BIOSOLIDS AND BIOAEROSOLS: THE CURRENT SITUATION

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ABSTRACT

Quebec has seen a major increase in the application directly onto farmland of biosolids produced by municipalities, the pulp and paper industry and food processors. In 1999, about 700,000 tons of biosolids, of which 83% were pulp and paper mill residuals, were applied to agricultural land. Supported by opposition groups, residents living close to fields where biosolids are being applied are increasingly opposed to the recycling of biosolids in spite of the known benefits to agriculture. The potential impact on health of bioaerosols that may be released when biosolids are spread is often cited in the controversy. Following a literature review, this article draws a general picture of the issue. The information consulted indicates that applying biosolids, particularly those originating from municipal wastewater treatment, may represent a potential source of airborne biological agents (bioaerosols). However, the scientific studies that we looked at indicate that the risks for exposed workers, such as farmers, are relatively low and even extremely low for people living in the vicinity of the sites where biosolids are being applied. Available information also suggests that the potential health risks are relatively lower than those associated with the management of manure. Thus the results of the study do not indicate the need for limits on applying biosolids that are more restrictive than those currently in force for biosolids in Quebec, in regard to pathogens and odours. Measurements of bioaerosol emissions linked to the recycling of manure and pulp and paper biosolids would however be welcomed, as the majority of studies had to do with municipal biosolids.

1.0 INTRODUCTION

1.1 Biosolids – definition and usefulness

Biosolids, better known as "sludge", come from municipal wastewater treatment plants or industrial processes, in particular pulp and paper mills and slaughterhouses. The particular characteristics of the biosolids vary depending on their origin (vegetable, animal, human) and the treatment process they have gone through (physicochemical or biological, aerobic or anaerobic digestion, lime stabilization, etc.). The agronomic and environmental benefits from the organic material and fertilizing elements contained in biosolids, essential for maintaining soil fertility, have been the subject of numerous scientific studies and have been extensively proven (N'dayegamiye, 2002 ; Simard et al.,1998).

The recycling of biosolids through application on farmland has increased greatly in Quebec as elsewhere in the world over the last decade. In 1999, about 700,000 wet metric tons of biosolids were applied agriculturally, of which about 577,000 tons were pulp and paper residuals, 56,000 tons were from municipalities and 70,000 tons came from slaughterhouses. Biosolids amounted to less than 3% of all the fertilizing material applied to farmland in 1999, while manure represented about 95%, or more than 30 million tons (Charbonneau et al., 2001).

In Quebec the great majority of applied biosolids are semi-solid in form. They are first transported from the plant by specially trained workers and are then usually deposited onto the soil or into temporary storage facilities close to the recycling sites. Just before application they are loaded by tractor into spreading equipment, usually manure spreaders. This management method is similar to that for solid manure.

1.2 The controversy – bioaerosols

Land application of biosolids is giving rise to more and more apprehension, or even opposition, especially from people living next to application sites. This is seen in the United States and in Ontario in particular, and concern is expressed mainly in connection with municipal biosolids.

The sometimes unpleasant, strong odour of certain biosolids, the greater visibility of this practice as a result of the increase in the amount of material applied and the public's growing suspicions regarding pathogenic organisms and their potentially negative effect on human health (following the Walkerton tragedy) are all factors that preoccupy the public (Crittenden, 2002 and 2001; OCAPS, 2001). Allegations of health problems caused in neighbouring populations and linked to odours or to the presence of pathogens in municipal biosolids are reported in the media and in certain cases, result in legal action (Crittenden, 2002 ; Epstein, 2002). Some municipalities are taking steps to limit, suspend or even ban the application of biosolids in their territory. Among the risks associated with the presence of pathogenic micro-organisms in municipal biosolids, the release of bioaerosols during application, has been raised by various opponents. Bioaerosols are airborne biological agents which may contain pathogens. The controversy over bioaerosols also applies to the application of pulp and paper residuals (Thériault, 2001).

1.3 Context of the study and methodology

This study was carried out in order to draw a general picture of the current knowledge on this subject from a review of the literature, and if necessary, to see if restrictive measures for land application in regard to bioaerosols should be considered by the Quebec Ministry of the Environment. In addition, it aims to assess the relative risk associated with biosolids and farm manure in this context and to identify avenues for research.

Most of the information gathered for this study was obtained directly from technical experts, researchers or municipal and government representatives and by research on the Internet. In particular, two major literature reviews carried out recently in Ontario (Anderson et al., 2001; Apedaile et al., 2002) identified references to the majority of pertinent information dealing with municipal biosolids. Specific information on pulp and paper residuals and manure was gathered from the following data banks: Medline, Current Contents, Agricola and Toxline. The information presented in this article reflects our best understanding of the current state of knowledge on the subject, gathered from information available at the time this article was prepared (June 2002). Thus the report by the National Academy of Science (NAS), published in July 2002, could not be taken into consideration.

