UNDERSTANDING AND SOLUTIONS TO CHALLENGES FOR OPTIMIZING LAND APPLICATION OF BIOSOLIDS OUTCOMES IN B.C.

LWS 548 Major Project

Source: adapted from https://www.surreynowleader.com/news/human-waste-as-fertilizer-proposal-prompts-shuswap-opposition/

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EXECUTIVE SUMMARY

Biosolids have been applied on land for more than a century. It has a high content of organic matter and nutrients and can improve soil quality effectively. In British Columbia, land application of biosolids has become a key solution to deal with land pressure and degradation, and the process is under strict regulations to preserve human and environmental health.

However, biosolids are recovered from wastewater, which means harmful pollutants may still exist in biosolids after standard treatment processes. Although the regulations introduced by the British Columbia Ministry of Environment have mentioned the level of common pollutants in wastewater and biosolids, the emerging organic pollutants researches since the 1970s and the public perception of biosolids have become two major factors hindering the widespread land application of biosolids.

Firstly, researches show that emerging organic pollutants are very stable in the environment and there is no effective method to remove them in a wastewater treatment plant. These pollutants may accumulate in soil when biosolids are applied on land repeatedly, posing potential threats to residents and animals. Secondly, there are still a number of residents in British Columbia opposite the biosolids land application for many reasons, including fear of pollution, unpleasant smell, feeling injustice, and so on.

This white paper presents a literature review, stating the properties of emerging organic pollutants and public perception of biosolids land application in British Columbia. In the end, it will provide solutions for the dilemmas to optimize the land application of biosolid outcomes.

INTRODUCTION

Biosolids are recovered from wastewater, at the end of the wastewater treatment process, and organic materials will go through high heat treatment to be stabilized to generate biosolids. As a result, biosolids may be used to improve soil quality and applied for other beneficial uses (Wijesekara et al., 2016). During the wastewater treatment process, microorganisms in wastewater absorb organic matter, nitrogen and phosphorus, in their body, to form a solid mass, which also becomes biosolids (Lu & Stoffella, 2012). Biosolids can improve soil quality and crop production by increasing the soil content of organic matter, nitrogen, phosphorus, potassium and other micronutrients. However, risky levels of pollutants, such as heavy metal, organic compounds and pathogens may also be present (Demetropoulou & Nikolaidis, 2012).

The cost of biosolids management is significantly influenced by transportation costs, however advanced treatment processes including thickening, dewatering, conditioning, and drying can reduce these costs greatly. For example, the transportation cost of pelletized biosolids is less expensive than non pelletized biosolids, due to the lower water content of these biosolids (EPA, 2003).

In British Columbia, 38,000 dry tonnes of biosolids are produced every year (BC Ministry of Environment, n.d.). Along with being rich in organic matter, the risk of pollutant accumulation raises. public concerns. Although biosolids land application, including element concentrations in biosolids and post-application soil contents, are under strict supervision in British Columbia, the public still lacks an understanding of biosolids and holds negative opinions (Whitehouse et al., 2018). Concerns expressed focus around a number of issues. Firstly, residents and their pets or livestock may be exposed to pollutants if biosolids are applied to the topsoil, that they and their animals may contact. Secondly, there is a potential risk that long-term biosolids application may contribute to high levels of nutrient elements in shallow-groundwaters, compared to standards of public drinking water (USGS, 2015). Thirdly, when organic matter in biosolids is decomposed by microorganisms, it releases gases such as hydrogen sulphide, ammonia, causing unpleasant odours. The first two factors determine that land application of biosolids must be strictly monitored, while the odour is not a harmful signal (EPA, n.d.), it is the most direct reason that the public is unwilling to accept biosolids application near residential areas.

Despite some concerns, land application of biosolids provides valuable benefits that can help address a number of environmental challenges. There are three major options to manage biosolids, including landfilling, incineration and land application. Landfilling was the most common one in the past prior to biosolids regulations. However, as the landfill capacity is reducing and the cost of waste disposal is increasing, as well as biosolids stored onsite contribute significantly to greenhouse emissions, alternative methods are becoming necessary (Demetropoulou & Nikolaidis, 2012; Ken, A. et al., 1996). Biosolids incineration generate the most stable materials and require minimal disposal area, but high levels of investment and maintenance fees, as well as air pollution, all lead to public opposition (EPA, 2003). At the same time, land degradation has become a global challenge (Imeson & Wiley, 2012). In this case, land application of biosolids has positive potential and can be the key solution to reverse land degradation.

