

November 2004

BIOSOLIDS PELLET REVIEW STUDY HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT TORONTO, ONTARIO

Prepared For: Toronto Public Health



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PROJECT NO. ONT 36194

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TORONTO, ONTARIO

Submitted To

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NOVEMBER, 2004



Acknowledgement

The preparation of the *Biosolids Pellet Review Study – Human Health and Ecological Risk Assessment, Toronto, Ontario* was a significant undertaking, and received input from the numerous authors listed below.

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Acknowledgement

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EXECUTIVE SUMMARY

Introduction

Biosolids are a product of sewage treatment that consists of a combination of physical, chemical and biological processes. The pathogen content of biosolids is significantly reduced during the digestion process. The solids remaining after the digestion process are further dewatered to produce biosolids cake. Further heating and processing can be used to produce pellets. Biosolids cake or pellets may then be landfilled, incinerated or land applied. The spreading of biosolids on land has become a common biosolids management practice by municipalities in Ontario and across North America. Their nutrient value and organic matter content make them potential useful fertilizers and soil amendments. Although biosolids are a potentially valuable resource, considerable public concern remains over their potential use.

Jacques Whitford Limited (Jacques Whitford) was contracted by Toronto Public Health (TPH) to conduct a review study of biosolids pellets (pellets), produced by the City of Toronto, at the Ashbridges Bay Treatment Plant (ABTP). The study findings will be used to assist in developing appropriate management practices for pellet use within the City of Toronto and to provide practical and scientifically defensible information to address public concerns related to pellets. The assessment took into consideration the regulatory framework for land application of biosolids in Ontario.

This study assessed the potential risks to people, pets (cats and dogs), birds and other wildlife, associated with the use of pellets in the City of Toronto. Qualitative evaluations were also undertaken for risks to plants and soil organisms, biological entities and emerging issues. Potential exposure to metals and organic chemicals in pellets were quantitatively evaluated for three types of use:

- use of pellets on City-owned recreational areas such as parks and golf courses;
- home use of pellets on lawns and gardens by City of Toronto residents; and
- use of pellets as part of a landfill topdressing mixture applied by the City of Toronto. Topdressing is a material applied on top of soil, without mixing.



Study Objectives

The overall objectives of the study were to:

- Improve knowledge and understanding about biosolids pellets and related issues;
- Provide information to assist in developing appropriate management practices for pellet use in the City of Toronto; and,
- Provide practical and scientifically defensible information to address public concerns related to pellets.

Study Background

Following a literature review of government documents, scientific literature and grey literature, very little information specific to pellets was found.

The Ashbridges Bay Treatment Plant (ABTP) is the largest of four wastewater treatment plants serving the City of Toronto. In 1998, the City of Toronto decided to pursue a policy of 100% beneficial use of biosolids at ABTP and installed a pelletizer. The pelletization plant was constructed at the ABTP in 2002 to convert 50% of the plant's biosolids into dry pellets, leaving 50% as dewatered cake. Both forms of biosolids could then be applied to land. The pelletizer plant that was installed was a Seghers HARDpelletizer which produces pellets through a process of coating a nucleus of dry biosolids with wet biosolids. The pellets are exposed to high temperatures and controlled dryer times. Pellets that are approximately 3 mm in diameter, 97% solid (with the remaining 3% as water), and with greatly reduced pathogen content can be achieved when the pelletizer is functioning optimally and meets all expected standards. Currently, the pelletizer is out of service following a fire in August 2003, but a portion of the dewatered cake continues to be land applied while the majority is shipped to a landfill in Michigan. The City of Toronto produced 4,416 dry tonnes of pellets in 2002 and plans to repair the pelletizer plant.

Regulatory Context

Land application of biosolids cake on agricultural land is regulated in Ontario through Regulation 347 of the Environmental Protection Act, the Nutrient Management Act and the Ontario Ministry of Environment's (MOE) *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land*. The Guidelines specify general rules for application of biosolids



regarding issues such as separation distances from surface water, wells and residences, application rates and quality standards for eleven inorganic elements. In addition, a Certificate of Approval containing site-specific terms and conditions for land application must be obtained for each application site. Soil testing is often required.

