CANADIAN HANDBOOK ON HEALTH IMPACT ASSESSMENT

Volume 2
Decision Making in Environmental Health Impact Assessment

DRAFT

DECEMBER 1999

Sewage sludge management

Use of municipal sewage sludge

Municipal sewage

A typical North American city produces from 225 to 380 litres of wastewater per person per day. The volume increases with population, since this figure also includes sewage from industrial and commercial establishments that are more numerous in large cities.

Municipal wastewater contains only 0.1% of pollutants in the form of solids and chemicals. Close to 70% of the pollutants occur in the form of organic compounds and 30% in the form of inorganic compounds. The concentration of total suspended solids (TSS), comprising both inorganics and organics, usually ranges between 100 and 400 mg/L, while the biological oxygen demand (BOD_5), basically a measure of the concentration of organics, also ranges between 100 and 400 mg/L. Phosphorus levels may be as a high as 15 mg/L. In addition to these pollutants, municipal sewage contains variable amounts of synthetic chemicals (solvents, PCBs, acids, etc.) from industries and businesses, along with many different types of microorganisms, particularly coliform bacteria, viruses and some parasites, such as protozoa and helminths. A significant quantity of these pollutants are also found in sewage sludge.

Origin of sewage sludge

Although sludge is generated at each stage of the treatment process, most of it is produced during primary and secondary treatment. During preliminary treatment, the water flows through screens that remove coarse materials such as plastics, tissues and pieces of wood, before being sent into a grit chamber where sand and other fairly dense particles are allowed to settle. Subsequently, the scum (oil and greases that are less dense than water and float on the top) is skimmed off. Primary treatment, carried out basically in settling tanks, removes total suspended solids (TSS) between 0.05 and 1.0 mm in size. The main purpose of secondary treatment (also known as biological treatment) is to remove any organic matter that was not removed in the settling process in the primary stage. Several different techniques are used, essentially based on digestion by aerobic or anaerobic bacteria, which metabolize the material. However, bacterial action also increases the volume of microorganisms at the bottom of the tanks, a significant portion of the sludge. The average volume of sludge produced in all stages of the process combined are 150 kg of dry solids per 1,000 m^3 of treated wastewater.

Sludge treatment

Raw sludge usually consists of over 95% water. It must be treated using several different processes to reduce the water content and stabilize it biologically.

The water content of sludge is reduced through thickening and dewatering. Thickening generally involves the use of mechanical processes (rotary drums) and gravity belts. Dewatering can be carried out using centrifuges, various screening equipment or thermal conditioning. This produces sludge with a water content as low as 10%. However, most sewage treatment plants produce sludge with a water content no lower than 50%, since reducing the water content further is costly. It is important to note that the concentration of non-biological pollutants usually increases as the solids content increases.

The purpose of stabilization is to reduce the fermentability of the organic matter in the raw (non-dewatered) sludge and to reduce the concentration of pathogenic microorganisms. Stabilization can be done through anaerobic or aerobic digestion, in which fresh organic matter (proteins, lipids, complex sugars, etc.) is broken down into simple substances (amino acids, fatty acids and simple sugars) and ultimately into mineral compounds (nitrates, ammonia, carbon dioxide, methane, phosphates, etc.) that do not support the development of an abundant microflora. Composting provides partial fermentation, reducing the concentration of fresh organic matter and eliminating most pathogens through heat under sufficiently high temperatures (55–70°C). Stabilization can also be done through chemical means: although the concentration of organics is not reduced, the reactants involved (notably quicklime, which increases the pH and the temperature) have a bactericidal effect.

Public health risks

The increasingly widespread use of sewage sludge as agricultural and tree fertilizers poses a public health risk. It is expected that over 180,000 t of sewage sludge, in the form of dry solids, will be generated in Quebec in the year 2000. Sludge contains key nutrients for plants, such as nitrogen and phosphorus, and can therefore be used in agriculture. Sludge can also be used as an organic and lime soil amendment. Sludge can therefore be used in silvicultural applications, particularly in tree nurseries, and on some types of agricultural land. However, some safety measures are needed; refer to the guides published by the Quebec Department of the Environment and Wildlife, on the use of sludge as a resource, for more information on the measures required.

Typical composition of sludge and health risks

Typical sewage sludge contains a wide variety of organic and inorganic substances. The pollution risks posed - and ultimately its toxic and pathogenic potential - depend on the presence or absence of the groups of pollutants described briefly in the following paragraphs.

Inorganic compounds

The inorganic compounds usually found in sewage sludge include nitrogen, phosphorus, potassium, calcium, magnesium and heavy metals.

Nitrogen concentrations range between 1% and 5% of dry weight. Before stabilization, most of the nitrogen occurs in organic form (proteins and amino acids). After stabilization, however, most of the remaining nitrogen (a significant proportion may volatilize during the process) is inorganic, either ammonia nitrogen (anaerobic stabilization) or nitrates or nitrites (aerobic stabilization). The presence of nitrates and nitrites in well water in total concentrations over 10 mg/L is a known health risk. When ingested, these pollutants may lead to the formation of methaemoglobin in the blood, or of nitrite or nitrosamine derivatives, the last two of which are well-known carcinogens.

Total phosphorus accounts for 1% to 4% of sewage sludge by dry weight. It is most common in inorganic form (50–75%) in both raw and stabilized sludge. When sludge is spread on fields, surface waters may be contaminated by phosphorus. This poses little risk to public health, except in the case of overfertilization, where phosphorus is transported by surface waters.

Elements such as potassium, calcium and magnesium all make up less than 1% of the dry weight of sludge. However, when sludge is chemically stabilized by liming, calcium concentrations may reach 25% of dry weight. These elements do pose public health concerns.

Sludge contains varying levels of heavy metals (Al, As, B, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Se and Zn), with manganese and copper being the most abundant in a typical sludge formed by taking the average of several samples. The presence of these two metals is due mainly to the presence of industrial effluents as well as stormwater runoff from streets and industrial and commercial land. Cadmium, mercury and lead pose the greatest concern, because they are highly toxic. Copper, chromium, nickel and zinc are also believed to represent a significant risk. However, the concentrations of these metals in the sewage sludge in Quebec are generally below the levels considered hazardous by the EPA. Furthermore, heavy metals are not very mobile in the soil and there is no detectable contamination after sludge is spread on agricultural or forest land. However, a risk of contamination of forest fauna by cadmium and zinc has been reported. Some studies also suggest that aluminium poses a hazard (in its role in Alzheimer's disease) but the results so far are not conclusive. The potential risk associated with aluminum may call into question the practice of using alum (aluminum potassium sulfate) as a flocculant in wastewater treatment.

Organic compounds

For the purposes of this discussion, organic compounds can be divided into nontoxic and toxic substances. Of the two, nontoxic compounds are most prevalent, comprising all materials of plant or animal origin, including proteins, amino acids, sugars and fats. These materials are present in fecal matter as well as in some kitchen and food industry waste. Although most oils and greases from non-food industries could also be included in this category, some can be quite toxic. The biological oxygen demand (BOD_5) associated with these substances shows that they tend to be polluting; increased BOD substantially reduces the amount of oxygen available for aquatic organisms. In stabilized sludge, the quantity of biodegradable nontoxic organic matter is reduced by microbial action.

Toxic organic compounds are very diverse by nature, comprising hundreds if not thousands of substances. The most prevalent groups in sewage sludge include polycyclic aromatic hydrocarbons (PAHs), pesticides, halogenated aliphatic compounds, PCBs, chlorobenzenes, volatile organic compounds (VOCs), phenols, dioxins and furans. Phtalates, surfactants (particularly nonylphenols and alkylbenzenes), chlorobenzenes and some PAHs are present in stabilized sludge at concentrations of over 10 mg/kg (and as high as 100 mg/kg). Phtalates, which are commonly used in manufacturing adhesives, glues and lubricants, are found in very high concentrations. The high concentration of surfactants is due to their use in laundry detergents and many cleaning products.