In British Columbia, under Organic Matter Recycling Regulation (OMRR), biosolids are used as an ingredient in compost and landscaping soils, in agriculture, forestry, and land reclamation projects to improve soil quality. Figure 1 below shows that if land application of biosolids is strictly done in compliance with OMRR, it could be the most competitive option to generate benefits to stakeholders.

Figure 1: A comparison of various biosolids management options (BC Ministry of Environment, 2016).

	Land Application	***Incineration (with waste to energy)***	***Pyrolysis***	***Gasification***	***Landfill***
Environmental Outcomes	✓✓✓(1)	✓✓(2)	✓✓(2)	✓✓(2)	**X**
Greenhouse Gas Reduction (3)	✓✓✓	✓ or **X**(4)	✓ or **X**(4)	✓ or **X**(4)	**X**
Food Security	✓✓✓	✓✓	✓✓(5)	✓✓(5)	**X**
Cost	✓✓✓	**X** (6)	**X**	**X**	✓✓
Commercial Success(7)	✓✓✓	✓✓✓	X	✓ or **X** (8)	✓✓✓
Authorization	Regulation	Permit	Permit	Permit	Permit or OC

Ratings Overview: √ √ √ = strong net benefit; √ √ = marginal net benefits; √ = small net benefits; X = net negative or neutral and improves its ability to retain water. Higher quality soil is more resistant to drought and can reduce surface runoff during peak rainfall. Moreover, biosolids can be used as soil amendments in land reclamation, to other soils in poor conditions to increase forestry production and to ease the burden of landfill sites. In this process, the recycling of biosolids does not deplete non-renewable resources including phosphorus (Jones, 2018).

Besides, the high similarity between biosolids and animal manure (organic matter, nutrients), the substances with which biosolid is treated also affect its properties. For example, Penn State in the USA reported that biosolids treated with limestone can neutralize soil acidity and therefore provide the same benefits as agricultural limestone for crop production (Richard, 2010a). Benefits also include improved nutrient retention, increased cation exchange capacity and increased microbial activity and diversity. Most nitrogen in biosolids is organic, which becomes available to crops as it is mineralized (Richard, 2010a).

A key challenge closely tied to the land application of biosolids is public fear of being exposed to harmful chemicals, which raises strong opposition. Runoff and leaching of nitrates and other chemicals are of primary concern, and organic contaminants, as well as heavy metals that can accumulate throughout the food chain, are posing threats (Richard, 2010a). This controversy over biosolids products has existed among the public for decades. The opinion over biosolids ranges from waste to commodity. When the technology is advanced enough, the issue holding back land application of biosolids is still public perception (Naylor, 2018).

OBJECTIVES

The objectives of this whitepaper are to:

- Provide a review of modern biosolids land application approaches and environmental concerns;
- Provide recommendations to optimize the beneficial outcomes of biosolids land application in the B.C. context;
- Improve public perception of biosolids and their beneficial uses.

METHOD

Literature Review

This report is based on a literature review on the properties and lifecycle of biosolids, as well as the associated challenges in British Columbia. Recommendations are given congruent with the guidance of existing regulations. Solutions are presented based on properties of emerging substances of concern (ESOCs), and public concerns. The selected sources include soil-reports, guidance and regulations from the B.C. Ministry of Environment and Climate Change Strategy (MOECCS).

LITERATURE REVIEW

BIOSOLIDS' PROPERTIES, BENEFITS AND RISKS

Properties

Municipal wastewater treatment plants receive discharges from households, industry and commercial sources that contain a variety of contaminants, which might pose risk to human health and the environment. As stated earlier, biosolids are primarily organic treated wastewater residues from municipal wastewater treatment plants. With proper management, biosolids can be safely applied in many beneficial ways, including soil conditioning, land reclamation, agriculture and forestry (Canadian Council of Ministers of the Environment, 2013a; Shammas and Wang, 2008).

Biosolids' properties vary widely depending on the source of wastewater, wastewater treatment process and solids treatment process. Their physical properties range from dewatered material with greater than 90% solids to liquid suspension with less than 4% solids. Alkalinity, the content of organic matter, nutrients and pathogens are also affected by those processes (Richard, 2010a).

Benefits

Rich in nutrients and organic matter, biosolids have the key elements to improve soil quality. Organic matter builds soil structure, helping soil retain water or drain excessive runoff to prevent soil erosion. When biosolids create a favourable soil environment, soil organisms break down organic matter and transform it into available nutrients. These changes often cause significant changes in the structure, diversity, or richness of plant and animal communities, eventually resulting not only in soil improvement but also in changing environment conditions (NORTHWEST BIOSOLIDS, n.d.).

