BIOSOLIDS CHARACTERISTICS AFFECTING LAND APPLICATION

THIS CHAPTER EXPLORES:

- **what's in biosolids**
- **the implications of the quality of biosolids on application, soil, and human health.**

Biosolids have physical, chemical and biological properties that affect:

- ▶ management or disposal options
- ▶ land application practices
- ▶ the nature and extent of environmental risk (e.g., loss of crop nutrients to the environment).

Biosolids are analyzed for these properties to determine their suitability for land application. Biosolids analyses also provide essential information for effective nutrient management practices.

TYPES AND PROPERTIES

Biosolids composition is directly related to the nature of the wastewater constituents and treatment processes. The resulting properties will determine suitability for application – and if suitable, the application method and rate.

CHARACTERISTICS OF THREE TYPES OF SEWAGE BIOSOLIDS

BIOSOLIDS TYPE	AEROBICALLY DIGESTED LIQUID	ANAEROBICALLY DIGESTED LIQUID	DEWATERED
TOTAL SOLIDS	1–2.4%	1.7–7.0%	18–40%
TOTAL NITROGEN	1.6–6.1% ***	2.8–9.0%	3.1–7.0%
AMMONIUM–NITROGEN	100–7,000 mg/kg	3,300–34,000 mg/kg	3,500–6,800 mg/kg
FERTILIZER EQUIVALENT NITROGEN*	Trace – 0.6 kg/m³ Trace – 6 lb/1,000 gal	0.2–1.9 kg/m³ 2–19 lb/1,000 gal	2.4–7.2 kg/tonne 4.8–14.4 lbs/ton (wet weight)
TOTAL PHOSPHORUS	1.8–4.0%	1.5–6.3%	2.2–4.5%
FERTILIZER-EQUIVALENT PHOSPHORUS AS P_2O_5 **	0.2–0.9 kg/m³ 2–9 lb/1,000 gal	0.2–2.6 kg/m³ 2–26 lb/1,000 gal	4.5–12.4 kg/tonne 9–24.8 lbs/ton (wet weight)

* Fertilizer-equivalent nitrogen equals ammonium–nitrogen plus 30% of the organic nitrogen.
** Fertilizer-equivalent phosphorus equals 40% of the total phosphorus expressed as P_2O_5.
*** Values are expressed on a dry weight basis (i.e., % dw or mg/kg of total solids) unless otherwise indicated.

Dewatered biosolids can contain up to 40% solids, allowing them to be handled like solid manure.

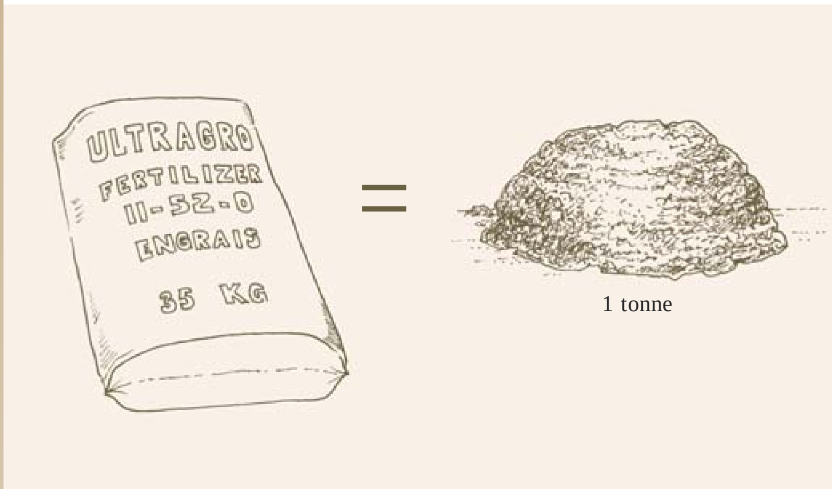
Anaerobic liquid biosolids have slightly lower levels of organic matter and nutrients than aerobic liquid biosolids.

