agronomic) rates are determined, the quantities of micronutrients, trace elements, and salts are examined to ensure that the health of the crop would not be adversely affected by the co-addition of constituents. Incorporation of the *municipal biosolids* and *treated septage* maximizes the distribution and retention of nutrients in the soil.

(b) Food Safety and Animal Health Considerations

The effects of *municipal biosolids* and *treated septage* application to forage land have been extensively examined by several research teams over the past 15 years. Research undertaken to date suggests that direct land application of *municipal biosolids* and *treated septage* to grazed land has not demonstrated any significant adverse effect on animals. One study, looking at human and animal health on 47 farms receiving *municipal biosolids* and *treated septage* and 46 control farms not receiving *municipal biosolids* and *treated septage* in Ohio, concluded that the risks of respiratory or digestive illness, as well as general symptoms, were not significantly different between the *municipal biosolids* and *treated septage* farms and control farms to crop production, and to the environment (Apedaile, 2001). This research is supported by over 17 years of land application to dryland ranches in the Pacific Northwest of the United States and Canada, among other places. *Municipal biosolids* and *treated septage* have been successfully applied to cut and carry forage grass crops, wheat, corn, barley, oats, canola, triticale, rye, and vegetable crops (Apedaile, 2001).

When *municipal biosolids* and *treated septage* are applied to agricultural land, waiting periods prior to harvesting crops or grazing animals must be considered to minimize the risks to human and animal health. The implementation and duration of waiting periods are influenced by the quality of the *municipal biosolids* and *treated septage* that are applied. Waiting periods are also included in some provincial/territorial standards, requirements or guidelines (British Columbia and Ontario for example; refer to Appendix 2 for access to provincial/territorial legislation).

Information Highlight

Waiting periods are used to increase the protection to human and animal health

Depending on the quality of *municipal biosolids* and *treated septage,* the method of application, and the type of crop grown, a waiting period following land application may be implemented. During the waiting period domestic animal grazing or planting and harvesting of crops for human consumption may be restricted or prohibited to allow time for further degradation of the wastewater residuals to further protect human and animal health.

Information Highlight

Protection of the Canadian food supply

Maintaining the safety of the Canadian food supply is a shared responsibility among government, industry and consumers. The Food Directorate of Health Canada is the main organization responsible for developing policies, guidelines and regulatory standards for the safety and nutritional quality of all foods sold in Canada. The Canadian Food Inspection Agency (CFIA) administers and monitors compliance with these standards.

Although the CFIA does not specifically monitor or trace foods grown on land treated with biosolids, there are a number of monitoring programs that analyze food for chemical and microbiological contaminants before they reach the consumer market. For further information on these programs, please consult the CFIA website.

There are tools which ensure the constant improvement of biosolids quality, protecting the environment and protecting the food supply. These include source control programs and bylaws; federal, provincial and territorial regulations; and, the restriction of pollutants under the *Canadian Environmental Protection Act* (CEPA).

As such, the protection of the food supply is administered at both ends of the crop production continuum: the inputs (fertilizer) and outputs (food).

2.6.2 Forestry

Forestry and agroforestry are under-represented as options for *municipal biosolids* and *treated septage* management throughout Canada, and yet are some of the largest potential areas, both in terms of land mass, and areas with specific nutrient requirements that would benefit from significant productivity improvements through judicious *municipal biosolids* and *treated septage* use. Wildlife health is a consideration, but long-term studies in areas of forest-based *municipal biosolids* management have not demonstrated any significant toxicological effects on endemic wildlife health (Henry, 2011).

Additional considerations include:

- nutrient requirements
- application timing
- forest practices codes
- forestry type (intensity) and
- opportunities for forestry-based reclamation.

(a) Nutrient Requirements

Key considerations in forestry are, in the first instance, similar to agriculture in that nutrient requirements are the first mechanism used to determine proposed rates. Foresters and agrologists are thus the best local sources of information regarding specific nutrient deficiencies and areas for productivity gains. Forest fertilization with nitrogen and phosphorus often requires that sulphur and boron also be added. *Municipal biosolids* and *treated septage* typically provide nitrogen and phosphorus as well as sulphur and boron. In addition, the mineralization rates of *organic* nutrients, such as *organic* nitrogen, should be taken into consideration when determining application rates for forest fertilization.

(b) Application Timing

Forestry is a long-term cyclical industry, depending on rotations that may extend 50 years or more. With this in mind, timing of applications to achieve maximum growth and yield benefits may differ from timing to achieve maximum profitability benefits. Other timing options are used to produce different outcomes, including:

- applications to encourage green-up or 'free to grow' status (where trees are considered self sustaining and have out-competed understory growth)
- fertilization or incorporation to correct specific macro- or micronutrient deficiencies
- opportunistic, low-cost fertilization spread only from roadways or skid trails.

(c) Forest Practices Codes

In most provinces, forest practices are usually codified in law. An understanding of how *municipal biosolids* and *treated septage* fit into the particular provincial or territorial forestry code, through amendment, fertilization, reclamation or other mechanisms, is required to understand the *municipal biosolids* and *treated septage* opportunities available to landowners and producers. Registered Professional Foresters, Agrologists, or other Qualified Professionals should assist with ensuring compliance.

(d) Forestry Type

There are many different methods of forestry, and with these methods come different *municipal biosolids* and *treated septage* use opportunities. Biomass forestry (also considered biomass agriculture), intensive forestry for pulp production, chipwood production, pest incursion salvage, and sawlog production all have different objectives in terms of growth and yield, wood quality and density, and stand management prescriptions. It follows naturally then, that these methods of managing forests will use *municipal biosolids* and *treated septage* differently. These uses are best determined by agrologists, biologists, and foresters involved in day-to-day forest management.

(e) Opportunities for Forestry-based Reclamation

Besides fertilization for forest productivity, there are also multiple opportunities for *municipal biosolids* and *treated septage* use in forest tenures that feature characteristics more akin to reclamation objectives than fertilization. *Municipal biosolids* and *treated septage* can and should be considered when forestry management requires the following actions in the course of operations:

- summer/winter road reclamation and replanting
- skid site rehabilitation and
- addition/incorporation of *organic matter* after fire.

Summer or winter roads are dedicated, short term roads that are installed in a forest block to obtain better access for harvesting and re-planting the area. Once the block entry is complete, these roads are often reclaimed and replanted to add to the forest productive areas. Their construction removes valuable *organic matter* and mineral soils, which cannot always be replaced, making *municipal biosolids* and *treated septage* amendment during the reclamation a valuable augmentation to the process.

Skid sites are temporary pads for the logs that are harvested from an area, and a place where they are prepared and managed for transport. Proactive forestry generally espies benefits in economically returning many of these areas to productivity, rather than leaving them in perpetuity for the next harvest, which can be over a generation away.

Severe forest fires can reduce the *organic* and nutrient concentration in the soil, reducing productivity of a once fertile system to marginal status. A proactive *organic matter* and nutrient replacement regime for these areas, through *municipal biosolids* and *treated septage* application, provides these systems with the head start they require for rapid rejuvenation. These special considerations require the cooperation of proactive forest managers, but may provide superior opportunities for *municipal biosolids* and *treated septage beneficial use*.

Case Study: Durham, ON Tree-Nursery Enhancement Project

A field-scale "Tree-Nursery Enhancement Project" was initiated at a tree nursery in the Regional Municipality of Durham, in Ontario in 2007 involving *municipal biosolids* from the region. It is a joint initiative between Durham Region, a land application company and a wholesale nursery. In 2010, the tree nurseries represented approximately 10% of Durham Region's landbase, or 260 hectares. The *municipal biosolids* application sites are approved by the Ontario Ministry of the Environment. Specialized equipment is used to apply anaerobically digested liquid *municipal biosolids* near the base of young trees. A low (approximately 60 m^3/ha) application rate satisfies the 45 kg/ha/year N requested by nurseries, allowing up to three applications over five years while keeping within the 135 kg/ha N Ontario approval limitations. The significant improvements in soil tilth have resulted from *municipal biosolids* application. This project is an effective complement to Durham's traditional land application program, allowing summer month applications when other crops are planted and inaccessible. Based on the Durham experience, there is potential for tree-nurseries to become significant users of Ontario *municipal biosolids* in the future.

2.6.3 Reclamation

Wastewater residuals, particularly *municipal biosolids*, have been used to reclaim areas which have been disturbed through mining and other industrial activities. Special considerations for the use of *municipal biosolids* in land reclamation include:

- subsequent and future land use
- application rates
- logistical/operational challenges for application equipment and
- trace elements, *pathogens*, substrate chemistry and the effect of *municipal biosolids* additions on the disturbed land substrate.

When applying *municipal biosolids* for reclamation purposes the subsequent and future land use must be taken into consideration. An area with industrial activities today may be used for commercial, recreational, agricultural or residential activities in the future. The land application of *wastewater residuals* should not impact future land use opportunities.

The soil in disturbed areas is often either lacking or is of poor quality for vegetation establishment and growth. To promote soil development in disturbed areas, higher than agronomic *municipal biosolids* application rates have been used; these are typically one-time applications to meet reclamation objectives. Application rates should be selected in accordance with applicable legislation and in recognition of subsequent, future and neighbouring land use. The effects of application rates which are substantially higher than agronomic application rates on ground and surface water must also be considered as higher application rates can present increased risk for negative environmental impacts if the considerations are not properly assessed.

Areas requiring reclamation include aggregate quarries and open pit mines characterised by steep and varied topography. Consideration should be given to the type of application equipment used to apply the *municipal biosolids*; various pieces of equipment may be used on the same site depending on the local topography. Tailings ponds at mineral mines can also provide a challenge as clay lenses can develop which retain water and make the operation of the application equipment challenging.

The addition of *municipal biosolids* can alter the pH of the substrate effecting trace element availability. Consideration should be given to the concentration of trace elements in the *municipal biosolids* and the receiving environment as well as to the pH as an increase in trace element availability can impact vegetation and the health of grazing animals. *Municipal biosolids*, particularly those with a high pH as a result of lime treatment process, have been used to successfully mitigate acid mine drainage.

2.6.4 Fabricated Growing Media

Some jurisdictions allow for the production of growing media using *municipal biosolids*. Depending on the quality achieved and the applicable legislation, growing medium may be distributed without restriction or subject to various regulatory mechanisms. Additional information on fabricating a *municipal biosolids* growing media can be found in Section 2.2.4.

The following considerations relate to the development of fabricated growing media using *municipal biosolids* and *treated septage*:

- feedstock quality
- consistency
- mixing technology and
- marketing.

The objective in fabricating growing media using *municipal biosolids* and *treated septage* is to create a soil which is similar to other fabricated soils with respect to aesthetics, odour, consistency and performance.

The quality of fabricated growing media depends on the quality of feedstock used in its production, the relative ratio of feedstock ingredients and the mixing technology employed. Feedstock quality includes *wastewater residuals* as well as other feedstock which are typically a carbon source such as wood waste, peat or compost and a mineral source such as sand. Feedstock should not contain foreign matter such as glass, plastics, metal and other materials which are not normally found in soil. The selection of feedstock is determined in part by the intended use of the fabricated growing medium. For example, the topography of the application area will influence the desired soil characteristics; soil applied to a slope will require more structural cohesiveness. Fabricated soil must be uniform, consistent and reliable in odour, appearance and performance. Characteristics that reduce the aesthetic quality of the soil include:

- excessive plasticity leading to aggregate formation (clumping)
- odour
- visible feedstock ingredients such as wood or sand
- heterogeneity such as aggregates of *municipal biosolids* and *treated septage* and
- discolouration caused by the selection of feedstock ingredients or an imbalance in the ratio of ingredients.

