Biosolids in Mine Reclamation?

A Review of the Literature
Canadian Institute for Environmental Law and Policy

June 2008




CANADIAN INSTITUTE FOR
ENVIRONMENTAL LAW AND POLICY

L'INSTITUT CANADIEN DU
DROIT ET DE LA POLITIQUE
DE L'ENVIRONNEMENT

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Executive Summary

Biosolids have been applied to farmland for decades as a fertilizer in North America and Europe. Recently, preliminary research studies and pilot projects have examined the possibility of using municipal biosolids as an aid to reclaim operational and abandoned mine sites. **This paper reviews available literature to address and analyze the effectiveness of the use of biosolids in mine reclamation, examines the risks of adverse environmental impacts and reviews the current state of regulations in Canada as they pertain to biosolids and mine reclamation.** The review is in no way comprehensive. Its purpose is to provide a clear, concise, and objective overview of the potential benefits and drawbacks of biosolids use in this context. The intent is that private and public stakeholders will be able to use this review to identify gaps in current research, policy and regulations and identify opportunities to further our understanding of whether or not biosolids should be used in this capacity.

In assessing the potential for adverse environmental impacts due to the use of biosolids in mine reclamation, it is important that decisions be made in the context of a number of core principles. These include, but are not limited to: ensuring a thorough assessment; taking an ecosystem approach; taking a precautionary approach; considering cumulative impacts; addressing risk and uncertainty; and ensuring meaningful and timely public consultation.

The primary objective for using biosolids in mine reclamation is to provide an available source of organic matter, nutrients, and biomass to the degraded area in order to create an environment that is conducive to promoting plant growth and regenerating the soil layer. This review of the literature suggests that the organic matter, inorganic matrix, and high levels of micro- and macronutrients in biosolids could be effective in reducing the bioavailability of potentially harmful substances in highly disturbed mine soils and promoting regeneration of the soil layer. However, there exists the potential for adverse environmental impacts such as the contamination of water resources from runoff and leaching of nutrients, metals, trace organic chemicals, and emerging contaminants.

Currently, the Canadian federal government and its regulatory agencies do not regulate the use of biosolids to reclaim degraded mine sites. Provincial governments typically undertake regulation of biosolids use. Several jurisdictions have developed federal, state/provincial and regional biosolids management regulations. Within Canada, British Columbia regulates its biosolids management under the Organic Matter Recycling Regulation (OMRR). In Ontario, the application of biosolids on agricultural land is currently regulated under the *Environmental Protection Act* (Reg 347) and the *Nutrient Management Act* (Reg 267/03). The application of biosolids on agricultural land in Alberta is currently regulated under the "Guidelines for the Application of Municipal Wastewater Sludges to Agricultural Land".

As biosolids contain both beneficial constituents and potential contaminants, their use should only be considered where the protection of human health and the environment can be ensured. Where biosolids are applied to land, regulations governing biosolids quality, supported by the best management practices, may minimize the risk of negative environmental impacts. If biosolids application to mine sites can be performed in a manner that minimizes the risk of

environmental contamination to an acceptable level, it may be both a cost-effective method for the addition of nutrients and organic matter to the degraded lands and an economical biosolids management solution.

After preparing this literature review CIELAP puts forward the following recommendations:

1. Where use of biosolids in mine reclamation is being considered**, biosolids quantity and quality, as well as the impacts of biosolids on air and water quality, should be studied from an environmental protection perspective. Biosolids quality** (i.e. constituent concentrations, pathogen limits and vector attraction reduction) **criteria must be met prior to biosolids use in mine reclamation and remediation. Monitoring should be completed** to ensure biosolids quality meets the criteria specified in applicable regulations.

2. **A review of existing research into the use of biosolids in mine reclamation and remediation, and the outcomes of operational programs, should be undertaken by any government interested in permitting or regulating such a program.** This review would: (a) synthesize research about the toxicity, fate, transport, and interactions with the receiving environment of compounds of emerging concern in biosolids applied to land (including trace elements, nutrients, PCBs, PCDD/Fs, PAHs, brominated flame retardants, pharmaceuticals and personal care products and sterols); (b) communicate the risks associated with these compounds; (c) identify and prioritize knowledge gaps and research opportunities about the implications of biosolids in mine reclamation on human health and the environment; and (d) support action to minimize the concentrations of environmentally deleterious constituents in biosolids, including source management initiatives including sewer use bylaw amendment and public education.

3. **Government and industry should assist in appropriate research as identified specific to biosolids use in mine reclamation and remediation.**

4. **Any application of biosolids to lands should be based on acceptable resultant contaminant concentrations in the receiving soil.** The quality of biosolids and the nature of degraded mine soils must be considered. Decisions about the appropriateness of using biosolids in mine reclamation should be completed on a case-by-case basis according to site-specific circumstances. In assessing the potential for adverse environmental impacts due to the use of biosolids in mine reclamation, decisions should be made in the context of principles that include: ensuring a thorough assessment; taking an ecosystem approach; taking a precautionary approach; considering cumulative impacts; addressing risk and uncertainty; and ensuring meaningful and timely public consultation.

5. **In addition to regulatory compliance, available best management practices should be followed to ensure the prudent management of biosolids.**

6. **It is essential to include a public education and awareness component in the initial stages of biosolids use.** This includes public education, scientific improvement and communication of scientific results to public, demonstration trials, and notification. A document summarizing the identification of stakeholders and successful consultation

approaches should be prepared that could serve as a guideline to biosolids generators and mine reclamation practitioners to assist in decision making regarding biosolids management options. Case studies on reclaimed mine sites in Canada and other jurisdictions should be reviewed to gain more information on community reaction to biosolids use and ultimate successes or failures.

7. **Following biosolids applications for mine reclamation there should be appropriate monitoring and management** to ensure that there is minimal potential for off-site movement of biosolids and biosolids constituents that could negatively impact water resources, additional environmental resources, and human health. An environmental monitoring program should include indicator parameters to identify changes in the risk to human health and the environment.

1. Introduction

Biosolids have been applied to farmland for decades as a fertilizer in North America and Europe. Recently, preliminary research studies and pilot projects have examined the possibility of using municipal biosolids as an aid to reclaim operational and abandoned mine sites. This review of the literature suggests that the organic matter, inorganic matrix, and high levels of micro- and macronutrients in biosolids could be effective in reducing the bioavailability of potentially harmful substances in highly disturbed mine soils and promoting regeneration of the soil layer. However, there exists the potential for adverse environmental impacts such as the increased runoff and leaching of nitrogen, phosphorus, and other nutrients and the contamination of water resources.

Currently, the Canadian federal government and its regulatory agencies do not regulate the use of biosolids to reclaim degraded mine sites. Provincial governments typically undertake regulation of biosolids use. Most research and operational programs relate to the agronomic use of biosolids in soil development and sustainable vegetation establishment. This paper reviews available literature to address and analyze the effectiveness of the use of biosolids in mine reclamation, examines the risks of adverse environmental impacts and reviews the current state of regulations in Canada as they pertain to biosolids and mine reclamation. The review is in no way comprehensive. Its purpose is to provide a clear, concise, and objective overview of the potential benefits and drawbacks of biosolids use in this context. The intent is that private and public stakeholders will be able to use this review to identify gaps in current research, policy and regulations and identify opportunities to further our understanding of whether or not biosolids should be used in this capacity.

It is important to make clear that, in assessing the potential for adverse environmental impacts due to the use of biosolids in mine reclamation, any decisions must be made in the context of a number of core principles. These include, but are not limited to: ensuring a thorough assessment; taking an ecosystem approach; taking a precautionary approach; considering cumulative impacts; addressing risk and uncertainty; and ensuring meaningful and timely public consultation.

2. Biosolids

2.1 Biosolids Treatment

During the process of treating municipal wastewater, the solid components contained in the wastewater are removed from the liquid. After processing to reduce volatile solids and pathogen concentrations, these solids are referred to as biosolids. While the term ‘‘biosolids’’ is often used interchangeably with ‘‘sewage sludge’’, biosolids are generally defined as sewage sludge that has undergone treatment to meet standards set for use.[1]

Biosolids consist of active and non-active microorganisms (biomass) and significant concentrations of plant nutrients, namely nitrogen, phosphorus and other elements essential for plant growth. Biosolids also most often contain low concentrations of trace organic compounds and pathogens that can adversely affect human health and the environment. The composition of biosolids varies between wastewater treatment plants and depends on the quantity and quality of wastewater inputs and on the type of wastewater treatment system used to remove and stabilize substances contained in the wastewater. There are four levels of wastewater treatment, namely screening, primary, secondary, and tertiary, which may be used in wastewater management facilities. Each treatment produces a product with different chemical and physical characteristics. The method and degree of treatment can impact biosolids quality, the physical form of the biosolids and thus decisions on end use options.

Specific unit operations in wastewater treatment vary between plants; however, there are several general steps that are common to most wastewater treatment plants in the production of biosolids. Oleszkiewicz and Mavinic (2002) summarized the biosolids production chain in the following steps:

- pretreatment (screening and grit removal);
- thickening to reduce volume;
- conditioning;
- stabilization processes to achieve pathogen and vector attraction reduction;
- dewatering to decrease biosolids volume and improve handling and transport; and
- drying.[2]

In addition to conventional treatment technologies to achieve pathogen and vector attraction reduction, new technologies are constantly under development. Recent researches have outlined several new technologies for advanced treatment of sewage sludge to produce biosolids that are suitable for land application. Most emerging new and improved processes are being promoted to meet the US EPA’s Class A treatment objectives, which require that the biosolids contain no

[1] USEPA (2003). Control of Pathogens and Vector Attraction in Sewage Sludge. EPA 625-R-92–013, Revised July (2003), Washington, DC.

[2] Oleszkiewicz J.A. and Mavinic D.S. (2002). Wastewater biosolids: an overview of processing, treatment, and management. Journal of Environmental Engineering and Science, 1:75-88.

detectible levels of pathogens.[3] New technologies can improve volatile solids reduction, increase gas production, improve dewaterability of digested biosolids and reduce or eliminate pathogens.[4]

For information about further studies on biosolids treatment, see Appendix A.

2.2 Biosolids Classification

Biosolids regulations may be developed on a federal, provincial or regional level to ensure that recycling of biosolids is protective of human health and the environment. Biosolids regulations typically stipulate quality and process-based criteria. Quality-based criteria can include concentration limits for trace elements, nutrients and organic compounds. Process-based criteria include requirements for pathogen and vector attraction reduction to ensure that biosolids are stable and microbiological risks are minimized. The degree to which these criteria are met determines how the biosolids can be used, and the amount of additional regulatory oversight required.

Biosolids meeting the most restrictive quality and process-based criteria are generally subject to less regulation than biosolids that meet less restrictive criteria. In some jurisdictions the highest quality biosolids may be distributed and used without further regulation, whereas lower quality biosolids are subject to further regulatory approval and conditions such as application rate limits, site management requirements, grazing and harvesting restrictions for agricultural applications, record-keeping and compliance monitoring and reporting.

Biosolids regulations in various Canadian and other jurisdictions are provided in section 5 below.

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[3] Kelly H.G. (2003). Emerging processes in biosolids treatment. 2nd Canadian Organic Residuals Conference, Princeton, BC, April 203.

[4] Jolly M., Nemeth L., Arant S. and Wilson T. (2004). Recent advances in biosolids stabilization 2004: case histories. http://www.earthtech.com/documents/Advanced_in_BioSolids_Stabilization.pdf.

3. Use of Biosolids in Mine Reclamation

Historically, biosolids were considered a waste product and were disposed of through landfilling, incineration or ocean discharge.[5] The ban on ocean dumping and the environmental and economic costs of incineration and landfilling have led to increased interest in land application. Biosolids have been recognized as a potentially useful soil amendment and source of nitrogen, phosphorus, organic matter, and other nutrients, which can enhance soil physical properties as well as plant yield. However, others have consistently expressed concerns about the application of biosolids on agricultural land. Many of these concerns are discussed in more detail below in section 4. Although land application of biosolids is predominantly on agricultural soil, biosolids have also been used in landscaping, remediation of abandoned and active mining sites, composting, landfill closure, silviculture and soil-surface revegetation.[6]

Treated and processed biosolids may be applied as a fertilizer and soil amendment to improve and maintain productive soils and stimulate plant growth. However, the application of biosolids to the natural environment is limited by a number of factors. Biosolids can only be applied to sites with the proper topographic properties because of concerns over water run-off and the potential for leaching. This means that a selected site cannot have geographic features, such as excessively steep slopes that would allow biosolids erosion in heavy rains or waterways in close proximity that could potentially become contaminated. Transportation and accessibility are other major contributing factors; most large mining operations are not located in close proximity to biosolids generators. If a site is densely covered in trees or brush, application vehicles may not have access to the desired lands. For these reasons, biosolids land applications are best suited for semi-level terrain away from water sources but near roads to allow for easy vehicle access.[7]

Other factors to consider when making decisions on biosolids use include cost, regulatory compliance, existing soil quality, final land use objectives, stakeholders and proximity to alternative land uses. Furthermore, section 4 explores some potential concerns for human and ecological health which must be considered before the application of biosolids on agricultural and other lands.