2.0 BIOAEROSOLS AND IMPACTS ON HEALTH

2.1 Definition of bioaerosols

Bioaerosols are defined as airborne particles consisting of or originating from micro-organisms (bacteria, viruses, moulds), for example metabolites, toxins or fragments of micro-organisms (Goyer et al., 2001). These particles come from organic matter, plants, soil, animals and humans. They may be put into suspension in the air, adhere to organic dust particles and tiny droplets of water that they come in contact with, and then be transported, creating bioaerosols. Fresh, wet organic material such as biosolids provide ideal conditions for the presence and growth of microbes and thus for the release of bioaerosols (Goyer et al., 2001).

Typically, bioaerosols consist of very fine particles measuring less than 20 microns in diameter (Goyer et al., 2001). Bioaerosols become airborne through the release of dust and water droplets (aerosolization). These particles can be inhaled by humans (breathed in and held in the nasal cavities and the mouth) while the smallest, less than 5 microns, are respirable and can penetrate deep into the lungs (Cole et al., 1999). This is the case in particular for the bioaerosols produced on the farm that cause hypersensitivity pneumonitis, known as "farmer's lung disease".

2.2 Potential effects on health

The great majority of micro-organisms present in the environment, especially in soil, manure or biosolids, have no negative effect on health. However, following aerosolization, some can be found in abnormally high concentrations in the air, and present a risk for individuals exposed to them, workers in particular.

For certain sensitive individuals such as those who suffer from allergies, are already ill, have undergone an organ transplant or are immunocompromised, young children, pregnant women and the elderly, inhaling bioaerosols can lead to inflammation, respiratory allergies and sometimes infection. On the other hand, exposure for healthy individuals does not usually lead to serious consequences although symptoms may occur in certain cases (Sattar and Springthorpe, 1997). The main types of bioaerosols likely to originate in residuals or manure, and the health symptoms associated with them, are presented in Table 1.

According to Goyer et al. (2001), gaps in our basic knowledge still remain:

- there is little documentation for the dose-response relationship for various bioaerosols (this defines the link between the effects on human health and conditions for exposure to bioaerosols, concentrations in the air and length of exposure);
- information is available on a case-by-case basis;
- individual susceptibility seems very important;
- synergic effects and toxicity relative to species and their toxins are not well known;
- the cumulative effect of exposure to a group of airborne agents is difficult to measure.

In addition, although there are special devices for measuring the bioaerosol content originating from industrial and agricultural activities, there are no current standards in Quebec, Canada or the United States for acceptable levels of micro-organisms and their toxins in the air or for exposure limits. However, certain guidance and criteria values are proposed to help assess exposure to bioaerosols and prevent harmful effects (Table 1).

Table 1. Principal bioaerosols associated with biosolids and effects on health.

PRINCIPAL BIOAEROSOLS	ORIGINS AND ASSOCIATIONS	REPORTED SYMPTOMS AND EFFECTS AND EXPOSURE LIMIT VALUES
BACTERIA: Gram negative bacteria (*E. coli*, *Salmonella*); thermophilic actinomycetes	Abundant in nature and in humans. Outdoors, they originate in water, soil and plants, and they are associated with the presence of humans and animals.	Mucous membrane irritation, gastro-intestinal and respiratory problems (Gram negative bacteria and endotoxins), hypersensitivity pneumonitis (thermophilic actinomycetes). From studies carried out in wastewater treatment plants and composting centres, the following limit for 8 hours of exposure, was suggested for Gram negative bacteria: 10^3 CFU/m^3 of air.
MOULDS *Aspergillus fumigatus*	Ubiquitous in nature; proliferates well in humid conditions. *Aspergillus fumigatus* is thermo-tolerant, sometimes pathogenic; it is found on manure, compost, wood, other organic material.	Allergic reactions, infections and irritation, toxic syndrome through exposure to organic dusts (ODTS). The nature of the dose-response relationship is not known, nor is the existence of a safe exposure threshold. Concentrations of up to 10^5 CFU/m^3 of *Aspergillus fumigatus* would not be considered a risk for healthy individuals but one spore could be infectious for immunocompromised persons.
METABOLITES OR TOXINS Endotoxins Mycotoxins	Ubiquitous, endotoxins are complexes that are integral parts of the outer membrane of Gram negative bacteria. Their presence is often associated with organic dust. Mycotoxins (spores and propagules) are released by moulds.	The effects of endotoxins and their role as a bioaerosol are not well known (Olenchock, 1994). Symptoms are a cough, shortness of breath, fever, obstruction and inflammation of the lungs, and gastro-intestinal problems. Since 1999, the ACGIH has recommended the use of REL (Relative Exposure Limit); these limits are 30 times the basic or ambient concentrations. The effects of mycotoxins are not well known. Symptoms are: skin and mucous membrane irritations, dizziness, immunosupression, headache, nausea, cognitive effects.
VIRUS Enteric viruses (*Rotavirus* and others)	A live host cell is required for a virus to survive, spread and reproduce. It may be spread when droplets from an infected source are released but it may not survive long in the air.	Certain enteric viruses could become airborne and under certain conditions lead to infections in susceptible individuals (Brenner et al., 2000). The release and transportation of airborne viruses and their potential effects on human health in the context of activities involving the application of biosolids are theoretical and have not been documented (Pillai et al., 1996).