Regulations in Canada and the United States permit the use of biosolids products (i.e., saleable items) outside of agriculture. Biosolids products sold as fertilizers or soil supplements are regulated by the Federal Fertilizers Act, which specifies standards for labelling, registration and product quality. The Act has no monitoring requirement regarding product use. Biosolids that are not sold but given away are regulated by the same Provincial regulations as the cake.

Levels of Chemicals in Biosolids

Quantitative exposure assessment was conducted only for entities of potential concern (EoPC) for which the City had adequate information on their levels in the biosolids, volatility and persistence in the environment. The Works and Emergency Services department of the City of Toronto collects and analyzes samples of biosolids cake for eleven regulated inorganic elements, nutrients and total solids every two weeks. Sample results are available for the past 14 years, from April 1989. Pellets were also analyzed for a similar set of parameters as biosolids cake. In addition to the biweekly monitoring, the City of Toronto performs annual plant performance evaluations and includes hourly sampling over a 22-hour period. During this sampling period, an extensive list of parameters is tested including polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (dioxins and furans).

Table I presents the chemical EoPCs that were evaluated in the study. Of the eleven inorganic elements that were selected, five (copper, cobalt, molybdenum, nickel and zinc) are considered essential micronutrients for plant growth.

The biosolids cake dataset from 1996 to 2003 was considered more representative of current biosolids quality and was therefore used in the analysis. The cake dataset was preferred because it was more complete than the pellet data set and pelletization did not generally appear to alter chemical concentrations significantly (Refer to Appendix F for statistical justification).



Table I: Selected Chemicals (Entities of Potential Concern) for Quantitative Evaluation

Inorganics		Trace Organics
Arsenic ^a (As)	Molybdenum (Mo)	PCBs ^a
Cadmium ^b (Cd)	Nickel ^b (Ni)	Dioxins ^a (PCDDs)
Cobalt (Co)	Lead (Pb)	Furans ^a (PCDFs)
Chromium III ^c (Cr III)	Selenium (Se)	
Copper (Cu)	Zinc (Zn)	
Mercury (Hg)		

Notes:

- a. Substances evaluated as cancer-causing when ingested and inhaled
- b. Substances evaluated as cancer-causing when inhaled
- c. Since the specific species of chromium were not measured, Chromium III was evaluated as representative of total chromium instead of Chromium VI. This is considered appropriate because it is unlikely that Chromium VI is the dominant species and therefore selecting Chromium VI to be representative of total chromium would grossly overestimate risk.

Levels of Chemicals in Pellet-amended Soil

The biosolids analytical data were used to estimate the potential future concentrations of chemicals in the soil as a result of biosolids application for each chemical EoPC. The pellets were assumed to be incorporated into garden soils to a depth of 15 cm and restricted to the top 5 cm when applied on sod (lawns). The pellets were assumed to be mixed into topdressing applied over final landfill cover to facilitate seeding.

A number of assumptions were adopted in the estimation of amended soil and landfill topdressing EoPC concentrations. First, it was taken into consideration that some people might use more than the recommended amount, therefore twice the maximum application rate was assumed. Second, pellets were assumed to be applied for twenty-five years. Although assumptions such as using twice the recommended application rate for 25 years continuously may be overly conservative, this conservatism may counter the lack of assessment of longer term use. Also not considered in the evaluation are other removal mechanisms including leaching from soils, removal via uptake by plants, removal in surface runoff from rain or other precipitation, or other removal mechanisms that will occur over this period of time.



As well, the levels of chemicals in the pellets were assumed not to be just the average of the biosolids samples collected from 1996 to 2003, but the 95% upper confidence limit of the mean - which is considered an upper estimate of the average pellet concentration and will tend to overestimate concentrations over time. The resulting chemical levels calculated for pellet-amended soil, for dust and vapour arising from this soil, and for garden produce grown on this soil are considered to be the reasonably conservative concentrations (i.e., an upper estimate of concentrations) for the evaluation of long term pellet application. These values are presented in Table II.