3.1 Soil Amendment

Biosolids have been used for reclamation of degraded mine lands in several parts of the world, including North America, Europe and Australia. The primary objective for using biosolids in mine reclamation is to provide an available source of organic matter, nutrients, and biomass to

[5] Bright D.A. and Healey N. (2003). Contaminant risks from biosolids land application: Contemporary organic contaminant levels in digested sewage sludge from five treatment plants in Greater Vancouver, British Columbia. Environmental Pollution, 126:39–49.

[6] USEPA (1999). *Biosolids Generation, Use, and Disposal in The United States*; United States Environmental Protection Agency, Office of Solid Waste, EPA530-R-99-009, September 1999. http://www.epa.gov/epaoswer/non-hw/compost/biosolid.pdf.

[7] Cogger, Craig, Dan M. Sullivan, Charles L. Henry, and Kyle P. Dorsey (2000). Biosolids Management Guidelines For Washington State. Washington State Department of Ecology Publication #93-80.

the degraded area in order to create an environment that is conducive to promoting plant growth and regenerating the soil layer.

Biosolids offer a number of potential benefits for reclaiming degraded mine lands:

- Lands disturbed by mining typically have low organic matter which limits site revegetation. The addition of biosolids to degraded mine land helps the process of soil formation. The nutrients in the biosolids can improve plant growth and survival on the site and provide a pool of macro- and micronutrients which plants can access over time. Typical degraded sites are deficient in these nutrients. Unlike nutrients in commercial fertilizers, nutrients added in the biosolids remain and cycle through time.
- Biosolids can positively affect the soil physical properties of the mine sites, which typically have low water holding capacity, infiltration, and percolation and can lead to drought-like conditions. The high organic matter content of biosolids can help keep moisture available to the soil and helps form stable soil aggregates, which can lead to increased percolation and infiltration. The development of a soil rich in organic matter and dense vegetation cover provides a plant/soil system that effectively absorbs water and limits the movement of water down the soil profile and into groundwater resources.
- Ussiri and Lal (2005) concluded that the use of biosolids could play a pivotal role in sequestering carbon through increases in soil organic carbon and biomass production at these highly disturbed sites.[8]
- Biosolids can be applied to mineral mine sites to achieve optimal soil pH. Typically, mine sites are characterized by low pH soils which exist naturally or are a consequence of mining operations, through the exposure of acid generating rock. Acidic soil conditions can facilitate trace element mobilization and inhibit plant growth.[9] (See Appendix C for further discussion about the use of biosolids for acid mine drainage).

See Appendix B for case studies of how biosolids have been used for soil amendment in mine reclamation.

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[8] Ussiri, D.A.N. and R. Lal. (2005). Carbon sequestration in reclaimed minesoils. Critical reviews in plant sciences. 24:151-165.

[9] Sydnor M.E.W., Redente. E.F. (2002). Reclamation of High-Elevation, Acidic Mine Waste with Organic Amendments and Topsoil. Journal of Environmental Quality, 31:1528–1537.

4. Health & Environmental Effects

Land application of biosolids is a way of recycling both the nutrients and the organic matter contained in the residuals. This practice holds some promise for the reclamation of degraded lands. However, the soil receives both the good and the bad constituents present in the biosolids. Potentially harmful constituents include low concentrations of trace organic compounds and pathogens that could adversely affect human health and the environment. People living near or applying biosolids have potential risk from low-level pathogens, endotoxins, and trace amounts of industrial and household chemicals, which could be airborne vectors for health problems.[10] The potential health risks associated with the presence of pathogens, trace elements and organic pollutants are well known, as well as the short and long-term effects that these contaminants have on the soil.[11]

There is also a rising concern about the presence of emerging contaminants, including pharmaceuticals, personal care products, and endocrine-disrupting substances in water sources. Increasingly, pharmaceuticals and prescription drugs are entering the natural environment through human and animal excretion. In humans, between 50- 90% of the active ingredients in drugs are not absorbed by the body and are excreted as waste. The figures are similar for other animals.[12] There is the potential for these antibiotics and hormones to be carried through biosolids to agricultural and degraded mining lands, and eventually enter local water sources as runoff. Many contaminants may be removed through wastewater and sewage treatment systems, but some may be present in sewage sludge. The physical fate of these contaminants will then vary greatly, depending on the substance. Some may degrade in the natural environment while others can be taken up by plants and animals or infiltrate a water source. The most persistent contaminants may survive even through drinking water treatment.[13]

Current research into these emerging contaminants indicates that the presence of these chemicals in water is widespread, although the concentrations are minute, often a thousand to a million times lower than human therapeutic doses of drugs.[14] The use of biosolids on degraded mine sites should be accompanied by research into water treatment technologies, safe sludge-handling methods, and appropriate systems for monitoring contamination levels.

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[10] Lewis D.L., Gattie D.K., Novak M.E., Sanchez S., and Pumphrey C. (2002). Interactions of Pathogens and Irritant Chemicals in Land-applied Sewage Sludges (Biosolids). BMC Public Health, 2: 11. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=117218.

[11] Albiach R., Canet R., Pomares F., Ingelmo F. (2000). Microbial biomass content and enzymatic activities after the application of organic amendments to a horticultural soil. Bioresource Technology, 75: 43–48; Vasseur L., Cloutier C., and Ansseau C. (2000) Effects of repeated sewage sludge application on plant community diversity and structure under agricultural field conditions on Podzolic soils in eastern Quebec. Agriculture, Ecosystems and Environment, 81: 209–216.

[12] Holtz, Susan. There is No "Away": Pharmaceuticals, Personal Care Products, and Endocrine-Disrupting Substances: Emerging Contaminants Detected in Water. Canadian Institute of Environmental Law and Policy. Toronto: CIELAP, 2006. http://cielap.org/pdf/NoAway.pdf.

[13] Ibid.

[14] Ibid.

4.1 Nutrient management and impacts on water quality

Mine reclamation with biosolids increases revegetation success, but nutrient addition well in excess of vegetation requirements has the potential to increase leaching of nitrate and other biosolids constituents. Large applications of low-C/N-ratio biosolids could negatively impact area water quality, and biosolids reclamation practices should be modified to reduce this possibility.[15]

Excess NO_3, which is mineralized from biosolids, moves readily through most soils if not taken up by the plant and microbial biomass. Composting or mixing biosolids with a high C material such as wood chips can reduce the risk of nitrate leaching. Amendment with sawdust drastically reduced NO_3 levels in leachates. Monitoring wells immediately down gradient from the research plots revealed no effects on shallow groundwater, however, confirming EPA's presumption of minimum ground water risks from one-time applications.[16]

In general, changes in surface water quality following biosolids applications are characterized by short duration, low magnitude increases in nutrient concentrations. Specific to groundwater, immediate establishment of vegetation following biosolids applications is important in providing a nutrient demand. A dense vegetative cover, which is the objective in mine reclamation, can readily assimilate nutrients, and reduce the risk of leaching. For a number of operational case studies and scientific studies evaluating nutrient dynamics, see Appendix D.

4.2 Trace metals

Degraded mining sites have elevated concentrations of mined metals in trace amounts (often referred to as trace elements) as a result of extraction and processing. These elevated metal concentrations are often reflected in the vegetation grown on the site and can be a concern if the area is to be used by wildlife or domestic livestock.[17] Trace metals can accumulate in soil and plants and enter the human food chain. Biosolids applied for their fertility and soil conditioning benefits also result in the transfer of additional trace metals to soil. Trace metal behavior in soils and plant uptake is difficult to generalize because it is strongly dependent on the properties of the metal, biosolids, soil and vegetation. Therefore, it is advisable to take a precautionary approach to understand the potentially toxic affects of metal additions to soil.[18] Daniels and Haering (2000) suggest that, provided trace metal concentrations, application rate limits and site management guidelines are followed, the risk of metals entering the food chain or contaminating

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[15] Stehouwer R., Day R.L., and Macneal K.E. (2006). Nutrient and Trace Element Leaching following Mine Reclamation with Biosolids. Journal of Environmental Quality, 35:1118-1126.

[16] Daniels W.L. and Haering K.C. (2000). Protocols for Use of Biosolids and Co-Amendments for Mined Land Reclamation. http://www.rmwea.org/tech_papers/mine_forest_land_2000/Daniels.pdf.

[17] Gardner W.C., Broersma K., Popp J.D., Mir Z., Mir P.S., and Buckley W.T. (2003). Copper and health status of cattle grazing high-molybdenum forage from a reclaimed mine tailings site. Canadian Journal of Animal Science, 83:479-485.

[18] McBride M.B. (2003). Toxic metals in sewage sludge-amended soils: has promotion of beneficial use discounted the risks? Advances in Environmental Research, 8:5–19.

groundwater is extremely low.[19] A study revealed that leachate concentrations of Al, Fe, Mn, K, Cu, Ni, and Zn were reduced while Ca, SO_4, Mg, F, B, P, and Cl showed an increase in leachate concentration.[20]

Brown et al. (2003) investigated the application of biosolids to a mine site to *reduce* metal toxicity and establish vegetation.[21] The Bunker Hill, Idaho Superfund site was formerly a zinc and lead mine and smelting facility. Tailings deposited in a central impoundment area contained elevated levels of zinc, lead and cadmium, little organic matter and were highly acidic. Conventional reclamation of these tailing involved covering with an impermeable plastic layer and the application of a layer of imported topsoil. However, failure of the plastic layer had been observed and the importation of topsoil was expensive and had deleterious effects to the area from which the topsoil was extracted. Several organic and inorganic residuals were investigated as alternatives to topsoil importation, including biosolids. Surface applications of a biosolids and wood ash mixture proved to increase soil pH, reduce metal availability and provide a suitable medium for vegetation establishment.

In an experiment evaluating biosolids amendment and metal extractability, Pond et al. (2005) applied biosolids to acidic copper tailings at rates of 134 and 200 tonnes per dry hectare.[22] The pH of the tailings increased from 3.3 to as high as 6.3, and was accompanied by a decrease in copper concentrations from leachate. At the higher biosolids application rate to neutral pH tailings, small increases of extractable metals (Cu, Ni, and Zn) were observed, but this effect could be mitigated by reducing biosolids application rates.

4.3 Pathogens

Biosolids, depending on the treatment process, may contain pathogens. There is a concern for the potential contamination of soil and water by pathogens present in sludge. Rogers and Smith note that populations of coliform bacteria, such as *Escherichia coli*, may be transferred to the soil upon application (2007).[23] Pharmaceutical products, as mentioned previously, may make their way to water sources through the application of sewage sludge to degraded lands.[24] The use and presence of antibiotics has the potential to lead to drug resistant strains of pathogens; the development of resistance in previously susceptible strains of bacteria is known as antimicrobial

[19] Daniels W.L. and Haering K.C. (2000). Protocols for Use of Biosolids and Co-Amendments for Mined Land Reclamation. http://www.rmwea.org/tech_papers/mine_forest_land_2000/Daniels.pdf.

[20] Abbott D.E., Essington M.E., Mullen M.D., and Ammons J.T. (2001). Fly ash and lime-stabilized biosolid mixtures in mine spoil reclamation: simulated weathering. Journal of Environmental Quality, 30:608-616.

[21] Brown, S.L., C.L. Henry, R. Chaney, H. Compton, and P.S. DeVolder. (2003). Using municipal biosolids in combination with other residuals to restore metal-contaminated mining areas. Plant and Soil, 249: 203-215.