Biosolid	Total-N (g kg^{-1})	P	Ca	Mg	K
USA, CO	30.0	13.8	–	–	–
Spain, Zaragoza	–	21.3	77.2	4.6	1.4
Australia, WA	50.0	22.5	58.5	6.0	1.7
Australia, NSW	68.0	29.0	11.0	6.9	9.7
USA, VA	–	155.1	80.4	1.5	2.3

Table 1: Micro-nutrients concentration in selected biosolids (Kim & Owens, 2019)

Risks

In 1970, research related to risk factors in biosolids and focused on excessive nutrients, heavy metals and pathogens. At that time, the research community was learning how to optimize the use of biosolids on land while ensuring environmental protection (EPA, 1979).

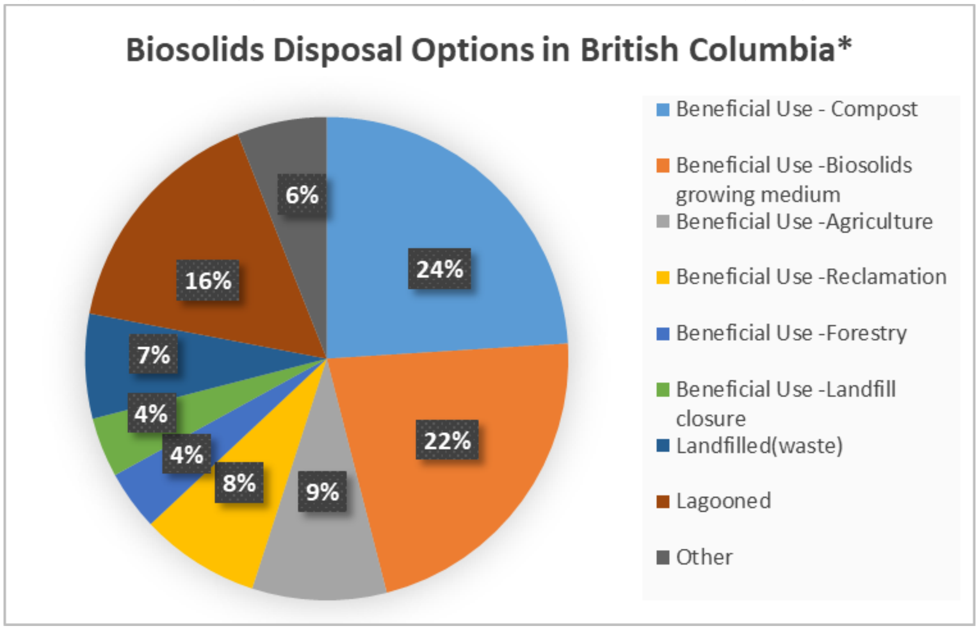
After strict government regulations were introduced, restricting the disposal of heavy metals into wastewater, biosolids' quality improved. Today wastewater contains much less risky substances, as do biosolids recovered from wastewater plants, which is one of the substances that are being subjected to the most intense scrutiny in the world (NEBRA, 2021). Related practices for biosolids application as fertilizers were also introduced, to prevent excessive nutrient leachates moving into surface water bodies and groundwater, as well as heavy metals accumulation in soil.

Although typical contaminants are under strict control, the development of analytical chemistry contributes to the discovery of ‘emerging substances of concern’ (ESOCs) and the emergence of new pathogenic organisms. These findings raise not only the risk level of biosolids in perception but also public anxiety towards waste re-utilization (Ken, A. et al., 1996; McCarthy & Loyo-Rosale, 2015).

Beneficial Uses

In British Columbia, biosolids are applied in many beneficial ways, as shown in the figure below.