Human Health Risk from Chemical Exposure

The risk to people from exposure to chemicals present in pellets was assessed for the most sensitive or representative receptors under each of the three types of pellet use. These receptors (summarized in Table III) included the following four exposure scenarios:

- City Parks Workers applying pellets on City-owned recreational areas such as parks and golf courses;
- City Landfill Workers applying topdressing to landfills, over the final cover to facilitate seeding;
- Recreational Users using City parks or golf courses where pellets were used;
- Home Users using pellets on their lawns or gardens and eating fruits and vegetables from their gardens;

For non-cancer risk, toddlers were selected to be protective of other age groups for the recreational and residential scenario. Toddlers are commonly selected as the most sensitive receptor due to their low body weight, higher ingestion rate and hand-to-mouth activity.

Cancer risk was evaluated for exposure over a lifetime. An additional composite (lifetime) receptor was therefore considered in the assessment. Under the Recreational Use Scenario, the composite receptor was assumed to go to City-owned recreational areas that use pellets throughout their lifetime. Under the Home Use Scenario, the composite receptor was assumed to live in a household that uses pellets on lawns and gardens through their 75 year lifetime. Differences in lifestyle and biological factors at different stages of life were incorporated in the assessment of lifetime exposures.



Table II: Estimated Upper Bound^c Chemical Levels in Pellet-amended Soil, Dust and Vapour, and Garden Produce

EoPC	Pellets (mg/kg)	Amended Soil ^a (mg/kg)		Landfill Top Dressing (mg/kg)	Garden Produce (mg/kg, wet weight)			Dust In Air (mg/m ³)		Vapours (mg/m ³)
		5 cm Depth	15 cm Depth		Fruit	Vegetables		From 5 cm Soil	From 15 cm Soil	From 5 cm Soil
						Root	Above Ground			
Inorganics										
As	8.1	4.1	3.0	0.32	0.0034	0.0034	0.033	3.1E-07	2.2E-07	NA ^b
Cd	5.1	1.3	0.65	0.20	0.018	0.018	0.092	1.0E-07	4.9E-08	NA ^b
Co	3.3	8.4	7.9	0.13	0.011	0.011	0.030	6.4E-07	6.0E-07	NA ^b
Cr	160	58	37	6.2	0.031	0.031	0.052	4.4E-06	2.8E-06	NA ^b
Cu	1200	260	110	45	5.1	5.1	2.3	2.0E-05	8.2E-06	NA ^b
Hg	1.7	1.1	0.92	0.067	0.035	0.035	0.066	8.7E-08	7.0E-08	NA ^b
Mo	13	2.8	1.1	0.50	0.013	0.013	0.053	2.1E-07	8.4E-08	NA ^b
Ni	39	23	18	1.5	0.20	0.20	0.18	1.7E-06	1.3E-06	NA ^b
Pb	93	54	41	3.6	0.071	0.071	0.40	4.1E-06	3.1E-06	NA ^b
Se	3.1	1.1	0.69	0.12	0.0033	0.0033	0.064	8.5E-08	5.3E-08	NA ^b
Zn	900	260	140	35	23	23	14	2.0E-05	1.0E-05	NA ^a
Trace Organics										
PCBs ^d	1.7E-04	0.011	0.011	6.5E-06	2.0E-05	2.0E-05	2.0E-05	8.0E-10	8.0E-10	1.3E-09
PCDD/Fs	1.5E-05	4.7E-06	2.7E-06	5.8E-07	2.9E-09	2.9E-09	2.9E-09	3.6E-13	2.1E-13	8.5E-14

Note:

- Chemical levels after 25 years of annual pellet application at double the recommended application rate (i.e. 5.4 tonnes per hectare per year).
- Inorganic compounds do not volatilize and therefore have not been considered for vapour inhalation.
- The upper bound concentration is based on the 95% confidence limit on the mean of measured concentrations in biosolids.
- Given the limited available data, the mean concentrations for trace organics were selected for this assessment.