[22] Pond, A. P., White S.A., Milczarek M., and Thomson T.L. (2005). Accelerated Weathering of Biosolid-Amended Copper Mine Tailings. Journal of Environmental Quality, 34:1293–1301.

[23] Rogers M., and Smith S.R. (2007). Ecological impact of application of wastewater biosolids to agricultural soil. Water and Environment Journal, 21:34–40.

[24] Holtz, Susan. There is No “Away”: Pharmaceuticals, Personal Care Products, and Endocrine-Disrupting Substances: Emerging Contaminants Detected in Water. Canadian Institute of Environmental Law and Policy. Toronto: CIELAP, 2006. <http://cielap.org/pdf/NoAway.pdf>.

resistance, or AMR. While the concentrations of antibiotics detected in water supplies have not been sufficient to lead to AMR, it is a concern highly worth monitoring in tandem with biosolid usage.

Rogers and Smith also cited several microbial processes that can contribute to the decay of pathogenic bacteria in land-applied biosolids (2007).[25] Competition for energy sources (i.e. nutrients) and antagonism of indigenous soil bacteria and microorganisms may inhibit the establishment of bacteria introduced from biosolids. Native soil microorganisms such as protozoa and bacteriophages are also known to preferentially graze and have a general deleterious effect on microbes introduced through biosolids applications.

Land application of biosolids has the potential for contamination of soil and water by pathogens present in biosolids. In a study on the survival of enteric micro-organisms in biosolids following direct land-spreading, it was found that the enteroviruses were not detected 2 weeks after spreading on the soil whereas the concentration of faecal indicators fell slowly over 2 months while the concentrations of *C. perfringens* remained stable.[26] It should be noted that this European study measured microbiological parameters not typically regulated in Canada, making it difficult to compare the quality of the biosolids, and the study did not describe the treatment processes used on the biosolids beyond stating that a conventional treatment system was used.

Members of the public have raised concerns about the presence of pathogens in biosolids. For example, in Mount Carmel Township, Pa., residents voiced concerns over water quality due to the use of Class B biosolids to revegetate ground cover for a nearby mine reclamation project. Residents fear the biosolids may contaminate local surface and groundwater. While Class A biosolids contain no detectable levels of pathogens and meet strict vector attraction reduction requirements and low trace element concentration limits, Class B biosolids are treated but still contain detectable levels of pathogens, according to EPA regulations.[27] However, the pathogen content is managed through land application and site restrictions to maintain a high level of environmental protection.

Daniels and Haering (2000)[28], in their analysis of protocols for the use of biosolids for mine reclamation, report that pathogen transmittal is not a concern if the biosolids have undergone appropriate pathogen reduction processes and proper application procedures are followed.[29]

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[25] Rogers M., and Smith S.R. (2007). Ecological impact of application of wastewater biosolids to agricultural soil. Water and Environment Journal, 21:34–40.

[26] Pourcher A., Francoise P., Virginie F., Agnieszka G., Vasilica S., and Ge´rard M. (2007). Survival of faecal indicators and enteroviruses in soil after land-spreading of municipal sewage sludge. Applied Soil Ecology 35: 473–479.

[27] CWR (2004). Mine reclamation with biosolids hits snag over concerns for water. *Clean Water Report*. Business Publishers, Inc. 42.13 p123.

[28] Daniels W.L. and Haering K.C. (2000). Protocols for Use of Biosolids and Co-Amendments for Mined Land Reclamation. http://www.rmwea.org/tech_papers/mine_forest_land_2000/Daniels.pdf.

[29] Ibid.

4.4 Trace organic chemicals

Biosolids can contain detectable concentrations of organic chemicals.[30] Trace organic chemicals are of particular concern due to potential toxicity, including carcinogenicity and endocrine disruption. Biosolids are highly enriched in organic wastewater contaminants, whose composition and fate in biosolids should be ascertained since about 50% of biosolids are land applied and thus become a potentially ubiquitous non-point source of organic contaminants into the environment.[31] A number of the chemicals detected in sludges have been shown to function as endocrine disrupters. For example, nonylphenols present in sludges at relatively high concentrations (concentrations greater than 1000 mg/kg are not unusual), may be of concern because of their potential impact on wildlife.[32]

Bright and Healey (2003) studied organic contaminants including volatile organics, chlorinated pesticides, PCBs, dioxins/furans, extractable petroleum hydrocarbons, PAHs, and phenols in biosolids from five wastewater treatment plants (WWTPs) within the Greater Vancouver Regional District (GVRD).[33] The study found that the mixing of biosolids with uncontaminated soils during land application, based on the known metal concentrations in biosolids, provides adequate protection against the environmental risks associated with organic substances such as dioxins and furans, phthalate esters, or volatile organics with the exception of these petroleum hydrocarbon constituents or their microbial metabolites.

Based on a modeling study, Wilson *et al.* (1996) found no threat to groundwater quality under routine operational practice with typical sludge application rates and usual range of compounds detected in sludge;[34] however, some organic contaminants, such as, tri-, tetra-, penta- and hexa-chlorobenzenes, tri-, tetra- and penta-chlorophenols, PCBs and PCDD/Fs have potential for accumulation in plants and animals.[35]

For information about studies offering a review of organic chemicals found in biosolids, see Appendix E.

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[30] Kinney C., Furlong E., Zaugg S., Burkhardt M., Werner S., Cahill J., and Jorgensen G. (2006). Survey of organic wastewater contaminants in biosolids destined for land application. Environmental Science and Technology, 40:7207-7215.

[31] Ibid.

[32] E.C. (2001). Assessment report—nonylphenol and its ethoxylates. Environment Canada, June 2001.

[33] Bright D.A. and Healey N. (2003). Contaminant risks from biosolids land application: Contemporary organic contaminant levels in digested sewage sludge from five treatment plants in Greater Vancouver, British Columbia. Environmental Pollution, 126:39–49.

[34] Wilson S.C., Duarte-Davidson R., and Jones K.C. (1996). Screening the environmental fate of organic contaminants in sewage sludges applied to agricultural soils: 1. The potential for downward movement to groundwaters. The Science of the Total Environment, 185:45-57.

[35] Duarte-Davidson R., and Jones K.C. (1996). Screening the environmental fate of organic contaminants in sewage sludges applied to agricultural soils: II. The potential for transfers to plants and grazing animals. The Science of the Total Environment, 185:59-70.

4.5 Bioaerosols

Concerns regarding land application of biosolids include the aerosolization potential of a wide variety of microbial pathogens and related pollutants forming bioaerosols that are a vehicle for the dissemination of human and animal pathogens. A review of research on the risks associated with bioaerosol dispersion by Pillai (2007) indicated that the risk of exposure of humans to aerosolized pathogens downwind of biosolids application areas is minimal.[36] Brooks et al. (2004) attribute the minimized risk to the affinity of bacteria and viruses present in biosolids to adsorb to organic matter, limiting their potential to aerosolize.[37]

Tanner et al. (2005) assessed bioaerosol emission rates and plume characteristics from the application of liquid biosolids.[38] As a control, groundwater was inoculated with equivalent concentrations of the coliforms and coliphages evaluated in the liquid biosolids and applied using the same method. Aerosolized coliforms and coliphages were not detected from a sample collection point 2 meters downwind of the spray applicator, and flux rates for these species were based on the lower detection limit of the methodology. However, the concentrations of bioaerosolized coliforms and coliphages from the inoculated groundwater were three orders of magnitude greater than that of the biosolids. It was concluded that the physical properties of the liquid biosolids are such that bioaerosolization is suppressed.

4.6 Odour

Nuisance odours are by far the number one complaint associated with land application,[39] and they are encountered frequently when the use sites are close to residential areas. As with animal manures, odours are generated from the degradation of biosolids under anaerobic conditions. For example, biosolids from activated sludge treatment contains 32–41% proteins, which are composed of many nitrogen and sulfur compounds. Due to the lack of oxygen in biosolids, the biological reactions produce various odorous compounds, with reduced sulfur and nitrogen compounds as the most offensive ones with odor threshold concentrations as low as 0.1 ppb. Table 2 provides a summary of common odour compounds generated from wastewater treatment.[40]

Table 2: Malodorous sulfide-containing compounds commonly found in biosolids.

Compound	Chemical Formula	Odour Threshold (ppm)	Characteristic Odour

[36] Pillai S.D. (2007). Bioaerosols from Land-Applied Biosolids: Issues and Needs. Water Environment Research 79: 270-278.

[37] Brooks, J.P., B.D. Tanner, K.L. Josephson, C.P. Gerba and I.L. Pepper. (2004). Bioaerosols from the land aplication of biosolids in the desert southwest USA. Water Science and Technology. 50:7-12.

[38] Tanner, B.D., J.P. Brooks, C.N. Haas, C.P. Gerba and I.L. Pepper. (2005) Bioaerosol emission rate and plume characteristics during land application of liquid class B biosolids. Environmental Science & Technology, 39:1584-1590.

[39] USEPA (2000a). Land Application of Biosolids Management. EPA 832-F-00–064. Washington, DC.

[40] Metcalf & Eddy Inc. 2003. Wastewater engineering: treatment and reuse – fourth edition. Tchobanoglous, G., F.L. Burton and H.D. Stensel (Eds.). McGraw-Hill Companies Inc.

Hydrogen sulphide	H_2S	0.00047	rotten eggs
Crotyl mercaptan	CH_3-CH-CH-CH_2SH	0.000029	skunk-like
Dimethyl sulphide	CH_3-S-CH_3	0.0001	decayed cabbage
Dimethyl disulphide	CH_3-S-S-CH_3	0.0001	alliaceous (onion/garlic)
Diphenyl sulphide	$(C_6H_5)_2S$	0.0047	unpleasant
Ethyl mercaptan	CH_3-CH_2S	0.00019	decayed cabbage
Ethyl sulphide	$(C_2H_5)_2$-SH	0.000025	nauseating
Methyl mercaptan	CH_3-SH	0.0021	decayed cabbage
Thiocresol	CH_3-C_6H_4-SH	0.000062	skunk-like, rancid

4.7 Ecological Effects and Impacts on Biodiversity

As biosolids application occurs on farms, forests, and mines, as well as residential and recreational land, organic chemicals in land-applied biosolids may pose environmental or ecological risks in addition to potential impact on human health.[41]

One study revealed that plant communities resulting from the addition of biosolids to the soil used in limestone quarry restoration have more biomass and cover, but fewer numbers of species.[42]

There is historical evidence that the uptake of trace elements in vegetation established in soil amended with biosolids is, however, limited. Sopper (1993) summarizes several research trials evaluating trace element concentrations in grass and legume species.[43] This study observed that plant uptake of trace elements was ephemeral, remaining comparable to concentrations of trace elements in plants in control treatments, and not approaching tolerable concentrations of trace elements in agronomic crops. The uptake of trace elements in tree species follows a similar trend to that of grasses and legumes, in that concentrations within all tree parts did not approach levels that would provide a health risk if grazed by animals

[41] Chaney RL, Ryan JA, O'Connor GA. (1996) Organic contaminants in municipal biosolids: risk assessment, quantitative pathways analysis, and current research priorities. Science of the Total Environment, 185:187–216; Harrison E.Z., Oakes S.R., Hysell M., and Hay A. (2006) Organic chemicals in sewage sludges. Science of the Total Environment, 367:481–497; Rogers H.R. (1996) Sources, behaviour and fate of organic contaminants during sewage treatment and in sewage sludges. The Science of the Total Environment, 185:3-26; Rogers M., and Smith S.R. (2007) Ecological impact of application of wastewater biosolids to agricultural soil. Water and Environment Journal, 21:34–40.

[42] Moreno-Peñaranda R., Lloret F., and Alcan˜ iz J.M. (2004) Effects of Sewage Sludge on Plant Community Composition in Restored Limestone Quarries. Restoration Ecology, 12:290-296.

[43] Sopper W.E. 1993. *Municipal Sludge Use in Land Reclamation.* Lewis Publishers, London.

5. Regulation in Canada, USA & Other Jurisdictions

Several jurisdictions have developed federal, state/provincial and regional biosolids management regulations. Section 5 summarizes several biosolids regulatory regimes, providing details on quality and process-based criteria, and illustrates the varying degrees to which biosolids are regulated depending on the quality achieved. Table 3 provides a comparison of metal concentration limits from the regulations reviewed.