Adapted from Goyer et al. (2001) showing the references of various authors, except where otherwise indicated in this table.

2.3 Odours and bioaerosols

Bioaerosols coexist with gaseous substances in the air, in particular volatile organic compounds whether perceived as odorous or not. Synergistic effects could thus result from the presence of bioaerosols or particles (dust or water droplets) in odorous air. Schiffman et al. (2000) reported on the current state of knowledge on the subject and indicated that dusts may concentrate certain odorous compounds, for example volatile organic acids or ammonia, which help to exacerbate respiratory irritation caused by the dusts. However, there is very little known about additive or synergistic effects of odorous volatile organic compounds that are irritants and/or toxic and the various bioaerosols (Olenchock, 1994 ; Schiffman et al., 2000).

Exposure to odours (or perhaps to an odour/bioaerosol mix) is giving rise to more and more complaints in relation to health symptoms in rural communities located close to intensive stock-raising farms, wastewater treatment plants and recycling centres for biosolids. Schiffman et al. (2000), reported that the most frequent complaints include eye, nose and throat irritation, headache, nausea, diarrhea, hoarseness, sore throat, cough, chest tightness, nasal congestion, heart palpitations, shortness of breath, stress, drowsiness and alterations in mood. These symptoms appear at the time of exposure and disappear shortly after. However, they may persist or aggravate existing health problems in sensitive individuals such as asthmatic patients. Schiffman et al. (2000) stressed however that in spite of evidence that physical and psychological reactions are caused by various odours perceived as disagreeable, these latter do not necessarily represent a toxicological danger.

2.4 Bioaerosols released by biosolids

Biosolids are likely to release bioaerosols when they are being handled, as is the case for other materials such as manure, wood residues, industrial or even domestic composts (Brassard et al., 1999). A higher pathogenic content in biosolids, a substrate rich in organic material and nutrients, increased humidity or inversely the presence of organic dusts all encourage the growth of bacteria, moulds and their toxins, and consequently the release into the air of biological agents that may be harmful to human health.

Certain pathogenic micro-organisms present in municipal biosolids, waste from slaughterhouses, manure and other fecal or animal waste matter may end up as bioaerosols. The ones that receive the most attention in terms of risk to human health are the enteric bacteria and viruses. The bacteria *Salmonella* and *Escherichia Coli* O157:H7, as well as certain viruses like *Rotavirus* and the enteroviruses (Cole et al., 1999), originate in human (municipal sewage) and animal waste (manure, slaughterhouse residuals). Pulp and paper residuals from wood products typically contain very few or no pathogenic organisms of this kind and so do not constitute a major airborne source as the other types of residuals do.

The risk of release rises as the pathogenic content in biosolids increases. Raw sludge from municipal sewage would be more likely to release airborne pathogens than those that have been treated to reduce the pathogens (Straub et al., 1993), e.g. aerobic or anaerobic digestion, lime stabilization, composting and thermal drying (pelletization). The same applies when one compares treated and untreated manure. However the application of raw sludge on farmland is prohibited in Quebec. Direct contact or the inhalation of bioaerosols from animal waste, manure, carcasses and other material of this type can also cause a variety of infectious diseases (Cole et al., 1999 ; Pell, 1996).

In addition, bacteria and moulds present in biosolids, or that develop during storage can release toxins. Endotoxins come from Gram negative bacteria and moulds release spores or mycotoxins. They are not necessarily human or animal in origin, but they may be harmful to human health. For instance, bacteria and moulds develop on wood residues, straw or grain, all of which are commonly found on farms (Olenchock, 1994). Pulp and paper biosolids, vegetable-based products and household compost are also likely breeding grounds for *Klebsiella pneumonia* bacteria (Brassard et al., 1999). These bacteria are on the whole inoffensive, except as agents of secondary infections in people with a weakened immune system or underlying diseases such as chronic lung disease, but little is known about their contribution to the risks associated with bioaerosols originating from pulp and paper biosolids (Brochert, 1999 ; Marc Hébert, personal communication).