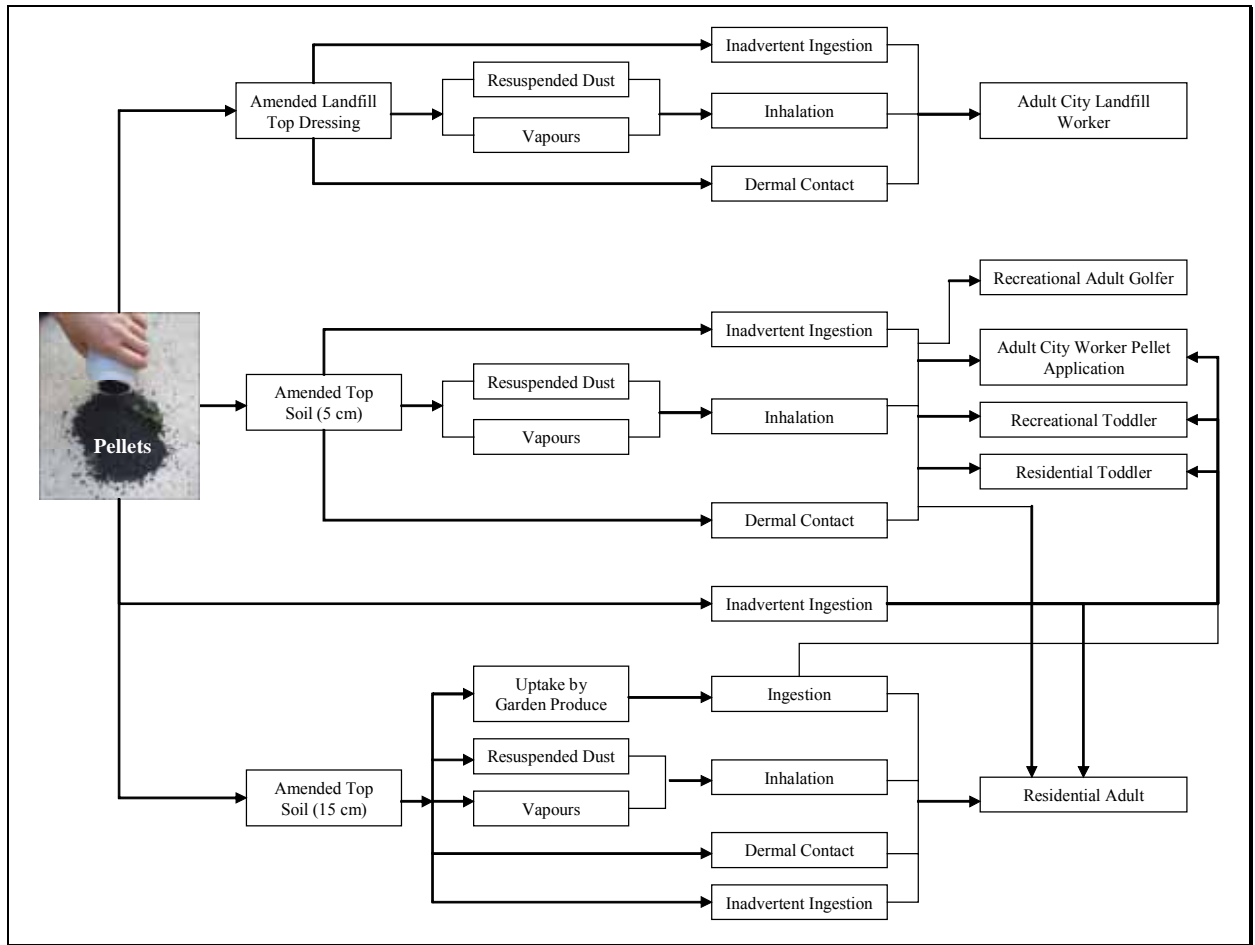
Table III: Selected Receptors

Scenario	Health Effect	
	Non-Carcinogen	Carcinogen
City Workers	Adult City Parks Worker exposed to pellets for 30 years in City-owned recreational areas (parks, golf courses, gardens).	Adult City Parks Worker exposed to pellets in City-owned recreational areas (parks, golf courses, gardens) for 30 years.
	Adult City Landfill Worker exposed to amended landfill top dressing for 30 years	Adult City Landfill Worker exposed to amended landfill top dressing for 30 years
Recreational Use (parks, golf courses)	Toddler exposed to pellets and amended soil for 4.5 years (between the ages of 7 months to 5 years)	Composite receptor that represents a lifetime of visiting the park for 75 years (from birth to 75 years old)
	Adult golfer exposed to amended soil for 30 years	Adult golfer exposed to amended soil for 30 years
Home use (garden, lawn)	Toddler exposed to pellets, amended soil and impacted garden produce for 4.5 years (between the ages of 7 months to 5 years)	A composite receptor that represents a lifetime of exposure for 75 years (from birth to 75 years old)
	Adult resident exposed to pellets, amended soil, impacted garden produce and exposure while applying pellets for 55 years (from 20 to 75 years of age)	

The receptors are exposed to pellets directly or to amended soil under various situations. The exposure pathways are presented in Figure I. The calculation for the ingestion pathway considered incidental ingestion of soil. Under the Home Use Scenario, the calculation also included exposure from ingestion of vegetables and fruits grown in home gardens. Since it could take days before pellets spread on lawns get incorporated into the soil under arid conditions, the calculation took into account the scenario that toddlers wandering on lawns may put pellets into their mouths that they find on the soil surface.

In general, where information gaps existed, conservative assumptions were made to assure that risks were not underestimated. For example, conservative assumptions include assuming amended soil concentrations based on twice the recommended application rate of pellets, assuming direct ingestion of pellets, and assuming continuous exposure to pellet amended soil over a lifetime.

Figure I: Exposure Pathways and Receptors



Risk from a given contaminant increases with the potency of the contaminant and with the dose to which people are exposed. The potencies of the EoPCs for inhalation and oral routes of exposure were adopted from published values by regulatory agencies such as Health Canada, United States Environmental Protection Agency (US EPA) and the Ontario Ministry of the Environment (MOE) after a review of their scientific basis. Potencies for dermal exposure were available for very few chemical substances. The common practice is to evaluate dermal exposure using oral potencies after correcting for differences in absorption for the two different routes of exposure. This practice implicitly assumes that health effects are related only to the total uptake of the chemical into the body and not dependent on the route of exposure.