These characteristics can be mitigated by selecting appropriate feedstock ingredients, mix ratios and mixing technologies. Mixing technologies include screens, hammer mills, tub mixers and bottom buckets. Considerations in selecting an appropriate mixing technology include the ability of the technology to:

- contend with the cohesive property of polymer-treated mechanically dewatered *municipal biosolids* and *treated septage* which have a high plasticity and tend to clump if the technology is inappropriate
- produce sufficient mechanical force to adequately mix the feedstock to provide a homogeneous product and
- produce a fabricated soil that is uncontaminated by oil and grease.

Once the fabricated soil has been developed, marketing is a key consideration. It is discussed in section 4.2.2.4.

2.7 Limitations on Land Application

There are situations when land application is not appropriate either temporarily (for example due to seasonal variations) or over the long-term (for example due to the characteristics of the *municipal biosolids* and *treated septage*). Limitations on land application include:

- high groundwater table or challenges in protection of water resources (e.g. due to steep topography and neighbouring water resources)

- high background (soil) concentrations of nutrients, trace elements and other constituents where land application would exacerbate the condition

- inappropriate climatic conditions such as frozen soil, snow or heavy rain

- indication that an input to the *wastewater residuals* stream is likely to cause a contaminated site if land applied (for instance knowledge of an industrial process discharging to the wastewater system)

- lack of available land base for the entire volume of *municipal biosolids* and *treated septage* produced (may be a challenge for larger municipalities with a large urban centre)

- *pathogen* concentrations not managed through treatment or management methods.

Knowledge of *municipal biosolids* and *treated septage* quality and an assessment of the proposed application area by a qualified professional are required to ensure these limitations are identified if present.

Focus on Beneficial Use

Special considerations in forestry applications include application timing, forestry type and compliance with forest practices.

PART 3: COMBUSTION

Combustion is a generic term used to describe the sequence of exothermic chemical reactions between a carbonaceous material (fuel) and an oxidant accompanied by the production of heat and conversion of chemical species. Combustion includes incineration and *gasification* with or without energy recovery. Complete combustion is almost impossible to achieve. Combustion reactions achieve equilibrium which results in a wide variety of major and minor species such as carbon dioxide, carbon monoxide, elemental carbon (soot or ash), and other gaseous or solid components (elements or chemical compounds). For instance, all combustion with air (78% nitrogen), and particularly combustion of a nitrogen rich residual such as *municipal sludge* in atmospheric air, will also create several forms of nitrogen oxides including nitrous oxide (N_2O) which is 310 times as potent as carbon dioxide in terms of its global warming potential (CCME, 2009).

Combustion of *wastewater residuals* that results in a positive energy balance and recovery of ash is a viable *beneficial use* management option. One of the benefits of combustion is that *wastewater residuals* (typically *municipal sludge* and untreated *septage*) that do not meet quality requirements for land application can be used. An advantage of combustion is that unlike land application which requires that the *municipal sludge* be treated to *municipal biosolids* standards for *beneficial use*, *municipal sludge* (and untreated/raw *septage*) does not require treatment or *stabilization* prior to combustion. This can reduce the costs associated with management of *municipal sludge* and *septage*.

As with land application there are benefits and risks associated with the combustion of *wastewater residuals* and considerations to mitigate those risks. Combustion is considered a *beneficial use* of *wastewater residuals* if key requirements are met:

- combustion meets all relevant jurisdictional air quality standards
- there is a positive energy balance through the combustion of the residuals
- significant ash recovery and utilization and
- low stack emissions of nitrous oxide and other contaminants.

If these criteria (as specified below) are not met, then combustion of *wastewater residuals* is not considered a *beneficial use* as defined by *CCME*. Where these criteria are met, some jurisdictions may also consider the combustion of *municipal biosolids* as a source of renewable energy.

Information Highlight
Greenhouse gas effects of nitrous oxide

Nitrous oxide (N_2O) is a greenhouse gas produced naturally during the processes of nitrification and denitrification carried out by microorganisms in the soil and anthropogenically during the combustion of nitrogen containing fuels which include *wastewater residuals*. N_2O is a potent greenhouse gas; its potency is 310 times higher than carbon dioxide (CCME, 2009). A literature review completed by Barton and Atwater (2002) found that increasing the temperature during combustion of *municipal sludge* may decrease the N_2O formation; literature presents variable results on whether or not there is a corresponding increase in NOx due to the high temperature required to reduce N_2O. Temperature is considered to be an effective surrogate monitoring tool for N_2O (Suzuki, 2008).

3.1 Properties of Wastewater Residuals that Enable Positive Energy Balance

Only combustion systems that produce a positive energy balance (produce more energy than they use) are supported as a *beneficial use* of *wastewater residuals* by *CCME*. Some *wastewater residuals* can be beneficially used for their heat value. The heat value of *wastewater residuals* is dependent on water content and the level of treatment they have undergone prior to combustion. On a dry weight basis, undigested *municipal sludge/septage* has a higher heat content than digested *wastewater residuals* that lose volatile compounds during the digestion process (Table 6). Consequently, raw *municipal sludge* is preferred to digested *municipal biosolids* for combustion. Mechanical dewatering of primary *municipal sludge* also generally achieves less water content. Jurisdictions such as Montréal and Longueuil, Québec generally do not have an extended digestion step in their wastewater treatment processes that allow the retention of volatile solids and optimize the heat value of the undigested wet *municipal sludge*.

Organic matter is combustible, provided the water content of the material is less than 65-70%. When the moisture content is greater than this limit, *organic matter* is not auto-combustible and supplemental energy must be used to combust the material. Conventional dewatering equipment at wastewater treatment facilities can produce *wastewater residuals* with total solids contents of 20-35% (65-80% moisture) (Tchobangolous et al., 2003). Additional energy would be required to produce sufficiently dry *wastewater residuals* for combustion which may make the overall thermal treatment process (drying and combustion) of *municipal sludge* endothermic rather than exothermic. Only some specific combinations of *municipal sludge* and dewatering equipment may provide more than 30% total solids. An exception to the requirement for further drying of the material is fluidised bed combustion, which can accept *wastewater residuals* down to 28% total solids.

In order to achieve a positive energy balance, the calculations have to demonstrate that the energy actually recovered from the burning of *municipal sludge* (electricity and/or steam) for beneficial uses (e.g. heating buildings and digesters, selling steam or electricity) exceeds the external energy supplied for thermal treatment of the sludge (power from the grid, supplemental fuel for drying or supporting combustion of *municipal sludge* or for treatment of combustion gases). For the purposes of energy balance, internal use of energy produced from combustion of *municipal sludge* to support combustion (drying of sludge prior to combustion) or treatment of the combustion gases is not considered energy produced. Table 6 provides heat values for dry *municipal sludge* and *municipal biosolids*.

Table 6: Heat values for dry *municipal sludge* and *municipal biosolids*.

Type	Heat Value Range (kJ/kg of total solids)
Raw primary *municipal sludge*	23,000 – 29,000
Activated *municipal sludge*	20,000 – 23,000
Anaerobically digested primary *municipal biosolids*	9,000 – 14,000
Raw chemically precipitated primary *municipal sludge*	14,000 – 18,000
Biological filter	16,000 – 23,000

Adapted from Tchobanoglous et al., 2003

Note: These values apply to dried materials only. However, dewatered *municipal biosolids*/*municipal sludge* typically contain 70-80% water, hence significantly reducing heat value for non dried materials

3.2 Beneficial Use of Ash from Combustion of Wastewater Residuals

Fly ash generated from combustion may be used as a fertilizer supplement or land applied to ameliorate acidic soil conditions. If the ash contains contaminant concentrations that do not allow its recovery as a plant nutrient or a soil conditioner, ash may be used in industrial processes e.g. as a supplementary cementing material in cement manufacturing to expand production capacity, reduce CO_2 emissions and reduce fuel consumption by using it as a recycled lime substitute. In this case the ash is added to the raw cement during the grinding stage. The recovery of a significant portion of the ash (> 25%) must be accomplished for combustion to be considered a *beneficial use*.

3.3 Management Consideration #1 – Monitoring the Quality of Wastewater Residuals

Combustion of *wastewater residuals* should be accompanied by ongoing monitoring of the *wastewater residuals* as per jurisdictional standards, requirements or guidelines. Jurisdictions should also assess the combustion process and determine whether or not there is a need to make changes to emissions control equipment or its operation.

The parameters to be monitored in the *wastewater residuals* include:

- trace element concentrations
- moisture content and
- heat value.

Trace element concentrations in the *wastewater residuals* are important from the perspective of atmospheric emissions and ash quality. Increasing trace element concentrations in the *wastewater residuals* may lead to increased trace element concentrations in the ash and may result in increased trace element concentrations in the stack emissions. An elevated trace element concentration in the ash has implications on how the ash is managed. Elevated trace element concentrations may dictate that the ash be disposed of or utilized in industrial processes rather than land applied as a phosphorus fertilizer or a soil amendment. Elevated trace element concentrations in stack emissions can lead to increased costs associated with stack emission pollution control, i.e. need for additional air pollution control equipment, increased use of consumables, and potential need for wastewater treatment if wet collection devices are used.

Conventional dewatering equipment at wastewater treatment facilities can reduce the moisture content of *wastewater residuals* to 65-80% moisture, as noted earlier. The implementation of additional thermal drying technologies can further reduce the moisture content of the *wastewater residuals*. In evaluating the need for additional drying, the costs of operating the drier must be weighed against the decrease in fuel requirements for combustion to determine the economical feasibility of implementing this additional process and whether or not a positive energy balance is achieved.

Ongoing monitoring of the heat value of the *wastewater residuals* also assists in determining if combustion of *municipal sludge* remains exothermic, and is recommended if the system is only marginally exothermic. Understanding the heat value of the *wastewater residuals* enables facility operators to optimize process conditions and make adjustments in response to changes in the quality of the feedstock (i.e. *wastewater residuals*).

3.4 Management Consideration #2 – Environment

To be considered beneficial *wastewater residuals* management, combustion must be protective of the environment and public health, as well as contribute an environmental benefit such as energy production while ensuring that combustion of the *wastewater residuals* will not have an adverse effect on the environment.

The main environmental considerations in connection with combustion facilities include:

- atmospheric emissions, including noise and odour
- wastewater/cooling water discharges (if applicable)

- site suitability and
- ash management.

A discussion of each of these aspects of environmental protection is provided below.

3.4.1 Atmospheric Emissions

A primary concern relating to combustion with respect to environmental protection is the management of emissions which include greenhouse gases and other constituents. Understanding the characteristics of feedstock and the air emission regulatory requirements will facilitate the implementation of appropriate pollution control systems.

Constituents emitted to the air from combustion facilities include:

- particulate matter
- volatile and semi-volatile *organic* compounds , including dioxins and furans
- metals, including mercury
- hydrogen chloride
- sulphur dioxide
- nitrogen oxides (NOx), and nitrous oxide (NO) which is a potent greenhouse gas and
- carbon monoxide and carbon dioxide.