Certain PCBs, PAHs, organochlorines and dioxins are known to be carcinogenic. However, they usually occur in very small concentrations in sludge and, after sludge has been spread, they are not believed to pose any real health risks. Phtalates and some surfactants (nonylphenols) are not considered highly toxic, although some studies suggest that they may disrupt hormone cycles regulating reproduction in mammals, even at very low concentrations. These results are not considered conclusive, however, and more studies are required.

Pathogens

Sewage sludge contains numerous microorganisms of varying pathogenicity, mainly parasites, viruses, bacteria and fungi.

Parasites of interest from a public heath perspective include protozoa, such as amoebae, *Toxoplasma gondii*, *Giardia lamblia* and *Cryptosporidium* spp., as well as helminths, such as *Ascaris* spp., *Trichuris* spp. and *Taenia* spp. These parasites may occur in sludge in the form of cysts or eggs, in numbers ranging from several hundred to a few thousand per kilogram. These numbers are high considering that infection can occur with the ingestion of as little as one cyst (in *Giardia* spp. for example). Eggs and cysts in sludge are very persistent and heat treatment at a temperature of at least 70°C is required to destroy them. After the sludge has been spread, some eggs or cysts may survive for several years in the soil. The health risks are mainly for workers on the site where the sludge has been applied.

Raw sludge may contain up to 1,000 viruses per gram. Stabilization can reduce that number by a factor of 10. Many viruses are found in sewage sludge, but the most prevalent are enteroviruses, such as the hepatitis A virus, which infect the digestive system. Some viruses can survive in the first 5 to 15 cm of soil for several months. Viruses are not very mobile, however, which limits the risks of water contamination.

Similarly, the most common bacteria in sewage sludge are the enteric bacteria (coliforms, shigellae, vibrios, etc.). Also present are bacteria of the genera *Streptococcus*, *Clostridium*, *Mycobacterium* and *Listeria*. The presence of a given pathogen (*Salmonella*, for example) depends on the prevalence of active or healthy (asymptomatic) carriers in the population. The number of bacteria from each of these genera in sludge varies. In general, a total coliform count of 10^8 to 10^9 can be found per gram of dry weight, while fecal coliform bacteria generally represent 10^6 to 10^7/g dry weight. *Salmonella* spp. represent from 10^2 to 0^3 g/dry weight; however, the infectivity of this genus is very high (1 to 6 cells), and when it is present at all, this is significant. In general, bacteria are able to survive in the ground for several months; some may be partially inactivated by below-freezing temperatures or a summer drought. However, it is recommended that farmers wait a full year (at a minimum, an entire summer) before using fields that have been treated.

Little research has been done on fungi (yeasts and moulds) in sewage sludge. However, it is known that a number of pathogens, including *Aspergillus fumigatus*, *Candida albicans* and *Cryptococcus neoformans*, are present. Since infection in humans occurs through direct contact or inhalation, those mainly at risk are workers handling sludge, which usually occurs during composting operations.

Air pollution

Some volatile organic compounds (VOCs) are released into the atmosphere following land application of sludge. Substances like benzene, chloroform, toluene, xylene and trichloroethylene largely evaporate within 48 hours of land application of sludge. However, substances like PAHs and PCBs do not evaporate to any significant extent. The health risk associated with VOCs resulting from land application of sewage sludge has not been established, but is generally believed to be low. The presence of fungal and bacterial spores and viruses in the air cannot be overlooked, but the main risk is probably to workers who apply the sludge or who move about on the treated site.

Water pollution

Most of the organic compounds in sewage sludge do not migrate into surface or ground waters because they are hydrophobic (e.g., PCBs, PAHs, organochlorines) and are well adsorbed by the soil. Although some pesticides and soluble substances like surfactants (nonylphenols) and chlorobenzenes leach into surface and ground waters to a large extent, the risk of water contamination is considered low or has not been established for the general population.

Heavy metals have been detected in water, but at concentrations lower than those thought to be of concern. However, contamination of surface waters and the water table by various forms of nitrogen (particularly nitrates) poses a real risk, particularly if excessive quantities are applied. Compliance with the Quebec Department of the Environment's standards respecting the land application of sludge will minimize the risk of water contamination by nitrogen. Phosphorus does not pose a risk of water contamination because it is retained to a large degree in the soil.

Soil pollution

Most pollutants present in sewage sludge find their way into the soil during land application, where they bind, with various degrees of reversibility, to soil components such as sand, loam and humus. Most synthetic organic compounds, even the most toxic ones like dioxins, are usually broken down by soil microorganisms in a relatively short time. Annual land application of sludge appears to lead to long-term accumulations of surfactants, given the high concentrations at which they are found in sludge. However, further research is needed.

Metals are usually not metabolized by soil microorganisms and, if they are not mobile, will persist in the soil. One important issue regarding metals in sludge is their absorption by plants. However, the rate of absorption by plants appears low, and the risk has been deemed minimal for consumers of the plants.

Nitrogen and phosphorus are essential nutrients for plants. When present in the soil, they are usually taken up by the plants for their growth. Therefore, the presence of these elements is of no concern, except where excessive concentrations result in leaching of nitrogen to the water table.

Finally, the presence of pathogenic microorganisms in the soil poses no public health risks. Most pathogens have a short lifespan and their persistent forms (spores, cysts, eggs) remain in the soil. Therefore, the risk is to people handling the soil in question, not to neighbouring communities.

Sector: Sewage sludge Activity: Land application of municipal sewage sludge

STRESSOR/ EXPOSURE	Nature of stressor	Impact on environment	Zone of influence	Control measures	Standards or recommendations
Technological disaster					
Gas or atmospheric emissions	- VOCs (mainly benzene, toluene, PAHs, chloroform (trihalomethane-THM), etc.	- pollution, smog- and ground-level ozone formation	- surroundings and region (for smog and ozone formation)	- worked into soil instead of spread on surface	- benzene: 30 mg/
	- fungal spores (*Aspergillus*, *Candida*, *Cryotococcus* and others	(with NO_x) - pollution, unhealthiness	- surroundings	- same as above, but not very efficient	m^3 (QC workplace standards)[24] - Aspergillus: <10,000 cfu
Liquid effluent or in water	- heavy metals	- toxic to aquatic organisms	Receptor watercourses. Distance varies depending on many different parameters: concentration and solubility of pollutants, temperature, spreading method, etc.	- Respect protective riparian strips, slope of terrain, do no spread in winter, stabilize sludge before spreading, etc. -For micro-organisms, preliminary heat treatment of sludge may be effective	see note [25] Al: < 0.1 mg/L (Alzheimer's) - THM: 350 Fg/L (Q-2. Reg. on potable water[26] - 3 - 7 mg/L (MEF criteria for untreated water to be chlorinated - none - fecal coli.: 0 total coliform: 10/100 mL (Q-2 Reg. potable water)
	- synthetic organic compounds: mainly surfactants (nonylphenols), chlorophenols, THM	- disrupt reproduction (surfactants) carcinogenic: THM			
	- degradable organic compounds (proteins, amino acids, etc.)	- reduction in dissolved oxygen in water			
	- eggs and cysts of parasites: *Giardia*, *Toxoplasma*, *Cryptosporidium, Taenia*	- unhealthiness			
	- enteric bacteria: *Salmonella*, *Shigella*, *Vibrio*	- unhealthiness			
	- enteric viruses				
Solid emissions or in the soil	- heavy metals	Soil pollution, unhealthiness Extent of pollution depends on content of sludge and quantity spread	Usually most of these pollutants not very mobile when spread	Do not spread too often on same site	- see note 2 - PCBs: 0.02-0.07 Fg/kg.d (EPA); dioxin (TCDD): 10^{-6}Fg/kg.d ATSDR - none - none
	- heavy or hydrophobic organic compounds (PCBs, PAHs, dioxins, etc.)				
	- eggs and cysts of parasites (see above)				
	-enteric viruses				
Nuisance	odours insects, vermin	unhealthiness	site and surroundings	buffer zone stabilization of sludge	municipal bylaws

---

[24] Acceptable daily intake (Fg/kg-d) according to EPA: toluene 200; chloroform 10; PAHs 40-300

[25] Acceptable concentrations in potable water (Fg/L) according to Quebec Potable Water Regulation and acceptable daily intake (Fg/kg-d) according to EPA: As 50 and 0.3; Cd 5 and 0.5 ; Cr 50 and 5; Hg 1 and 0.3; Pb 50.