For non-cancer effects, hazard quotients are calculated as the ratio of the estimated exposure levels and selected toxicity reference values, below which health effects are not expected. According to MOE guidance, a hazard quotient for each exposure pathway less than 0.2 is considered protective of health. The hazard quotients for the inhalation pathway and the combined oral and dermal exposure pathways from exposure after 25 years of pellet application were below 0.2 for all the chemicals evaluated under all exposure scenarios being considered.

Cancer risks were calculated as a product of estimated exposure levels and selected toxicity reference values. Exposure ratios (ERs) were estimated as the ratio of the cancer risk estimate and the exposure limit. The exposure limit corresponds to a cancer risk of one in one hundred thousand deemed acceptable by Health Canada or a cancer risk of one in one million deemed acceptable by the MOE. In general, exposure ratios of one or less are below the level of regulatory concern. Exposure ratios greater than one do not necessarily imply an elevated level of risk because of the uncertainties inherent in the risk assessment. With the exception of arsenic, for all carcinogenic chemical entities of potential concern, there was no increased lifetime cancer risk found above either benchmark of acceptable risk (one in one hundred thousand for Health Canada and one in one million for the MOE).

In the case of arsenic, the exposure ratio for the composite (lifetime) receptor resulting from ingestion/dermal exposure after 25 years of pellet use in the home environment was within the acceptable range (i.e. between one in one million and one in one hundred thousand cancer risk). The exposure based on incremental risk (excluding background) indicates an acceptable level of risk as defined by the MOE. The lifetime cancer risk was estimated to be five in one million. Many fertilizers contain traces of arsenic; the levels of arsenic in the biosolid pellets are below allowable limits for fertilizers and soil quality guidelines. The estimated risk was within the range of uncertainty generally associated with risk assessments; the many assumptions used in the calculations tend to overestimate the risk, meaning the actual risk may be overstated. For example, assuming twice the recommended pellet application rate in calculating amended soil concentrations may overestimate risk.