2.5 Pathways for pathogen transmission

Workers who come in contact with biosolids containing pathogens, such as employees at wastewater treatment plants and farmers who apply biosolids onto the soil, have the greatest exposure to pathogens (frequency, length of time and concentration) and are thus the most at risk (Jacques Lavoie, IRSST, personal communication). The main pathways for transmission of pathogens for workers applying biosolids are shown in Figure 1.

According to Sattar and Springthorpe (1997), the risk of transmitting pathogenic organisms to workers is more likely through direct contact than through the air in the form of bioaerosols. Moreover, the concentration of bioaerosols in the air lessens as the distance downwind from the releasing source increases. The lifespan and transportation of airborne pathogenic organisms depend on, among other things, their nature and the ambient temperature and humidity conditions (Sattar and Springthorpe, 1997). The survival of and the potential for infection from these organisms are lessened by the natural processes of attenuation such as ultra-violet radiation and desiccation . The shorter the transportation time, the less effect inactivation processes have. This is why high winds may increase both the rate of emission from a bioaerosol source and the concentration in the air at a given distance from the source (Dowd et al., 2000 ; Cole et al., 1999).

From the point of view of public health, Straub et al., (1993) reported that for people other than these workers, such as individuals living close to fields where biosolids are being applied, the consumption of contaminated ground water would be the most likely and significant pathway for pathogens, rather than exposure to bioaerosols.

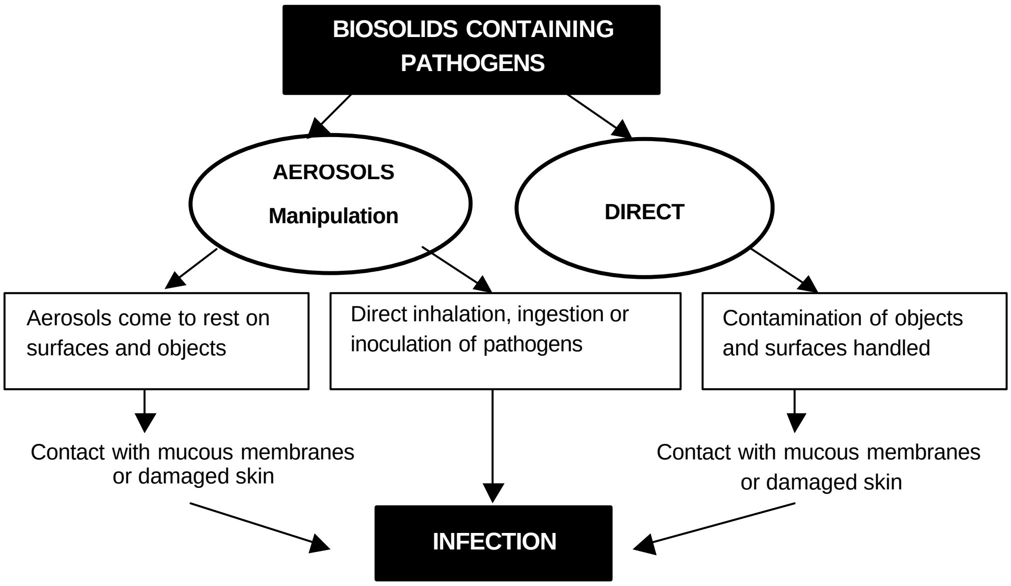

Figure 1. Usual Means of Exposure to Pathogens for Handlers of Biosolids (modified from Sattar and Springthorpe, 1997).

2.6 Bioaerosols in closed work areas

Given that exposure to high concentrations of bioaerosols is more likely to occur in a confined space, studies on the impact of bioaerosols on workers in closed work areas are more numerous than those concerned with the risks to communities neighbouring outdoor sites for treating, storing or applying biosolids and other residuals (J. Lavoie, personal communication).

Several authors have reported high concentrations of bioaerosols in a variety of work settings such as peat moss bagging plants, sawmills, mushroom farms, potato processing plants and cotton mills (Goyer et al., 2001). They are also found in composting plants (Lavoie and Marchand, 1997; Van der Werf and Van Opstal, 1996; Millner et al., 1994) and in municipal and pulp and paper wastewater treatment plants (Lavoie, 2000; Goyer and Lavoie, 1998). In its most recent guide for bioaerosols, the Quebec Occupational Health & Safety Research Institute (IRSST) presents data compiled from the literature on this subject (Table 2). Note that the typical concentration of Gram negative bacteria measured in the workplace of workers in pulp and paper wastewater treatment plants is below that obtained from municipal plants. In composting centres for municipal biosolids, the bioaerosols most often found are the mould *Aspergillus fumigatus* and endotoxins (Millner et al., 1994). The risks for workers can be controlled through measures of hygiene and personal protection, and with proper ventilation in enclosed areas.