Currently, Canada-wide Standards exist for emissions of mercury and dioxins and furans from waste combustion, including *municipal sludge* combustion. The Government of Ontario has adopted these standards and has published Guideline A-8 "Guideline for the Implementation of Canada-wide Standards for Emissions of Mercury and of Dioxins and Furans and Monitoring and Reporting Requirements for Municipal Waste Incinerators, Biomedical Waste Incinerators, Sewage Sludge Incinerators, Hazardous Waste Incinerators, Steel Manufacturing Electric Arc Furnaces and Iron Sintering Plants" (Ontario Ministry of the Environment, 2004).

Historically combustion has been identified as a significant source of emissions of these constituents. The Canada-wide Standard for Mercury Emissions (CCME, 2000) set a numeric target for mercury emissions specifically from *municipal sludge* combustion of 70 micrograms per reference cubic metre ($\mu g/Rm^3$) for new or expanding facilities, and existing facilities. A reference cubic metre refers to the volume of dry gas at 25°C, 101.3 kilopascals pressure and 11% oxygen.

The Canada-wide standard for dioxins and furans (CCME, 2001) sets numeric targets for new or expanding facilities and existing facilities from sewage *municipal sludge* combustion of 80 picogram International Toxicity Equivalent per m^3 (pg I-TEQ/m^3) and 100 pg I-TEQ/m^3 respectively. A summary of the Canada-wide standards for exhaust gases from the combustion of sewage sludge is provided in Table 7.

Table 7: Summary of Canada-wide Standards for Combustion of Sewage Sludge

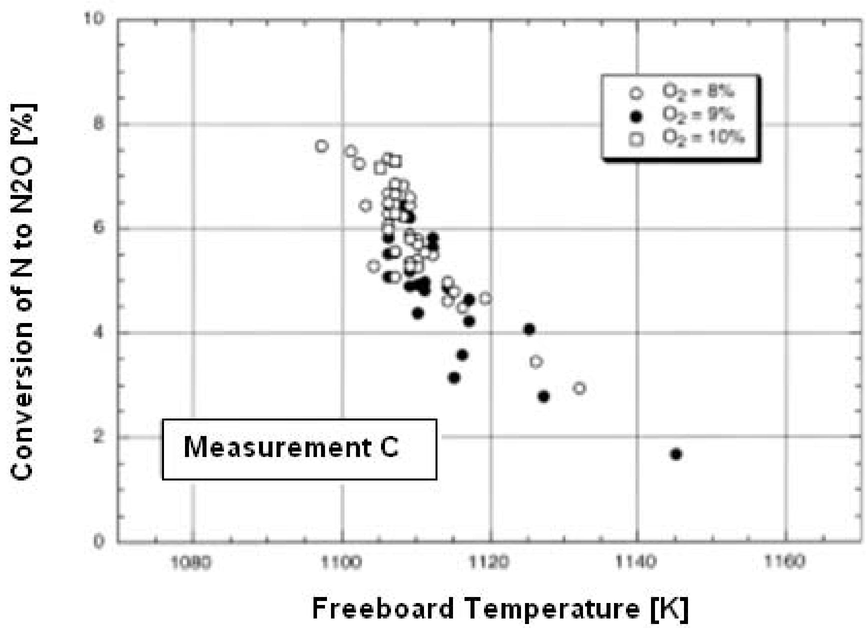
Standard	Criteria
Canada-Wide Standards for Mercury Emissions	
Existing facilities – maximum concentration in exhaust gases	70 µg/Rm^3[a]
New facilities – maximum concentration in exhaust gases	70 µg/Rm^3[a]
Canada-Wide Standards for Dioxins and Furans	
Existing facilities – maximum concentration in exhaust gases	100 pg I-TEQ/m^3
New facilities – maximum concentration in exhaust gases	80pg I-TEQ/m^3

[a]Reference cubic metre (Rm3) refers to the volume of dry gas at 25°C, 101.3 kilopascals pressure and 11% oxygen.

Nitrogen oxides (NOx) include several oxides of nitrogen but in practice the term NOx is often used in connection with the two most reactive forms of oxides of nitrogen, namely nitrogen dioxide and nitrogen monoxide (nitric oxide). NO_x plays an important role in the production of urban smog. Combustion facilities operating at high temperatures must be aware of the potential for NOx production (Suzuki, et al., 2003). Combustion facilities can also release nitrous oxide (N_2O) which is a primary greenhouse gas, approximately 310 times as potent as carbon dioxide. Research has demonstrated that at combustion temperatures less than approximately 880°C (1153 K), nitrous oxide emissions can substantially increase the greenhouse gas emissions from a combustion facility (Suzuki, et al., 2003).

A rate of 2% corresponds to the typical loss of nitrogen when *municipal biosolids* are land applied. It would be a best available technology approach criteria since land application is carbon-neutral and most GHG emissions from incineration come from N_2O (Sylvis, 2009; Brown et al, 2010). Operation at a minimum combustion temperature of 880°C is considered the best technique to reduce nitrous oxide emissions from combustion of *wastewater residuals*. However, this minimum temperature is seldom achieved with combustion of wet *wastewater residuals*, such as most dewatered *municipal sludge*.

Figure 2: Percentage of nitrogen from *municipal sludge* transformed into N_2O gas according to combustion temperature (K) from fluidized bed incinerators in Japan (Suzuki et al., 2003).



Modeling undertaken using these data within the BEAM shows that GHG emissions from a Canadian wastewater treatment facility that burns primary *municipal sludge* (30% d.m.) at 760 °C are greater than 1.5 t CO_2-eq/ dry ton (CCME, 2009). These emissions were mainly due to N_2O. These N_2O emissions are much higher than default values from the Intergovernmental Panel on Climate Change (IPCC) but correspond to actual N_2O emissions measured from a Canadian *municipal sludge* incinerator (CCME, 2009). Decreases in GHG emissions from *municipal biosolids* combustion systems were observed as operating temperatures increase from 760 to 880 °C, with the use of auxiliary natural gas (CCME, 2009). Emissions further decrease with the burning of *municipal sludge* pellets at higher temperatures in a cement kiln (CCME, 2009).

Minimizing GHG emissions is an important environmental aspect of combustion of *wastewater residuals* rich in nitrogen. It is also important to note that both emissions of N_2O and *organic* compounds, including dioxins and furans can be mitigated by maintaining a high combustion temperature (> 880 °C) together with a reasonably long retention time at that temperature. However, to achieve this temperature one may need to use supplementary fuels from external sources, hence reducing or eliminating the positive energy balance.

Emissions of particulate matter, including most metals, from *municipal sludge* combustion can be controlled by add-on control equipment. Control of mercury emissions can, however, be more problematic as mercury can be emitted in gaseous or particulate form. Source control initiatives directed at minimizing mercury in wastewaters and hence in *wastewater residuals*, may be an effective strategy to mitigate emissions of these constituents from combustion of *wastewater residuals*. Refer to Section 2.3 for more information on source control.

Selected pieces of international legislation pertaining to the combustion of *wastewater residuals* are summarized briefly below.

International Legislation

The European Union Directive 2000/76/EC on the combustion of waste provides limits on gaseous stack emissions as well as discharge limits for wastewater from exhaust gas cleaning (European Commission, 2001). Regulated stack emission constituents include:

- trace elements
- dioxins and furans
- total dust
- SOx and NOx
- gaseous and vaporous *organic* substances (expressed as total *organic* carbon), and
- hydrochloric and hydrofluoric acid.

The United States Environmental Protection Agency (USEPA) published their Final Rule on Standards for Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Sewage Sludge Incineration Units in March 2011 (USEPA, 2011). This rule expands upon the Code of Federal Regulation (CFR) Part 503 Biosolids Rule which governed *wastewater residuals* combustion facilities and stipulates requirements for pollutant limits for selected trace elements in the *wastewater residuals*, stack emission concentrations of mercury, beryllium and total hydrocarbons or carbon monoxide; and continuous monitoring requirements for stack oxygen concentration, moisture content in stack gas, and combustion temperature. *Wastewater residuals* incinerators are exempt from Part 503 if the auxiliary fuel for the incinerator contains more than 30% municipal solid waste, in which case it is regulated by CFR 40 Parts 60 and 61.

3.4.2 Site Suitability

As with all *wastewater residuals* management options, site selection for a combustion facility is evaluated in consideration of environmental, economic and social criteria. Site suitability considers the distance of the combustion facility from specified features such as water bodies, sensitive habitats, residential use and major thoroughfares as well as the location of the facility within the region. An evaluation of neighbouring land uses and an assessment of stakeholder interests are required to understand the likelihood of social acceptance of a planned facility.

The facility must be sited within a reasonable distance of the wastewater treatment plant such that *wastewater residuals* transportation is not a significant cost. An advantage of combustion is the relatively small land requirement for this option in comparison to the potentially large area required for a land application program. This often enables the establishment of the facility within the wastewater treatment plant property. Siting the combustion facility at the wastewater treatment plant significantly reduces *wastewater residuals* transportation costs and can circumvent some of the challenges relating to facility siting such as concerns with respect to odour issues and aesthetics.

Pelletized dried *municipal sludge* may also be used as a fuel in cement kilns; an example is the pellets produced from Laval (SYLVIS, 2009).

3.4.3 Ash Management

Combustion processes produce fly ash and bottom ash that require management. Fly ash is captured when the gases generated during the combustion of *wastewater residuals* are treated by air pollution control equipment before the exhaust is discharged into the atmosphere through a stack. Combustion of *wastewater residuals* also produces solid residues that contain non-combustible materials as well as some carbonaceous material that is not burnt. Depending on the type of feedstock combusted, bottom ash can contain high concentrations of metals or other substances that can make it unsuitable for beneficial reuse. If this is the case it may have to be disposed of at a landfill. It may happen with the co-burning with wood wastes contaminated with arsenic, copper and cromium or with co-burning with municipal solids waste (MSW). As discussed in Section 3.2, *beneficial use* of a component of fly ash is considered a requisite for the consideration of combustion as *beneficial use*.

Depending on the combusted feedstock, fly ash will contain varying concentrations of base cations and phosphorus which are of value as crop nutrients. Fly ash also has a high pH and can be used as a lime substitute in the amendment of acidic soils. Fly ash from *wastewater residuals* combustion may also contain toxic *organic* compounds such as dioxins and furans as well as metals, such as lead, cadmium and mercury including their compounds. These contaminants may be found in higher concentrations in fly ash compared to bottom ash and therefore, if the ash is unsuitable for agronomic purposes then it may have to be disposed of at a hazardous waste landfill. If the ash is sold commercially as a soil conditioner then it would be required to meet CFIA standards. As with the land application of other *wastewater residuals*, the fly ash application rates should maximize the benefits of the fly ash while being protective of the environment. The pH, macronutrient and trace contaminant concentrations in the ash are considerations in determining the quality of fly ash and the appropriate application rate. To assess ash quality for agronomic purposes, one may refer to the standards BNQ 0419-090: Liming Materials from Industrial Processes (BNQ, 2005). Additional information on the *beneficial use* of fly ash can be found in the Land Application Guidelines for the Organic Matter Recycling Regulation and the Siol Amendment Code of Practice (BC Ministry of Environment/SYLVIS, 2008) and in a literature review by Hébert and Breton (2008).

3.5 Management Consideration #3 – Operations

Transportation, and stockpiling/storage considerations for combustion programs are similar to the considerations for land application programs, refer to Sections 2.5.1 and 2.5.3 respectively.