Human Health Risk from Exposure to Biological Agents

There are well-developed guidelines for conducting chemical risk assessments and guidance on acceptability of risk for both human and ecological receptors; however, there are no well-defined guidelines for assessing risk from environmental exposure to biological agents and no clear definition for acceptability. The science of assessing such risks is under development at the present time. Therefore, the study focussed on the effectiveness of the pelletization process to destroy biological agents of potential concern and the likelihood of biological agents to be present in biosolids.

Although not entirely relevant to Ontario, the US EPA classifies biosolids based on their qualities. The information available on the pelletization process and the limited analytical results on pathogen content suggest that the pellets produced at the ABTP pelletizer might be of similar quality to that required for Class A biosolids as defined by the US EPA. Confirmatory testing would be required to verify this. Class A biosolids that fall under the US EPA's jurisdiction can be distributed and used without site restriction if they also meet the US EPA chemical pollutant concentration limits.

Limitations of Biological Agents Literature Review

The literature data suggest a minimum process time of 60 to 90 minutes at a temperature of 80°C in order to achieve the destruction of most pathogens.

The pelletizer manufacturer asserts that the process meets the requirements of the US EPA for Class A biosolids. The available information seems to support this assertion; however, some biological entities in the biosolids pellets may not be deactivated by the pelletization process. Exposure to such entities increases with frequency and duration of handling, as well as quantities used, and would be greater for workers than for residents. Because of the increased contact time for workers routinely handling large quantities of pellets, and thus increased exposure via inhalation, accidental ingestion, and dermal pathways, some degree of care to minimize potential exposures to trace biological entities during handling would be reasonable.



Although the pelletization process appears to provide the conditions for effective destruction of micro-organisms, additional monitoring would be needed to confirm this capability. This can be done by routine monitoring for selected bacteria and phages.

This study of biological agents addressed types of pathogenic organisms shed in faeces that may be present in sewage. This included vegetative bacteria and enveloped viruses, bacterial spores, human enteric viruses, protozoan parasites and helminths.

Ecological Risk

Ecological risk assessment (ERA) is a process that evaluates the likelihood that adverse environmental effects may occur, or are occurring, because of exposure to one or more stressors. Chemicals present in pellet-amended soil are the stressors considered in the present study.

The assessment was carried out for a set of ecological (non-human) receptors deemed representative of species in the Toronto area that are important to the human population. The selection of potential ecological receptors (also known as valued ecological components or VECs) was based on a review of the intended and likely uses of pellets on private and public property in the City of Toronto or on landfills, and of the biota typically found in the Toronto area. Only soil and soil-based exposures were assessed in the selection. Table IV summarizes the valued ecological components selected for this assessment.

Table IV: Summary of Valued Ecological Components Selected

Receptor Type	Selected VEC ^a
Plants and soil invertebrates	Screening assessment only
Domestic pet – Carnivore	House cat
Domestic pet - Omnivore	Dog
Mammal - Herbivore	Meadow vole
Mammal – Carnivore	Masked shrew
Mammal – Omnivore	Raccoon
Mammal – Carnivore	Red fox
Fowl – Carnivore	American Robin
Fowl – Carnivore	Red-tailed hawk

Note:

a. VEC = valued ecological component



The scenarios selected for evaluation were the Home or Recreational Use Scenario and the Landfill Use Scenario.

Ecological risk assessment for wildlife and pets was not conducted for scenario use of pellets on gardens. Pellets applied to gardens are incorporated into greater depth than on lawns. Also because of the limited land area reserved for home gardens, the gardens would not form a large or continuous habitat for wildlife and pets.

The Landfill Use Scenario was not considered for the evaluation of toxicity to plants and soil organisms because the chemical levels are much lower than the other scenarios that are more conservative.

Plant Toxicity

A preliminary qualitative assessment was conducted to evaluate the potential for impact on plant life and soil organisms. A screening assessment is considered appropriate in light of the intended use of pellets as a nutrient-containing soil supplement. The levels that could accumulate in soil (summarized in Table II) after years of pellet use were compared to the Ecotoxicity values developed by MOE and Canadian Council of the Ministers of the Environment (CCME) for the protection of plants and invertebrates.