Figure 2: Biosolids Applications in British Columbia (Source: adapted from BC Ministry of Environment)

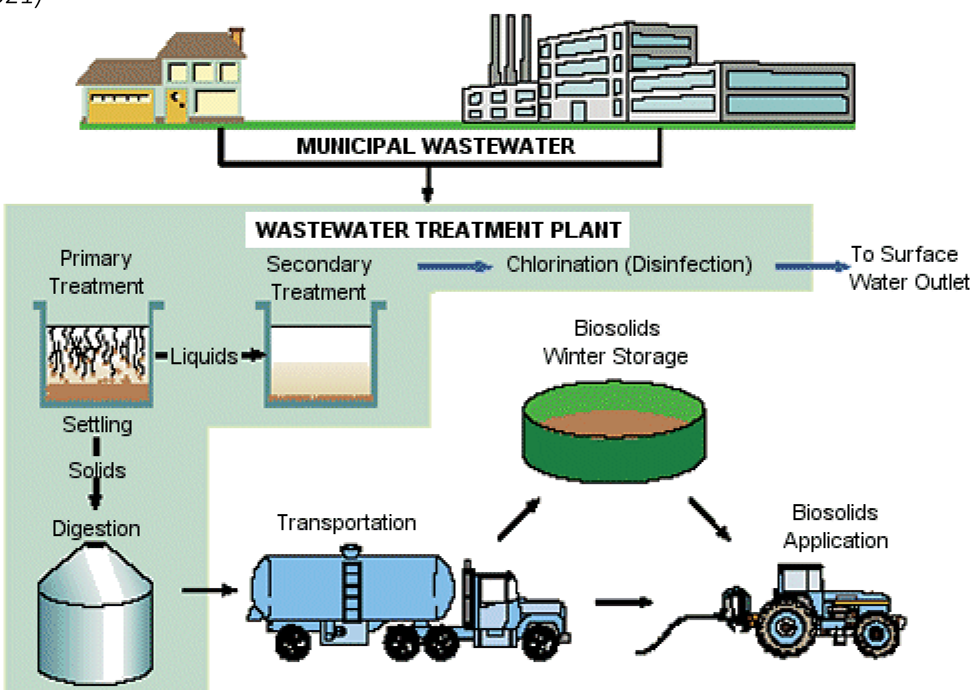


Though the framework for managing wastewater residuals varies among federal, provincial, territorial and municipal jurisdictions, guidance was developed by the Canadian Council of Ministers of the Environment (CCME) Biosolids Task Group (BTG) for regulators to apply better management practices in a Canadian context (Canadian Council of Ministers of the Environment, 2013b).

LIFECYCLE: THE GENERATION, TRANSPORTATION, STORAGE AND MANAGEMENT OF BIOSOLIDS

Almost 100% of the wastewater that enters a treatment plant is discharged as rejuvenated water. The remainder is a dilute suspension of solids that have been settled and captured by the treatment facilities. These wastewater residual solids are generally referred to as "sewage sludge". "Biosolids" refers to sewage sludge that has undergone sufficient treatment for stabilization and pathogen reduction, and that is of sufficiently high quality for beneficial use. This term aims to distinguish high-quality, treated sewage sludge from raw sewage sludge, and from sewage sludge that contains large quantities of environmental pollutants (Richard, 2010b).

Figure 3: Municipal wastewater treatment (Source: Ontario Ministry of Agriculture, Food and Rural Affairs, 2021)



Dewatered biosolids can be transported to the land application sites via covered or enclosed trucks, in the same manner as commercial fertilizers and soil amendments. During transportation, it is necessary to clean excess biosolids from the exterior of the vehicle before the transportation and after unloading, to avoid unexpected pollution (Australian Water Association, n.d.). Safety requirements also include regular inspections and servicing of equipment, full-coverage tarps, leak-proof trucks, emergency contacts, cell phones, gloves, boots, flares, cones, shovel and bagged hydrated lime. The transportation stage is a major concern of the public and landowners.

Appropriate transportation processes and a biosolids spill plan play important roles in raising stakeholders' acceptance (Tony & Dave, n. d.).

Biosolids can be stored on-site for repeated land application. Storage site selection requires comprehensive considerations for climate, topography, soil/geology, buffer zones, odour prevention/aesthetics, accessibility and hauling distance, and property issues. Official recommendations not only aim to protect water quality, minimize pathogen exposure risks, and reduce the potential for unacceptable off-site odours, but also contribute to public safety, to maintain partnership and good communication between the biosolids generators and managers responsible for storage and land application to ensure community-friendly operations (EPA, 2000). According to the Soil Amendment Code of Practice prepared by SYLVIS for the BC Ministry of Environment, soil amendments made from biosolids can be stored onsite temporarily without a storage facility, and it is recommended that the storage site be 30m from any watercourse or domestic water source to prevent the escape of soil amendments and provide buffer zone (McDougall et al., 2008).