Table 3: Biosolids Trace Element Concentrations in Reviewed Regulations[44] (mg/kg total solids, dry weight)

Trace Element[1]	Canada		United States			EU		Australia	
	BC	Ontario	Part 503	Rhode Island	Mass.	Directive	Proposed	Western Australia	NSW
Arsenic	75	75	41	41	-	-	-	20	20
Cadmium	20	20	39	39	14	20	10	3	3
Chromium	-	1,060	-	1,200	1,000	-	1,000	100	100
Cobalt	150	150	-	-	-	-	-	-	-
Copper	-	760	1,500	1,500	1,000	1,000	1,000	100	100
Lead	500	500	300	300	300	750	750	150	150
Mercury	5	5	17	17	10	16	10	1	1
Molybdenum	20	20	-	75	10	-	-	-	-
Nickel	180	180	420	420	200	300	300	60	60
Selenium	14	14	100	36	-	-	-	3	5
Zinc	1,850	1,850	2,800	2,800	2,500	2,500	2,500	200	200

[1] Limits provided represent most restrictive limit stipulated in the respective regulation.
[2] Directive recommended concentration ranges for most trace elements. Where applicable, values provided represent most restrictive value of range.

5.1 Regulations in Canada

In British Columbia, biosolids management is regulated under the Organic Matter Recycling Regulation (OMRR), made under the *Environmental Management Act*. Under the OMRR, biosolids are classified as either Class A or B. Class A biosolids are the highest quality biosolids achievable under the OMRR. Class A biosolids contain lower fecal coliform densities (< 1,000 most probable number (MPN) g^{-1}) and do not exceed the most stringent trace element concentration limits provided for biosolids under the OMRR. Achieving stringent quality standards allows for more liberal distribution and use of Class A biosolids under the OMRR, including unrestricted distribution of volumes not exceeding 5 m^3 and unrestricted distribution as feedstock to compost and biosolids fabrication facilities. Class B biosolids are subject to less stringent trace element and fecal coliform requirements than Class A biosolids. As such, they are generally of lower quality and are subject to more land application and distribution restrictions. Class B biosolids can be distributed to composting facilities without restriction. Additionally,

[44] Table courtesy of SYLVIS Environmental, New Westminster, British Columbia; www.sylvis.com.

Class B biosolids meeting Class A pathogen limits and pathogen and vector attraction reduction criteria can be distributed without restriction to a biosolids growing medium facility.

A Land Application Plan (LAP) is required for the application of Class A and Class B biosolids (excluding the noted exceptions above). The primary function of the LAP is to ensure that residuals are land applied for their fertilizing or soil conditioning properties and that the application will not lead to degradation of the environment, or impair any designated future use of the environment. This includes protection of soil quality, surface and ground water, air quality and the quality of the vegetation grown as a result of the application. The LAP ensures that trace element additions to the soil are within allowable limits, and appropriate residuals and site management practices are implemented to protect human health. Information required in the LAP can be divided into several sections: preliminary information, determining the appropriate application rate of the residual, calculating the soil concentration of trace elements following application, ensuring that public health requirements are met, outlining any special management concerns and outlining required post-application monitoring.

In accordance with the LAP, the Code of Practice for Soil Amendments prohibits the application of waste in quantities that exceed the nutrient needs of plants at the application site. A qualified professional must prepare a land application plan in which they predict the expected concentration of constituents in the soil and calculate the amount of soil amendment that can be applied to provide for the plant or crop needs. The discharger is responsible for ensuring that the application of a soil amendment to land has a positive effect on the soil. They must analyze the soil and the soil amendment, and then have a qualified professional calculate the predicted concentration of contaminants in the soil after land application. The calculated level in the soil must stay below contaminated site criteria levels.[45]

Although a discharger must notify the government of the land application of managed organic matter at least 30 days prior to the application,[46] there is no requirement in the regulation that the discharger consult with the public (including adjacent land owners).[47]

In Ontario, a guideline was issued in 1996 that outlines criteria for the land application of biosolids or other residuals on agricultural land. These materials must be shown to be of benefit to crop production or soil health and not degrade the natural environment before the Ministry of Environment (MOE) will give approval for their use. The residuals should supply essential plant nutrients and/or organic matter, or other constituents that will maintain or enhance crop production and soil health.[48] In Ontario, biosolids meeting trace element concentration requirements are not applied to soils with pH values of less than 6.0. Biosolids containing lime may be applied to soils of lower pH, when they will raise the soil pH to at least 6.0. The

[45] Ministry of the Environment of British Columbia, Code of Practice for Soil Amendments, 2007.

[46] Organic Matter Recycling Regulation, B.C. Reg. 18/2002, s. 22.

[47] Andrew Lewis, Greater Vancouver Regional District, Regulatory Framework for Biosolids Management in Canada, February 2006 at 8.

[48] MOE, OMAFRA (1996). Guidelines for the utilization of biosolids and other wastes on agricultural land. Ministry of Environment, Ministry of Agriculture, Food and Rural Affairs, Ontario March 1996, Revised January 1998. http://www.ene.gov.on.ca/envision/gp/3425e.pdf.

guidelines have also specified separation distances from water table, bedrock, drilled well, individual residences and residential areas and have specified minimum separation distances of spreading sites from watercourses.

The application of biosolids on agricultural land in Ontario is currently regulated under the *Environmental Protection Act* (Reg 347) and the *Nutrient Management Act* (Reg 267/03). The 1996 guidelines remain in effect in Ontario at present with respect to the utilization or land application of biosolids regulated under the *Environmental Protection Act*. However, MOE is currently consulting on a proposed regulatory framework for the management of non-agricultural source materials to eliminate overlapping approval requirements and develop and revise existing standards under the *Nutrient Management Act* to focus on the quality of the materials.

Under the Environmental Protection Act, municipalities or contractors must apply to the Ministry of the Environment's Regional Offices for a Certificate of Approval for an "organic soil conditioning site". Certificates of approval usually contain site-specific conditions and require compliance with general standards set out in Regulation 347. Before issuing an approval, the Ministry staff may inspect proposed sites to make sure that they meet the standards. Although many types of approval must be posted for public notice and comment on Ontario's Environmental Bill of Rights Registry, proposals for organic soil conditioning sites are exempt from this requirement.[49]

The Ministry also uses the "Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Lands", issued in March 1996, to evaluate the suitability of sites. The guidelines state that "the use of biosolids and other waste materials must be of benefit to crop production or soil health". Furthermore, they require that "such use shall not degrade the natural environment or cause any degradation in drinking water supplies".[50]

The *Nutrient Management Act* relates specifically to biosolids and other non-agricultural source materials such as food processing residuals that are utilized as a nutrient on agricultural land. Under this regulation generators (wastewater treatment plants, paper mills or food processors) are required to have a Nutrient Management Strategy and all application sites are required a Nutrient Management Plan. Generators are "phased-in" under the regulation based on the design capacity of the WWTP or the type of residual to be land applied. At the present time the utilization of biosolids and other residuals for land reclamation is regulated under the *Environmental Protection Act*.

In Alberta the land application of biosolids is governed by the "Guidelines for the Application of Municipal Wastewater Sludges to Agricultural Land".[51] These Guidelines were prepared by Alberta Environment in 1982 and revised in 1996 through a process of peer review. Criteria contained in the Guidelines were developed through a review of information collected by Alberta Environment, the requirements of other jurisdictions and published technical information. Land

[49] O. Reg. 681/94 made under the *Environmental Bill of Rights, 1993*, ss. 5(2)6.ii.

[50] Canadian Environmental Law Association. Biosolids and Septage FAQs, 2004. http://www.cela.ca/faq/cltn_detail.shtml?x=1501

[51] Alberta Environment (2001): http://environment.gov.ab.ca/info/library/6378.pdf

treatment of biosolids is an authorized activity under the Alberta *Environmental Protection and Enhancement Act*.

The Guidelines provide criteria for development of a biosolids spreading program, sampling and analytical methodology, equipment calibration and application of biosolids. Written permission for the land treatment of biosolids is required under the *Environmental Protection and Enhancement Act*. To accomplish this, the owner of the facility producing the biosolids must complete an application form submit it to the Regional Director of Alberta Environment requesting a Letter of Authorization. The application includes questions pertaining to the requirements stipulated in the guideline and includes a map delineating the proposed application site and the signature of the land owner agreeing to the crop and grazing restrictions. In the Letter of Authorization, Alberta Environment specifies the amount of biosolids that can be applied to land; it is the responsibility of the biosolids producer (i.e. the municipality) to ensure that the application rates are achieved.

The Guidelines provide criteria for representative sampling of the biosolids, analytical methodologies and the associated reference materials and worksheets for completing calculations. In addition the Guidelines specify required monitoring parameters: solids content, ammonia-nitrogen (dry solids), total phosphorus and seven strong acid extractable metals (cadmium, chromium, copper, mercury, nickel, lead and zinc).

5.2 Regulations in USA

In USA, the Part 503 Biosolids Rule classifies biosolids on their level of pathogen and vector attraction reduction and trace element concentrations.[52] Class A biosolids undergo advanced treatment to reduce pathogen levels to less than 1000 MPN fecal coliforms per gram of total solids, dry weight or density of *Salmonella* less than 3 MPN per 4 grams of total solids, dry weight. Heat drying, composting, and high-temperature aerobic digestion are treatment processes that achieve Class A pathogen reduction requirements. Class A biosolids, often sold in bags, can be beneficially used without pathogen related restrictions at the site. If Class A biosolids also meet approved vector attraction reduction requirements and Part 503 concentration limits for trace elements, Class A biosolids, known as Exceptional Quality (EQ) biosolids, can be used as freely and for the same purposes as any other fertilizer or soil amendment product. Class B Biosolids are treated to reduce pathogens to levels protective of human health and the environment, typically containing less than 2,000,000 MPN fecal coliforms per gram of total solids, dry weight. Thus, Class B biosolids require crop harvesting and site restrictions, which minimize the potential for human and animal contact until natural attenuation of pathogens has occurred. Class B biosolids cannot be sold or given away for use on sites such as lawns and home gardens, but can be used in bulk on agricultural and forest lands, reclamation sites, and other controlled sites, as long as all Part 503 vector, pollutant, and management practice requirements also are met.[53]

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[52] USEPA (1994). A plain English guide to the EPA part 503 biosolids rule. EPA/832/R-93/003, U.S. Environmental Protection Agency, Washington, D.C.

[53] Ibid.

While some states have adopted the Part 503 regulation, several states have elected to develop their own biosolids management regulations. In cases where state regulations are more stringent than the Part 503, the state regulations supersede the Federal Rule. Provided below are summaries of biosolids management regulations for the states of Massachusetts and Rhode Island.

The Massachusetts Department of Environmental Protection's (MDEP) Regulation 310 CMR 32.00 – Land Application of Sludge and Septage is an example of a regulation that supersedes the Part 503. This regulation classifies biosolids into three categories.[54]

- Type I biosolids meet the most stringent criteria set out in Regulation 310 CMR 32.00. Type I biosolids can be sold and distributed without further approval.
- Type II biosolids meet less stringent criteria than Type I biosolids. Type II biosolids can be sold, offered or distributed for the growing of any vegetation only with prior approval from the MDEP.
- Type III biosolids have also been treated for pathogen reduction, but exceed trace element limits for Type II biosolids. Type III biosolids may be used for growing vegetation except for direct food crops only with prior approval from the MDEP. Land application of Type III biosolids to a site must be recorded in the registry of deeds in the chain of title for the site.

In 1997, the Rhode Island Department of Environmental Management promulgated Regulation #12-190-008 – Rules and Regulations for the Treatment, Disposal, Utilization and Transportation of Sewage Sludge. Under this regulation, biosolids are described as Class A, B or C, depending on the degree to which they meet quality criteria provided in Appendices 7 and 8 of the regulation

Class A biosolids do not exceed the most restrictive trace element concentration limits provided in Appendix 7. In addition, Class A biosolids do not exceed the pathogen concentration limit of 1,000 MPN g^{-1} fecal coliform bacteria. Composted biosolids that meet the criteria specified in Appendix 7 are also considered Class A biosolids. Class A biosolids may be packaged and distributed in containers not exceeding 23 kg (50 lbs). Packaged Class A biosolids are subject to labeling requirements indicating that the contents are derived from sewage sludge, that the product is lead-safe but not lead-free, and application instructions. Class A biosolids distributed in bulk are subject to further regulation depending on whether the bulk volume is greater or less than 19 m^3 (25 yd^3). There are additional management requirements for bulk distribution of Class A biosolids exceeding 19 m^3, including additional record-keeping requirements, and the requirement for biosolids users to follow a "user guide" issued by the Department of Environmental Management and developed in conjunction with the biosolids distributor.