For most of the chemicals, the soil levels after 25 years of pellet use were less than the relevant MOE and CCME ecotoxicity criteria (Refer to Table 7-1). The estimated concentrations of copper, selenium and zinc in soils amended with pellets down to 5 cm depth after 25 years of application at twice the recommended application rate were found to be greater than either one or both of the guideline criteria (Table V). The soil levels were well below the MOE ecotoxicity criteria for both selenium and zinc. The slight exceedance of the CCME ecotoxicity criteria, particularly for selenium, is unlikely to be a concern. The exceedance of both criteria for copper may have different implication. The copper soil level was expected to exceed the CCME ecotoxicity criteria after 10 years of pellet application on lawns although it still would meet the MOE ecotoxicity criteria.



Table V: Ecotoxicity of Soil Based on Plants or Invertebrates for Selected Metals

Soil Concentration	Cu	Se	Zn
MOE ecotoxicity Criteria^a			
(mg/kg)	225	10	600
CCME ecotoxicity Criteria^b			
(mg/kg)	63	1	200
Pellets Amended Soil Concentration Assuming 5 cm depth (Lawns)^c			
1 year (mg/kg)	39	0.51	82
10 year (mg/kg)	120	0.73	150
25 years (mg/kg)	260	1.1	260
Pellet Amended Soil Concentration Assuming 15 cm depth (Gardens)^c			
1 year (mg/kg)	33	0.49	77
10 year (mg/kg)	61	0.56	99
25 years (mg/kg)	110	0.69	140

Notes:

- MOE Rationale for the Development and Application of Generic Soil, Groundwater and Sediment Criteria for the Use at Contaminated Sites in Ontario, May 1996, Table B, coarse texture, residential; parkland land use – ecological based criteria
- CCME, Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health, 1999, rev. 2002, residential/parkland land use, soil quality guideline for protection of environmental health.
- Based on an assumed application rate of 5.4 dry tonnes/ha.
- Values in **BOLD** are greater than one or both criteria.

The species that determine the criteria value may not be normally found in the urban park and home environments. Furthermore, the criteria are developed for regular soil and not pellet-amended soil. It has been reported that most metals are organically bound or in less bioavailable forms for plant uptake in heat dried or composted biosolids.

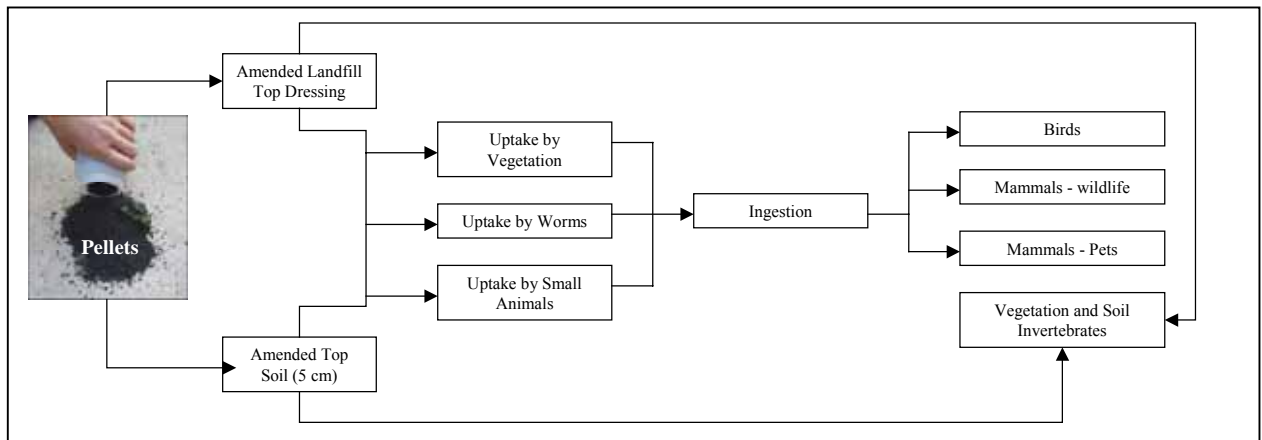
Although these long-term chemical levels are greater than the ecotoxicity criteria, firm conclusions regarding toxicity cannot be reached based on the preliminary evaluation. A more comprehensive analysis would be required using toxicity values based on plants most commonly found in parks and gardens in the Toronto area, in order to make firm conclusions on plant or soil organism toxicity. Possible lower plant uptake of copper from pellets could also be considered.