CHALLENGES

EMERGING SUBSTANCES OF CONCERN (ESOCS) IN BIOSOLIDS

Todays' society depends heavily on large amounts of organic compounds, these substances eventually may become contaminants and enter wastewater treatment systems. Unfortunately, significant numbers of the organic compounds are lipophilic or hydrophobic, with limited degradability, so that they tend to accumulate in sewage sludge and exist in biosolids (Smith, 2009). These resistant organic compounds generally have strong toxicity (at a certain level), and maybe more toxic than parent compounds according to Semblante, (2015).

Emerging substances of concern (ESOCs) are a distinct group of agents that are causing growing concern for human and ecological health (Bolong et al., 2009, Estévez et al., 2012). Generally, ESOC's include personal care products, endocrine-disrupting chemicals, steroids, hormones, surfactants, and surfactant metabolites, flame retardants, pesticides, industrial additives, nanomaterials, and gasoline additives (McKeown & Bugyi, 2015).

Some of the more concerning organic compounds are antibiotics, flame retardants and personal care products; and their presence in biosolids and land application has the following properties:

- **Antibiotics:** Antibiotics are chemicals that interfere with metabolic processes that inhibit the growth of or kill microbes, especially bacteria (Vallero, 2016). Generally, the goal of the wastewater treatment process is to reduce chemical oxygen demand and biochemical oxygen demand, these treatment processes can not remove antibiotics effectively, due to their lipophilicity, only absorption can reduce antibiotics concentration in water. Study results suggest that land application of biosolids-borne ciprofloxacin, a common antibiotic used to treat many bacterial infections, poses minimal risks to plants (Sidhu & Kruse, 2019). This observation indicates that some antibiotics have a negligible impact on specific plants. There are various groups of antibiotics and may have a synergistic effect with other contaminants (e.g. heavy metals), and become more toxic. Plants may take up these insoluble and ungraded antibiotics, and move them up to the food chain potentially to be absorbed by humans.
- **Polybrominated diphenyl ethers (PBDEs):** PBDEs belong to a group of brominated flame-retardants, widely used to produce household electric appliances, decorating materials, and textiles. PBDEs may enter the environment through emissions from manufacturing processes, volatilization from various products that contain PBDEs', recycling wastes and leachates from waste disposal sites. PBDEs are very resistant and stable in the environment, and can also accumulate and move up the food chain (ATSDR 2015; EU 2001; Frederiksen et al., 2009). Exposure to PBDEs is associated with a decrease in the thyroid hormone, which is critical to growth and metabolism (Lisa, 2015).
- **Polychlorinated alkanes (PCAs):** PCAs, also referred to as chlorinated paraffin, are commercially used to produce lubricants for extreme pressure conditions, plasticizers, flame-retardants and paint additives since the 1930s. Its production and use volumes exceeded 1,000,000 tons in 2016 globally (Glüge et al., 2018). The Government of Canada has determined that all chlorinated paraffin are considered harmful in terms of human health, while short-, medium- and only long-chain chlorinated paraffin with up to 20 carbon atoms are considered harmful to the environment. A Czech study shows that chlorinated paraffin can accumulate in earthworms (Bezchlebová et al., 2007).

  Polychlorinated naphthalene (PCNs): PCNs have similar properties as other commercial ESOCs. PCNs were widely used to produce many products, including engine oil additives, wood preservatives, lubricant and colourant before the 1980s. In 2000, the global production of PCNs reached approximately 150,000 metric tons (Yamashita, 2000). Sludge amended soil samples from the Luddington experiment station in the U.K. from 1968 to 1990 shows that the concentration of PCNs in Luddington Control Soil may reach 250μg/kg, which is 40 times the concentration of soil in the natural environment. 125 tonnes dry weight of sludge per ha was applied in 1968, mixed to 15cm. Data suggests that PCNs can accumulate in the food chain (Meijer et al., 2001). PCNs have potential toxicity, carcinogenicity and teratogenicity, as a result, it is of great importance to conduct more research on environmental impact, and degradation rates/pathways.