Class B biosolids must meet the quality requirements provided in Appendix 8 of the regulations. Class B biosolids can be used on agricultural and non-agricultural land, but applications must be conducted under an Order of Approval and meet requirements pertaining to:

[54] MDEP (1992). Land application of sludge and septage, Regulation 310 CMR 32.00, Massachusetts Department of Environmental Protection. http://www.mass.gov/dep/service/regulations/310cmr32.pdf.

- soil analysis;
- land application rates;
- cumulative loading rates;
- crop and turf harvesting restrictions;
- animal grazing and public access restrictions;
- frozen ground application and odour control requirements;
- water resource and property line buffers;
- groundwater monitoring requirements;
- erosion control; and
- biosolids transportation requirements.

Class C biosolids exceed the quality criteria provided in Appendices 7 and 8. The use of Class C biosolids is limited to use as daily, intermediate or final cover on landfills, or the application to dedicated disposal sites.

5.3 Regulations in Other Jurisdictions

In Australia, individual states or regions are responsible for biosolids management. Following are examples of how biosolids are regulated in two Australian states.

New South Wales (NSW), Australia developed the Environmental Guidelines for the Use and Disposal of Biosolids Products. Under this guideline, biosolids are classified based on the level of contaminants in the biosolids and the stabilization processes they undergo to achieve pathogen and vector attraction reduction. Contaminant grading for biosolids ranges from A to E, with A being the most restrictive. Stabilization grading for biosolids ranges from A to C, with A being the highest level of stabilization achievable. The combination of contaminant and stabilization grading determines allowable biosolids land use options. Biosolids achieving the highest levels of contaminant and stabilization grades (i.e. Grade A contaminant levels and Grade A stabilization) can be used without restriction. Biosolids that do not meet the minimum requirements for contaminant concentrations and/or stabilization must be disposed of in a landfill or surface disposed within the boundary of the wastewater treatment plant where they were generated.[55]

In Western Australia, the classification system involves two separate factors and is used to determine the permissible end uses for biosolids products. These are: Contaminant Grade - based on the concentration of chemical contaminants; and Pathogen Grade (also called Stabilization Grade) - based on the levels of treatment to reduce pathogens, vector attraction (ability for the biosolids to attract insects such as flies and mosquitoes) and odour. Each contaminant level is graded C1, C2 or C3 using the Contaminant Acceptance Concentration Thresholds. Biosolids achieving Grade C1 contaminant grade are the highest quality (lowest concentration of contaminants), while Grade C3 is the lowest quality (highest concentration of contaminants). The contaminant grade for a biosolids product is determined by the lowest grade for any one contaminant. For example, if most of the contaminant concentrations in a biosolids product passed Contaminant Grade C1, but one contaminant was Grade C2, then the entire product would

[55] NSWEPA (1997). Environmental Guidelines: Use and Disposal of Biosolids Products. NSW Environment Protection Authority, Chatswood, NSW, Australia. www.epa.nsw.gov.au.

be classified as Contaminant Grade C2. All biosolids products are assumed to be Contaminant Grade C3 until proven otherwise. Similarly, the biosolids are classified in one of four categories with regard to pathogens limits and approved treatment processes.[56]

Several European jurisdictions have adopted a non-risk based approach to the regulation of biosolids. Thus, many European countries have more stringent standards with regard to permissible trace element concentrations in biosolids. In 1986, The Council of European Communities published the Sewage Sludge Directive 86/278/EEC to provide recommendations for biosolids quality criteria, including trace element concentration limits. By 1989, all EU members were required to publish their own biosolids regulations based on the recommendations of this directive. Many jurisdictions elected to implement more stringent standards than stipulated in Directive 86/278/EEC. A summary of the Directive 86/278/EEC and EU members' biosolids trace element concentration limits is provided in "Biosolids Applied to Land – Advancing Standards and Practices", published by the National Research Council of the National Academies.

New biosolids regulations have been proposed but have yet to be adopted. The most recent iteration of EU biosolids management regulations is the "Working Document on Sludge - 3rd Draft." This document provides proposed future trace element concentrations for biosolids as well as trace organic compound regulations.

In the United Kingdom, biosolids are classified into 2 categories: Treated and Advanced Treated somewhat corresponding to Class B and Class A biosolids. Rather than providing regulations that stipulate trace element concentration limits in biosolids, the UK regulations specify annual trace element loading rates that are similar to those recommended in the Sewage Sludge Directive.

[56] WADEP. (2002). Western Australian Guidelines for direct land application of biosolids and biosolids products. Department of Environmental Protection, Perth, Western Australia. http://www.health.wa.gov.au/envirohealth/water/docs/WA_Guidelines_Biosolids.pdf

6. Biosolids Management

As biosolids contain both beneficial constituents and potential contaminants, their use should only be considered where the protection of human health and the environment can be ensured. Biosolids show some promise in the reclamation of degraded mine sites. Regulations governing biosolids quality, supported by best management practices, may minimize the risk of negative environmental impacts resulting from land application. If biosolids application to mine sites can be performed in a manner that minimizes the risk of environmental contamination to an acceptable level, it may be both a cost-effective method for the addition of nutrients and organic matter to the degraded lands and an economical biosolids management solution. As a result, most research and operational programs are conducted with the intent of determining a biosolids application rate, or combination with other beneficial feedstock prior to application, which will facilitate achieving reclamation objectives while minimizing the potential for adverse environmental effects.

6.1 Biosolids quality

Various processes are implemented over the course of wastewater treatment to stabilize biosolids and reduce microbiological risks while minimizing the removal of beneficial constituents such as nutrients.[57]

Pathogen reduction is a treatment method that reduces the concentrations of microbiological organisms in biosolids. These organisms include certain bacteria, fungi, viruses, protozoa and their cysts, and parasites and their ova (eggs). Treatment processes such as heat, adding lime to change pH, aerobic or anaerobic digestion, and drying are used to directly reduce pathogen levels or create an environment that pathogens can't live in. This treatment is essential for protecting human health and the environment from diseases. Pathogen reduction has a major impact on the relative safety of biosolids. From a regulatory perspective, pathogen reduction and meeting pathogen density limits can influence management options as discussed in section 5. Biosolids used in disturbed land reclamation typically meet Class B or equivalent pathogen reduction standards or employ site-specific management practices such as immediate incorporation and site access restrictions.

Vector attraction reduction refers to direct treatment methods that stabilize biosolids to reduce the attraction of vectors (organisms like rodents, flies, birds and mosquitoes) that can carry pathogens. Vector attraction may also be planned for indirectly by incorporating biosolids into the soil immediately following application. It is important to minimize the attractiveness of biosolids to animals that could carry pathogens. In this way, diseases that could endanger people or the environment as a result of land applying biosolids are also reduced. Direct treatment processes include heat and adding lime or alkali to increase pH. These treatments reduce odors, food value and other properties that would tend to attract vector organisms. As with pathogen

[57] Neyens E., Baeyens J., De heyder B., and Weemaes M. (2004). The potential of advanced treatment methods for sewage sludge. Management of Environmental Quality, 15:9-16.

reduction, biosolids used in disturbed land reclamation typically meet Class B or equivalent vector attraction reduction requirements.

6.2 Nutrient leaching

Nitrate leaching to groundwater is a potential risk from non-agronomic application rates of biosolids. Daniels and Haering (2000) suggest that it does not appear to be a significant risk from one-time applications and recommend that nitrate leaching from higher than agronomic rate loadings can be limited by adjusting the carbon to nitrogen (C:N) ratio of the applied materials with sawdust or woodchips.[58]

6.3 Trace elements

Biosolids use in the remediation of contaminated soils allows for remediation at low cost, and can be applied to prevent further dispersal of the contaminated soil materials at many locations.[59] However, the potential exists for long-term trace element mobilization biosolids-amended soils if soil pH is allowed to decline below 5.5, and particularly if potential acid-forming sulfides are not fully neutralized. Therefore, the use of high rates of biosolids on potentially acidic materials such as coal refuse must be coupled with accurate determination of potential acidity, and sufficient lime must be added with the biosolids treatment to assure that the pH of the biosolids incorporation zone will be maintained at pH 6.0 for an extended period of time. When high levels of phytotoxic Zn are present in a mine spoil or waste, the pH must be maintained above 7.0 to limit Zn solubility.[60] Brown *et al.* (2005) report that combined application of biosolids and lime to highly acidic and contaminated mineral mine tailings can reduce trace element availability and increase soil fertility to restore function to the ecosystem.[61]

6.4 Biodiversity

The addition of nutrients to soil following biosolids applications can lead to long-term dominance by early-successional species, most notably grasses, and, consequently, a low establishment of woody and volunteer species. Additionally, many grass species commonly planted in reclamation have aggressive growth habits that lead to their dominance in coal mine plant communities. Several species, e.g. Canada bluegrass (Poa compressa) and a mixture of P. compressa, Switch grass (*Panicum virgatum*), and white clover (*Trifolium repens*) provided adequate coverage while still allowing the highest species richness and survival of woody species. Use of these species

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[58] Daniels W.L. and Haering K.C. (2000). Protocols for Use of Biosolids and Co-Amendments for Mined Land Reclamation. http://www.rmwea.org/tech_papers/mine_forest_land_2000/Daniels.pdf.

[59] Chaney R.L., Brown S.L., Angle J.S., Stuczynski T.I., Daniels W.L., Henry C.L., Siebielec G., Li Y.-M., Malik M., Ryan J.A. and Compton H.. (2000). In situ Remediation/Reclamation/Restoration of Metals Contaminated Soils using Tailor-Made Biosolids Mixtures. In Proceedings of *Symposium on Mining, Forest and Land Restoration: The Successful Use of Residuals/Biosolids/Organic Matter for Reclamation Activities* (Denver, CO, July 17-20, 2000). Rocky Mountain Water Environment Association, Denver, CO. www.rmwea.org/tech_papers/mine_forest_land_2000/Chaney.pdf.

[60] Daniels W.L. and Haering K.C. (2000). Protocols for Use of Biosolids and Co-Amendments for Mined Land Reclamation. http://www.rmwea.org/tech_papers/mine_forest_land_2000/Daniels.pdf.

[61] Brown S., Sprenger M., Maxemchuk A., and Compton H. (2005). Ecosystem function in alluvial tailings after biosolids and lime addition. Journal of Environmental Quality, 34:139-148.

mixtures in coal mine reclamation with biosolids in the eastern United States led to establishment of a more species-rich plant community with a greater woody species component while still providing erosion control and site protection.[62]

6.5 Phytotechnology

Although biosolids can limit the phytoavailability and bioavailability of trace elements, they do not remove them from the soil. Biosolids application serves to reduce the availability and mobility of trace elements and other contaminates, such as sulfates, through the soil. When combined with phytotechnologies, biosolids could not only contain contaminants, but could also provide higher degrees of trace element extraction than that offered by typical vegetative covers. Phytotechnologies use plants to contain, stabilize, reduce, detoxify, and degrade contaminants in soil, ground water, surface water, or sediments.[63] Phytotechnologies can be applied in situ or ex situ and can address organic compounds such asetroleum hydrocarbons, gas condensates, crude oil, chlorinated compounds, pesticides, and explosive compounds plus inorganics including high salinity, trace elements, metalloids, and radioactive materials. Jenness (2001) suggests that if biosolids and phytoremediation were used in tandem, they could possibility restore and return a site to near its original condition.[64]

6.6 Public Participation

The recycling of biosolids onto land for reclamation brings biosolids closer to more people, with the result that more people are becoming aware of biosolids and assessing whether or not they represent a risk to their health or environment. Therefore, public participation and seeking public acceptance has been an important aspect of biosolids management.[65]

A number of best practices for the managing recycling of biosolids include: engaging the public in dialogue with sharing of information and understanding; stakeholder participation; joint fact-finding; and consensus building. Public participation is crucial because public opinion and political resistance may present significant limitations to a biosolids management program, particularly when the biosolids management program involves transporting biosolids from one municipality to another. Resistance may take the form of NIMBY (not-in-my-backyard) and NIMTOO (not-in-my-term-of-office).