[26] This standard should drop to 100 Fg/L when the regulation is revised in accordance with the new MPC from Health Canada.

Indirect impacts					

STRESSOR/ EXPOSURE	Health effects	Population at risk	Probability of occurrence	Biological/ environmental indicators (monitoring)	Information/ references
Technological disaster					
Gas or atmospheric emissions	- irritation of resp. tract, possible carcinogen	-mainly workers	- very rare	- VOCs in ambient air	Couillard *et al*. (1993) Labelle (1995)
	- allergies, resp. irritations, infections	- workers, maybe neighbours	- unknown	- cfu per m^3	
Liquid effluent or in water	- various toxic effects, possible carcinogen	- people consuming polluted water	- rare or unknown	For all pollutants concerned: determine concentration in runoff from treated area, analyze well water Epidemiological monitoring of local populations near places frequently treated	Couillard *et al.* (1993) Labelle (1995) Beauchemin *et al*. (1993) Dubé and Delisle (1995) Colborn *et al.* (1996) (for surfactants and nonylphenols)
	- trihalomethanes, carcinogenic; nonyl-phenols disturb hormone cycles and reproductive system	-people consuming polluted water	- rare or unknown		
	-unhealthiness, no direct effect, formation of THM if water chlorinated	-people consuming polluted water	- rare or unknown		
	- various types of parasitosis	-people consuming polluted water	- rare or unknown		
	- mostly gastro-enteritis	-people consuming polluted water	- rare or unknown		
	- gastroenteritis	-people consuming polluted water	- unknown		
Solid emissions or in the soil	- see above	- workers	- unknown	For all soil pollutants: determine whether most dangerous are present. Monitor workers if necessary.	Beauchemin *et al.* (1993) Labelle (1996) Couillard *et al.* (1993)
	- carcinogenic	- workers	- unknown		
	- various types of parasitosis	- workers	- unknown		
	- gastroenteritis	- workers	-unknown		
Nuisance	- quality of life	- neighbourhood and community	- rare or unknown	- complaints, perception studies	
Indirect impacts					

References

Beauchemin, S., M.R Laverdière and C. Scraire (1993) *Revue de littérature sur les métaux, l'azote et le phosphore dans les boues d'origine municipale de pâtes et papiers et de désencrage en prévision de leur valorisation en milieux agricole et forestier*. Cogisol Inc. (produced for Quebec Department of Natural Resources), 112 p.

Chevalier, P. (1995) *Gestion de l'environnement en milieux urbain et industriel.* Presses de l'Université du Québec, 577 p.

Colborn, T., D. Dumanoski and J.P. Meyers (1996) Our stolen future. Dutton Books, 306 p.

Dubé, M. and S. Delisle (1995) *Suivi environnemental effectué à la suite de l'épandage de boues d'épuration des eaux usées municipales à la pépinière de Normandin*. Department of Natural Resources, Government of Quebec, 95 p.

Couillard, D., P. Chouinard and G. Mercier (1993) *Risques environnementaux associés à la présence de contaminants organiques de synthèse dans différentes boues résiduaires lors de leur valorisation en milieux agricole et forestier*. INRS-Eau, Université du Québec, 108 p.

Gossels, T.A. and J. D. Bricker (1994) Principles of clinical toxicology. Raven Press, Third edition, New York, 447 p.

Labelle, A. (1995) *Utilisation des boues d'usines d'épuration et risques à la santé. BISE (Bulletin d'information en santé environnementale*), 6(3):__ - __.

Labelle, A. (1996) *Valorisation des boues d'épuration municipales; quels sont les risques de contamination? Direction de la santé publique Mauricie-Bois-Francs* 46 p.

Quebec Department of the Environment and Wildlife (1996) *Évaluation sylvicole, environnementale et technico-économique de la valorisation de trois types de boues de stations d'épuration municipales dans la région des Laurentides.* Department of the Environment and Wildlife (Government of Quebec), final report, 284 p.

Quebec Departments of the Environment and Wildlife and of Agriculture, Fisheries and Food (1991) *Valorisation agricole des boues de stations d'épurations des eaux usées municipales.* Quebec Departments of the Environment and Wildlife and Quebec Department of Agriculture, Fisheries and Food (Government of Quebec), 91 p.

Quebec Departments of the Environment and Wildlife and of Agriculture, Fisheries and Food (1991) *Valorisation sylvicole des boues de stations d'épurations des eaux usées municipales.* Quebec Departments of the Environment and Wildlife and Quebec Department of Agriculture, Fisheries and Food (Government of Quebec), 83 p.

Septic tank sludge

Individual sewage treatment systems are those that are not connected to a sewage system. The simplest way of containing fecal manner is the old-fashioned pit privy, a simple hole dug in the ground and covered over when full, which is still used by hundreds of millions of people around the world. One of the most highly evolved forms of individual sewage treatment is the septic tank, which is used in the industrialized world to treat domestic sewage from isolated residences. This sewage must be treated, because of its polluting nature. The typical effluent from a single-family house in North America contains around 450 mg/L of total suspended solids (TSS) and an organic load equivalent to a BOD_5 of 400 mg/L (this figure must be no higher than 3 mg/L to support aquatic life and 7 mg/L for untreated potable water destined for chlorination).

Septic tanks have become increasingly common for treating sewage from small businesses and industries. This sewage often contains pollutants not usually present in domestic sewage, such as synthetic organic compounds. However, there is not enough data to characterize this type of sludge. Thus the data given in this section concerns sludge from septic tanks used to treat household sewage.

How a septic system works

Sewage treatment in a septic system is a two-step process: first, the sewage is channelled into an underground tank with a volume of several thousand litres (between 1,500 and 5,000); the average residence time is two or three days. The partially treated sewage is then evacuated from the tank into the ground through perforated pipes under the surface. The soil acts as a purifier, having all the qualities needed to complete the treatment that began in the tank.

Septic tanks are installed underground and are usually made of concrete or fibreglass. They generally have two separate compartments through which the wastewater can flow. The tank is designed to allow suspended solids (SS) denser than water to settle out, while oils, greases and low density suspended solids accumulate on the surface to form the crust or scum. The water flows continually through the tank; the crust and the sediments forming the sludge must be pumped out regularly (every few years or so) to avoid overloading the system.

Microbial dynamics of septic tanks

As in larger municipal sewage treatment systems, in a septic tank, the raw organic matter that goes into the tank is digested by various microorganisms and thus stabilized.

A first group of facultative anaerobic and aerobic bacteria transforms the complex organic compounds (proteins, carbohydrates, lipids) into simple substances such as monosaccharides, amino acids and volatile fatty acids. A second group of bacteria, strict anaerobes, then transforms the primary metabolites into molecules such as carbon dioxide (CO_2), H_2, methane (CH_4) and hydrogen sulphide (H_2S). However, methane formation does not occur often in Quebec because methane bacteria grow very slowly at temperatures below 20°C. The gases produced form bubbles in the sludge and rise to the top, carrying with them solids which form a layer of scum at the top of the tank.

Mineralization of the organic matter generally occurs after a year in the tank. Methane production, if it occurs at all, does not begin until the second year if the tank has not been pumped out. Therefore, pumping out the tank every two years prevents the methanization process from occurring. However, regular pumping of the tank is required to prevent the sludge from overflowing into the tank's second compartment and into the disposal field; excessive TSS in the effluent from the tank will plug up the pipes that take the water to the disposal field.