Biosolids are analyzed to determine suitability for land application.

KEY PROPERTIES ASSESSED BY BIOSOLIDS ANALYSES

PROPERTY	DETAILS	TYPICAL LEVELS
TOTAL SOLIDS (TS)	• suspended and dissolved solids are expressed as the concentration present in biosolids • TS depend on the type of wastewater process and biosolids treatment prior to land application	• solids contents of various biosolids processes are: liquid (1–7%), dewatered (18–40%), and dried or composted (50–95%)
pH	• pH is a measure of the degree of acidity or alkalinity of a substance • the pH of biosolids can be raised with alkaline materials to reduce pathogen content and attraction of disease-spreading organisms (vectors)	• alkaline treatment of biosolids results in a high pH (greater than 11) that kills most micro-organisms and reduces the solubility, biological availability, and mobility of most metals • lime also increases the gaseous loss (volatilization) of the ammonia form of nitrogen (N), thus reducing the N-fertilizer value of biosolids and creating the potential for additional odour generation during treatment with lime
MICRO-ORGANISMS – BACTERIAL INDICATORS OF PATHOGENS	• pathogens are disease-causing micro-organisms that include bacteria, viruses, protozoa, and parasitic worms • pathogens can present a public health hazard if: ○ transferred to food crops grown on land to which biosolids are applied ○ contained in runoff to surface waters from land application sites, or ○ transported away from the site by vectors such as insects, rodents, and birds	• regulations specify pathogen and vector-attraction reduction requirements that must be met before biosolids can be applied to land • for a partial list of pathogens that may be found in **untreated** sewage and the diseases or symptoms that they can cause, see page 43
NUTRIENTS	• nutrients are elements required for plant growth	• these include nitrogen (N), phosphorus (P) and potassium (K)* • additional nutrients found in sewage biosolids include calcium (Ca), magnesium (Mg), sodium (Na), sulphur (S), boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn) • concentrations in biosolids can vary significantly – the actual material being considered for land application must be analyzed
TRACE ELEMENTS	• trace elements are found in low concentrations in biosolids • the trace elements of interest in biosolids are those commonly referred to as “heavy metals” • some of these trace elements (e.g., copper, molybdenum, and zinc) are nutrients needed for plant growth in low concentrations, but all of these elements can be toxic to humans, animals, or plants at high concentrations	• possible hazards associated with a buildup of trace elements in the soil include their potential to cause phytotoxicity (i.e., injury to plants) or to increase the concentration of potentially hazardous substances in the food chain • provincial regulations have established standards for 11 trace elements: arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), mercury (Hg), molybdenum (Mo), nickel (Ni), selenium (Se), cobalt (Co), chromium (Cr), and zinc (Zn)

* K may be present in low concentrations in some sewage biosolids, depending on treatment process.



One tonne of dewatered biosolids is approximately equivalent to the amount of nutrients found in 35 kg of mono-ammonium phosphate (MAP) (11-52-0).

NUTRIENTS IN BIOSOLIDS

PLANT NUTRIENTS

Like applying livestock manure to cropland, land-applying biosolids is a way of utilizing organic forms of plant nutrients. Biosolids contain many nutrients needed for plant growth including nitrogen, phosphorus, zinc, and copper. The amounts of nutrients in sewage biosolids vary from source to source, based on treatment process, origin, types, and the volume of wastewaters treated.

Nutrients in biosolids are not as concentrated as in commercial fertilizer. Nitrogen (N) and phosphorus (P) levels in biosolids are about one-quarter to one-fifth of those found in typical blended fertilizers. It would take much larger application rates of sewage biosolids to match the nutrient content of commercial blended fertilizer.

Moreover, much of the N and P in sewage biosolids is in the organic form and is not readily available to plants. When applied to land, part of the organic nitrogen is mineralized or converted into ammonium (NH_4^+), nitrate (NO_3^-), or both to become available to plants over time.