The expected benefits of implementing and maintaining a strong stakeholder consultation program are to increase and promote awareness and education of biosolids use and to gain public support. Costs incurred during the public education and awareness process and communication

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[62] Halofsky J.E., McCormick L.H. (2005b). Establishment and Growth of Experimental Grass Species Mixtures on Coal Mine Sites Reclaimed with Municipal Biosolids. Environmental Management, 35:569–578.

[63] Ginocchio R., Baker A.J.M., and Cucuzza J. (2004). Phytoremediation, In *Mining Environmental Management*, November 2004, pp 7-10.

[64] Jenness N. (2001) Mine Reclamation Using Biosolids. Report Prepared for USEPA, August 2001. http://clu-in.org/download/studentpapers/biosolids.pdf.

[65] Beecher N., Harrison E.Z., Goldstein N., McDaniel M., Field P., and Susskind L. (2005). Risk perception, risk communication, and stakeholder involvement for biosolids management and research**.** Journal of Environmental Quality, 34:122-128.

programs should be weighed against the costs of overcoming potential future public opposition. Lack of public acceptance can lead to failure of the preferred biosolids management program, resulting in a potentially significant increase in overall cost.[66]

The potentially beneficial uses of biosolids should be proposed to the public with scientific support. However, the public must also be informed of potential negative health and environmental impacts and then measures to be taken to mitigate against these possibilities. With appropriate management, biosolids may be a useful resource, and may contribute to national sustainable development goals. However, legitimate public concerns about odours, pathogens and illness need to be addressed.

[66] InfraGuide (2003) Biosolids Management Programs, National Guide to Sustainable Municipal Infrastructure. Federation of Canadian Municipalities, November 2003. http://sustainablecommunities.fcm.ca/files/Infraguide/storm_and_wastewater/biosolids_managmnt_programs.pdf.

7. Recommendations

1. Where use of biosolids in mine reclamation is being considered, biosolids quantity and quality, as well as the impacts of biosolids on air and water quality, should be studied from an environmental protection perspective. Biosolids quality (i.e. constituent concentrations, pathogen limits and vector attraction reduction) criteria must be met prior to biosolids use in mine reclamation and remediation. Monitoring should be completed to ensure biosolids quality meets the criteria specified in applicable regulations.
2. A review of existing research into the use of biosolids in mine reclamation and remediation, and the outcomes of operational programs, should be undertaken by any government interested in permitting or regulating such a program. This review would: (a) synthesize research about the toxicity, fate, transport, and interactions with the receiving environment of compounds of emerging concern in biosolids applied to land (including trace elements, nutrients, PCBs, PCDD/Fs, PAHs, brominated flame retardants, pharmaceuticals and personal care products and sterols); (b) communicate the risks associated with these compounds; (c) identify and prioritize knowledge gaps and research opportunities about the implications of biosolids in mine reclamation on human health and the environment; and (d) support action to minimize the concentrations of environmentally deleterious constituents in biosolids, including source management initiatives including sewer use bylaw amendment and public education.
3. Government and industry should assist in appropriate research as identified specific to biosolids use in mine reclamation and remediation.
4. Any application of biosolids to lands should be based on acceptable resultant contaminant concentrations in the receiving soil. The quality of biosolids and the nature of degraded mine soils must be considered. Decisions about the appropriateness of using biosolids in mine reclamation should be completed on a case-by-case basis according to site-specific circumstances. In assessing the potential for adverse environmental impacts due to the use of biosolids in mine reclamation, decisions should be made in the context of principles that include: ensuring a thorough assessment; taking an ecosystem approach; taking a precautionary approach; considering cumulative impacts; addressing risk and uncertainty; and ensuring meaningful and timely public consultation.

5. In addition to regulatory compliance, available best management practices should be followed to ensure the prudent management of biosolids.

6. It is essential to include a public education and awareness component in the initial stages of biosolids use. This includes public education, scientific improvement and communication of scientific results to public, demonstration trials, and notification. A document summarizing the identification of stakeholders and successful consultation approaches should be prepared that could serve as a guideline to biosolids generators and mine reclamation practitioners to assist in decision making regarding biosolids management options. Case studies on reclaimed mine sites in Canada and other

jurisdictions should be reviewed to gain more information on community reaction to biosolids use and ultimate successes or failures.

7. Following biosolids applications for mine reclamation there should be appropriate monitoring and management to ensure that there is minimal potential for off-site movement of biosolids and biosolids constituents that could negatively impact water resources, additional environmental resources, and human health. An environmental monitoring program should include indicator parameters to identify changes in the risk to human health and the environment.

Appendix A: Further Studies on Biosolids Treatment

Neyens *et al*. (2004) have found thermal hydrolysis (neutral, acid, alkaline) and chemical oxidation using hydrogen peroxide promising.[67] The iron nanoparticle technology offers a potentially sustainable and unique solution to a vexing environmental problem.[68]

A unique biological process known as BIOSOL has been developed by the University of Toronto, Canada to remove trace elements and destroy pathogens from biosolids and the method has been successfully used in wastewater treatment facilities operated by the Greater Moncton Sewerage Commission.[69]

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[67] Neyens E., Baeyens J., De heyder B., and Weemaes M. (2004). The potential of advanced treatment methods for sewage sludge. Management of Environmental Quality, 15:9-16.

[68] Li X., Brown D.G. and Zhang W. (2007). Stabilization of biosolids with nanoscale zero-valent iron (nZVI). Journal of Nanoparticle Research, 9:233–243.

[69] LeBlanc R.J., Allain C.J., Laughton P.J. and Henry J.G. (2004). Integrated, long term, sustainable, cost effective biosolids management at a large Canadian wastewater treatment facility. Water Science and Technology, 49:155–162.

Appendix B: Further Studies on the Use of Biosolids for Soil Amendment in Mine Reclamation

Although biosolids use has been limited in the past, there is a new interest from industry, government, and the private sector to develop innovative ways to recycle biosolids. One example is the U.S. Environmental Protection Agency's Superfund program, which has used biosolids to restore sites negatively impacted by hard rock mining activities. Biosolids use is part of EPA's strategy to reclaim some of the largest Superfund sites in the country including Jasper County, MO and Leadville, CO.[70] Bunker Hill in Idaho, the second largest Superfund site in the USA, and Palmerton in Pennsylvania, have both benefited from the application of biosolids to produce vegetative covers which minimize erosion and mitigate trace element toxicity.[71] Interest from industry can be seen in the development of higher margin biosolid-based products which have been sold commercially as fertilizers under such names as Compro®, Bay State Fertilizer®, and Milorganite®.

Studies conducted at three aforementioned Superfund sites in the United States: Bunker Hill, Idaho; Palmerton, Pennsylvania; and the Summitville Mine near Del Norte, Colorado have shown that biosolids and biosolids amendments in mine reclamation improve soil fertility and establish vegetative cover. For example, due to a high metal content waste materials, the Bunker Hill site was treated with a wide range of soil amendments including biosolids, wood ash, woody debris, pulp and paper residuals, and compost.[72] Results showed that high nitrogen (N) biosolids in combination with the other amendments was able to restore vegetative cover to the test plots within 2 years.[73] Comparatively, conventional amendments including lime application and microbial stimulation were less effective in restoring vegetative cover during the same period.[74]

Pierce County Water Resources, Washington, is working with the sand and gravel mine adjacent to its treatment facility to establish vegetation on past mining sites. Twenty acres of this site are dedicated to demonstrating the value of Pierce County biosolids as a soil amendment, through forestry, landscaping and application rate trial research conducted by the University of Washington College of Forest Resources. A large strip mine near Centralia, Washington, used biosolids from a number of cities during the 1970s and 1980s to reclaim disturbed sites. Several hundred acres were amended with biosolids, then planted with tree seedlings. With the addition of structure-improving and nutrient-providing amendments, plant growth on these kimberlite tailings under field conditions was significantly improved over unamended tailings material.

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[70] AgeCanada. Land Reclamation. A&M Greenland Environmental Co. (AGE), Vancouver, Canada. http://www.agecanada.com/land%20reclamation.htm.

[71] Bastian, R.K. (1997). Biosolids Management in the United States. Water Environment & Technology, May 1997.

[72] Brown S. and Henry C. (2001). *Using Biosolids for Reclamation/Remediation of Disturbed Soils*. University of Washington. http://www.brownfieldstsc.org/pdfs/BiosolidsWhitePaper-UWash.pdf.

[73] Ibid.

[74] Ibid.

Tailings properties, including cation exchange capacity, organic carbon, and macronutrient availability, were also improved with amendment addition.[75]

The City of Toronto started a beneficial biosolids recycling program in 2001 with a design to pelletize and then use for fertilizer or for soil enhancement half of the biosolids produced with the other half being applied directly to agricultural land or used in mine reclamation projects.[76] Land reclamation is included in the biosolids management strategy of the City of Kingston.[77]

In Sechelt, BC, approximately 1.5 hours away from Vancouver, biosolids and biosolids products have been used in the reclamation of Canada's largest sand and gravel mine. Liquid and dewatered biosolids from wastewater treatment plants within the region as well as from Metro Vancouver (formerly the Greater Vancouver Regional District) have been used alone or in the creation of soil amendments in the reclamation of aesthetic berms, in the establishment of poplar plantations and in the creation of a wetland and other features of a wildlife corridor that will eventually traverse the mine site. Long-term monitoring of ground and surface water features on and adjacent to the mine site has not indicated any negative impacts to water quality resulting from biosolids use at the mine.

Metro Vancouver in British Columbia has begun using biosolids to reclaim portions of the Similco copper mine near Princeton, B.C. In 1992, Metro Vancouver in partnership with the Town of Princeton established four demonstration plots on the Granby Tailings, to show how mine spoils can be successfully reclaimed using biosolids. The tailings were fertilized with biosolids, seeded, and monitored over the past five years. Extensive soil, water, and vegetation sampling in and around the plots, before and following the applications, confirmed that biosolids can be used as a soil amendment. The biosolids provided organic matter and essential plant nutrients that helped establish a healthy, mixed grass and legume cover, which in turn eliminated the dust and wind erosion problems, and reclaimed the area for recreation, cattle, and wildlife use.[78] The goal of this project is to revegetate extensive areas of piled rock and mine tailings and stabilize slopes. Tree establishment screening trials through the University of British Columbia were completed to determine the best species for establishment in reclaimed mine tailings.[79] The land reclamation strategy used at Similco was the first of its kind in Canada. Areas mined in the past now support wildlife and provide range for cattle.

The Hedley Gold Tailings Project was a heap leach gold extraction mine that operated between 1988 and 1995 near Hedley, BC. Tailings from the historic Mascot and Giant Nickel mines were

[75] Reid N.B. and Naeth M.A. (2005). Establishment of a Vegetation Cover on Tundra Kimberlite Mine Tailings: 2. A Field Study. Restoration Ecology, 13:602-608.

[76] Fortner B. (2001). Toronto brings biosolids recycling program on stream. Civil Engineering, 71(3):18.

[77] City of Kingston. (2003). *Kingston Biosolids Management Strategy.* City of Kingston September 2003.

[78] Peddie C., Duynstee T., and Taylor L. (1998). Demonstrating self-sustaining vegetation: Granby tailings, Princeton, B.C., Greater Vancouver Regional District.
http://www.gvrd.bc.ca/nutrifor/pdfs/SelfsustainingVegetationGranby.pdf.

[79] AgeCanada. Land Reclamation. A&M Greenland Environmental Co. (AGE), Vancouver, Canada.
http://www.agecanada.com/land%20reclamation.htm.

deposited to the north and southeast of Hedley between 1904 and 1955. These tailings were mined, agglomerated, stacked into a heap and leached for gold, most recently by Candorado Operating Company Ltd. Metro Vancouver progressively reclaimed some of the disturbed tailings areas in three phases during 1996, 1997 and 2000 utilizing biosolids. Forage establishment with biosolids was successful for all reclaimed tailings areas, improving their aesthetics and dust control. Public consultation was integral to each reclamation phase that utilized biosolids. Effective collaboration between public agencies enabled successful project execution. Continued reclamation progress at this site has demonstrated the value of public consultation and the capacity for collaboration between public agencies to enable progressive reclamation at the financially constrained mine site.[80]

Highland Valley Copper (HVC) is an active, open-pit copper mine located approximately 400 km northeast of Vancouver. HVC has been in production for approximately forty-five years and currently produces 163,000 tonnes of copper and 1,900 tonnes of molybdenum annually. While chemical fertilizer is used on the mine site, it has been demonstrated that the use of chemical fertilizer alone on tailings and low quality overburden would not be able to sufficiently address the unique reclamation challenges at the mine, specifically the ability to establish vegetation on low fertility soils in a cool, dry climate further restricted by a short growing season.