It should also be noted that the penetrating, foul odour of sludge is caused by the products of anaerobic decomposition. Gases such as H_2S cause some of the odours, but volatile fatty acids, butyric acid and substances with a fecal odour, such as indole and skatole, are also to blame.

Quantity of sludge produced

Considerable research has been conducted on septic tank sludge production. Unfortunately, few studies have been carried out in Quebec, and data from the United States and Europe must be used. However, a similar trend is observed everywhere: annual accumulation of sludge decreases with time. During the first year of operation of a tank, the scum and sludge produced ranges from 80 to 180 litres per person, but falls to 40 to 100 litres after three years of operation. Pumping out the tank completely promotes greater sludge production the following year. The decrease in the accumulated sludge over time is a normal process inherent in anaerobic digestion, which gradually reduces the organic mass, mainly through bacterial autolysis. Anaerobic digestion takes some time to get established and as many as five years may be required before it reaches peak efficiency.

Sludge accumulation varies widely depending on various conditions. A low annual temperature promotes accumulation because of the slowing of bacterial activity responsible for breaking down the organic matter. At temperatures below 10°C, bacterial metabolism is almost completely inhibited, which means a significant increase in sludge accumulation during the winter. Furthermore, when the input of organic matter into the tank is high, sludge formation increases, while reduced water flow tends to result in decreased functioning of the tank.

It does not seem to be currently possible to determine the actual quantity of septic tank sludge produced annually in Quebec. There are approximately 400,000 permanent residences and 200,000 summer cottages that are not served by a sewage system. If all these dwellings were connected to a regulation septic tank that was pumped out every two years, as prescribed in the Quebec *Regulation Respecting Waste Water Disposal Systems for Isolated Dwellings* (Q-2, r.8), the volume of sludge produced would be 1,000,000 m^3 per year. However, given the fact that many tanks do not conform to standards and the rule of pumping out the tank every two years is not always respected, the volume of sludge pumped out of tanks every year in Quebec can be estimated at between 200,000 and 340,000 m^3 per year.

Composition of sludge

Domestic sludge consists of scum (a mixture of grease and floating suspended solids), sediments and water drawn from the tank when it is pumped out. Technically speaking, it is liquid anaerobic sludge since water makes up 95% to 98% of the sludge by weight. Aside from various non-decomposable solids (sand, pieces of plastic or metal, hair, etc.), the sludge consists essentially of a dark brown to black mass with no identifiable particles.

Septic tank sludge has a very high pollutant load, as shown by the following figures: a biological oxygen demand (BOD_5) of 5,000 to 10,000 mg/L; total suspended solids (TSS) of 20,000 to 40,000 mg/L; total nitrogen (N) of 100 to 1,000 mg/L; total phosphorus (P) of 30 to 300 mg/L. According to the data available, septic tank sludge contains no dangerous organic compounds, such as PCBs, PAHs or chlorinated organic compounds. However, surfactants from detergents, such as nonylphenols and alkylbenzenes, may be present, as well as phtalates, which are used in the manufacture of adhesives, glues and lubricants. However, the current scientific literature contains no studies in this regard.

When the tank is functioning normally, the pollutant load of the liquid discharged from the tank (effluent) is less than that of the sludge: BOD_5, 30–250 mg/L; TSS, 30– 200 mg/L; total N, 10–300 mg/L; and total P, 1–20 mg/L. As explained above, this effluent is discharged into a disposal field where the concentration of pollutants is reduced by the activity of soil microorganisms. The sludge pumped from the tanks has a high pollutant load, posing management problems.

Heavy metals

Heavy metals are found in small concentrations in septic tank sludge. They come mainly from domestic cleaning products and metal outflow pipes. The main metals found in septic tank sludge are iron (approximately 200 mg/L), aluminium (50–250 mg/L), zinc (around 35 mg/L) and copper (approximately 10 mg/L). These concentrations are well below the recommended values set out in the guide on the use of treated sludge in agriculture (i.e., Fe, 1000 mg/l; Zn, 500 mg/L; Cu, 100 mg/L), except for aluminium, for which the maximum allowable concentration is 100 mg/L. In Quebec, up to 1,380 mg/L of aluminium has been

found in septic tank sludge. In Quebec, the average arsenic concentration is 14.7 mg/L, with a maximum of 44 mg/L, which is much higher than levels in the United States (average of 0.16 mg and maximum of 0.5 mg). This raises the question of whether the Quebec sample is representative. However, the concentrations are below the maximum values set out in the above-mentioned guide, of 50 mg/l for inorganic arsenic and 100 mg/L for organic arsenic.

Microorganisms

The microorganisms found in septic tank sludge are similar to those in primary sludge from municipal wastewater treatment facilities. The main organisms identified and their concentrations (per 100 mL) are as follows: total coliforms, 10^7–10^9; fecal coliforms, 10^6–10^8; fecal streptococci, 10^6–10^7; anaerobic spore-forming bacteria (mainly *Clostridium* and *Bacteroides*), around 10^5; *Salmonella*, 1–100. A number of parasites are also found, such as *Ascaris* and *Trichuris*, as well as several viruses, including rotaviruses, the Norwalk virus and enteric adenoviruses.

Special precautions must therefore be taken in the handling and management of septic tank sludge, since it can cause a range of gastrointestinal infections, just like sludge from wastewater treatment plants (see section on "*Use of municipal sewage sludge" p.177*).

Management of septic tank sludge

Quebec has no management plan for septic tank sludge. However, dumping or using this sludge in any environment is unthinkable. Quebec Department of the Environment and Wildlife guidelines state that the regional county municipalities (RCM) are responsible for managing sludge to ensure that it is treated and disposed of at an acceptable final destination. It is preferable to reuse sludge, but disposal at sanitary landfills is acceptable if there are no alternatives. Although there exist a number of different sludge treatment technologies, in actual practice only four are used in Quebec: lagooning, dewatering, reuse for agricultural purposes and direct disposal in municipal sewerage systems. Composting also looks promising, and is currently being developed.

Lagooning is a type of anaerobic stabilization in which the inert settleable solids settle to the bottom. The sludge is poured into lagoons which are most often near a sanitary landfill. The liquid portion of the sludge seeps into the soil and is treated by the natural microflora. Although this management method is inexpensive, it can result in contamination of the water table. This practice is coming under increasing criticism and is not a viable long-term solution.

Dewatering using fixed or mobile equipment creates sludge that is "shovellable" and therefore fairly solid, which can be disposed of in a sanitary landfill. However, the filtrate (the liquid portion removed from the sludge) must either be treated on site or at a municipal sewage treatment plant.

The agricultural use of raw (non-dewatered) sludge is also an option, but it poses two problems: the cost of transporting small volumes of sludge, and the need to stabilize the sludge to destroy pathogens. Furthermore, since sludge can only be spread at certain times of the year, temporary storage facilities are required.

Direct discharge into municipal sewers can be done if the volume of sludge is small enough in relation to the capacity of the treatment facilities. However, sewage treatment plants are not designed to treat sewage containing high concentrations of suspended solids or a very high BOD, and this type of management is not recommended.

Land application of raw sludge is also not recommended because the organic matter is not sufficiently degraded to meet fertilization requirements. In addition, raw sludge contains pathogenic microorganisms, another factor that must be taken into account. Studies have shown that composting septic tank sludge is technically feasible. The compost produced is suitable for agricultural use in that it has the available minerals (mainly N and P), can be used as an organic soil amendment and the quantity of pathogens, mainly coliforms and *Salmonella*, is greatly reduced.

While there is no universal solution to the management of septic tank sludge, the current trend is to dewater sludge prior to its disposal. Dewatered sludge may be spread on the soil as a fertilizer, sent to a sanitary landfill or be put back in septic tanks to "seed" them with the microorganisms required to metabolize organic matter.