Several factors must be considered in the operation of *wastewater residuals* combustion facilities. Malfunctions and upset conditions can occur at any thermal treatment facility, including a sewage sludge incinerator. At times these conditions can necessitate shutdown of the incinerator for repair and/or maintenance. Shutdown and subsequent start up of a combustion process are considered transient operating conditions during which the emissions of a number of contaminants may be higher than during normal, stable operating conditions. Therefore, regular and effective preventative maintenance and good operating practices are of utmost importance to minimize the need for shutdowns and start ups.

If the *wastewater residuals* are extremely dry, consideration should be given to the potential explosion/fire hazards during storage.

Combustion facilities often require auxiliary fuel to achieve optimum temperatures or to treat combustion gases. Auxiliary fuel sources include natural gas, fuel oil, wood, and municipal solid waste. These fuels are generally considered during the development phase of a combustion facility. Auxiliary fuel use, including those from renewable forms of energy (e.g. wood chips), can offset the energy produced from combustion of *wastewater residuals* and in some cases results in a negative energy budget.

As discussed in Section 3.4.3, ash produced from combustion must be managed in a manner that is environmentally protective and cost effective. Combustion is considered a *beneficial use* if a significant portion of the ash is recovered. With respect to land application, ash must be transported, stored and land applied following sound management practices. Fly ash is often collected as a fine, dry powder. Wetting of the fly ash prior to transportation and land application can minimize dispersion of the fly ash from the application site, but may provide challenges in land application as the ash can solidify upon wetting.

Table 8 shows a synthesis of technical requirements for combustion of *municipal sludge* to be considered a *beneficial use*. When one of the main objectives is not met, the whole combustion process is not considered a *beneficial use*.

Table 8: Considerations for the *beneficial use* of *municipal sludge* and *municipal biosolids* through combustion.

Objectives	Technical requirements
Emit low levels of nitrous oxides	• continuous temperature monitoring and minimal temperature of combustion > 880 °C, or • regular measurement of N_2O emissions to allow greenhouse gas budgets and < 2% total nitrogen in the sludge/biosolids transformed into N_2O. This criterion is based on best available technology*.
Result in a positive net energy balance	• > 30% dry matter of *municipal sludge/biosolids* to allow auto combustion and exothermic reaction; > 28% for fluidized bed systems. • the overall calculation has to show that the energy actually recovered from the burning of sludge (power or heat), exceeds energy required from external fuels to further dry or combust mechanically dewatered *municipal sludge* or to treat combustion gases from the facility (destruction of *organics*, N_2O, etc.). • the energy produced that is used to sustain the combustion process (heat for drying of sludge after mechanical dewatering) must not be credited in the energy balance calculation
Recover a significant portion of ash or phosphorus	• recover > 25% of ashes or phosphorus as fertilizer, soil conditioner or as cement or another industrial ingredient.

[a]Land application is the best technology for greenhouse gas emissions and is typically < 2% N transformed into N2O emissions (SYLVIS, 2009).

3.6 Limitations on Combustion

There are situations when combustion is not appropriate. Limitations on combustion may include:

- restrictive regional airshed polices
- indication that the emissions from combustion would adversely affect air quality to an unacceptable level or contribute extensively to an already impacted airshed
- lack of options for ash management

An assessment of the proposed combustion facility and the associated by-products (air emissions, ash) by a qualified professional is required to ensure these limitations are identified if present.

Information Highlight

Opportunities for the beneficial use of ash: land application and cement production

As with *wastewater residuals*, there are opportunities for the beneficial use of ash and considerations for use to minimize the risk potential. Use opportunities include the land application of fly ash as a liming agent and the use of ash as a feedstock in cement manufacture.

Focus on Beneficial Use

Fly ash is land applied as a liming agent using a side-discharge spreader.

PART 4: REGULATORY FRAMEWORKS, BEST MANAGEMENT PRACTICES, RESEARCH AND TECHNOLOGY DEVELOPMENT

4.1 Development of Regulatory Frameworks in Canada

Information on federal, provincial and territorial legislative frameworks for *wastewater residuals* was compiled by *CCME*. It can be found in the Review of the Current Canadian Legislative Framework for Wastewater Biosolids (CCME, 2010).

As discussed in Section 1.1.3, there are no Canada-wide standards, requirements or guidelines for *wastewater residuals* management. *Wastewater residuals* management is regulated on a provincial/territorial basis. The extent and type of regulatory mechanism is variable and differs across the country. *Wastewater residuals* represented as fertilizers or supplements when sold and/or imported into Canada are regulated federally under the *Fertilizers Act and Regulations*.

Some provinces/territories do not have *wastewater residuals* specific legislation but rather refer to standards and guidelines produced by other agencies. This Section provides background information for provinces/territories that are considering the development of new legislation or those considering an expansion of their regulatory requirements and guidance on best management practices to include other *beneficial use* opportunities.

This Section provides guidance on the development of regulatory requirements and criteria for the land application and combustion of *municipal biosolids* and *treated septage*. *CCME* does not support the land application of untreated *septage.* Typically regulatory frameworks contain requirements for:

- municipal governance to identify the types of wastewater that may be introduced to the sewer system
- treatment processes and quality of *municipal biosolids* and *treated septage*
- emissions from combustion
- land application and
- monitoring and reporting.

Jurisdictions developing or expanding their regulatory requirements and guidance are encouraged to review the criteria and requirements developed by other jurisdictions in light of best-available science and best management practices and to contact other jurisdictions to learn from their success and challenges in regulatory development and implementation. Examples of international guidelines and best management practices are provided in Appendix 4: Key Legislation Relating to the Use of Residuals.

Attention to terminology should be considered when reviewing other legislative frameworks, particularly from Canadian jurisdictions. Consistency in terminology amongst Canadian legislative frameworks will facilitate Canada-wide dialogue and promote Canada-wide collaboration in *wastewater residuals* management. Terminology in the glossary of this guidance document should be used when possible.

4.1.1 Municipal Governance: Sewer Use and Sewer Bylaws

The first step in any regulatory framework begins with the effective management of what wastewater sources enter the wastewater treatment plant from the sewer system. Municipal governance is the first step in managing residuals quality. By limiting the input of chemical constituents from industry, or re-directing them to specialty management, the influent to the wastewater treatment plant may be significantly improved, resulting in improved outcomes for a *wastewater residuals beneficial use* program.

CCME developed a model sewer use bylaw (CCME, 2009) to assist municipalities in developing this important first aspect of a regulatory framework designed to enhance the quality of the wastewater treatment process and the outcomes of that process. For more information on municipal governance see Section 1.3.

4.1.2 Treatment Processes and Quality of the Municipal biosolids and Treated Septage

The quality parameters/requirements for *municipal biosolids* and *treated septage* typically include criteria for trace elements/heavy metals, *vector* attraction reduction and *pathogen* reduction. The parameters/requirements may specify: the treatment processes used to achieve *vector* attraction reduction (for example a digestion process that reduces the volatile solids concentration by a given percentage) and/or measures of *municipal biosolids* and *treated septage* quality that indicate that treatment has been achieved (for example setting a maximum limit for the specific oxygen uptake rate in *municipal biosolids* and *treated septage*).

Similar requirements are often stipulated for *pathogen* reduction. The regulations may indicate processes to achieve *pathogen* reduction (for example digestion or heat treatment may be specified with criteria for temperature and retention time). Regulations commonly include criteria for maximum *pathogen* concentrations in the *municipal biosolids* and *treated septage* as measured by the concentration of the *pathogen* or indicator organisms: fecal coliform, *Escherichia coli* (*E. coli*) and *Salmonella* are common. *Pathogen* reduction criteria are typically based on best available technology.

In addition to criteria for maximum *pathogen* concentrations, maximum concentrations of trace elements in the *municipal biosolids* and *treated septage* are often stipulated. Regulated trace elements typically include: arsenic, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium and zinc. These elements were selected based on their prevalence in the environment and in *municipal biosolids* and *treated septage*, and their toxicity profiles.

Unregulated metals include aluminum, antimony, asbestos, barium, beryllium, boron, cyanide, fluoride, manganese, silver, thallium and tin. Recent work assessing the fate of these unregulated metals concludes that loadings of these metals are unlikely to exceed effects-based limits developed to ensure environmental safety and protection of public health (WEAO, 2010).

Maximum trace element limits in *municipal biosolids* and *treated septage* are typically based on risk assessments of trace elements in soil coupled with assumptions about *municipal biosolids* application rates. Risk-based guidelines for trace elements in soil have been developed by *CCME* (CCME, 2006). Some jurisdictions have developed risk based guidelines specifically for *municipal biosolids* (USEPA, 1993; UN-HABITAT, 2008). *Municipal biosolids* may not be land applied if soils have reached certain concentrations of trace elements specified by jurisdictions.

Tiered maximum concentration limits, such as the establishment of *municipal biosolids* 'Classes' (Class A or Class B for example), are often used to support source control initiatives. The CFIA has heavy metal standards as well as standards for dioxins and furans that apply to all fertilizers and supplements, including *municipal biosolids* that are intended to be sold in or imported into Canada. The type of opportunities available, the level of benefits and risks, and the magnitude of considerations are directly related to *wastewater residuals* quality. Opportunities are facilitated when the *wastewater residuals* are subjected to increased levels of input control through source control initiatives and increased treatment including *stabilization*, *pathogen* reduction and *vector* attraction reduction. The need for additional risk management measures is inversely related to the quality of the residual; lower quality *wastewater residuals* are subject to increased management considerations. Furthermore, some jurisdictions have criteria for *organic* contaminant (dioxins and furans) concentrations in the product or as a part of site-specific risk analysis.

Legislative frameworks may also include criteria relating to the nutrient concentration of the *municipal biosolids* and *treated septage*. Rather than specific criteria for maximum nutrient concentrations, regulatory frameworks typically focus on land application rates, cumulative additions to the soil, and efficacy of the product (application rates, mineralization rates etc). Similarly when considering combustion, frameworks focus on the product and effect of combustion through mechanisms such as air quality and net energy balance.

4.1.3 Land Application

Land application and distribution criteria are related to the treatment process used and the resulting quality of the *municipal biosolids* and *treated septage*. Several Canadian jurisdictions have implemented a class system for *municipal biosolids* which recognizes differences in treatment and *municipal biosolids* quality. Under this class system higher quality *municipal biosolids* are subject to fewer land application and distribution restrictions.

Measures of ensuring protection of human health and the environment where *municipal biosolids* and *treated septage* have been applied include site-specific nutrient management plans, land applications plans, permits and approvals.

Nutrient management or land application plans take into account all materials applied to land whether from *municipal biosolids* and *treated septage* or other sources. These regulatory mechanisms may include requirements for:

- nutrient and trace element concentrations in the *municipal biosolids* and *treated septage* and in the soil before and after application including any other nutrients applied to the soil such as commercial fertilizer or manure
- *buffer* distances and *setbacks* from water resources, highways, residential and community facilities
- land owner authorization and signs to be placed at the application site
- consultation with stakeholders including regulatory agencies
- post-application restrictions including waiting periods for animal grazing and planting crops for human consumption and
- application rates and methods of application.

Distribution requirements include maximum volumes that can be distributed, and specifications on where the *municipal biosolids* or *treated septage* can be used. In some jurisdictions *municipal biosolids* and *treated septage* which have been treated to a high standard (by composting for example) can be distributed without restriction provided that specific process and quality criteria are met. The sale and import of *municipal biosolids* and *treated septage* products are subjected to other regulations, including the federal *Fertilizers Act*.