Some nitrogen in the biosolids may be lost to the air – especially if left at the surface – due to ammonia volatilization. If biosolids have an ammonia-like odour, some nitrogen is being lost. To reduce the amount of nitrogen lost, biosolids can be injected or incorporated into the soil directly after application. Incorporation also reduces any potential for odour problems sometimes associated with land application of biosolids.

Most sewage biosolids are low in potassium (K), and this nutrient may need to be added as a supplement to the biosolids.

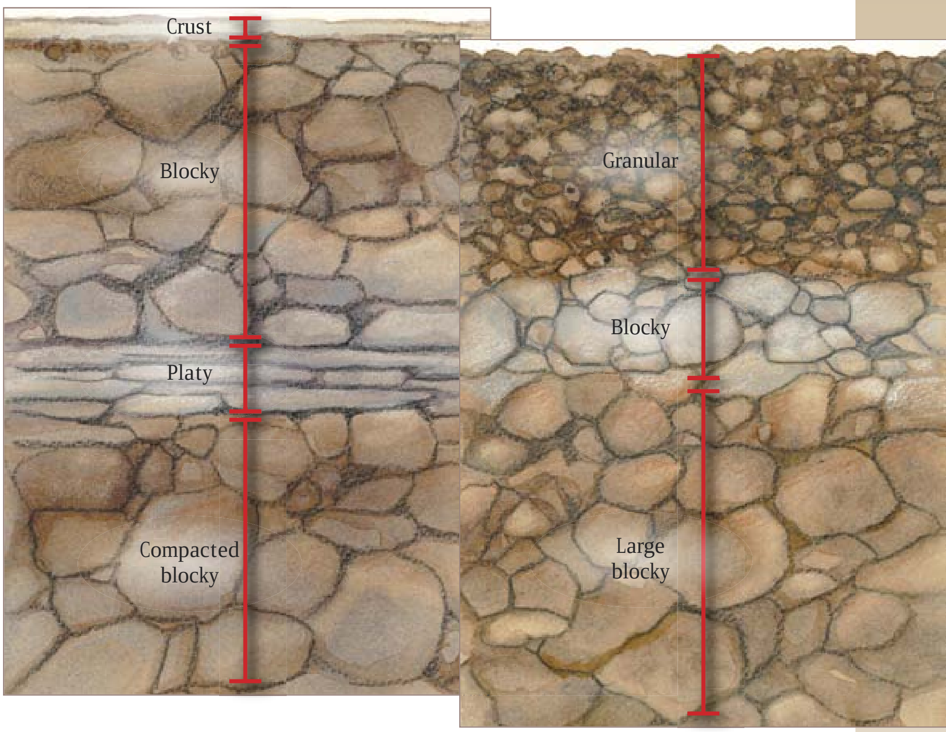
Nitrogen in biosolids tends to release slowly. Because of the slow release, plants can use the nitrogen in biosolids more efficiently over time than the nitrogen in a single application of fertilizer.

ORGANIC MATTER

Organic matter from applied biosolids improves soil structure and the workability (tilth) of most soils.

In sandy soil, organic matter increases the soil's ability to hold water. In clayey soil, organic matter opens up the soil to allow better air and water movement into and through the soil. Organic matter also improves water retention, permits easier root penetration, and reduces water runoff and soil erosion.

Cropland requires regular additions of organic matter to improve soil quality. The soil profile on the left has not received regular additions of organic matter: note the poor seedbed structure. The soil on the right demonstrates how additions of organic matter result in improved seedbed structure, root exploitation, and available moisture.



Poor soil condition can be improved with regular applications of biosolids, as seen in the soil on the right.

APPLICATION RATES

In order to balance nutrient use efficiency with environmental protection, biosolids application is limited to the agronomic rate.

Nitrogen

The agronomic rate for nitrogen is defined as the amount of biosolids that provides the amount of nitrogen needed by the crop, or whatever plants are grown on the land – while minimizing the amount of nitrogen that is unused and could potentially leach below the root zone and into groundwater.