Regulations

Individual sewage treatment is covered mainly under the Quebec *Regulation Respecting Waste Water Disposal Systems for Isolated Dwellings* (Q-2, r. 8). These regulations, which are fairly comprehensive, set out the characteristics and specifications of various technologies used to treat domestic wastewater, including septic tanks and tile fields, sand filters, latrines and peat biofiltration. The capacity of the septic tank is determined on the basis of on the number of bedrooms in the residence. Tanks used year-round must be pumped out every two years. There are no specific requirements respecting sludge disposal, except that it must be done in accordance with section 22 of the *Environment Quality Act*, which stipulates that an authorization certificate is required to dispose of contaminants in the environment.

Public health risks not yet fully known

Efforts directed at the chemical and, especially, microbiological characterization of septic tank sludge must be pursued. Little information is available on the presence of some pollutants (such as surfactants and alkylbenzenes) and some groups of parasites. In addition, no epidemiological monitoring seems to have been done on people handling septic tank sludge on a daily basis. In this context, the public health risks can only be determined after better characterization of sludge has been carried out.

Sector: Septic tank sludge
Activity: Handling or land application of septic tank sludge

STRESSOR/ EXPOSURE	Nature of stressor	Impact on environment	Zone of influence	Control measures	Standards or recommendations
Technological disaster					
Gas or atmospheric emissions	- fungal or bacterial spores	- pollution, unhealthiness	- site	- careful handling, mixed into soil instead of on surface	- none
Liquid effluent or in water	-some heavy metals (mainly Fe, Al, Zn and Cu)	- toxic to some aquatic organisms	-receiving waters	- respect protective riparian strips	- Al < 0.1 mg/L to prevent Alzheimer's
	- biodegradable organic compounds (proteins, sugars, lipids)	-reduction of dissolved oxygen in water	- " "	- " "	- 3 - 7 mg/L (MEF criteria for untreated water to be chlorinated)
	- enteric bacteria and viruses	- unhealthiness	- " "	- " "	- fecal coli.: 0 total col.: 10/100 mL (Potable Water Reg. QC)
	- eggs and cysts of parasites (*Ascaris*, *Trichuris*, etc.)	- unhealthiness	- " "	- " "	- none
Solid emissions or in soil	- heavy metals	- soil pollution	- usually site only (not very mobile)	Do not spread too often at same site	- none
	- eggs and cysts of parasites, bacteria and virus spores	- unhealthiness	- usually site only (not very mobile)		- none
Nuisance	- odours	- unhealthiness	site and surroundings	buffer zone, inject sludge into ground	municipal bylaws
Indirect impacts or other exposure	handling sludge (micropathogens)	unhealthiness	site	protective equipment and clothing	

STRESSOR/ EXPOSURE	**Health effects**	**Population at risk**	**Probability of occurrence**	**Biological and environmental indicators (monitoring)**	**Information/ references**
Technological disaster					
Gas or atmospheric emissions	- allergies, resp. irritations	- unknown	- unknown	- cfu per m^3 for handling or application of sludge	Boulanger *et al*. (1988) Labelle (1995; 1996)
Liquid effluent or in water	- various toxic effects, risk of Alzheimer's because of aluminium	- people who drink polluted water	- unknown	For all pollutants, determine concentration in runoff from treated areas and in drinking well water epidemiological monitoring of local populations near areas treated frequently	Boulanger *et al* .(1988) Consultants RSA (1997) Marin and Roy (1996) Labelle (1995; 1996)
	- unhealthiness, formation of trihalomethane if water if to be chlorinated	- people who drink polluted water	- unknown		
	- mainly gastro-enteritis	- people who drink polluted water	- unknown		
	- direct parasitosis	-people who drink polluted water	- unknown		
Solid emissions or in soil	- see above	- people handling sludge	- unknown	Determine presence of most dangerous pollutants. Monitor workers if necessary	
	-see above	- " "	- unknown		
Nuisance	- quality of life	- neighbours and community	unknown	- complaints, perception studies	
Indirect impacts or other exposure	infections	workers	unknown	- epidemiological monitoring of local populations near treated areas	

References

Blanchard, J., M. Joseph and P. Purenne (1990) *Programme expérimental de réception et de traitement des boues de fosses septiques*. Environmental Department, Montreal Urban Community, 24 p.

Bossé, Y. (1990) *Gestion des boues d'épuration et de fosses septiques et effets potentiels de leur valorisation en milieu agricole. Commission de protection du territoire agricole du Québec* (Quebec agricultural land protection commission), 89 p.

Boulanger, D., J.-M. Jalbert and A. Terreault (1988) *Guide sur la gestion des boues de fosses septiques*. Department of the Environment (Government of Quebec), various pagings..

Caron, J.-J. and F. Poulin (1995) *Démonstration et optimisation du système DAB™ pour la déshydratation des boues de fosses septiques et municipales*. Prepared by Valoraction for the Quebec Department of the Environment and Wildlife, Government of Quebec, final report, 206 p. + appendices.

Consultants RSA (1996) *Développement d'un camion-usine servant à déshydrater les boues de fosses septiques sur place*. Prepared for Canmex Inc. and the Quebec Department of the Environment and Wildlife (Government of Quebec), summary report, 54 p. + appendices.

Côté, L. and D. Potvin (1994) *Essais de compostage de boues de fosses septiques*. Report to Fourth Annual Convention of Canadian Composting Board (Toronto), p. 359-389.

Labelle, A. (1995) *Utilisation des boues d'usines d'épuration et risques à la santé. BISE (Bulletin d'information en santé environnementale*), 6(3):__ - __.

Labelle, A. (1996) *Valorisation des boues d'épuration municipales; quels sont les risques de contamination?* Direction de la santé publique Mauricie-Bois-Francs 46 p.

Lalumière, A. (1993) *La gestion des boues des stations d'épuration et des fosses septiques.* Proceedings of conference entitled *"La gestion de l'eau par les municipalités, à quel prix?"*, *Union des municipalités du Québec*, 8 p + figures.

Marin, M. and R. Roy (1995) *Évaluation de l'accumulation des boues dans les fosses septiques au Québec.* Prepared by the Groupe Steica for the Department of the Environment and Wildlife, Government of Quebec, final report, 98 p. + appendices.

Construction and operation of a sewage disposal plant

Nature of project

This grid is based in part on an impact study on a sewage disposal plant for Halifax and Dartmouth, Nova Scotia, involving the primary treatment of raw wastewater, followed by chlorination, prior to disposal in Halifax Harbour. Solid residues recovered through tertiary treatment would be incinerated. Since the Halifax project is very specific, the following paragraphs include information relevant to other types of sewage disposal to give a larger scope to the grid.

General information on urban wastewater treatment

Each wastewater treatment plant is designed to suit the needs of a given region and can include multiple combinations of treatment processes. However, the basic concepts are almost always the same and are briefly described below.

In most cases, urban wastewater is treated using so-called conventional methods (pretreatment, primary treatment and secondary treatment); occasionally, tertiary treatments called special or complementary treatments are used. Pretreatment involves screening to remove coarse solids larger than 15-25 millimetres and grit removal to sediment particles between .2 and 25 millimetres in diameter. Pretreatment can also include oil and grease removal to remove water-insoluble liquids (oils, hydrocarbons, grease, etc.). Primary treatment, carried out essentially by decantation, eliminates about 70% of the small inorganic particles (0.05 mm to 1 mm) called suspended solids (SS) and 40% of the biochemical oxygen demand (BOD), which indicates the level of organic matter pollution.

Secondary treatment is a biological process that uses various indigenous microorganisms, mainly bacteria, to metabolize organic matter into microbial biomass, mineral elements (nitrogen, phosphorus, etc.) and CO_2. It removes non-settling organic matter that was not caught in the primary treatment and usually destroys pathogenic microorganisms (bacteria, viruses, fungi and zoomicrobes) The most commonly used processes are activated sludge and trickling filters. Biological treatment is increasingly considered indispensable since it is the only process capable of significantly reducing organic and microbial pollution.