- **Perfluorochemicals (PFCs):** PFCs was discovered in the 1930s, used to produce non-stick coatings, surface active agent, food packaging, fire-fighting foams and other products. As a result, PFCs are widely distributed in the environment and can be detected in soil, water bodies and organisms (even human bodies), which can present a risk to environmental and human health (New Hampshire Department of Health and Human Services, 2017). Previous studies showed that PFCs can impact organ functions, reproduction and body growth. And PFCs could be a risk factor for breast cancer development in Inuit (Bonefeld-Jorgensen, 2011). Unlike other chemical compounds, PFCs are highly mobile in water, as a result, general methods for preventing persistent organic pollutants from entering the environment are not known. Gottschall et al. (2010) found that stormwater may cause migration of some PFCs in applied biosolids under certain conditions, potentially leading to water contamination and subsequent, pollution exposure. Since PFCs are still widely used globally, concerns about these substances will exist for a long time. As a result, when industrial impacted biosolids with high concentrations of PFCs are used in the land application, PFCs will have a profound effect on surrounding environmental health, especially human health (AWWA, n.d.; Gottschall et al., 2010).
- **Triclocarban (TTC) & Triclosan (TCS):** TTC and TCs are highly effective and broad-spectrum antimicrobials and are widely used to produce textile, laundry detergent, deodorant and skincare products. The United States Geological Survey surveyed organic compounds in 139 rivers from 30 states, and TCs has the highest frequency of detection (Kolpin et al., 2002). A study conducted in a wastewater treatment plant in the Mid-Atlantic region of the U.S. suggests that 79% of TCC and 64% of TCs in sewage are transferred to the solids (Lozano et al., 2013). Studies of Australian biosolids and Michigan wastewater treatment plants also suggest high concentrations of TCC and TCs are transferred to final residuals. When applied in agriculture, TCC and TCs can accumulate in an organism, such as earthworms. TCC and TCs are of increasing concern, in addition to a negative impact on the environment, they can also cause DNA damage, reproduction inability and cancer (Lin et al., 2014).

Although few existing risk assessments show that ESOCs' presence in the soil environment has no noticeable negative impact on human health, there is a very limited number of risk assessments. The toxicity and ecotoxicity data of ESOCs are generally not available, and there is not enough information on the long-run consequences of biosolids application as soil amendments in different specific environmental conditions (McCarthy & Loyo-Rosale, 2015). Repeated biosolids applications in one specific area can lead to a gradual accumulation of trace elements in the soil. When their concentrations reach a threshold, these chemicals may pose threats to vegetation and crops, enter the food chain at unacceptably high levels (Richard, 2010a).

PUBLIC PERCEPTIONS

Among the general public, there are conflicting conceptions between those who support biosolids as an affordable resource for agriculture or economic booster for the rural community, and those who see the intrusion of urban sewage waste into their pastoral landscapes as a risk to their "way of life". Local communities worry about the transportation of biosolids (e.g., trail pollution, spill accidents), and long-term outcomes. (Mason et al., 2015). In B.C., biosolids have been a decade-long conflict in Greater Victoria. Under public pressure, the Capital Regional District (CRD) banned biosolids land application in 2011. But the ban was reversed in 2020, the CRD agreed to accept 700 tonnes of biosolids, from the Lafarge cement plant, to be disposed of at the Hartland Landfill. However, this decision was met with fierce opposition from people concerned about water and air pollution (Jane, 2021).

"Hartland is one of the least desirable places to do it (spread biosolids) because if there are problems there are residences quite close, there are farms, there are schools and also it's the headwaters for Tod Creek," said Hugh Stephens, vice-chair of the Mount Work Coalition (Jane, 2021).

A study conducted at a rural middle-class community in Ontario, with ownership of private residences and a large proportion of young children, as well as lower median age and educational attainment, suggests that although the pro-biosolids coalition is very confident in providing scientific evidence and successful experience from other developed countries, the anti-biosolids coalition usually use long and engaging arguments to connect with public emotions. The pro-biosolids coalition argues based on probabilities of risk while the anti-biosolids coalition focuses on fairness, voluntariness and health effects. It is recommended that more scientific public education programs will help the residents themselves to make rational choices without subjective emotions, which is more significant than simply overwhelming the public with pure science (Mason et al., 2015).

To maintain a healthy and safe environment, and consider public opinion, supporting measures to prevent disturbance to residents are needed. As an example, the site of the former Brenda Mines could be home to a natural gas and high-nutrient compost facility, Glencore and Brenda Renewables partnered to reopen the site and turn it into a facility that can process local municipal organic waste, yard waste, as well as biosolids and turn it into renewable natural gas and high-nutrient compost. (Twila, 2021). Glencore project manager Mark Tenbrink said the system is designed so there won't be odour, noise or liquid discharge from the site.

A study on of the shift in community perceptions pre- and post-siting of a biosolids processing facility is – the Organic Material Recovery Centre – in the rural Township of Southgate, Ontario shows that once the facility came into use, and residents have a window to learn about operational regulations and directions, they are likely to accept the opinion that the facility as less threatening to human and environmental health (Mason-Renton & Luginaah, 2019). Another study of biosolids land application within the south-eastern United States shows that if the official decisions and risks were not fully communicated to the public, it will lead to inadequate perception about the project in communities. This result indicates that community-specific outreach programs must offer a solution for public risk perceptions to assist in local solid waste management, to develop a successful and acceptable plan for the public (Robinson et al., 2012).