Table 2: Concentrations of bioaerosols measured in the workplace (CFU/m^3).

Workplace	Gram negative bacteria	Thermophilic actinomycetes	Molds
Outside air in summer	10^1	10^1	10^3
Composting centre	10^2	10^4	10^4
Municipal wastewater treatment plant	10^4	10^0	10^3
Pulp and paper mill	10^2-10^3	-	10^3
Farm building (barn with mouldy hay)	10^3	10^9	10^9
Pig farm	10^3-10^4	-	10^4
Sawmill	10^3-10^4	10^3	10^6
Peat moss drying plant	-	-	10^8

Adapted from Goyer et al. (2001). (CFU/m^3) = colony forming unit per m^3 of air
- = not documented

Besides the municipal and industrial sectors, agriculture is among the most important potential sources of bacteria, moulds and their toxins, as well as organic dusts. Very high concentrations of airborne bacteria have been measured in livestock housing, in particular pig and poultry units (Cole et al., 1999; Cormier et al., 1990).

3.0 LAND APPLICATION AND BIOAEROSOLS

3.1 The practice of application on farmland

In Quebec, the majority of biosolids applied on farmland are semi-solid in form and come from pulp and paper mills (83%). They are temporarily stored on the farm close to the application sites and then spread on the soil. The farmers often carry out this task themselves, or else it is contracted out to companies specializing in manure application. This management method is similar to that for solid manure, although the Quebec Ministry of the Environment (MENV) constraints for application are more restrictive for biosolids than for manure. As for liquid biosolids, these are not usually stored on the farm and are usually applied by specialized workers. The application of liquid biosolids by air-spraying presents the highest risk for dispersion (Sorber et al., 1984). This practice is however prohibited in Quebec.

The temporary storage stage for biosolids on the farm (solids) can encourage the release of bioaerosols during loading into spreaders, especially if they are biologically unstable. In fact it is the increase in microbial degradation activity during storage that increases the risk of biological agents being emitted into the air (Goyer and Lavoie, 1998). However, although quantities of bioaerosols could be released during storage, loading and land application, they are diluted and scattered through atmospheric dispersion in ambient air (Goyer and Lavoie, 1998). Thus, in addition to controlling application methods, separation distances and atmospheric conditions limit the amount of exposure to bioaerosols for populations adjacent to land application sites. The risk of bioaerosol emissions is also lessened when applied solids are subsequently incorporated into the soil (Straub et al., 1993). However, very dry biosolids tend to release more dust.

3.2 Quebec criteria for land application of biosolids

In Quebec, the environmental criteria for the management of biosolids are set out in the document *Critères provisoires pour la valorisation des matières résiduelles fertilisantes* (provisional criteria for land application of fertilizing residuals) or CPVMRF (Quebec Ministry of the Environment, MENV, 2001). Regulations for use depend on the levels of organic and inorganic contaminants (categories C1 and C2), pathogens (categories P1, P2 and P3) and odour (categories O1, O2 and O3) in the biosolids. The pathogenic content of the biosolids is obtained by analyzing the concentration of *E. coli* and *Salmonella*, two parameter indicators of fecal contamination. The level of odour itself is established by the MENV from surveys of the perception of odours, the number of complaints and/or olfactometric measurements (Groeneveld and Hébert, 2002).

Biosolids that do not meet minimum requirements (C2-P3-O3) cannot be applied on the land. Constraints for land application for categories P1, P2 and P3, as set out in the CPVMRF (2001), are based on US regulations for applying municipal sludges (US EPA, 1993). These constraints are aimed at protecting the environment, the communities adjacent to land application sites and the farmers handling these materials. They do not apply to manure applied to farmland. There are additional constraints for malodorous residuals classified as O2 or O3 depending on their level of odour. The constraints set out in the criteria are the same as or harsher than those currently in force in the United States and Ontario. They are generally more restrictive than those for manure and slurries, and specify hygiene and personal protection measures that workers in contact with biosolids containing pathogens must take (Appendix 10 of the CPVMRF, 2001).

Constraints for the management of malodorous biosolids or those containing human pathogens directly or indirectly provide protection with regard to potential risks linked with bioaerosols. These are principally separation distances (residences, residential zones, property boundaries, roads, etc.), a restricted period of one year to limit public access to land application sites, the obligation to incorporate the biosolids into the soil after application and the obligation to spread liquid waste at a height of less than one metre above the surface of the soil, which help to protect residents adjacent to the application sites. The separation distance from an adjacent residence (see Table 3) is at least 90 m for P2 and P3 residuals, and this distance increases to 500 m for 'very malodorous' category 03 (MENV, 2002). Other constraints are needed for malodorous wastes such as setting up a communications plan and restrictions on times of application, in particular, weekends.