Tertiary treatments are rarely used and are aimed at producing water that is almost pure, although not drinkable. They include physical processes like sand filtration (removal of particles and microorganisms), activated carbon (absorption of organic matter resistant to other treatment phases) and disinfection through the addition of ozone and through exposure to ultraviolet rays. Chemical processes include flocculants and coagulants to precipitate certain organic particles, phosphorus, which has a very high eutrophication capacity; and chlorine compounds for disinfection. Biological processes use bacteria to eliminate nitrogen (nitrification or denitrification) or phosphorus (phosphate removal).

Several types of treatment can be involved without necessarily following the usual sequence of primary, secondary and tertiary. The Halifax-Dartmouth project, for example, uses primary treatment followed by chlorination (tertiary chemical treatment).

Atmospheric waste

Machinery used during construction emits various pollutants, principally nitrogen oxides (NO_x), carbon dioxide (CO_2), carbon monoxide (CO) and volatile organic compounds (VOCs), which may also be emitted during the plant operation.

Carbon monoxide (CO) is an odorless gas that can cause potentially fatal carboxyhemoglobinemia, and carbon dioxide (CO_2) is one of the principal greenhouse effect gases.

Nitrogen oxides (NO_x) include nitric oxide (NO) and nitrogen dioxide (NO_2). NO_2 is a brownish gas with a sharp, irritating odour that can oxidize cell membranes. This gas can decrease odour perception, alter pulmonary function and in cases of severe exposure, can lead to pulmonary edema. One of the most significant effects of chronic exposure is emphysema and a reduction in forced expiratory volume. NO_2 reacts with VOCs to form photochemical smog (see below).

Volatile organic compounds (VOCs) are hydrocarbons that evaporate at ambient temperature and exist in the atmosphere in the form of vapour; they number in the thousands, and some are relatively toxic. The average concentration of VOCs in wastewater would be in the order of 10 to 50Fg/L, with peaks of close to 200Fg/L. Certain VOCs, like benzene and chloroform, are carcinogens.

The photochemical reaction between NO_x and VOCs produces secondary pollutants, collectively called photochemical smog. This smog contains ozone (O_3) at ground level (tropospheric), various free radicals and oxygenated hydrocarbons like aldehydes (e.g. formaldehyde) as well as peroxyacetyl nitrates (PAN). All these substances can be major respiratory irritants, and some are mutagenic (PAN) or carcinogenic (formaldehyde).

The incineration of sludge from primary treatment (Halifax project) or secondary treatment can produce the pollutants already mentioned (CO, CO_2, NO_x and VOC), as well as sulphur dioxide (SO_2), heavy metals (Pb, Hg, Cr or Cd), polycyclic aromatic hydrocarbons (PAH) and hydrogen chloride (HCl).

Incineration effluents usually contain gases, particles and fly ash, which are small, easily airborne particles that penetrate deep into the respiratory tract. Particles and fly ash contain diverse inert materials like silica and various volatilized metals.

Incompletely incinerated organic substances in the form of vapour can also condense on the particles. Volatile organic compounds (VOCs), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and, above all, dioxins and furans have been identified in incineration effluents. According to the literature on the subject, the carcinogenic risk from incinerator dioxins and furans is fairly insignificant when the equipment includes various depollution systems.

Polycyclic aromatic hydrocarbons (PAHs) include a large group of compounds created through pyrolysis and organic matter carbonization. They are made up of benzene rings and include several carcinogenic compounds, the most well-known being benzo[a]pyrene (BaP). The PAHs are released into the atmosphere, but can contaminate lakes and waterways during precipitation (rain or snow), accumulating in sediments and contaminating bottom fish and crustaceans like lobster.

As a general rule, atmospheric pollutants released during the construction or operation phase are not considered human health hazards in view of their low concentrations, which are comparable to those found in major urban Canadian centres. However, the inhalation of small doses of certain compounds (such as nitrogen oxides) can lead to disease in the long term, and can add to other pollutants causing climatic changes, destroying the ozone layer and causing acid rain or urban smog. Smog is a concern because of the health problems it causes and because it is an urban atmospheric pollutant that is on the rise in Canada.

Waste in the aquatic environment

Water treatment plants improve the quality of liquid waste in receiver waters by reducing inorganic, organic and microbial pollution. This reduction, however, depends on the types of treatment used. Because secondary treatment is not used in the Halifax project, organic matter and microbial pollution are not reduced significantly, and water is disinfected with chlorine. This is a questionable process because of its weak performance when there is a significant concentration of particles that interfere with its action.

Pollution problems with treatment plants are generally limited to the waste zone (the location of the treated water line) and downstream, in the discharge plume.

Health risks are assessed according to water uses: recreational (swimming, water skiing, canoeing, etc.) and the consumption of water and filter-feeding organisms (shellfish) or other species (fish and crustaceans). In risk assessment, the type of treatment must be taken into account. Secondary treatment is far more effective than primary treatment for the removal of pathogenic microorganisms. The effectiveness of disinfection (ultraviolet rays, ozone and chlorination), is highly relative since the presence of various contaminants (SS, organic particles, agglomerated microorganisms) can make it almost entirely ineffective. In chlorination there is the added risk of carcinogenic trihalomethanes forming because of high concentrations of organic matter when there has been no secondary treatment.

Recreational water uses

The recreational health risk is primarily due to pathogenic microorganisms that create gastrointestinal problems . The greatest bacterial risk is the family of *Enterobacteriaceae* (gram-negative bacilli of enteric origin). The bacteria most often involved are: *Escherichia*, *Enterobacter*, *Proteus*, *Salmonella cholerasuis* (responsible for non-typhoid enteric infections), *Shigella* and *Yersinia*. Other bacteria include *Campylobacter jejuni*, which is now considered the most widespread bacterial enteric infection of dietary origin in North America, and *Enterococcus faecalis*, which is resistant to antibiotics. Many of these bacteria colonize naturally in healthy individuals, and are only a risk for those who are immunodeficient. These are often opportunistic infections whose risk of triggering illness among exposed swimmers would be around 0.02 to 0.3%. Some bacteria survive for a long time in the aquatic environment, notably *Enterococcus faecalis,* with a risk infection for swimmers of about 1 to 2% (or 10 to 100 times greater than the enterobacteria). The detection of this bacteria is a good estimate of the quality of swimming water, although the presence of coliforms remains the determinant used by official methods. These data are compiled from fresh water studies; the survival of microorganisms can be different in salt water.

Scientific documentation on viruses associated with wastewater disposal notes risks from two virus groups of the family of *Picornaviridae*, belonging more specifically to the genus *Enterovirus*: the Coxsackievirus and the echovirus, whose clinical manifestations include aseptic meningitis, conjunctivitis, pericarditis, diarrhea and encephalitides causing Reye and Guillain-Barré syndromes. Coxsackieviruses are responsible for a significant proportion of acute myocardites. The risk of the transmission of the poliomyelitis virus (*Picornaviridae*) via wastewater is a very slight probability. In the family of *Calciviridae*, the Norwalk virus often causes violent gastroenteritis that lasts from 24 to 48 hours among patients who drank non-potable water or practiced primary contact water activities. Urban wastewater can also cause *Hepadnaviridae* (hepatitis B) infections.

Giardia lamblia and *Cryptosporidium parvum* are the zoomicrobial parasites most commonly carried by wastewater. The cysts and oocysts of these organisms are extremely resistant to wastewater treatment processes, including chlorine disinfection, and have a high level of infectiousness (a handful of Giardia cysts can cause giardiasis). Cases of giardiasis and cryptosporidiosis of hydric origin are rising steadily in North America; giardiasis is now the most frequently occurring non-bacterial enteric infection.

Primary contact sports like swimming and water skiing in urban wastewater disposal zones are generally not permitted, even if the water has been treated. Secondary contact activities like canoeing should only be allowed after an adequate assessment of the presence of various pathogenic microorganisms including the detection of groups other than coliforms.