In addition to the crop's nutrient requirements, one of the key determinants of agronomic rate is the estimation of available nitrogen. Nitrogen from biosolids has two forms: organic and inorganic.

Organic nitrogen refers to any nitrogen tied up in material that either is or used to be alive, such as plant material.

Inorganic nitrogen refers to nitrogen in the mineral form, such as ammonium-nitrogen and nitrate-nitrogen. Inorganic nitrogen is immediately available for crop uptake.

Determining the Nitrogen Contribution from Applied Sewage Biosolids

The amount of nitrogen from an application of sewage biosolids that's available to the crop being grown is called "plant-available nitrogen" or PAN.

Once it's applied to land, organic and inorganic nitrogen each has characteristics that can influence the amount of nitrogen that will be available for a crop to use.

- organic nitrogen
  - organic matter degrades slowly over time
  - following land application, a portion of the organic nitrogen is mineralized, or converted to an inorganic form
  - only a portion of the organic nitrogen can be counted as PAN
- inorganic nitrogen
  - most of the inorganic nitrogen is in the form of ammonium and ammonia
  - the remainder of the inorganic nitrogen is in the form of nitrate and nitrite
  - all of the inorganic nitrogen is considered PAN

The following step-by-step example illustrates the nitrogen availability calculation for aerobically digested sewage biosolids.

The laboratory analysis reports the following nitrogen concentrations on a dry weight basis:

- ▶ 5.75% Total Kjeldhal Nitrogen (TKN)
- ▶ 0.8% ammonium-nitrogen
- ▶ 0.5% nitrate-nitrogen.

The sewage biosolids in this example will be surface-spread, then immediately incorporated.

Step 1. Contribution of Nitrogen from the Organic Fraction of Biosolids
The rate at which organic N becomes PAN can change from material to material. The following table provides an estimate of how much PAN will be supplied by an application of different sources of sewage biosolids.

ESTIMATES OF ORGANIC NITROGEN MINERALIZATION RATES FOR VARIOUS SEWAGE BIOSOLIDS

TREATMENT PROCESS	MINERALIZATION FACTOR (MF)
ALKALINE STABILIZED	0.3
AEROBICALLY DIGESTED	0.3
ANAEROBICALLY DIGESTED	0.3
COMPOSTED	0.1

Sewage biosolids analysis results for nitrogen are usually reported as TKN. TKN estimates **all** of the nitrogen contained in a material, regardless of the form that it is in. Therefore, to determine the level of organic N, the inorganic fraction (ammonium-nitrogen + nitrate-nitrogen concentrations) must be subtracted from TKN.

Organic nitrogen = TKN − (ammonium-nitrogen + nitrate-nitrogen)
Organic nitrogen = 5.75% − (0.8% + 0.5%)
Organic nitrogen = 4.45%

Next, the organic nitrogen content is multiplied by the mineralization factor to obtain the contribution of organic nitrogen to the PAN. The amount of PAN from the organic fraction is:

% PAN from organic nitrogen = % organic nitrogen × mineralization factor
% PAN from organic nitrogen = 4.45% × 0.3
% PAN from organic nitrogen = 1.335%

Step 2. Contribution of Nitrogen from the Inorganic Fraction of Biosolids
Ammonium-nitrogen and nitrate-nitrogen content of sewage biosolids does not have to be calculated. It can be read directly from the analysis. Portions of this inorganic fraction can, however, be lost.

Ammonium-Nitrogen

Ammonium-nitrogen is subject to loss by volatilization. Ammonia losses decrease the amount of PAN in the soil. Obviously, plants can only use the nitrogen retained in the soil. Losses are greater for material left on the surface of the soil. Injection or immediate incorporation below the soil surface reduces losses. Actual losses of ammonium-nitrogen vary with weather and soil conditions, but the amount of nitrogen retained in the soil can be estimated using the simplified table below.