4.1.4 Monitoring

Monitoring policies and procedures should be established with the goals of:

- ensuring representative sampling
- confirming residual quality
- protecting the environment and
- protecting human health.

Monitoring programs should be proactive, statistically significant and sufficiently comprehensive to allow for the detection of indicators prior to adverse impacts, and the identification of benefits (positive impacts) that result from the *beneficial use* of *wastewater residuals*.

Monitoring requirements may include the frequency of monitoring and procedures for sample collection and data reporting. The monitoring requirements may apply to the *municipal biosolids* and *treated septage* as well as the receiving environment (soil, water resources, vegetation, air quality) or to monitoring air quality or stack emissions.

Monitoring frequency should ensure representative sampling, and may be based on:

- the volume of *municipal biosolids* and *treated septage* produced or the area of land on which *municipal biosolids* and *treated septage* are applied
- a set calendar-based schedule (i.e., weekly, monthly, annually)
- changes in the treatment process, or
- a combination of the above.

Criteria for sampling may stipulate:

- type of sample (discrete versus representative samples, grab samples versus composite samples)
- number of samples and sampling plans (random, systematic etc.)
- sample location or methods for selecting the sample location
- location (for example depth at which soil samples are collected or port location on emissions stack) and
- analytical methods, quality assurance and control procedures (for instance the requirement that a certified laboratory be used) and established review and revision dates for the quality assurance program.

Reporting requirements and record maintenance may include:

- submission of a pre-test plan for stack sampling, data or a program report to a regulatory agency
- duration of monitoring records and data that must be kept and
- specific units that must be used when reporting results.

Additional information on sampling is provided in Appendix 5: Overview of Sampling and Analysis .

Case Study: Analytical Quality Assurance – Neepawa, Manitoba

The town of Neepawa, MB (approximate population 3,300) proposed the removal of *municipal biosolids* from the primary cell of its domestic wastewater treatment lagoon. A Licence was issued following submission and review of an Environment Act Proposal (EAP), identifying specifications, limits, and conditions for the activities. These included monitoring and reporting specifications for the sampling and analysis requirements for the *municipal biosolids*, soil and crops.

A key component of the License was an acceptable quality assurance program for the analyses including National Institute of Standards and Technology (NIST) soil and *municipal sludge* reference comparisons. The accuracy of the *municipal biosolids* and soil analyses was monitored for each set of ten or fewer samples. Tolerance criteria for the analytical results were identified, and failure to meet the criteria required re-analysis of the samples. All analytical procedures and results were required to be submitted with the field sample results.

Approximately 5,680 cubic metres of *municipal biosolids* has been land applied to date in accordance with the Licence.

4.1.5 Summary of Recommended Criteria for Developing a Regulatory Framework

Municipal, provincial and territorial governments have a shared responsibility to mitigate the risks associated with management of *wastewater residuals* through bylaw controls on influent quality, controls on *residuals quality*, and controls on the combustion or land application end use process. To augment these Guidelines, provincial and territorial governments may desire to develop their own regulatory framework for the management of *wastewater residuals*.

The recommended criteria for developing a regulatory framework are summarized in Table 9 below.

Jurisdictions are encouraged to implement a consultation process to seek input from stakeholders during the development of a regulatory framework.

Table 9: Summary of recommended criteria and rationale for inclusion in a regulatory framework.

Criteria	Rationale	Applicable to:
Limitations on utilization of sewers for discharge of industrial wastewaters	• allows municipalities and regional jurisdictions to manage industrial waste sources to the wastewater treatment plant, limiting input of high contaminant loads.	• residuals quality • land application • combustion
Treatment process for *pathogen* reduction	• reduces *pathogen* concentrations verified using appropriate indicator organisms	• land application
Treatment process for *vector* attraction reduction	• ensures that *municipal biosolids* and *treated septage* are stabilized • reduces odours and mitigates the attraction of *vectors* such as insects, rodents, birds and mammals	• land application
Pathogen concentration	• protects human health and the environment • measures *pathogen* reduction	• land application
Trace element concentration in *municipal biosolids and treated septage* and receiving environment (e.g. soil)	• protects human health and the environment • limits soil accumulation and ecosystem impacts • protects the safety of the food supply	• land application • combustion (as it relates to the *beneficial use* of ash through land application)
Nutrient concentrations and addition to the soil (primarily nitrogen and phosphorus)	• knowledge of nutrient concentrations allows for calculation of application rates that are appropriate for the intended use (agriculture, mine/brownfield reclamation, forestry etc.)	• land application • combustion (as it relates to the *beneficial use* of ash through land application)
Air quality parameters and limits on exhaust	• protects air quality • ensures that the facility is a *beneficial use*	• combustion

Table 9 Continued...

Criteria	Rationale	Applicable to:
Operating temperatures	• efficient operation of the facility • protection of air quality	• combustion
Application rates	• appropriate application rates mitigate the movement of constituents and provide appropriate nutrient additions • knowledge of nutrient concentrations in *municipal biosolids* or *treated septage*, and the properties of nutrients (*organic*/inorganic forms), their mineralization rates and availability allows for calculation of application rates that are appropriate for the intended use (agriculture, mine/brownfield reclamation, forestry etc.)	• land application • combustion (as it relates to the *beneficial use* of ash through land application)
Buffer distances and *setbacks*	• provides contingency in the event of migration of constituents, including nutrient leaching (land application) • mitigates aesthetic and odour issues	• land application • combustion
Signage and waiting periods	• signage advises stakeholders that *municipal biosolids* and *treated septage* have been applied allowing for implementation of appropriate management practices • waiting periods provide time for pathogen die-off for additional protection of human health	• land application
Monitoring frequency, sampling and reporting requirements	• provides assurance of product (land application) and emissions (combustion) quality over time and compliance with applicable standards and regulatory requirements • consistency in sampling, analysis and reporting allows for comparisons between jurisdictions and legislated criteria • protects human health and the environment	• land application • combustion

Table 9 Continued...

Criteria	Rationale	Applicable to:
Land application plans or nutrient management plans and the requirement for qualified professionals	• provides all relevant information in one document which can be submitted to regulatory agencies • may also include maps or drawings of the site with *buffers* and *setbacks* delineated, proof of property ownership and landowner authorization • use of qualified professionals that are accountable to their organizations standards of practice ensures responsibility	• land application • combustion – reuse of ash, design of facilities, monitoring
Facility operating plans	• provides information on the operation of the combustion facility including emergency and contingency plans • specifies ash management practices	• combustion
Contingency	• contingency plans provide an alternative option in the event that the primary management method is unavailable for example due to climatic conditions for land application or operational challenges for combustion • may include storage requirements or specify secondary use options	• land application • combustion

4.2 Best Management Practices and Planning

In order to promote success, best management practices and advance planning should be employed in all aspects of *wastewater residuals* management from production through to treatment and *beneficial use*. Ideally, a plan for managing the *wastewater residuals* should be developed during the planning stage of the wastewater or *septage* treatment facility.

The following Section provides best management practices relating to identification and evaluation of management options, effective communication and education, and quality assurance.

4.2.1 Identification of Management Options

The following should be considered when identifying management options:

- *wastewater residuals* quality including the presence/absence and concentration of trace elements, *pathogens* and other contaminants
- mineralization rates to determine nutrient availability and hence fertilisation value
- storage, stockpile and transportation challenges
- opportunities to diversify the *wastewater residuals* management program
- capacity to manage secondary materials and the potential synergies in co-management (i.e. fly ash, yard and garden waste)
- opportunities for partnerships (i.e. industry, First Nations)
- revenue generation or potential to offset existing costs, for example heating costs or disposal costs
- harmonization with current management and community plans
- carbon balance from a greenhouse gas perspective (carbon credit or debit) and commitments to climate action targets.

At the outset of residual management program development it is beneficial to identify *wastewater residuals* management options and refine a short-list of these options. This is often undertaken with the assistance of an evaluation matrix incorporating multiple considerations involved in developing a successful management program: social, environmental, economic and regulatory. Information on option evaluation is provided in Section 4.2.2 below.

4.2.2 Evaluation of Management Options

There are benefits and potential risks associated with each *wastewater residuals* management option. Careful planning and selection of a *beneficial use* option and the implementation of best management practices promotes the beneficial aspects of the *wastewater residuals* and mitigates risk.

There are a number of factors which influence the selection of a beneficial management option and should be taken into consideration in evaluating and short-listing potential residual management options including social, environmental, economic and regulatory considerations. These are discussed individually under separate headings in the text that follows.

In addition to the considerations discussed in Sections 4.2.2.1 and 4.2.2.4, program diversity, contingency and redundancy are important factors in the selection of a *beneficial use*. Successful *wastewater residuals* management programs have the diversity and flexibility to withstand changes in legislation, public opinion, and residual quality, and to manage operational challenges. Diversification of management options within the *wastewater residuals* management program allows for contingency and flexibility in the event that one avenue of *beneficial use* is unavailable, for example due to access restrictions to a land application site during a severe storm, combustion equipment requiring maintenance, or reduced *wastewater residuals* quality. Developing a *wastewater residuals* management program in haste can result in limited opportunities or high costs; having a variety of well-established opportunities allows for a cost effective, proven alternative in the event of unforeseen circumstances.

4.2.2.1 Social

Social considerations play a critical role in the development of a successful *wastewater residuals* management program. *Wastewater residuals* management involves stakeholders who are interested in, or affected by, the program. Stakeholder acceptance of a *wastewater residuals* management program often hinges on their values or social perceptions and often involves questions or concerns with respect to health and environmental protection although other considerations are present such as:

- noise, dust, and odour issues (for land-based systems)
- airshed, particulate and noise issues (for combustion/energy systems)
- traffic patterns, road conditions and access
- realizing social or community benefit in *wastewater residuals* use within the local economy
- employment and education opportunities and
- historical, cultural and environmental values.

There are innumerable factors which may contribute to any of the above becoming a considerable issue in a potential *beneficial use* program.

There are a broad range of factors that should be considered in beneficial *wastewater residuals* management:

- proximity of the proposed site to neighbouring land uses

- level of *wastewater residuals* treatment and timing of land application (odour issues)
- prevailing winds
- perceived traffic impacts of commercial traffic and transportation distances
- road conditions and transportation routes (suburban routes versus highway and rural routes)
- accessibility concerns (seasonal or road condition issues)
- cultural and historical concerns, including First Nations interests, recreational uses, and right-of-ways and
- proliferation and availability of information on the internet that is not subject to the scientific scrutiny, validation or challenge associated with the traditional scientific peer-review processes.

Once identified, many social considerations can be addressed and mitigation measures put in place that will satisfy the concerned parties. An open dialogue that addresses perception issues will require time and effort on behalf of all parties.

Communication and Education

Stakeholder education, support, and awareness of the associated benefits and risks are crucial to ensuring the success of a *wastewater residuals beneficial use* program. Stakeholders are individuals, businesses or organizations that have an interest in and/or are affected by the *wastewater residuals* management program. The number of stakeholders depends on a number of factors including the proximity of the application area or combustion facility to alternative land uses such as residential and commercial areas, the scale of the project, and environmental sensitivities. Stakeholders represent a number of groups including private citizens, government agencies, generators of *wastewater residuals*, neighbours, special interest groups, project partners, producer groups and landowners. Aboriginals may also have a significant interest in biosolids projects within or near traditional territories.