Consumption of water and filtering organisms (mollusks) or non-filtering organisms (crustaceans, fish)

Filter-feeding organisms like mollusks are highly susceptible to bacterial and viral contamination. The main pathogenic bacteria that can be found in mollusks are *Campylobacter jejuni*, *Salmonella cholerasuis* (non-typhoid species) and *Shigella* sp which can cause gastrointestinal infections. *C. jejuni* is very saline-sensitive and rarely found in marine zones. Contamination by the same viruses transmitted through recreational activities is also possible. As a general rule, mollusks in urban or polluted zones should not be eaten, and drinking water should undergo complete treatment.

Risks due to the consumption of drinking water and non-filtering aquatic organisms are measured by the bioaccumulation of various inorganic toxic substances like heavy metals (especially copper, cadmium and mercury) and of organic substances (especially polycyclic aromatic hydrocarbons - PAHs - and polychlorinated biphenyls - PCBs).

Copper is essential for the maintenance of physiological functions, but in excessively high concentrations it causes necrosis of the liver. This intoxication, however, is extremely rare. Mercury intoxication by ingestion is caused by absorption of its methyl form, methylmercury. Methylation is facilitated by microorganisms that can the inorganic mercury in wastewater. Methylmercury attacks the nervous system and creates irreversible effects; affecting visual and auditive functions and coordination. Cadmium is principally industrial in origin, and can persist up to 20 years in the human body after ingestion. Chronic exposure results in renal necrosis. Although it is potentially carcinogenic when inhaled, this is not a risk when ingested.

Polychlorinated biphenyls (PCBs) are organochlorines that bioaccumulate in the food chain. They have a great environmental stability because they are thermoresistant and can only be destroyed at temperatures approaching 1000 º C. When burned at temperatures below 800 º C, they can produce large amounts of dioxin and furan. Although they have been banned in Canada since 1980, they persist in the environment and contaminate almost all human and natural environments. Chronic exposure can lead to liver damage and congenital defects, and they have been found to be carcinogenic in laboratory animals.

The characteristics of PAHs were covered in the section on atmospheric emissions. As noted, PAHs result from the pyrolysis and carbonization of organic matter. In wastewater they are produced through cleaning or washing activities in certain industries (especially heavy industry like metallurgy). Public health risks are due to mutagenic, teratogenic and carcinogenic compounds like benzo[a]pyrene.

Obviously, this list is not exhaustive. Numerous domestic use pesticides, oils and greases (from machinery and from the illegal dumping of motor oil) and endocrine disruptors, whose potential effects have only begun to be assessed, can also be factors. Endocrine disruptors include several pesticides (especially insecticides and fungicides), organochlorinated compounds (including PCBs) and ethoxylated nonyl phenols, which belong to the chemical family of alkylphenols. Nonyl phenols are present in several consumer products like liquid laundry detergents and aerosol stain removers. They are thought to affect the male and female reproductive systems and in certain cases are considered carcinogenic, but the scientific community has not reached a consensus on these risks.

Trihalomethanes (THMs), several of which are carcinogens, are produced by the reaction of chlorine with various organic compounds. Chloroform is the principal THM, followed by other highly toxic compounds like halogenated furanon, bromoform and dibromoethane. THMs can cause bladder cancer; in Ontario, 14% to 16% of bladder cancer cases are attributed to drinking chlorinated water. THM formation is clearly facilitated by wastewater treatment using chlorination. THMs are diluted in the receiving waterway, but if a drinking water plant is located downstream, their concentration could rise. Since most THMs have chronic toxic properties in concentrations of 50 Fg/L, all situations that could produce them must be monitored.

Heavy metals can contaminate humans through the consumption of drinking water, fish or crustaceans, and bioaccumulative organic substances (PCBs and PAHs) contaminate through the consumption of fish and crustaceans. The ingestion of water seems to be sufficient for contamination by trihalomethanes and endocrine disruptors. Impact studies do not demonstrate serious contamination by heavy metals and organic substances following conventional wastewater treatment . However, in view of the other sources of contamination, concentrations of these substances in treated wastewater does represent a further risk . Consumption of fish or crustaceans living in polluted waters should be restricted or regulated.

Solid wastes

Two principal groups of solid residue are produced by wastewater treatment: sludge and incinerator ash.

Wastewater sludge is generated mainly by primary and secondary treatment, and makes up the lion's share of solid residue. Liquid residue containing 92% to 95% water when leaving the settling tank undergoes several drying treatments. Prior to dehydration the sludge usually has to be stabilized to mineralize organic matter and destroy active pathogenic and non-pathogenic microorganisms. Stabilization also reduces odour; fresh sludge, especially after primary treatment, is extremely foul-smelling. Stabilized and dried sludge produces a humid sludge cake; further drying would be too expensive.

Sludge can be used as agricultural and forestry fertilizer, but this use is limited by the potential presence of numerous toxic substances, especially heavy metals and persistent organic compounds like organochlorinated pesticides, PCBs, phenols and hydrocarbons, as well as certain pathogenic microorganisms. Composting and spreading kills microorganisms but has no effect on toxic substances, although some evaporate through the heat of composting or drying or through the metabolic action of microorganisms. Sludge must be disposed of in sanitary landfills or isolated, disused quarries (sand pits and gravel pits) if it cannot be used as fertilizer.

Sludge or any other waste incineration produces flying ash containing combustion gases and volatile particles that contribute to atmospheric pollution (see above section), as well as non-volatile bottom ash. Bottom ash is very dense and contains noncombustible refuse, steel and vitrified, carbonized or crystallized organic matter. Its principal ingredients are heavy metals in the form of oxides and insoluble silicates, PAHs, chlorobenzenes and chlorophenols. The health risk varies according to the presence and concentration of these substances, but bottom ash is not generally considered toxic. However, it must be buried in special isolated landfill sites to avoid dust inhalation. Contamination of the water table must also be avoided by choosing landfill sites with impervious soil or using waterproof geomembranes and leach water collection systems.

Psychological and social impacts

Wastewater treatment plants generally have positive social impacts since they reduce water pollution, improving the appearance and quality of water courses for recreational use. A major wastewater treatment complex can, however, impact psychologically and socially on adjacent residents because of the odours generated by the treatment process and sludge disposal. This is why plants are usually built in less populated sectors; provision can also be made for a large buffer zone, usually a grassed or wooded area. If sludge is incinerated on site, the smoke must be neither too thick or foul-smelling. In most cases, psychological and social impacts are reduced quality of life and reduced property values.

Sector: Sewage Sludge Management
Activity: Construction and Operation of a Wastewater Treatment Station

STRESSOR/ EXPOSURE	Type of Stressor	Environmental Impact	Zone of Influence	Control Measures	Standards or Recommendations[27]
Technological Disaster	fires and explosions	pollution from smoke, particulates	air and water: site and perimeter	confinement, containment, emergency measures	CSA Z731-05: emergency measures planning for the industry?
Gaseous or air emissions	- CO	- negligible	- site and perimeter	- combustion control	- 35 mg/m^3 (1h)
	- NO_2	- smog and tropo-spheric ozone	- local to regional	- catalytic reduction	- 200 µg/m^3 (24h)
	-dioxins, furans, PAH	- bioaccumulation in land and aquatic animals	- continental and global	- improved combustion	- 100-200 ng/m^3 for PAH, 30 pg/m^3 for dioxins and furans
	- heavy metals (Hg, Cr, Cd)	- contamination of animals	- regional and continental	-flue gas cleaning	- none for Hg, Cr or Cd
	- VOC	- smog and tropo-spheric ozone	- local to regional	- containment or 8 combustion performances	- none
Liquid emissions or discharge into water	- heavy metals (Hg, Cr, Cd)	- toxic for certain aquatic organisms	For all pollut-ants: receiving waterways. Contamination distance varies according to concentration, solubility, temperature, pH, etc.	For all pollutants: use high-performance, adequate treat-ment tech-niques. At the least, secondary treatment to remove pathogenic micro-organisms. Resistant organic substances (PCB, PAH) may require tertiary treatment.	- Hg: 1 µg/L; Cr: 40 µg/L; Cd: 0.2 µg/L
	- PCB	- bioaccumulation in food chain			- 0.02-0.07 µg/kg.j (EPA standard)
	- trihalomethanes	-mutagenic and carcinogenic			- 100 µg/L
	- endocrine disruptors	- reproduction dis-turbance, fetal malformations			- none (except for compounds like pesticides)
	- suspended solids (SS)	- unsanitary and reduced visibility			- 0.5 mg/L (raw water, for drinking water)
	- enterobacteria and *Enterococcus* sp.	- unsanitary			- for micro-organisms, standards for coliforms only: 0 fecal coli and 10 total coli/100 mL
	- *Picornavididae* and hepatitis B	- unsanitary			
	- *Cryptosporidium* and *Giardia*	- unsanitary			
Solid emissions or discharge into soil	-sludge/ sedimentation	- unsanitary, toxicity	- site and perimeter	- confinement, burial or fertilization	- municipal or prov-incial regulations
	- fly ash	- unsanitary	- site and perimeter	- confinement or burial	- municipal or prov-incial regulations
Nuisances	- odours	- unsanitary	- site and perimeter	buffer zone	- municipal regulations