ESTIMATES OF RETAINED AMMONIUM-NITROGEN FOR THREE METHODS OF APPLICATION

APPLICATION METHOD	AMMONIA RETENTION FACTOR
SURFACE SPREADING	0.50
SURFACE SPREADING FOLLOWED BY INCORPORATION (within 24 hours)	0.75
SUBSURFACE INJECTION	1.00

To calculate the amount of ammonium-nitrogen retained in the soil, the ammonium-nitrogen concentration is multiplied by the ammonia retention factor to obtain the percentage of ammonium that will be PAN. For our example, the material is incorporated within 24 hours; therefore, the ammonia retention factor is 0.75.

Retained ammonium PAN = Ammonium-nitrogen concentration × retention factor
Retained ammonium PAN = 0.8% × 0.75
Retained ammonium PAN = 0.6%

Nitrate-Nitrogen

Small amounts of nitrate-nitrogen, another inorganic form of nitrogen, are present in biosolids. All of the nitrate-nitrogen is considered PAN.

Nitrate PAN = 0.5%

Step 3. Total Nitrogen Contribution from Sewage Biosolids
Total % PAN = Organic PAN + Ammonium PAN + Nitrate PAN
Total % PAN = 1.335% + 0.6% + 0.5%
Total % PAN = 2.435%

This PAN value can now be used in determining the appropriate application rate to meet the N requirements of the crop to be grown. If the material were to be applied at 8,000 kg of dry matter per hectare, the total PAN contribution from this application would be approximately 195 kg per hectare.

8000 kg/ha × 2.435% PAN = 194.8 kg/ha PAN

Because nitrogen can leach down through the soil below the root zone of the crop and possibly into groundwater, care should be taken to ensure that nitrogen applications are closely matched to crop requirements to limit the amount of nitrogen available for loss through leaching.

The effects of biosolids on soil physical properties (such as increased soil aggregate formation and aggregate stability) may be greater than animal manure due to the stability of organic compounds in biosolids.

Phosphorus

Some phosphorus in biosolids becomes crop-available during the year of application. In fact, it's estimated that 40% of the total phosphorus in biosolids becomes plant-available in the year of application. It's thought that another 40% becomes available during subsequent years.

Nutrient management planning is needed to avoid excessive buildup of soil phosphorus, which increases potential for phosphorus loss in runoff and erosion, and contamination of surface waters.

Soils should be tested after three to four years to ensure adequate phosphorus availability and to avoid excessive soil phosphorus levels.

Potassium

Biosolids don't supply much potassium. Potassium is soluble and most of this element stays in the liquid fraction of the treated wastewater. Additional sources of potassium might be required to meet agronomic crop requirements.

CHEMICAL PROPERTIES OF BIOSOLIDS

The characteristics of both the biosolids and the application site can influence the quantity of biosolids applied and the application method.

Some heavy metals, including zinc and copper, are micronutrients that are necessary for plant growth. Excessive amounts of some heavy metals (zinc, copper, nickel) can be damaging to plants, resulting in reduced yield or even plant death.

In addition to crop nutrients, biosolids quality criteria address pathogen levels and concentrations of chemical contaminants.

In order to be land-applied, all biosolids must:

- be treated to reduce pathogen levels (see page 42)
- not exceed the maximum allowable concentration limit for each of the regulated metals listed in the following chart.

The total amount of the regulated metal applied to a piece of land over time cannot exceed the standard for cumulative loading. Pre-harvest and pre-grazing waiting periods are an added precaution.

REGULATED METAL STANDARDS IN SEWAGE BIOSOLIDS APPLIED TO LAND

REGULATED METALS	MAXIMUM PERMISSIBLE METAL CONCENTRATION IN BIOSOLIDS	MAXIMUM METAL ADDITION TO SOIL	MAXIMUM METAL CONCENTRATION IN SOIL*
	mg/kg of total solids dry weight	kg/ha/5 years	mg/kg of soil, dry weight
ARSENIC	170	1.40	14
CADMIUM	34	0.27	1.6
COBALT	340	2.70	20
CHROMIUM	2,800	23.30	120
COPPER	1,700	13.60	100
MERCURY	11	0.09	0.5
MOLYBDENUM	94	0.80	4
NICKEL	420	3.56	32
LEAD	1,100	9.00	60
SELENIUM	34	0.27	1.6
ZINC	4,200	33.00	220

* in soil prior to receiving sewage biosolids

Remember that all of these metals are naturally occurring in all soil. Sewage biosolids exceeding these standards or concentrations cannot be land-applied.