Table 3. Separation distances as set out in the CPVMRF from the MENV.

	Category and applicable limits for biosolids	Required distance (m) from an adjacent residence
P1	Fecal coliforms <1000 MPN/g (dry basis) and *Salmonella* <3 MPN/4 g (dry basis) and, except for paper mill biosolids (2), other requirements equivalent to the US EPA's Class A	—
P2	Fecal coliforms < 2 x 10^6 MPN/g (dry basis) and other requirements equivalent to the US EPA's Class B. Paper mill biosolids (2) are considered P2 if they do not meet the concentration limits required for category P1.	90(1)
P3	Fecal coliforms < 2 x 10^6 MPN/g (dry basis) and biological treatment with a 20-day equivalent retention time for sludge	90(1)
O1	Odour level < than solid dairy manure	—
O2	Odour level similar to solid dairy manure	75
O3	Odour level > than solid dairy manure and < than pig slurry	500

(1) 500 m from a residential zone.
(2) If a written declaration is provided by the paper mill stating that no domestic sewers empty into the wastewater treatment system.

3.3 Impacts on the health of workers

The potential risks to the health of workers involved in land application of biosolids have not been given much study. However, an extensive prospective epidemiological study on the risks associated with pathogens was carried out over a three-year period from 1978 to 1982 in the United States by the University of Ohio for the "Ohio Farm Bureau Federation" and the US EPA. This study aimed to assess the risks to the health of farm workers and their families in relation to land application of aerobically and anaerobically digested municipal biosolids. The epidemiological study concluded that the risks for the health of the populations studied were not significant under the conditions of the study (Dorn et al., 1985). There was no significant difference in the risks for respiratory or gastro-intestinal problems or various symptoms such as headaches in the group of families exposed (47 farms, 164 people) compared to the control group (46 farms, 130 people).

Some studies have in addition measured concentrations of airborne bacteria in the workers' immediate environment, in particular while spreaders are being loaded (Pillai et al., 1996), and suggested protection measures for those who handle Class B biosolids (similar to categories P2 and P3 in Quebec). In an investigation carried out in 1999 by the NIOSH (National Institute of Occupational Security and Health), enteric bacteria were detected in some samples of the air to which workers had been exposed during land application of biosolids. However these biosolids had concentrations of fecal coliform indicators that were sometimes 4.5 times the limit for Class B, and thus should not have been applied to the land. The organization also published a descriptive sheet (NIOSH, 2000) and more recently, revised its recommendations as guidance for controlling potential risks to the health of workers who handle Class B municipal biosolids (NIOSH, 2002). The NIOSH states that its guidance complements the US EPA's regulations on the application of biosolids which aim to protect the public and not workers specifically.

In Quebec, the criteria for applying biosolids (MENV, 2001) prescribe the appropriate health and safety regulations for employees involved in transportation, land application and incorporation (into the soil), and are similar to those of the NIOSH (2002). However, it is not known what proportion of these fairly constrained measures for protection are respected by farmers and specialized workers (Marc Hébert, personal communication).

We should mention however that farmers who carry out land application of biosolids have usually already been exposed in their farm environment to various sources of bioaerosols associated with livestock housing, and the handling of hay, grain and silage (Cole et al., 1999; Olenchock, 1994). Moss et al. (2002) also reported that fresh manure and slurries contain up to 3 x 10^7 CFU/g (dry basis) of fecal coliform indicators. The application of solid manure and untreated slurries may thus theoretically represent a significant source of airborne pathogens. Unlike manure, biosolids likely to contain human pathogens must undergo a hygienization treatment (digestion, liming, composting, etc.). Farmland application of biosolids containing more than 2 x 10^6 MPN/g (dry basis) is also prohibited in Quebec (MPN equivalent to CFU).

3.4 Potential impacts for neighbouring populations

While there are theoretical risks for the health of populations close to biosolids application sites, the results from studies carried out on this subject are reassuring. From the most recent reviews of the literature, it is clear that there is no scientific evidence that populations close to biosolids application sites are at risk from bioaerosols (Apedaile et al., 2002; Epstein, 2002; Anderson et al., 2001). However, all the studies listed deal only with municipal biosolids.