Metro Vancouver biosolids use at HVC was initiated in 1996. To date, over 260,000 bulk tonnes of biosolids have been applied to 590 hectares of reclaimed land. In 2008, approximately 23,000 bulk tonnes of Metro Vancouver biosolids will be applied at HVC.

Class B biosolids from Metro Vancouver have been used in reclamation activities at Mount Polley, and open-pit copper and gold mine near Williams Lake, BC. Reclamation research trials were implemented at the mine in 1998 with ongoing monitoring conducted since. These tree-growth trials were established on the rock disposal sites using mixtures of overburden, biosolids and chemical fertilizer. Final reclamation plans include the use of till, overburden, biosolids and coarse woody debris to re-establish vegetation on waste rock dumps and tailings.

At the Summitville mine site near Del Norte, Colorado, plant growth was greatly inhibited when it reached the acidic soils of the mine site.[81]

Furthermore, a study by Pond *et al* (2005) on the application of municipal biosolids to copper mines revealed that the low pH of mine sites can inhibit nitrification in soils and result in marginal increase in nitrate runoff from leaching, although no adverse environmental impacts by increased trace element leaching, NO_3^- leaching was suggested.[82] Biosolids application to acid (pH 3.3) tailings resulted in pH values as high as 6.3 and leachate pH as high as 5.7, and the

[80] Horton R., and Kempe R. (2002). Progressive reclamation utilizing biosolids at the Hedley gold tailings project, Hedley, British Columbia, Canada.

[81] Sydnor M.E.W., Redente. E.F. (2002). Reclamation of High-Elevation, Acidic Mine Waste with Organic Amendments and Topsoil. Journal of Environmental Quality, 31:1528–1537.

[82] Pond, A. P., White S.A., Milczarek M., and Thomson T.L. (2005). Accelerated Weathering of Biosolid-Amended Copper Mine Tailings. Journal of Environmental Quality, 34:1293–1301.

increased pH of the acidic tailings after biosolids addition should aid in the establishment of a plant and microbial community.[83]

Stabilization of pH was also an important factor in re-establishing vegetative cover at a mine site in Katowice, Poland.[84]

Biosolids applications resulted in a reduction in cadmium bioavailability. Positive long-term revegetation results have been reported in Pennsylvania, Illinois, Virginia and Poland following utilization of biosolids at high rates coupled with appropriate liming materials.[85]

The Palmerton, PA site is one of the largest Superfund sites and has been degraded by years of zinc ore smelting. The amendment mixture applied was a combination of biosolids, fly ash, potash, and limestone.[86] Application rates were enough to stabilize the pH level of the site to 7.0 in order to precipitate trace elements and were applied in both 1:1 and 3:1 biosolids to fly ash ratios. Vegetative cover was re-established with the 1:1 ratio being more successful in promoting grass growth and the 3:1 ratio being better for trees.[87] Inorganics (N, P, K, Ca, Mg) were all within tolerable limits however, plant trace element concentrations were higher in the 3:1 application rate possibly because the amendment with more fly ash had more $Ca(OH)_2$ available to precipitate trace elements and render them less phytoavailable.

A Superfund study at the Summitville Mine to compare organic matter soil amendments (mushroom compost and biosolids) against addition of topsoil for mine reclamation found that the incorporation of organic matter was more successful in increasing aboveground biomass and preventing toxicity in plants from excessive trace nutrient uptake than the topsoil.[88]

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[83] Ibid.

[84] Chaney R.L., Brown S.L., Angle J.S., Stuczynski T.I., Daniels W.L., Henry C.L., Siebielec G., Li Y.-M., Malik M., Ryan J.A. and Compton H.. (2000) In situ Remediation/Reclamation/Restoration of Metals Contaminated Soils using Tailor-Made Biosolids Mixtures. In Proceedings of *Symposium on Mining, Forest and Land Restoration: The Successful Use of Residuals/Biosolids/Organic Matter for Reclamation Activities* (Denver, CO, July 17-20, 2000). Rocky Mountain Water Environment Association, Denver, CO. www.rmwea.org/tech_papers/mine_forest_land_2000/Chaney.pdf.

[85] Daniels W.L. and Haering K.C. (2000) Protocols for Use of Biosolids and Co-Amendments for Mined Land Reclamation. http://www.rmwea.org/tech_papers/mine_forest_land_2000/Daniels.pdf.

[86] Chaney R.L., Brown S.L., Angle J.S., Stuczynski T.I., Daniels W.L., Henry C.L., Siebielec G., Li Y.-M., Malik M., Ryan J.A. and Compton H. (2000) In situ Remediation/Reclamation/Restoration of Metals Contaminated Soils using Tailor-Made Biosolids Mixtures. In Proceedings of *Symposium on Mining, Forest and Land Restoration: The Successful Use of Residuals/Biosolids/Organic Matter for Reclamation Activities* (Denver, CO, July 17-20, 2000). Rocky Mountain Water Environment Association, Denver, CO. www.rmwea.org/tech_papers/mine_forest_land_2000/Chaney.pdf

[87] Ibid.

[88] Sydnor M.E.W., Redente. E.F. (2002) Reclamation of High-Elevation, Acidic Mine Waste with Organic Amendments and Topsoil. Journal of Environmental Quality, 31:1528–1537.

Appendix C: Use of Biosolids for Acid Mine Drainage

Pyritic rock containing iron sulphide found in association with silica, coal and other materials can be acid generating. Precipitation coming into contact with exposed pyritic rock can result in the generation of acidic surface water runoff. Acid mine drainage occurs when water and air come in contact with pyrite. The sulfate-oxidizing *Thiobacillus* ferrooxidans bacteria catalyzes a reaction between the iron sulfide minerals, water, and oxygen to form sulfuric acid, which solubilizes metals, leaves deposits, seeps into soil and ground water, and runs off into rivers.[89] This acidic run-off (pH 1-3) can negatively impact adjacent surface water and aquatic life. The iron hydroxide ("yellow boy") precipitate associated with acid mine drainage smothers plant life and inhibits further growth. Solutions, such as covering the rock to minimize acid generation and using lime to raise the pH levels of water on site, are often ephemeral and maintenance intensive.

Acid mine drainage (AMD) and the runoff from mine sites can have high acidity and contain elevated concentrations of trace elements. Biosolids have been beneficial as surface amendments for mine reclamation because of the organic material and nutrients they can add to often phytotoxic spoil material. Biosolids may also be effective in limiting or ameliorating AMD.[90] Biosolids also can help to raise the pH of the mine site, particularly if they are stabilized with lime. If applied at sufficient rates, biosolids are beneficial in correcting both subsoil and surface acidity, which has the twofold benefit of reducing AMD from the site, as well as making trace elements from the site less bioavailable.

Biosolids have also been used as a biosorbent for recovery/separation of metal ions from acid mine drainages and mitigation of their toxicity to sulfate reducing bacteria.[91]

In column experiments, Peppas et al. (2000) investigated the ability of biosolids as a barrier layer to reduce AMD generation from unoxidized sulphide concentrates and tailings.[92] Approximately 0.30 m of biosolids was placed over arsenopyrate concentrates in a series of columns. Although the pH of the AMD (control treatment) was not stated, preliminary data showed the pH of the drainage from biosolids-treated concentrates was above 8 throughout a three week wetting and one week drying cycle. Most trace element concentrations tested were below detection limits. Other data indicated that the efficiency and lifetime of the biosolids cover depends on sufficient moisture and hydraulic conductivity of the biosolids layer.

The biosolids cover suppressed pyrite oxidation by acting as both a physical and chemical barrier

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[89] Sajjad, Ash. 1998 New Beneficial Use Alternatives for Biosolids Include Cleanup of Brownfields and Other Contaminated Sites. Water Environment & Technology.

[90] Stehouwer R. and Day, R. 2003. *Use of Biosolids for Mine Reclamation: Assessment of Impacts on Acid Mine Drainage and Nutrient Discharge*. Project Report NC90271, Department of Crop and Soil Sciences, Pennsylvania State University. http://environmentalsoils.cas.psu.edu/Finalprojectreportscootack.pdf.

[91] Utgikar V., Chen B., Tabak H.H., Bishop D.F., and Govind R. (2000) Treatment of acid mine drainage: I. Equilibrium biosorption of zinc and copper on non-viable activated sludge. International Biodeterioration and Biodegradation, 46:19-28.

[92] Peppas, A., K. Komnitsas, and I. Halikia. (2000). Use of organic covers for acid mine drainage control. Minerals Engineering. 14: 563-574.

against oxygen diffusion. The inhibition of sulphate production minimized AMD generation and the toxic effects associated with this highly acidic water. Additionally, the organic matter and the metal oxide present in the biosolids may reduce the availability of the trace elements by precipitation as sulphide and oxyhydroxide species, further reducing the toxicity of any leachate associated with the column experiments.

Appendix D: Case Studies and Scientific Studies Evaluating Nutrient Dynamics

A phased approach was taken in the reclamation of a gravel pit located in Metro Vancouver's Aldergrove Lake Regional Park bordering Aldergrove and Abbotsford in BC's Fraser Valley. A research trial was conducted where several amendments, primarily combinations of biosolids and compost, were evaluated as soil amendments as well as for their effects on groundwater quality. The second phase involved operational reclamation using a fabricated soil incorporating biosolids, and groundwater monitoring to ensure environmental protection.

The research trial involved an on-site lysimeter study to evaluate the potential of trace element and nutrient leaching to groundwater. Six treatments were established in the study: biosolids (thermophilic anaerobically digested biosolids from Metro Vancouver's Annacis Island Wastewater Treatment Plant; biosolids compost; NT (a product composed of waste paper fibre and biosolids); biosolids with biosolids compost (biosolids compost); inorganic chemical fertilizer; and a control (no treatment).

The amendments were applied by hand to the surface of three replicate lysimeters in August 1997. Lysimeter water was sampled every two weeks from September 14, 1997 to April 26, 1998 and analyzed for the following constituents:

- carbon (dissolved organic and total organic);
- nitrogen (total Kjeldahl, NH_3, NO_3^-/NO_2^-, mineral and organic); and
- phosphorus (dissolved reactive and total).

Concentrations of the constituents were reported, as well as total mass losses. The determination of the total amount of a constituent moving down and out of the soil profile is the preferred method in assessing the potential for constituent movement. Using this method, high or low concentrations that are observed in either small or large volumes of soil water are given equal consideration.

In assessing the loss of N and P in the lysimeter water the Biosolids with Compost treatment resulted in minimal mass loss of P and N as compared to the other treatments. While the treatment of Biosolids with Compost resulted in a N loss greater than that of the Control treatment, this treatment resulted in less N losses than that of the Chemical Fertilizer treatment. The Biosolids with Compost treatment, which resulted in the production of the most vegetation, had a significant reduction in the quantity of water moving down through the soil profile though soil storage and evapotranspiration losses. Standard inorganic fertilization practices, requiring several applications of inorganic fertilizer, or hydro seeding with mineral N and readily available P, would result in N and P losses significantly greater than that of the Biosolids with Compost treatment.

Following the outcome and recommendations of the research trial, operational reclamation of the gravel pit was initiated in 1999. Shortly before application Metro Vancouver biosolids and compost were delivered to the site, and mixed with native soil at a volume ratio of 1:1:4

compost:biosolids:native soil. The compost and biosolids mixture was applied to 11 hectares of the mine site, incorporated to a depth of 0.15-0.30 m and seeded.

An environmental monitoring program was established concurrently with the reclamation, which finished in 2000. A component of the environmental monitoring program was the monitoring of five water sampling sites for two years following the first application of biosolids. The five water sampling sites consisted of three local residential groundwater wells, a groundwater well on the reclamation site, and a surface water site in the canoeing lake created using the fabricated biosolids soil.

The biosolids and compost applications did not have a negative effect on the water quality of the canoeing lake. The concentrations of the analyzed constituents did not exceed the aquatic life and drinking water quality standards. Although NO_3^- concentrations varied throughout the sampling period, they were always well below regulatory limits. These fluctuations were likely due to natural seasonal cycles. NO_3^- concentrations rose during the cooler parts of the year when photosynthesis and NO_3^- reduction rates decrease dramatically.