The following table summarizes the potential health effects of micro-constituents in sewage biosolids.

POTENTIAL CHEMICAL CONTAMINANTS IN SEWAGE BIOSOLIDS AND WAYS TO MANAGE THEM

CONTAMINANT	POTENTIAL CONCERN	SOLUTION
HEAVY METALS		
COPPER, ZINC, NICKEL	• accumulate in topsoil • are toxic to plants at high levels	✔ reduce source of metal in sewage biosolids ✔ apply according to soil-loading limits ✔ adjust soil pH to a value greater than 6.0
CADMIUM	• accumulates in topsoil • taken up by plant and accumulates in leafy material • accumulates in animal organs • linked to human health problems	✔ reduce source of metal in sewage biosolids ✔ apply according to soil-loading limits ✔ adjust soil to greater than pH 6.0
LEAD	• accumulates in topsoil • can be harmful if excessive amounts are ingested with soil particles by animals	✔ reduce source of metal in sewage biosolids ✔ apply according to soil-loading limits ✔ adjust soil to greater than pH 6.0
MERCURY, CHROMIUM, SELENIUM, ARSENIC	• typically present in low concentrations and therefore of little concern	
ORGANICS		
CHLORINATED HYDROCARBON PESTICIDES, POLYCHLORINATED BYPHENOLS (PCBs), ETC.	• present a health hazard if directly ingested by animals • typically present in low concentrations (ppt or ppb) and therefore of little concern	✔ inject or disk into soil – most are biodegradable

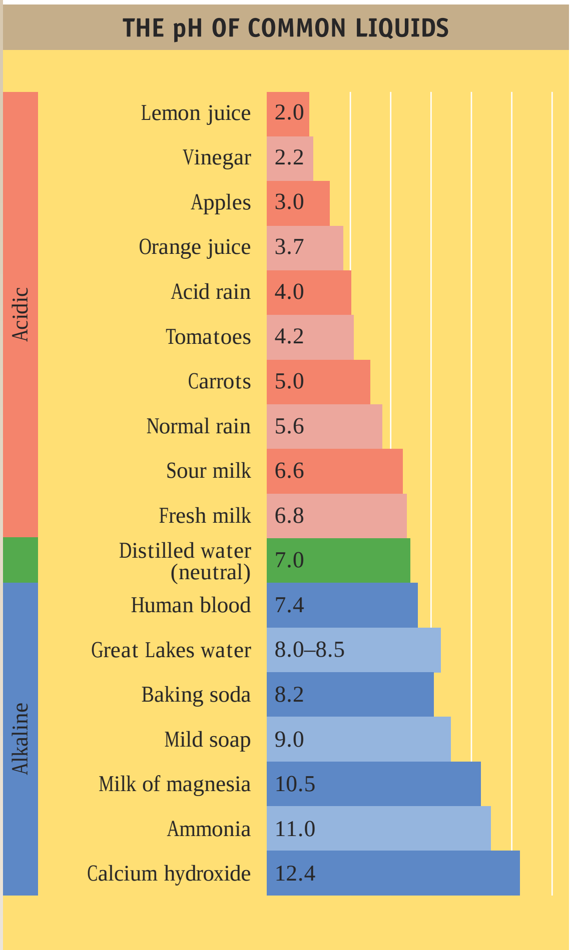
BIOSOLIDS CHARACTERISTICS LIMITING APPLICATION RATE

Metals

At one time, wastewater treatment plants in highly industrialized urban centres – especially those with metal-plating factories – produced sewage biosolids with high concentrations of metals. Sewer use bylaws and other wastewater source management initiatives have been used to drastically reduce these concentrations. Biosolids currently produced by most municipalities have metal concentrations substantially lower than the maximum permissible concentrations.