27 These are federal standards and guidelines. For air pollution, this is the maximum allowable concentration (MAC).

Indirect impacts or other exposures	-social conflict, property devaluation	- economic value	- perimeter and vicinity	-financial comp-ensation, communication	- provincial and municipal regulations

STRESSOR/ EXPOSURE	**Effects on Health**	**Population at Risk**	**Probability of Occurrence**	**Environmental/ Biological Indicator (Monitoring)**	**Information/ References[28]**
Technological Disaster	- trauma, injury, death	- workers, persons onsite	-very rare	- morbidity/mortality re-ports; fire service reports	
Gaseous or air emissions	- 8 in % of carboxyhemoglobin, death	- drivers, persons in vicinity	- rare	- % of carboxyhemo-globin	Bio-Response System Ltd and Jacques Whitford Environment Ltd (1992)
	- irritation of respiratory tracts	- urban and near-urban zones	- rare to moderate in large cities	- measure in ambient air	
	- some compounds are carcinogenic	- none in particular	- rare or unknown	- measure in ambient air if possible, epidemiological studies	
	- some cancers; renal or hepatic toxicity	- workers and persons close to emission sources	- rare or unknown	- measure in ambient air, epidemiological studies	
	- irritation of respiratory tracts, smog provoking tissue inflammation	- urban and near-urban zones, workers exposed	- rare to moderate in major urban centres	- measure VOC and ground-level ozone in ambient air, epidemi-ological studies	
Liquid emissions or discharge into water	- some cancers, renal or hepatic toxicity	- consumers of fish or crustaceans	- unknown or rare	- measure in flesh of fish, crustaceans; epidemiological studies	Bio-Response System Ltd and Jacques Whitford Environment Ltd (1992)
	- potential carcinogenic effects	- primarily con-sumers of oily fish	- unknown or rare	- measure and epidemiological studies	
	- potential carcinogenic effects	- water consumers	- unknown or rare	- measure in flesh and epidemiological studies	
	- effects on repro-duction, decreased sperm count?	- unknown	- unknown	-epidemiological studies	
	- unsanitary, no direct effect	- recreational use	- rare to frequent	- measure SS in recreational waters	
	- gastroenteritis, bacteremia, resistance to antibiotics	-recreational use	- rare to moderate, depending on place	- coliform, enterbacteria and *Enterococcus* measurement, medical reports	
	- encephalitis, men-ingitis, pericarditis and other diseases	- recreational use	- rare to moderate, depending on place	- epidemiological follow-up, public health reports	
	- gastroenteritis	- recreational use, drinking water	- rare to moderate, depending on place	- epidemiological follow-up, public health reports	
Solid emissions or discharge into soil	- possible toxic or carcinogenic effects, pathogenic microorganisms	- workers or sludge handlers	- rare or unknown	- medical follow-up	
	-possible toxicity	- workers, ash handlers	- rare or unknown	- medical follow-up	

[28] Several of these references are drawn from other impact matrices presented in this document.

Nuisances	- quality of life	- vicinity	- rare to moderate	- complaints, perception	
Indirect impacts or other exposures	- role of municipal assessment, quality of life	- vicinity and community	- rare to frequent	- complaints, role of assessment, perception studies	

References

Altekruse, S.F., N.J. Stern, P.I. Fields and D.L. Swerdlow (1999). *Campylobacter jejuni*, an emerging foodborne pathogen. *Emerging Infectious Diseases*, 5: (Internet pagination) www.cdc.gov/ncidod/EID/vol5no1/altekruse.htm

Bio-Response System Ltd and Jacques Whitford Environment Ltd (1991) Draft Report to Halifax Harbor Cleanup inc. on Air Quality in the Environs of Halifax Harbour. 21p, + appendices.

Bio-Response System Ltd and Jacques Whitford Environment Ltd (1992) Final Report to Halifax Harbor Cleanup inc. on Human Health Risk Assessment. 43p. + appendices.

Bolduc. D.G., P. Maurice and M.-C. Messely (1992) L'enfouissement des cendres de l'incinérateur de la CUQ à Saint-Tite-des-Caps. Département de santé communautaire, Hôpital de l'Enfant-Jésus, Québec, 64p.

Chevalier, P. (1995) Gestion de l'environnement en milieux urbain et industriel. Presses de l'Université du Québec, 577p.

Chevalier, P. (1997) Technologies d'assainissement et prévention de la pollution. Presses de l'Université du Québec, 440p.

Crisp, T.M. *et al* (1998) Environmental endocrine disruption: an effects assessment and analysis. Environmental Health Perspective, 106 (suppl 1): 11-56.

Current, W.L. and L.S. Garcia (1991) *Cryptosporidiosis*. *Clinical Microbiological Reviews* , 4: 325-358.

Environment Canada, Health and Welfare Canada (1990) Canadian Environmental Protection Act. List of priority substances, substantiating document no. 1: polychlorinated dibenzodioxins and polychlorinated dibenzofurans. Environment and Health Departments, Government of Canada, 64p. *(translation*)

Environment Canada (1993) Canadian Environmental Protection Act. List of priority substances, substantiating document no. 3: pathways, ecotoxicities and regulations for PAHs in the environment. Department of the Environment, Government of Canada, 102p.*(translation)*

Gorbach, S.L., J.G. Bartlett and N.R. Blacklow (1998) Infectious Diseases, 2nd edition. W.B. Saunders Company, 2594p.

Gray, L.D. (1995) *Escherichia*, *Salmonella*, *Shigella* and *Yersinia*. In: Murray, P.R. (editor), *Handbook of Clinical Microbiology*, ASM Press, Washington, pp.: 450-455.

Hunter, P.R. (1997) Waterborne Diseases, Epidemiology and Ecology. John Wiley & Sons, England, 372p.

Levallois, P. (1997) Qualité de l'eau potable et trihalométhanes. Bulletin d'information en santé environnementale (BISE), 8(6): 1-4.

Mara, D.D. and D. Clapham (1997) Water-related carcinomas: environmental classification. Journal of Environmental Engineering, May: 415-422.

Parker, M.T. and L.H. Collier, editors (1990) Topley & Wilson's Principles of Bacteriology, Virology and Immunity. Edward Arnold, Volume 4, Virology, 719p.

Wolfe, M.S. (1992) Giardiasis. *Clinical Microbiology Reviews* , 5: 93-100.

See also texts and references used for the preparation of the following grids:

- Aluminum Production (for atmospheric pollutants);
- Roads and Highways (for atmospheric pollutants);
- Incineration (for atmospheric pollutants);
- Municipal Wastewater Treatment Plant Sludge Spreading (for water and soilborne pollutants);
- Domestic Septic Tank Sludge Handling or Spreading (for water and soilborne pollutants).