The research conducted determined that a biosolids and compost mixture was the best amendment for the gravel pit reclamation. Monitoring showed no adverse impacts to the sensitive groundwater located very close to the soil surface.

Located on BC's Sunshine Coast, Lehigh Northwest Materials Construction Aggregates Limited's CAL Sechelt mine is the largest sand and gravel mine in Canada, occupying more than 600 acres (240 ha) and producing over 5 million tonnes of product per year. After identifying reclamation as a significant challenge and important component of their operation, the Sechelt mine explored the opportunity to use biosolids in their reclamation activities.

As a condition of their regulatory authorization to use biosolids in reclamation activities, the mine must monitor surface and groundwater quarterly and report results to the BC Ministry of Environment. This water quality monitoring program was initiated in December 1998. A total of four sites are monitored in this quarterly sampling program. Two of the sampling locations are groundwater wells, and two are surface water samples from a creek traversing the mine site. The creek surface water samples are collected upstream and downstream of the mine site

The water quality results are compared with the BC Approved Water Quality Guidelines (Criteria) for drinking water and freshwater aquatic life. Concentrations of the measured constituents have remained relatively unchanged over the last four sampling events, and are similar to the pre-application concentrations. A small increase in NO_3^- concentrations has been observed, but NO_3^- levels remain well below the drinking water and freshwater aquatic life standards of 10 mg L^{-1} and 200 mg L^{-1}, respectively.

Tian *et al*. (2006) found that application of biosolids for land reclamation at high loading rates with adequate runoff and soil erosion control had only a minor impact on surface water quality.[93]

[93] Tian G., Granato T.C., Pietz R.I., Carlson C.R., and Abedin Z. (2006) Effect of Long-Term Application of Biosolids for Land Reclamation on Surface Water Chemistry. Journal of Environmental Quality, 35: 101-113.

Despite the elevated concentrations of NO_3^--N and NH_4^+-N, the study did not find any impairment of water resources.

Stehouwer and Day (2003) found no effect of biosolids on groundwater quality; however, following biosolids application, nitrate concentrations in runoff water and percolate water reached high levels.[94] Phosphorus was not increased in surface water runoff, but was increased in percolate water, suggesting that current biosolids reclamation practices need to be reassessed and strategies developed to reduce the potential for offsite transport of N and P. Two possible approaches could be considered: determining application rates on nutrient loading rather than on biosolids loading; and co-application of biosolids with a high carbon material such as sawdust, leaves, or paper mill residuals.[95]

Pond et al. (2005) assessed changes in nitrate and sulfate leaching resulting from biosolids application to copper mine tailings.[96] While they observed higher rates of nutrient leaching with increasing biosolids application rates, it was noted that the conditions of this lab-scale assessment simulated rainfall rates much higher than natural conditions. Consequently, nutrient leaching, particularly for nitrate, was expected to be much lower from field sites than in this laboratory setting. Research conducted by others corroborates this assertion.

Ground water quality was monitored at a gravel mine in New Hampshire reclaimed with biosolids.[97] Wells were installed to evaluate the groundwater quality from areas within the biosolids application areas, as well as the biosolids stockpile areas. Groundwater was monitored from 1998 to 2001 via six wells in the treatment area and four in the control, as well as zero-tension lysimeters at 20 to 24 in. (0.5 to 0.6 m) depths, every two weeks from April to October and monthly from November to March. Mean NO_3^- levels were significantly increased in some locations beneath the biosolids-treated areas. NO_3^--N levels peaked at just below 60 mg L-1, or 100 mg L-1 in one well, in the late summer and fall. However, the stockpiling of residuals was believed to cause this, rather than the actual application, because NO_3^--N concentrations only increased in groundwater directly under stockpiling areas and were similarly low (<10 mg L^{-1}) between groundwater from other wells in the amended plot and the control treatment. The authors also believe stockpiling and not timing of biosolids applications explained the elevated NO_3^- levels, since concentrations were greatest over a year after the final application, instead of in the spring following this fall application.

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[94] Stehouwer R. and Day, R. (2003) *Use of Biosolids for Mine Reclamation: Assessment of Impacts on Acid Mine Drainage and Nutrient Discharge*. Project Report NC90271, Department of Crop and Soil Sciences, Pennsylvania State University. http://environmentalsoils.cas.psu.edu/Finalprojectreportscootack.pdf.

[95] Ibid.

[96] Pond, A. P., White S.A., Milczarek M., and Thomson T.L. (2005) Accelerated Weathering of Biosolid-Amended Copper Mine Tailings. Journal of Environmental Quality, 34:1293–1301.

[97] McDowell, W. H. and T. J. Chestnut. 2002. Monitoring Demonstration at a Top-Soil Manufacturing Site in New Hampshire. Final Report to DES and NH State Legislature, June 1998 - November 2001.

Appendix E: Studies Reviewing Organic Chemicals in Biosolids

A review of organic chemicals in biosolids conducted by Harrison et al. (2006) found data for 516 organic compounds detected in biosolids, representing 15 classes of compounds. More rigorously studied classes of trace organic compounds in biosolids include:[98]

- polychlorinated dibenzo-*para*-dioxins and polychlorinated dibenzofurans (commonly referred to as dioxins and furans and hereinafter abbreviated PCDD/F);
- polychlorinated biphenyls (PCB);
- polybrominated diphenyl ethers (PBDE);
- surfactants; and
- polycyclic aromatic hydrocarbons (PAH).

Of the persistent organic compounds detected in biosolids, PCDDs and PCDFs are among the most well understood constituents in terms of physical and chemical properties including toxicity, environmental fate, plant uptake, dose response and stability. PCDDs and PCDFs exist as mixtures of congeners. The most toxic congener is 2,3,7,8 -tetrachlorodibenzo-*para*-dioxin. To allow comparisons among samples containing PCDDs and PCDFs, a system of factors called toxic equivalency factors (TEFs) have been devised to weight the toxicity of the congeners compared to that of 2,3,7,8 - TCDD, which is assigned a TEF of 1. The most widely adopted system of TEFs is that proposed by the North Atlantic Treaty Organization, Committee on Challenges to Modern Society (NATO/CCMS), known as the International Toxic Equivalent Factor (I - TEF). This system assigns TEFs to 17 of the PCDDs and PCDFs – the remaining congeners are considered biologically inactive and are assigned a TEF of zero. In 1997, the World Health Organization (WHO) modified the I - TEFs such that the TEF value for 1,2,3,7,8 - pentachlorodibenzo-*para*-dioxin (PeCDD) increased from 0.5 to 1.0 and the TEF values for octachlorodibenzo-*para*-dioxin (OCDD) and octachlorodibenzofuran (OCDF) decreased from 0.001 to 0.0001. The WHO – TEF and I - TEF values are presented in Table 4.

[98] Harrison E.Z., Oakes S.R., Hysell M., and Hay A. (2006) Organic chemicals in sewage sludges. Science of the Total Environment, 367:481–497.

Table 4: WHO – TEF and I – TEF values

Congener	WHO - TEF Values (Human)	I - TEF Values
PCDDs		
2,3,7,8-TCDD	1	1
1,2,3,7,8-PeCDD	1	0.5
1,2,3,4,7,8-HxCDD	0.1	0.1
1,2,3,6,7,8-HxCDD	0.1	0.1
1,2,3,7,8,9-HxCDD	0.1	0.1
1,2,3,4,6,7,8-HpCDD	0.01	0.01
OCDD	0.0001	0.001
PCDFs		
2,3,7,8-TCDF	0.1	0.1
1,2,3,7,8-PeCDF	0.05	0.05
2,3,4,7,8-PeCDF	0.5	0.5
1,2,3,4,7,8-HxCDF	0.1	0.1
1,2,3,6,7,8-HxCDF	0.1	0.1
1,2,3,7,8,9-HxCDF	0.1	0.1
2,3,4,6,7,8-HxCDF	0.1	0.1
1,2,3,4,6,7,8-HpCDF	0.01	0.01
1,2,3,4,7,8,9-HpCDF	0.01	0.01
OCDF	0.001	0.001

Following analysis of a sample, the concentration of each detected toxic congener is multiplied by the TEF. This is repeated for each congener and then summed for the entire sample, yielding a single value referred to as the toxic equivalent (TEQ) of the sample.

Methodologies for quantitative analysis of PCDDs and PCDFs present at trace concentrations are well established.[99] Consequently, more recent research on trace organic compounds in biosolids has focused on conducting human health risk assessments for PCDDs and PCDFs in biosolids. While not specific to the application of biosolids to mine sites, the research addresses some of the general environmental and health related questions arising from the transfers of PCDDs and PCDFs to land through biosolids applications.

Schoof and Houkal (2005) summarize a risk assessment conducted by the USEPA in 2002 that

[99] Kester, G.B., R.B. Brobst, A. Carpenter, R.L. Chaney, A.B. Rubin, R.A. Schoof and D.S. Taylor. 2005. Risk characterization, assessment, and management or organic pollutants in beneficially used residual products. Journal of Environmental Quality. 34:80-90.

involved the development of a conceptual site model to simulate all possible pathways for PCDD and PCDF exposure through biosolids application for a farm family.[100] This risk assessment was completed by the USEPA in consideration of amendments to 40 CFR 503, Standards for the Use of Disposal of Sewage Sludge, and the potential to include constituents such as PCDDs and PCDFs in future iterations of this standard.[101] PCDD and PCDF concentrations were derived from a previously completed national biosolids survey. The conclusion of the risk assessment was that given current biosolids concentration and exposure pathways, numerical limits for PCDD and PCDF in biosolids would not be required to adequately protect human health and the environment.

Another priority in recent PCDD and PCDF research is investigation of the exposure routes to PCDDs and PCDFs for animals. A review conducted by Rideout and Teschke (2004) examined current data available on the correlation between PCDD and PCDF concentrations in soil, plants and livestock.[102] Their findings suggest a weak correlation between soil PCDD and PCDF concentrations and plant uptake, with the exception of plants from the cucumber family. Conversely, there appears to be a very strong correlation between PCDD and PCDF contaminated feed and incidental ingestion of soils and an increase in PCDD and PCDF concentrations in cattle fat and tissue that is indicative of bioaccumulation.

Jones and Sewart (1997) provided a thorough review on PCDD/F concentrations in biosolids, their fate, behaviour and significance in biosolids-amended agricultural systems, concentrating on applications within the UK.[103] They noted that atmospheric deposition and biosolids amendment appeared to supply equal amounts of PCDD/Fs to UK soils each year. However deposition resulted in greater TEQs than biosolids amendment due to composition of the PCDD/F congeners in each matrix. Biosolids tended to be enriched with lower quantities of the T- and PeCDD/Fs, which have higher TEFs, than the material accumulated through atmospheric deposition. Webber et al. (1996) estimated that municipal biosolids application on agricultural land accounts for approximately one third of Canadian biosolids production and concluded that PCDD/F contaminants do not represent a significant risk to agriculture and the environment in many Canadian biosolids.[104]

[100] Schoof, R.A. and D. Houkal. 2005. The evolving science of chemical risk assessment for land-applied biosolids. Journal of Environmental Quality. 34:114-121.

[101] USEPA. 2002a. Exposure analysis for dioxins, dibenzofurans, and coplanar chlorinated biphenyls in sewage sludge [Online]. Available at http://www.epa.gov/waterscience/biosolids/tbd.pdf (verified 7 March 2008). USEPA, Washington, DC, USA.

[102] Rideout, K and K. Teschke. 2004. Potential for increased human foodborne exposure to PCDD/F when recycling sewage sludge on agricultural land. Environmental Health Perspectives. 112:959-969.

[103] Jones, K., and A. Sewart. 1997. Dioxins and furans in sewage sludges: a review of their occurrence and sources in sludge and of their environmental fate, behaviour, and significance in sludge-amended agricultural systems. Critical Reviews in Environ. Sci. Technol. 27: 1-85.

[104] Webber, M., Rogers, H., Watts, C., Boxall, A., Davis, R., and R. Scoffin. 1996. Monitoring and prioritization off organic contaminants in sewage sludges using specific chemical analysis and predictive non-analytical methods. Sci. Total Environ. 185: 27-44.