For regulators and scientists, a better understanding of what is defined as natural/unnatural for residents will contribute to the understanding of why part of the residents is angry because of feeling injustices between rural and urban regions, while others support biosolids as resources to boost local circular economies (Mason-Renton & Luginaah, 2018).

In some American counties, negative public perception is strong enough to put pressure on policymakers to ban the land application of biosolids. This measure is potentially limiting options for biosolids management at the municipal scale. While at the same time, as more and more farmers take biosolids as fertilizer/soil amendment, they start to worry about increasing biosolids demand and associated price increases (McCarthy & Loyo-Rosale, 2015).

Besides the public perception of biosolids definition, communication between public and regulators, other factors and detailed descriptions are listed in Appendix II.

SOLUTIONS

Optimizing biosolids land application outcomes

According to the Soil Sampling Report (2016) conducted by the BC Ministry of Environment and Climate Change Strategy (MOECCS), that examined soils that had received biosolids or compost containing biosolids, found that most of the persistent organic pollutants that were analyzed were not detected in the soils at the three study sites with one exception (on a control plot, 3-chlorophenol). The few pollutants that were detected were present in low concentrations and were below the CCME and CSR soil standards. In another study conducted by MOECCS, Biosolids Sampling Project (2019), a range of organic pollutants were analyzed in biosolids. Because there are no relevant regulatory standards for comparison in North America, the results were compared against available European standards. Contaminants in biosolids were below European standards with one exception: di(2-Ethylhexyl) phthalate that was below the draft EU standard, but slightly above the Danish standard. Currently, advanced compost/thermal treatment methods to produce stabilized biosolids have been widely used, so the following solutions will focus on the prevention of ESOCs accumulating in the natural environment and moving up the food chain.

Suggestions going forward include:

- Cut down sources of emerging pollutants

  Biosolids producers should be educated to maintain high-quality biosolids to benefit their communities, by separating wastewater from chemical industry areas with stormwater. Inform biosolids producers that they should take the concerns of their community to limit the ESOCs levels in the environment.

  Governments can introduce regulations to limit the industrial use of organic pollutants, and provide subsidies for using alternatives.
- Choose appropriate application site

  Besides basic factors including climate, soil properties, depth to the groundwater table, and topography and slope of the site, consider the properties of ESOCs gradually to determine the application site.
- Mandatory check for emerging ESOCs

  Comprehensive soil sampling including ESOCs prior to biosolids application should be promoted in British Columbia.
- Supporting Measures

Currently, some scientists are researching emerging organic compound behaviour on different crops, their results suggest that growing specific crops can effectively reduce pollution risks.

Improving public perceptions

- Voluntary choice
  Before biosolids are applied, it is necessary to inform all stakeholders in the community, take their advice and answer their questions.
- Cooperation with the local community
  Stakeholders are encouraged to act as project supervisors to make sure every stage is indisputable.
- Full communication
  Inform residents about how, when and where biosolids will be applied, host frequent discussion events to gather residents' feedback and provide solutions to convince them that the goal of biosolids application is to provide welfare and benefits to the soil environment.
- Price subsidy
  For those individuals/communities willing to accept biosolids, the government can provide subsidies as encouragement for biosolids to be used as fertilizers.
- Transparency
  The information of the application project should be easily accessible, both online and paper documents including how, when and where biosolids will be applied, promote an annual sampling report, list names of supervisors and consultants, and the plans and soil conditions are required.

CONCLUSIONS

This report conducted a systematic literature review on two factors concerns that hinder biosolids land application in British Columbia, namely, emerging contaminants and public perception.

Most sampling results indicate that EOSCs in the soil is below existing standards, however, several EOSCs are largely undegradable, which raises concerns of bioaccumulation/biomagnification in the food chain and threatens human health.

Studies in Ontario, Canada, and the United States indicate the public perception of the biosolids definition, and fear of long-term irreversible impact are major factors making the public unwilling to accept biosolids.

This report list some of the concerning EOSCs and their properties, sources, related studies, and provides suggestions on how to prevent possible harmful consequences, as well as how to improve public perceptions based on listed factors.

RECOMMENDATIONS

The conclusion of this literature review is based on the author's personal view.