In order to assess potential effects on the health of populations close to biosolids application sites, some studies measured concentrations of bioaerosols to which they could have been exposed. Sorber et al. (1984) reported lower concentrations of aerosols when liquid municipal biosolids where applied than when the soil was irrigated with municipal wastewater. The authors did not detect any significant effect on the health of people living more than 100 m downwind of the biosolids application site. By comparison, Boutin et al. (1988) isolated airborne enteric micro-organisms (pathogen indicators) at distances of up to 130 m from spraying equipment applying pig and cow manure. The release of bioaerosols was clearly less when solid manure was spread compared to airspraying of slurries. According to Cole et al. (1999), exposure to bioaerosols originating in manure can present risks comparable to those associated with municipal biosolids under similar land application conditions.

Pillai et al. (1996) also measured bioaerosols over a four-month period during the application of biosolids that had undergone aerobic and anaerobic digestion. These measurements were taken at one of the most extensive commercial spreading operations for municipal biosolids in the United States (7000 hectares under application). In the conditions for the study, pathogen indicators (bacteria) were only detected in the air released during intensive agitation of the biosolids while the hopper was being loaded. No pathogen indicator was measured in the air either on the application site or in residential zones downwind, in spite of elevated concentrations of fecal coliforms in the biosolids that were above the US (and Quebec) limit of 2×10^6 MPN/g (Pillai et al., 1996).

We would remind you that during the prospective epidemiological study done in Ohio from 1978 to 1982, no effect was observed on the health of farming families living close to application sites for municipal biosolids, and thus potentially exposed to bioaerosols released by these sludges, when compared to families in the control group who were not exposed (Dorn et al., 1984). However, epidemiological studies are complex and do not always provide the level of sensitivity required. Anderson et al. (2001) noted that monitoring programs involving case follow-ups for health problems in the population are used in several countries as an alternative to prospective epidemiological studies. Monitoring is continuous and is aimed at determining the factors responsible for health problems. An extensive program to monitor human health was set up in the United Kingdom in 1989, and it showed that the application of stabilized biosolids using proper management practices presented little risk to human and animal health or to the environment.

Another way to assess the potential risks for populations close to application sites is modelling. This type of risk analysis is theoretical, but it allows extreme situations to be assessed in order to determine if more thorough studies are needed. In this way, using emission levels found in the air-spraying application of liquid municipal biosolids (Dowd et al., 1997), Dowd et al. (2000) modelled the dispersion of microbial aerosols (*Salmonella* and F-specific coliphages) and the risk of infecting populations. The risks of viral and bacterial infections of 3:100 and 2:100 respectively (3% and 2% risk of infection) were modelled for workers exposed to bioaerosols 100 m downwind of application surfaces, for one hour of exposure with wind conditions of 2 m/s. The authors noted however that this modelling represented a worst-case scenario and suggested that epidemiological studies on workers would need to be carried out. In addition, they stated that the risks for neighbouring populations were extremely low. However, the high-pressure air-spraying used in the modelling by Dowd et al. (2000) is a type of application that is already prohibited in Quebec. Liquid sludge must be land applied at a height of less than 1 metre above the surface of the soil (MENV, 2001).

No study was found in the literature on bioaerosols released during land application of paper mill and slaughterhouse biosolids. However, the theoretical risks to human health should theoretically be comparable to or lower than the risks associated with Class P2 municipal biosolids. Paper mill biosolids in particular that come from wood products and that have not been contaminated by sewage typically contain far fewer pathogens than municipal biosolids. Slaughterhouse residuals however must be stabilized with lime (or a suitable alternative) at the plant before they are transported to the application sites to comply with the criteria for category P2. Almost no biosolids recycled in Quebec can be applied at a distance of less than 90 m from a neighbouring residence.

So although few studies have been carried out, it appears from a review of the literature that under proper management conditions such as those prescribed in the Quebec criteria, significant concentrations of bioaerosols that could be harmful to the health of people living nearby would not be found beyond the sites where biosolids are applied.

In addition and in comparison, several studies reported that concentrations of various bioaerosols measured 100 metres downwind from outdoor composting sites for municipal biosolids, municipal wastewater treatment plants, pulp and paper mills and landfill sites for paper mill biosolids are not significantly higher than those measured upwind of these sites (Lavoie, 2000; Goyer and Lavoie, 1998; Millner et al., 1994). This distance compares to 90 m from an adjacent residence for residuals in categories P2 and P3 or a distance of 500 m for Category 03 residuals such as a good proportion of the biosolids from pulp and paper mills.

The use of biosolids by home gardeners is prohibited in Quebec except for residuals offering the best quality in terms of hygienization (category P1). However, some category P1 pulp and paper residuals may contain a significant microbial flora, as is the case for domestic compost from backyard composting (Brassard et al, 1999).