The following are examples of tools and resources that can be used in establishing and maintaining effective stakeholder communication and education programs:

- public meetings
- media including newspapers, websites, TV interviews, articles in trade magazines and social media sites which provide information on the *beneficial use* of the *wastewater residuals* and risk mitigation measures
- risk communication strategies that are balanced (addressing risks and benefits) and based on sound science
- handouts such as newsletters, fact sheets, photographs and responses to frequently asked questions

- pilot project and demonstration areas
- individuals and organizations that see the value of the program and can act as local sponsors
- liaison with local regulators including regular written and/or verbal communication and site or facility tours, and
- site signs which provide information on the project and the name and phone number of a point person that stakeholders can contact if they would like further information.

These tools can be used to develop a proactive approach to ensure that stakeholders understand the properties and treatment of *wastewater residuals* that lead to:

- the production of a high quality material
- *beneficial use* opportunities
- risk management practices
- an understanding of how residual use can benefit the environment and the community.

Addressing Common Stakeholder Concerns

Stakeholders are often interested in the health and environmental aspects of a *wastewater residuals* program. Common concerns relate to:

- soil – food safety, grazing of domestic and wild animals
- water – nutrient leaching, protection of surface and ground water quality
- air – air quality, odours
- constituents in the *wastewater residuals*– environmental persistence, potential for bioaccumulation, fate and effects of: trace elements, *ESOC*, legacy compounds, and *pathogens.*

Obtaining and retaining stakeholder trust and acceptance of *beneficial use* of *wastewater residuals* is a crucial element in sustaining a *beneficial use* program.

Table 10 provides organisations that have additional information pertaining to responses to frequently asked questions, fact sheets and risk assessments. Additional references to publications and primary literature are provided in Part 5 and Appendix 2 of this document.

Table 10: References for More Information to Address Common Stakeholder Concerns.

Reference	Topics
Frequently Asked Questions (FAQs) – questions and answers	
Canadian Biosolids Partnership (CBP)	• Biosolids background - general definition - production and use
Québec Ministère du Développement durable, de l'Environnement et des Parcs	• Biosolids recycling • Land reclamation • Agriculture • Environment
Water Environment Association of Ontario (WEAO)	• Biosolids background - definition - wastewater treatment - constituents including odour, *organic* compounds, pharmaceuticals and personal care products - comparison to manure - some aspects specific to Ontario
Mid-Atlantic Biosolids Association (MABA)	• Biosolids background - US centric - general definition - wastewater treatment - constituents including: *pathogens*, trace elements, *organic* chemical compounds
North East Biosolids and Residuals Association (NEBRA)	• References pertaining to the "Science of Biosolids Recycling"

Table 10 *Continued...*

Reference	Topics
Factsheets	
United States National Biosolids Partnership (US NBP)	• Biosolids recycling • History of biosolids • How wastewater treatment works • Understanding biosolids issues • Worker health and safety • Prions
Northwest Biosolids Management Association (NBMA)	• Wastewater treatment • Landscaping • Forestry • Land reclamation • Agriculture • Environment
Risk Assessments	
US Environmental Protection Agency (EPA)	• Guide to the Biosolids Risk Assessments for the EPA Part 503 Rule

4.2.2.2 Environmental

A sustainable *beneficial use* program is of immense value to *wastewater residuals* producers, landowners, and to the public-at-large, as it promotes longevity of the program and long-term benefits to the ecosystem. Protection of the environment should be a priority for all *beneficial use* programs. Protection of human health and the environment is contingent upon minimizing air emissions, ensuring appropriate application rates that can be assimilated by the ecosystem to provide benefit, while simultaneously maintaining appropriate *buffer* distances to water resources, protecting air quality and ensuring that sensitive flora or fauna will not be adversely impacted.

A background study and site assessment of all potential *beneficial use* areas should be completed concurrently with the management opportunities assessment. At a minimum, the following topics should be evaluated during the site assessment:

- site topography and natural hydrology – it is important that *municipal biosolids* and *treated septage* have no reasonable direct pathway for runoff or drainage to a waterway, ditch, or drainage feature, as typically surface waters cannot assimilate *wastewater residuals* constituents in a beneficially effective manner

- soil type and potentially limiting characteristics – soils may have naturally high occurrences of some trace elements that would preclude the land application of *municipal biosolids* and *treated septage*, or knowledge of the deficiencies of a particular soil type (lack of *organic matter* or a particular nutrient) may be justification for increasing land application rates to boost soil productivity

- flora and fauna with particular attention to known habitat of sensitive native species – application of *municipal biosolids* and *treated septage* should incorporate knowledge of what flora and fauna exist at the site and might be impacted, positively or otherwise, by land application of the *municipal biosolids* and *treated septage*

- airshed characteristics for combustion systems – understanding prevailing air movement around a discharge is a key requirement to develop an understanding of the discharge plume and the impacts of potential inversions or lack of circulation

- endemic greenhouse gas issues – the carbon sequestration or emission of a system should be quantified during the options assessment and development phases

- presence of features which may promote or restrict land use – application of *municipal biosolids* and *treated septage* may be particularly beneficial on degraded or marginal land, other features such as water wells, neighbouring residential or community facilities, and adjacent transportation corridors dictate the implementation of *buffer* areas and *setbacks* where no *municipal biosolids* or *treated septage* are applied.

Additional assessment including the collection of environmental samples should be completed once a short-list of sites has been established. Environmental samples (soil, water, vegetation) may all be collected to further assess site sensitivity or nutrient status in developing a *beneficial use* system.

Greenhouse gas emissions are an environmental consideration associated with *wastewater residuals* management. Management opportunities can be assessed from a greenhouse gas perspective with the aid of the Biosolids Emissions Assessment Model (*BEAM*) (CCME, 2009). The model can be used to assess the carbon credits and debits associated with a *wastewater residuals* management opportunity and identity opportunities for reduction of greenhouse gas emissions from existing *wastewater residuals* management programs.

4.2.2.3 Economic

The overall cost of a *wastewater residuals* management program is the sum of a series of smaller component costs. Short term costs inherent in the start-up of a program include the assessment of options and the costs of implementing the selected option(s) for the first time. This includes obtaining regulatory approval and setup costs for the selected sites. Longer term costs involve the transportation, program management and long-term monitoring of the *wastewater residuals*. As a general rule, costs decrease over time as a well managed program finds efficiency through experience and scale. Costs of *wastewater residuals* management programs are related to:

- quantity of residual produced – there may be opportunities for economies of scale when increased volumes of *wastewater residuals* are managed at a single facility, for example, the *municipal biosolids* from multiple jurisdictions used to reclaim the same mine site

- transportation distance – shorter transportation distances and reduced handling of the *wastewater residuals* minimizes cost

- site preparation, capital and operational and maintenance costs – costs related to preparing a site for *beneficial use* can be estimated through completion of a site assessment. Capital and operational costs will vary depending on the opportunity selected

- value of the residual as a fertilizer, soil amendment or fuel source – costs of the management program may be offset through reducing the use of chemical fertilizers or use of the residual in the place of another fuel source and

- value to be realized as a viable carbon sink, or carbon sequestration device for a municipality or province - judicious beneficial land application of *municipal biosolids* and *treated septage* includes many opportunities that will provide either direct sequestration or incrementally through biomass growth that will eventually qualify for carbon credits in a carbon economy.

In determining the cost of a *wastewater residuals* management program, it is important to consider the short and long-term costs and benefits.

Marketing Value Added Products

Of particular interest when managing *municipal biosolids* through production of a *municipal biosolids* product such as compost or topsoil/growing media is distribution and marketing of the product. Developing a market for distribution and/or sale of the material is a vital consideration in the economic viability of the program. Once the fabricated soil has been developed, marketing is a key consideration if the soil is of sufficient quality, and local regulations permit, for public distribution or retail sale. The sale of fabricated soils may be subject to the federal *Fertilizers Act*, depending on the associated label claims.

The following are key considerations in developing a marketable product:

- regular monitoring and meticulous record keeping for each batch of fabricated soil produced

- contingency storage for excess product and for storage of the product while analytical tests to confirm product quality are being completed
- completion of a market assessment to identify opportunities and ascertain the likelihood of success within the target region and
- adherence to applicable federal/provincial/territorial and municipal standards for product quality such as trace element and *pathogen* concentration and nutrient guarantees.

The following activities contribute to the development and establishment of a market for fabricated soil:

- development and maintenance of third party partnerships, for example with university researchers and landscapers who can attest to the quality and performance of the growing media
- creation of demonstration areas utilizing the fabricated soil to allow the public to visually assess the product and its performance
- establishment of product outlets and retail locations
- completion of testimonials from satisfied customers and ensuring these are accessible to potential customers and
- preparation of samples for distribution to potential customers to allow them to try the product.

Additional information pertaining to special considerations for fabricated growing media can be found in documents prepared by Van Ham et al. (2007) and the National Biosolids Partnership (2006).

4.2.2.4 Regulatory

Beneficial use opportunities must abide by all relevant provincial/territorial and federal standards, requirements or guidelines. Additional information pertaining to legislation and regulatory considerations is provided in Section 4.1 and Appendix 4: Key Legislation Relating to the Use of Residuals. A sustainable *wastewater residuals* management program understands and adheres to jurisdictional standards, requirements and guidelines, and adapts to the changing regulatory environment. *Beneficial use* options are generally successful if there is some familiarity with the option within the jurisdiction, or if the jurisdiction has had success with similar programs, although precedent should not be misinterpreted as a guarantee of acceptability.

The individuals responsible for the *wastewater residuals* management program should develop lasting, healthy working relationships with stakeholders including regulators. The levels of knowledge and experience within this working team will jointly guide a *wastewater residuals* program through inevitable growth and diversification over time. The team should be rounded out by any additional regulators or experts, including qualified professionals where required or desired, to ensure that the group has a full suite of knowledge with which to apply jurisdictional understanding to achieve a sustainable program.

4.3 Contingency Planning and Storage

Contingency planning is a key aspect in any *wastewater residuals* management program. It is recommended that *wastewater residuals* generators develop contingency plans concurrent with development of their primary *beneficial use* option.

Storage and landfilling may form part of the contingency plan provided they are used for a finite period and value is obtained from the *wastewater residuals* when possible. Storage is not a method of managing *wastewater residuals* but a short-term solution when factors outside the generators control prevent the *wastewater residuals* from being used beneficially. Storage may also form part of a *beneficial use* program; seasonal storage of the biosolids or *treated septage* in anticipation of land application. Storage facilities should be designed and operated according to best management practices and applicable regulations including preventing the migration of *wastewater residuals*.

If landfills are part of the contingency plan, effort should be made to use the *wastewater residuals* to provide environmental benefit at the landfill rather than using the landfill as a disposal method. Opportunities exist at the landfill to use *municipal biosolids* and *treated septage* in development of biocover to mitigate fugitive methane emissions and as a feedstock or fertilizer in development of soil for landfill closure. Specific landfill use opportunities will vary based on landfill regulations and the characteristic and quality of the *wastewater residuals*.