Unfortunately, studies on public perception of biosolids application in British Columbia, and the long-term impact of ESOCs in the applied application are scarce.

Solutions are based on the Soil Sampling Report (2016) and Biosolids Sampling Project (2019) conducted by BC Ministry of Environment, current public perception reflected in news, as well as relevant regulations. Soil samples were drawn from 3 different sites and biosolids samples are from two wastewater treatment plants, the final solutions may be deficient due to insufficient samples.

More data and case studies of ESOCs and public perception of biosolids land application in B.C. are required to support a comprehensive strategy to gain better outcomes.

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APPENDIX (CES)

Appendix I: Common methods for treating and stabilizing sewage sludge (Source: Richard, 2010b).

Treatment method	Description	Effects on sludge
Thickening	Sludge solids are concentrated either by settling due to gravity or by introducing air, which causes sludge solids to float.	Sludge retains the properties of a liquid, but solids content is increased to 5 to 6%
Dewatering	Several processes are used: ● air drying on sand beds ● centrifugation ● belt pressing (filtration)	● Increases solids content to 15 to 30% ● Air drying reduces pathogens ● Centrifugation and filtration result in some loss of nutrients
Anaerobic digestion	One of the most widely used methods for sludge treatment. Sludge is held in the absence of air for 15 to 60 days at temperatures of 68 to 131°F. Anaerobic bacteria feed on the sludge, producing methane and carbon dioxide. In some treatment plants, the methane is collected and burned to maintain the treatment temperature.	● Increases solids content ● Reduces odors ● Decreases volatile solids ● Decreases viable pathogens ● Conserves plant nutrients
Aerobic digestion	Sludge is agitated with air or oxygen for 40 to 60 days at temperatures of 59 to 68°F. Aerobic bacteria feed on the sludge, producing carbon dioxide.	● Increases solids content ● Reduces odors ● Decreases volatile solids ● Reduces viable pathogens ● Some loss of nitrogen usually occurs
Alkaline stabilization	Sufficient alkaline material, most commonly lime (CaO), is added to the sludge to increase its pH to at least 12 for 2 hours. The pH must remain above 11.5 for an additional 22 hours.	● Decreases volatile solids ● Reduces viable pathogens ● Loss of ammonia (NH_3) ● Phosphorus may be converted to forms not readily available to plants
Composting	Sludge is dewatered to increase solids content to around 20%, then mixed with a high-carbon	● Volume reduction of sludge ● Reduces odors

	organic material such as sawdust. The mix is composted under aerobic conditions at temperatures of at least 131°F for several days during the composting process.	• Decreases volatile solids • Stabilizes organic matter • Eliminates most pathogens • Decreases plant nutrient value

Appendix II: Factors influencing negative public perception of biosolids land application (Source: McCarthy & Loyo-Rosale, 2015).

Biosolids land application perceived to be:	
Involuntary	Imposed on the community, and out of their control
Artificial and industrial	Distrust of artificial or industrial products/processes
Exotic and/or unfamiliar	Biosolids are not familiar to most people, unlike manure
Hard to understand	The biosolids concept is not self-explanatory
Memorable	Due to odours and other nuisances
Dreaded	The “yuck” factor of biosolids’ origins creates dread
Potentially catastrophic	Issues raised about biosolids suggest potential short-or long-term negative effects at the application sites
Not reversible	Some persistent pollutants might be permanent additions to soils
Unknowable	There is a level of uncertainty in the exact content of a biosolids batch. The diverse inputs from municipal sewers make the constituents variable
Having delayed effects	Some effects from biosolids may not be evident immediately
Affecting children and mothers	Because they may happen to play around biosolids and/or consume foods grown on biosolids-amended fields
Affecting future generations	Because there is some uncertainty about long-term effects
Having identifiable victims	Reported cases of harm to cattle and people
Being controlled by “the system” or people considered untrustworthy	Social science surveys have shown that government officials, people from out of town, and those who have a financial interest are perceived as less trustworthy
Unfair	A neighbour may feel that it is unfair to put up with odours when he or she receives no apparent benefit from a biosolids program

Morally and/or ethically objectionable	If biosolids are seen as a potential threat, then it can be perceived as morally wrong for cities to foist biosolids on a rural community
Operating by a closed process	Communities around land application sites may find the process closed and difficult to understand
Receiving more media attention	Media stories about a biosolids project heighten local interest and, if they report opposition, public concern tends to increase
Having limited or no visible benefits	Land application occurs far from the wastewater facility and in communities that perceive little benefit to them