Materials discharged to municipal sewage collection systems are monitored to ensure they meet local sewer use bylaw limits.

If the metal concentrations in sewage biosolids applied to agricultural land were at the maximum permissible concentrations, it would take approximately 25 to 55 years for a typical Ontario soil to reach the maximum recommended limits set in these standards. However, since the metal concentrations in biosolids are continuing to be reduced, applications may be allowed to continue for a longer period of time.



pH

The pH of biosolids applied to a living crop should be in the 6.0 to 8.5 range. Materials with pH levels outside of this range should be applied to cropland only when crop damage will not be an issue, such as before planting or after harvest, or prior to ploughdown. Care should be taken when applying lime-stabilized biosolids with a high pH to avoid crop damage.

In some cases, analytical information about other elements may be requested to help the applicant and the Ministry assess the suitability of a particular biosolids for land application. The applicant will be required to provide appropriate analytical documentation upon request.

Industrial Organic Contaminants

Industrial organic contaminants such as organic acids, solvents, and complex compounds can have adverse health effects on humans and the environment. These compounds may be found in industrial wastewater discharged to municipal wastewater collection systems.

Research indicates that many of these compounds either volatilize or degrade quickly within the treatment plant and in the soil after land application. Other research shows crop uptake is minimal as these constituents are not generally taken up by crops.

As experience is gained and research reviewed, standards may be established for:

- maximum permitted concentrations of industrial organic contaminants in materials approved for land application
- application-rate limits based on the concentration of these contaminants, limits that continue to be protective of human and animal health and the environment.

Non-Biodegradable Constituents

Biosolids should not contain foreign non-biodegradable material such as plastics, glass and/or pieces of metal that may cause human or animal injury or damage to equipment. Check the regulatory standards for specifications.

ARE FIRE RETARDANTS IN SEWAGE BIOSOLIDS?

Yes. Fire retardants are ubiquitous in the environment – present in outdoor and indoor air, both in urban cities and rural farming communities. Fire retardants are not manufactured in Canada, but they are used in many common household products such as carpets, upholstery fabrics, clothes, computers, appliances and televisions.

A Health Canada report indicated that air (outdoor and indoor) is the major source of fire retardants for human exposure. It has been proposed by scientists that indoor air and dust pose the greatest risk to human health from fire retardants. Indoor air has been found to contain 15 to 50 times higher concentrations of fire retardants than outdoor air.

ARE OTHER INDUSTRIAL / HOUSEHOLD CHEMICALS, SUCH AS DIOXINS, PCBS, PHARMACEUTICALS AND DETERGENTS, IN SEWAGE BIOSOLIDS?

Yes, there are trace concentrations of these chemicals in sewage biosolids. However, the presence of a chemical does not equate to a risk. Risk depends on the concentration of the chemical present, the properties of the compound such as toxicity, and how the chemical will move from the biosolids to the receiving environment.

The Ontario Ministry of the Environment, the U.S. government, and the European Union have done substantial research and risk assessment on the presence of industrial chemicals, including dioxins, PCBs, pharmaceuticals, and detergents, in sewage biosolids. Their conclusion to date is that sewage biosolids are safe to be used as a fertilizer on agricultural land as long as government standards for their application are followed. Some of the reasons for such conclusions are:

- these chemicals are present at very low concentrations in sewage biosolids (ppb or ppt)
- sewage biosolids are applied at controlled and low rates to agricultural land based on an approved NASM plan
- some chemicals, e.g., detergents, break down rapidly in the environment – within a few days to a few months.

A study by the Ontario Ministry of Agriculture, Food and Rural Affairs found no difference in dioxin concentrations in soils that had received up to three applications of sewage biosolids and soils that had not received any sewage biosolids.