Although it would not meet *CCME's* criteria for *beneficial use*, *wastewater residuals* can be used at the landfill as alternative daily cover when no other options exist. Landfill disposal of the *wastewater residuals*, without any environmental benefit, should be viewed as a last resort for use when other options are unavailable. If landfill disposal is the only available option, effort should be made to capture the emissions and energy created through disposal of the *wastewater residuals*.

Another contingency option is the use of *wastewater residuals* as an ingredient in cement manufacture where allowed. Although this may be a contingency option, it may be considered a beneficial use if it meets *CCME*'s *beneficial use* criteria for combustion.

4.4 Ongoing Research and Technology Development

This Section provides indications of the directions that research is taking at this time. Research and technology developments include:

- enhancing wastewater treatment processes to improve *municipal biosolids* quality and further mitigate risk to human health and the environment

- development of technologies used to process or derive alternative *beneficial uses* from *wastewater residuals*

- improvement of management practices.

Research and technology development contributes to improved outcomes for the regulators, public, landowners and producers of *wastewater residuals*. The Northwest Biosolids Management Association's Online Library provides information on ongoing research and technology development.

Wastewater residuals regulators and generators should implement a system of continuous improvement to keep well-informed of current research and to consider new scientific information as it becomes available.

With intention, this guidance document pertains only to technologies and management methods that are well defined and practiced in Canada. Development of new and emerging technologies and awareness of technologies used outside Canada will support continuous improvement in the management of *wastewater residuals*. Specific technologies such as thermal reduction and *gasification* are used for *residuals management* elsewhere but are not a common practice in Canada (at the time of writing this document); knowledge and application of these and other technologies used elsewhere will aid in refining *wastewater residuals* management in the Canadian context.

4.4.1 Wastewater Residuals Quality

Wastewater residuals quality, particularly *municipal biosolids*, is continuously evolving. Part of this evolution is driven by ongoing improvement in source control practices, treatment technologies and analytical ability to detect contaminants at increasingly low concentrations. Current (as of 2012) and ongoing research involves emerging substances of concern, *pathogens*, viruses and nano-particles.

One impact on *wastewater residuals* quality will come from the emergent technologies that explore nutrient and constituent harvest or removal from *municipal biosolids*. Phosphorus and ammonium removal through struvite production is the first of many potential constituent harvest techniques that could eventually work in series to systematically recover elements of value from the *municipal biosolids* stream (Jaffer, 2002). It is anticipated that new technologies of a similar nature will follow, and will be developed as the economics of extraction become favourable.

Current research into the constituent concentration of *municipal biosolids* identifies emerging substances of concern as a broad area of research and development. This area of research is in the modelling, fate and transport stage. The outcomes of such research will support any potential risk assessments on these substances.

As further information about emerging substances of concern and their behaviour in the environment is understood and risk assessments completed, this information will strengthen *wastewater residuals* quality recommendations, requirements and standards development.

4.4.2 Technology Development

The technology with which *municipal biosolids* is processed, for the most part, is relatively mature, with most components of wastewater treatment, such as thickening and *stabilization*, having been available for many years. In reviewing new technologies, consistency in the process and the product quality are considerations.

New technologies for *municipal biosolids* processing and management are continuously being developed. The greatest impact on the process, and the product, appears to be coming from nutrient removal technologies, however improvements to co-firing or mingling as a fuel source, and process development to cultivate biomass for energy recovery post-digestion (such as algae growth, or microbial media development) are ongoing.

Continuous improvement in the digestion of thickened solids is also a priority, as is the goal of improved methane generation, which is commonly used for energy production. As a result, many digesters are exploring direct feed opportunities for other digestible feedstock, including coarse separated *organics*, rendering wastes and waste cooking oils, in an effort to maximize energy production from digestion processes.

There are numerous technologies in different stages of development relating to more efficient combustion or incineration processes, but few have been developed to an operational scale for *wastewater residuals* combustion in Canada. *Gasification* as a technology for *wastewater residuals* management is in the emerging stages in Canada. *Gasification* thermochemically converts biomass into process gas (referred to as "syngas") consisting of hydrogen gas, carbon monoxide and methane with minor contributions of carbon dioxide and nitrogen gas. Syngas can be burned directly to produce energy, or further refined for use in gas engines or in the production of synthetic biofuels. Many *organic* feedstocks can be gasified including municipal solid waste, wood, *wastewater residuals* and plastics. *Gasification* capitalizes on the energy content of *wastewater residuals* to produce renewable fuel sources, reducing dependencies on fossil fuels and generating carbon offsets. *Gasification* differs from combustion in that combustion is the direct use of *wastewater residuals* for fuel; *gasification* is the conversion of *wastewater residuals* into syngas which can then be used for fuel.

4.4.3 Management Practices

Management practices evolve as knowledge grows. Use of *municipal biosolids* and *treated septage* is expanding beyond use as soil conditioners, to include use for mitigation of fugitive methane emissions from closed and reclaimed landfills.

Land application systems have become more prescriptive and many jurisdictions have specialized regulations to manage the *beneficial use* of *municipal biosolids* to land. Increasing jurisdictional regulation includes the implementation of source control mechanisms such as local bylaws and industry-specific codes of practice and the implementation of the federal Chemical Management Plan to prioritize the assessment and management of chemicals in Canada.

It is anticipated that management practices will continue to evolve towards a system that identifies environmental sensitivities and matches management practices specifically to those opportunities and limitations. Forward thinking jurisdictions look to the production and management of *wastewater residuals* from the perspective of *beneficial use*. *M*eeting *beneficial use* as outlined in this document provides an opportunity to enhance or restore environmental values, generate energy and capitalize on the beneficial attributes of the *wastewater residuals*.

4.5 Guidance Document Summary

Wastewater residuals are continually produced and require management. *CCME* promotes the *beneficial use* of valuable resources such as nutrients, *organic matter* and energy contained within the *municipal biosolids*, *municipal sludge* and *treated septage*. There exists opportunities for the *beneficial use* of these *wastewater residuals* through land application and combustion. Both land application and combustion have inherent benefits and risks which can be mitigated through the management, environmental, operational, use-specific and regulatory considerations presented in this guidance document. *Beneficial use* should be based on sound management that includes:

- consideration of the utility and resource value (product performance)
- strategies to minimize potential risks to the environment and human health
- strategies to minimize greenhouse gas (GHG) emissions and
- adherence to federal, provincial, territorial and municipal standards and regulations.

It is a shared responsibility between all levels of government, generators, users and professionals to ensure that the *wastewater residuals* are managed in a manner that is protective of the environment and human health. This can be accomplished through implementation of the management practices and mitigation measures provided herein.

Focus on Beneficial Use

The beneficial use of wastewater residuals must include environmental, social, economic and regulatory considerations including protection of flora and fauna.

PART 5: REFERENCES AND FURTHER READING

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APPENDICES

Appendix 1: Glossary

BEAM: The Biosolids Emissions Assessment Model (**BEAM**) is a calculator tool and guidance document developed by *CCME*. The BEAM is designed to assist users in determining greenhouse gas emissions associated with various *municipal biosolids* management options and to demonstrate how changes to wastewater treatment processes or *municipal biosolids* management practices can impact greenhouse gas emissions.

Beneficial use: use of *municipal biosolids*, *municipal sludge* and *treated septage* according to the *Canada-wide Approach for the Management of Wastewater Biosolids*.

Biosolids Task Group (BTG): a group of provincial, territorial and federal government representatives from the Ministries and Departments of Environment, established by *CCME* to develop the *Canada-wide Approach for the Management of Wastewater Biosolids.*

Buffer: land to which *municipal biosolids* and *treated septatge* are not applied that is adjacent to an environmental receptor. *Buffers* are typically used for environmental protection of receptors, such as water resources (lakes, streams, wells). Also see *setbacks*.

Canadian Council of Ministers of the Environment (CCME): the primary minister-led intergovernmental forum for collective action on environmental issues of national and international concern. The 14 member governments work as partners in developing nationally consistent environmental standards and practices.

Emerging substance of concern (ESOC): a group of substances that have recently become the focus of research into their fate and effects in the environment. They include pharmaceuticals, personal care products, plasticizers, surfactants and brominated flame retardants. These constituents may be present in biosolids, in quantities measured in the parts per million to the parts per trillion. Emerging substances of concern is a Canadian term, and these constituents are also known as microconstituents.

Gasification: a technology that thermochemically converts biomass into process gas (referred to as “syngas”) consisting of hydrogen gas, carbon monoxide and methane with minor contributions of carbon dioxide, dinitrogen and potentially nitrous oxide gas.

Municipal biosolids: *organic*-based products which may be solid, semi-solid or liquid and which are produced from the treatment of *municipal sludge*. *Municipal biosolids* are *municipal sludge* which has been treated to meet to jurisdictional standards, requirements or guidelines including the reduction of *pathogens* and vector attraction.

Municipal sludge: a mixture of water and non-stabilized solids separated from various types of wastewater as a result of natural or artificial processes (CAN/BNQ 0413-400/2009).

Organic: the branch of chemistry concerned with compounds that contain carbon. *Organic* as used in this document does not cover *organic* farming practices. Also see *organic matter*.

Organic matter: *organic* compounds which result from the decomposition of once-living organisms (plants, animals, microorganisms). Also see *organic*.

Pathogens: organisms, including some bacteria, viruses, fungi, and parasites, that are capable of producing an infection or disease in a susceptible human, animal, or plant host (as defined in **CCME**, 2005).

Setback: land to which *municipal biosolids* or *treated septage* are not applied that is adjacent to areas used or occupied by people. For example there may be *setbacks* from roads, houses and properties zoned for recreation. Also see *buffers*.

Septage: the waste contained in or pumped directly from domestic septic tanks and similar on-site treatment units. *Septage* may be comprised of various proportions of sediments, water, grease, and scum.

Stabilization: the process of making the *organic* or volatile portion of *septage* or *municipal sludge* less putrescible, less odorous and to decrease the concentration of pathogenic microorganisms

Treated septage: refers to *septage* (see *septage* definition) which has been treated to reduce *pathogens* and *vector* attraction.

Vector: refers to rodents, insects or other organisms capable of transmitting *pathogens*.

Wastewater Residuals: for the purpose of this guidance document, the term '*wastewater residuals*' refers to the specific subset inclusive of *municipal biosolids*, *municipal sludge* and *treated septage*.

Appendix 2: Policy Statement and Supporting Principles

Policy Statement

The Approach promotes the *beneficial use* of valuable resources such as nutrients, *organic* matter and energy contained within *municipal biosolids, municipal sludge* and *treated septage*. *Beneficial uses* should be based on sound management principles that include:

- consideration of the utility and resource value (product performance)
- strategies to minimize potential risks to the environment and human health
- strategies to minimize greenhouse gas (GHG) emissions
- adherence to federal, provincial, territorial and municipal standards, requirements or guidelines.

Beneficial uses include the land application of *municipal biosolids* and *treated septage* to grow vegetation, when it is done according to applicable standards, requirements, guidelines and best management practices. Landfilling is not considered to be a *beneficial use*, even if it meets all applicable standards, requirements or guidelines, since landfilling results in the loss of nutrients and the release of GHG emissions.

Anaerobic digestion, which is a process to treat *municipal sludge,* has several advantages, including the production of *municipal biosolids* and the generation of methane that can be recovered to generate electricity or heat. Other *organic* materials (e.g., grease trap waste) can also be added to an anaerobic digester to increase the amount of energy generated, while diverting material from landfill and producing *municipal biosolids* that meet jurisdictional quality standards, requirements or guidelines for land application.