3.5 The need for knowledge

While it is possible to measure concentrations of bioaerosols or volatile organic compounds in enclosed spaces (livestock housing, etc.) the maximum levels to which near-by residents are exposed are still more difficult to determine precisely (Goyer et al., 2001). Conditions for exposure actually differ greatly depending on time and location because of atmospheric dispersion. It is therefore very difficult to measure through sampling of ambient air the actual and cumulative exposure to the bioaerosols in the places (e.g. a neighbour's nose or mouth) where they are perceived. Moreover, a variety of sources that release bioaerosols at intervals or sometimes simultaneously may contribute to the exposure. In addition, according to Schiffman et al. (2000), although there may be evidence that bioaerosols either alone or in combination with odours and other volatile organic compounds may cause health effects, additional research is needed to determine if the concentrations of bioaerosols in atmospheric plumes are high enough to cause health symptoms in communities adjacent to farms or land application sites.

Regulations in the United States upon which the Quebec criteria for pathogens (MENV, 2001) are largely based, were not themselves based on a risk analysis for individuals with high exposure levels. In fact it seems that the methodologies for such an analysis were not sufficiently developed at that time (1993) and no case study was able to establish a link between the epidemic effects on health and the land application of biosolids in agriculture (Anderson et al., 2001). This absence of risk analysis was however criticized in a recent report by the National Academy of Science (NAS, 2002). Such an analysis of risk should include the exposure pathway for bioaerosols.

Major scientific studies funded by the Water Environment Research Foundation (WERF) are also being carried out in the United States to develop suitable methodologies for risk analysis and management of public concerns on this subject. In addition, a specific study on the potential emission of odours and bioaerosols during land application of municipal biosolids is currently being carried out by the USDA (U.S. Department of Agriculture) and other US researchers.

There is little documentation however on the potential for the release of bioaerosols from pulp and paper residuals, and their possible effects on health. No specific study on land application has in fact been listed in this particular study. Considering the large quantities of pulp and paper residuals that are applied in Quebec, measurements of bioaerosols released during land application would be welcomed.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The information consulted shows that the application of biosolids, especially those from municipal sources, can represent a potential source of bioaerosols that can be harmful to human health. However the scientific studies referred to indicate that the risks are relatively low for the workers who are most likely to be exposed to bioaerosols, such as farmers and those who specialize in the management of biosolids. Furthermore, the risk of transmitting pathogenic organisms to workers would more likely be through direct contact than through the air in the form of bioaerosols. The risk can be controlled through hygienic and personal protection measures already set out in the Quebec criteria for land application of biosolids. Similar measures are used in a variety of workplace settings where bioaerosols are released and can present health risks for workers. In addition, farmers are already exposed on their farms to various sources of bioaerosols associated with livestock, handling manure and harvesting.

With regard to risks for people other than the workers themselves, an extensive prospective epidemiological study, completed in 1982 and put together by numerous public health experts in the United States, concluded that the risks associated with pathogens are extremely low for people living close to sites where municipal biosolids are applied. These results have been corroborated in more recent and more specific studies that measured airborne pathogens. These studies dealt with the application of liquid municipal biosolids by air spraying, which is more likely to release bioaerosols, in particular airborne pathogens. The risks are thus theoretically lower in Quebec, where relatively few municipal biosolids or liquids are applied. In fact the great majority of biosolids come from paper mills and are semi-solid in form. Nevertheless, the bioaerosols actually produced by this type of waste have not been measured close to application sites.

Current knowledge about bioaerosols also suggests that theoretically, potential health risks associated with the application of biosolids for farmers and the general population are relatively low when compared to those associated with manure management, for the following reasons in particular:

- ✓ The quantities applied are lower, with 700,000 tons of biosolids applied to farmland in 1999 compared to about 30 million tons of manure and slurries;
- ✓ These wastes are usually semi-solid in form, which makes them less susceptible to aerosolization;
- ✓ The amount of pathogenic indicators *(E. coli* and *Salmonella*) is comparable to or considerably lower than in manure;
- ✓ The constraints for application, especially the distances away from neighbouring residences, are more restrictive for biosolids than for manure (MENV, 2001), especially if they are extremely malodorous.

Thus, based on the scientific information consulted and available at the time this study was prepared (June 2002), the results do not for the moment suggest the need for more restrictive measures than those already existing in Quebec. We should mention however that we were not able to include an analysis of the recent report by the National Academy of Science on US standards for the application of municipal biosolids (published in July, 2002) in this review of the literature.

With regard to the need for research, because major scientific studies are already underway in the United States, and the US EPA may proceed with an analysis of the risks specific to pathogens, it would seem that in the short term, similar research in Quebec is not warranted. On the other hand, it would be important to further document the principal sources of potential bioaerosol emissions during spreading in Quebec, that is, manures and pulp and paper residuals

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