PATHOGEN REDUCTION

The upper table on page 43 shows some typical ranges of micro-organisms in biosolids and background levels in non-amended soils. For example, the total aerobic (oxygen-requiring) and anaerobic (organisms that cannot grow in the presence of oxygen) bacterial numbers can be almost as high in nutrient-rich soil as they are in biosolids.

Over 150 enteric pathogens have been found in raw human sewage. Enteric pathogens grow in the gut of infected individuals and can be shed in the feces in high numbers, potentially causing food and waterborne disease.

Examples of pathogens of concern in raw sewage are presented in the lower table on page 43. The types of pathogens and their concentration in raw sewage fluctuate dramatically over time, depending on the level of endemic illness in the population served by the waste treatment plant. The wastewater treatment process destroys most of these pathogens, reducing their numbers to levels that are acceptable for land application.

TYPICAL RANGES OF MICRO-ORGANISMS IN SOILS AND BIOSOLIDS		
MICROBE	SOIL	BIOSOLIDS
	COLONY-FORMING UNITS PER GRAM OF DRY SOLIDS	
TOTAL AEROBIC BACTERIA	10^5–10^8	10^8–10^{10}
TOTAL ANAEROBIC BACTERIA	10^5–10^8	10^8–10^{11}
E. COLI	BD*–10^3	10^4–10^6

* Denotes "below detection."

PARTIAL LIST OF POTENTIAL PATHOGENS IN RAW MUNICIPAL SEWAGE	
PATHOGEN	DISEASE AND SYMPTOMS
BACTERIA	
Salmonella spp.	salmonellosis (food poisoning)
Shigella spp.	shigellosis (bacillary dysentery), severe gastroenteritis
Campylobacter jejuni	gastroenteritis (diarrhea, vomiting, nausea, fever, etc.)
Pathogenic E. coli	gastroenteritis
VIRUSES	
Hepatitis A virus	infectious hepatitis
Rotavirus	acute gastroenteritis with severe diarrhea
Norovirus	gastroenteritis with severe diarrhea
PROTOZOA	
Giardia lamblia	giardiasis: diarrhea and abdominal cramps
Cryptosporidium spp.	cryptosporidiosis: gastroenteritis
PARASITIC WORMS	
Ascaris lumbricoides (roundworm or Helminth)	ascariasis: abdominal pain and digestive disturbances
Trichuris spp. (whipworm)	trichuriasis: cramping and diarrhea, anemia, weight loss

Wastewater treatment processes, from the initial aerobic treatment step to final sludge digestion, all contribute to significantly reduce pathogens in sewage biosolids when the treatment plant is operating properly. Biosolids treatment can achieve a pathogen reduction of 90 to 99.9%, depending on the pathogen, and typically over 99% reduction in the fecal indicator organism, E. coli.

After sludge treatment, there may still be pathogens present in the biosolids. However, if land application of biosolids is regulated and controlled, the potential risk of exposure to crops, livestock and humans will be minimized. Appropriate management will also limit the movement of pathogens to surface water and groundwater after land application.

The survival of pathogens in soil and on plants varies widely, from days to months. Their survival depends on several factors, including temperature, exposure to sunlight, and moisture levels.

Restrictions in the Nutrient Management Act, 2002 and Ontario Regulation 267/03 provide protection measures against exposure to humans, animals and the environment. These include required separation distances, loading limits, and pre-grazing and pre-harvest wait times, all of which promote natural pathogen decay in soil and sunlight with time.

RISK OF VECTOR ATTRACTION

Vectors such as rodents, birds and insects can spread pathogens from application sites to surrounding areas. The goal is to reduce the biosolids' attractiveness to possible vectors. Here are two general approaches:

- reducing the attractiveness of the biosolids to vectors with specified organic matter decomposition and stabilization processes (e.g., digestion, alkaline addition)
- preventing vectors from coming into contact with the biosolids (e.g., biosolids injection or incorporation below the soil surface within specified time periods).