Supporting Principles

Principle 1: ***Municipal biosolids, municipal sludge*** **and** ***treated septage*** **contain valuable nutrients and organic matter that can be recycled or recovered as energy.**

Land application of *municipal biosolids* can be considered a *beneficial use* when properly managed to enhance soil fertility, soil structure and plant growth (LeBlanc et al., 2008; SYLVIS, 2009). *Municipal biosolids* and *treated septage* applied to land can also provide nutrients such as nitrogen and phosphorus and *organic matter*, which are wasted if the material is landfilled or combusted without energy and ash recovery. Phosphorus is a limited non-renewable resource that should be recycled from *municipal biosolids* (Institute for Sustainable Development, 2010; Soil Association, 2010).

Principle 2: **Adequate source reduction and treatment of** ***municipal sludge*** **and** ***septage*** **should effectively reduce pathogens, trace metals, vector attraction, odours and other substances of concern.**

Applicable safety, quality and management standards, requirements or guidelines for *municipal biosolids* must be met. All jurisdictions should encourage and support the continuous improvement of the quality of *municipal biosolids* through source control initiatives and the implementation of best management practices in order to limit any potential adverse impacts associated with their use.

Principle 3: The beneficial use of *municipal biosolids*, *municipal sludge* and *treated septage* should minimize the net GHG emissions.

Land application of *municipal biosolids* can supplement and may reduce fertilizer use. Land application results in the storage of carbon in the soil, thereby minimizing greenhouse gas (GHG) emissions to the atmosphere (SYLVIS, 2009).

Landfilling of *municipal biosolids* and *municipal sludge* is not considered a *beneficial use* because *organic matter* decomposition contributes to methane emissions, even if a landfill is equipped to collect a significant portion of the gas for use as energy (SYLVIS, 2009). However, the use of *municipal biosolids* as an amendment to final cover at landfills is considered as a *beneficial use* since it may act as a biofilter and reduce GHG emissions.

Other *municipal biosolids* treatment processes may also produce methane, including anaerobic digestion. To minimize GHG emissions, methane should be captured to generate heat and/or energy to be considered a *beneficial use*. Another option would be to neutralize the methane to carbon dioxide (CO_2) by flaring.

Principle 4: Beneficial uses and sound management practices of *municipal biosolids*, *municipal sludge* and *treated septage* must adhere to all applicable safety, quality and management standards, requirements and guidelines.

Sound management of *municipal biosolids* and *treated septage* includes the best management practices outlined in the guidance document..

The manufacture, transport and use of *municipal biosolids* are regulated at the federal, provincial, territorial and/or municipal levels. *Municipal biosolids* to be used as fertilizers or soil supplements, when imported or sold in Canada, are also regulated under the federal *Fertilizers Act* and *Regulations* which are administered by the Canadian Food Inspection Agency.

Appendix 3: Unit Conversion Table

Mass		
1 gram	=	1,000 milligrams (mg)
	=	1,000,000 micrograms (µg)
	=	1,000,000,000 nanograms (ng)
1,000 kilograms (kg)	=	1 tonne (T)
Concentration		
1 part per million (1 ppm)	=	1 microgram per gram (µg/g)
	=	1 milligram per kilogram (mg/kg)
	=	1 kilogram/tonne (kg/T)
	=	0.0001 percent (%)
Area		
1 hectare (ha)	=	10,000 square metres (m^2)
	=	0.01 square kilometres
	=	107,639.104 square feet (ft^2)
	=	2.47 acres
Application Rates		
Dry tonnes	=	Bulk (wet) tonnes x $\frac{\text{\% total solids}}{100}$
Bulk (wet) tonnes	=	Dry tonnes x $\frac{100}{\text{\% total solids}}$

Appendix 4: Key Legislation Relating to the Use of Residuals

CCME Legislative Review

A review of the current (March 2010) Canadian legislative framework pertaining to **residuals** management was completed by *CCME*

Canadian Federal Acts

Federal acts and regulations that govern **residuals** management can be accessed online through the relevant federal government department:

Canadian Food Inspection Agency, www.inspection.gc.ca
Fertilizer Act and regulations

Environment Canada, www.ec.gc.ca
Canadian Environmental Protection Act

Canadian Provincial and Territorial Environment Ministries

Provincial and territorial legislation can be accessed online through the relevant government Ministry:

- Alberta: www.environment.alberta.ca/
- British Columbia: www.gov.bc.ca/env/
- Manitoba: www.gov.mb.ca/conservation/
- New Brunswick: www.gnb.ca/0009/index-e.asp
- Newfoundland and Labrador: www.env.gov.nl.ca/env/
- Northwest Territories: www.enr.gov.nt.ca/_live/pages/wpPages/home.aspx
- Nova Scotia: www.gov.ns.ca/nse/
- Nunavut: www.gov.nu.ca/env/
- Ontario: www.ene.gov.on.ca/
- Prince Edward Island: www.gov.pe.ca/eef/index.php3
- Québec: www.mddep.gouv.qc.ca/
- Saskatchewan: www.environment.gov.sk.ca/
- Yukon: www.gnb.ca/0009/index-e.asp

Canadian Standards and Guidelines for Land Application

The following websites provide standards and guidelines pertaining to *municipal biosolids* and compost:

Bureau de normalisation du Québec (BNQ), www.bnq.qc.ca
- Soil Amendments - Alkaline or Dried Municipal Biosolids
- Soil Amendments - Alkaline or Dried Municipal Biosolids - Certification Protocol

Canadian Council of Ministers of the Environment, www.ccme.ca
- Guidelines for Compost Quality

CCME Canadian Standards and Guidelines for Thermal Treatment

Canada-wide Standards for Dioxins and Furans Emissions from Waste Incinerators and Coastal Pulp and Paper Boilers

Canada-wide Standards for Mercury Emissions

International Standards, Guidelines and Best Management Practices

- European Union
  Industrial Emissions Directive on Industrial emissions (integrated pollution prevention and control)
  http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:334:0017:0119:EN:PDF

- US Environmental Protection Agency
  Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Sewage Sludge Incineration Units; Final Rule March 21, 2011
  http://www.epa.gov/ttn/atw/129/ciwi/fr21mr11.pdf
  Factsheet: http://www.epa.gov/ttn/atw/129/ssi/2011/20110221ssifs.pdf

- Australia
  Environment Protection Authority Guidelines for Environmental Management of Biosolids Land Application:
  http://epanote2.epa.vic.gov.au/EPA/publications.nsf/2f1c2625731746aa4a256ce90001cbb5/822b33fca69d0a58ca256dc6000e7835/$FILE/943.pdf

- Australia
  National Resource Management Ministerial Council Guidelines for Sewerage Systems Biosolids Management.
  http://www.environment.gov.au/water/publications/quality/pubs/sewerage-systems-biosolidsmunicipal biosolids-man-paper13.pdfhttp://www.environment.gov.au/water/publications/quality/pubs/sewerage-systems-biosolids-man-paper13.pdfhttp://www.environment.gov.au/water/publications/quality/pubs/sewerage-systems-biosolids-man-

paper13.pdfhttp://www.environment.gov.au/water/publications/quality/pubs/sewerage-systems-biosolids-man-paper13.pdf

- New Zealand
  Guidelines for the Safe Application of Biosolids to Land in New Zealand
  http://www.waternz.org.nz/documents/publications/books_guides/biosolids_guidelines.pdf

- United Kingdom
  UK Department of the Environment Code of Practice for Agricultural Use of Sewage Sludge
  http://www.southhams.gov.uk/code_of_practice__for_agriculture_use_of_sewage_sludge.pdf

- United States
  National Biosolids Partnership - National Manual of Good Practice for Biosolids
  http://www.wef.org/Biosolids/Default.aspx?id=7506&ekmensel=c57dfa7b_127_0_7506_1

- United States
  US Environmental Protection Agency - A Plain English Guide to the EPA Part 503 Biosolids Rule:
  http://water.epa.gov/scitech/wastetech/biosolids/503pe_index.cfm

Appendix 5: Overview of Sampling and Analysis

The following references provide detailed information on sampling and analysis for land application and/or combustion of *wastewater residuals*:

- **British Columbia - Land Application Guidelines for the Organic Matter Recycling Regulation and the Soil Amendment Code of Practice.**
  SYLVIS. Document no. 758-08. Prepared for the BC Ministry of Environment. 2008. Accessed online December 6, 2011.
  http://www.env.gov.bc.ca/epd/industrial/regs/codes/soil_amend/pdf/land-app-guide-soil-amend.pdf

- **Ontario - GUIDELINE A-7 Air Pollution Control, Design and Operation Guidelines for Municipal Waste Thermal Treatment Facilities.**
  Ontario Ministry of Environment. R.R.O. 1990, Regulation 347 (General – Waste Management) Ontario Regulation 419/05 (Air Pollution – Local Air Quality). March 2009. Accessed online December 6, 2011.
  http://preventcancernow.ca/wp-content/uploads/2011/02/Incin-Guideline.pdf

- **Ontario - GUIDELINE A-8 Guideline for the Implementation of Canada-wide Standards for Emissions of Mercury and of Dioxins and Furans and Monitoring and Reporting Requirements for Municipal Waste Incinerators, Biomedical Waste Incinerators, Sewage Sludge Incinerators, Hazardous Waste Incinerators, Steel Manufacturing Electric Arc Furnaces, Iron Sintering Plants.**
  Ontario Ministry of Environment. Environmental Protection Act, Part V, Section 27, and Part II, Section 9. Ontario Regulation 347, General B Waste Management Regulation. Ontario Regulation 346, General B Air Pollution. August 2004. Accessed online December 6, 2011.
  http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_079113.pdf

- **Ontario - Sampling and Analysis Protocol for Ontario Regulation 267/03 Made under the Nutrient Management Act, 2002 - September 14, 2009.**
  Website last Modified: April 7, 2011. Queen's Printer for Ontario 2011. Accessed online December 6, 2011.http://www.omafra.gov.on.ca/english/nm/regs/sampro/samprotc_09.htm

- **Québec – Guidelines for the Beneficial Use of Fertilising Residuals. Reference Criteria and Regulatory Standards.**
  Devéloppement durable, Environnement et Parcs. Dépôt légal - Bibliothèque nationale du Québec, 2008. ISBN 978-2-550-54514-9 (pdf). 2008 edition with addenda 1, 2 and 3. Accessed online December 6, 2011.
  http://www.mddep.gouv.qc.ca/matieres/mat_res-en/fertilisantes/critere/guide-mrf.pdf

- **New Zealand – Guidelines for the safe application of Biosolids to Land in New Zealand.**
  New Zealand Ministry for the Environment and New Zealand Water and Wastes

Association. August 2003. Accessed online December 6, 2011.
http://www.waternz.org.nz/documents/publications/books_guides/biosolids_guidelines.pdf

- **USA National Biosolids Partnership – Manual of Good Practice for Biosolids**
  Last updated January 2005. Available through the Water Environment Federation. Accessed online December 6, 2011.
  http://www.biosolids.org/ems_main.asp?sectionid=48&pageid=189&pagename=Manual%20of%20Good%20Practice

- **United Kingdom Department of the Environment – Code of Practice for Agricultural Use of Sewage Sludge.**
  Accessed online December 6, 2011.
  http://archive.defra.gov.uk/environment/quality/water/waterquality/sewage/documents/sludge-cop.pdf