Wildlife and Pets

A preliminary quantitative ecological assessment was conducted for wildlife and pets, using an assessment framework similar to that used for human health. Wildlife valued ecological components selected for assessment represent species at different strata of the food chain. Receptors include animals that feed on vegetation only (vole), animals that feed on invertebrates (masked shrew), animals that primarily feed on other smaller animals (red fox), animals that feed on both smaller animals and vegetation (raccoon), birds that eat invertebrates only (American Robin), and birds of prey (red-tailed hawk).

Evaluation of the exposure and risk to the chemical entities of potential concern involves an analysis of the exposure routes, which expose a receptor species to the source. For surface soils and terrestrial receptors, including mammals and birds, exposure to the entities of potential concern resulting from pellet use may occur through the exposure routes as depicted in Figure II.

Figure II: Ecological Exposure Pathways and Receptors



The ingestion pathway is most important for wildlife and pet receptors. This assessment considered ingestion of plants or prey species that have accumulated chemicals from the soil as well as ingestion of soil as a result of feeding or grooming.

Different assessment endpoints were selected for pets than for wildlife, reflecting the importance to people of pets as individuals.

- Wildlife Assessment Endpoint: Populations of birds or mammals that may be reduced as a result of increased mortality or decreased reproduction because of the presence of constituents of concern in soils.
- Pet Assessment Endpoint: Individual pets that may have increased risk of health effects because of the presence of constituents of concern in soils.

Risks were characterized by calculating ecological hazard quotients. An ecological hazard quotient is the ratio of estimated exposure level to a reference exposure level. For wildlife, the reference exposure level was based on the Lowest Observed Adverse Effect Levels or the No Observable Adverse Effect Levels in relation to survival or reproduction. For domestic dogs and cats, the No Observable Adverse Effect Level was used to respect the special relationship between humans and pets. A hazard quotient less than one indicates that no effects to wildlife at a population level or pets at an individual level are expected. A hazard quotient greater than one does not necessarily imply an adverse effect; rather it indicates that the risk of an effect cannot be ruled out based on the analysis performed. Taking into consideration the uncertainty associated with ecological assessment, marginal exceedances are not necessarily a cause for concern.

For the home lawn and City parkland scenarios, all hazard quotients calculated are less than one, except for exposure of American robins to chromium III, exposure of domestic dogs and house cats to arsenic, and exposure of house cats to dioxins and furans. The exceedance is marginal and is within the range of uncertainty of the assessment. This finding indicates that all the other receptors evaluated are not expected to be at risk for the selected assessment endpoints.

For the landfill scenario, all hazard quotients are less than one indicating that no risk to receptors evaluated is expected for the selected assessment endpoints.

In the home use scenario, a hazard quotient was estimated for the exposure of dogs and house cats to arsenic and the exposure of house cats to dioxins and furans. The hazard quotient is estimated as equal to the benchmark and indicates no expected risks to these receptors.



A hazard quotient of 3 was estimated for exposure of robins to chromium III, indicating that risk to robins cannot be ruled out based on the analysis performed, should pellets be widely used across their home range. If the robin is considered to migrate out of the Toronto area for approximately half of each year, unless pellets are applied to more than 60% of the robin population's home range, the hazard quotient can be considered to be less than one and hence no effects to robins would be expected. Additionally, bioavailability of chromium III in soil would be expected to be less than the 100% assumed in the assessment. Either of these factors alone would be sufficient to reduce the hazard quotient for robins to below one, indicating that no effect to robins should be expected.

Emerging Issues

Some concerns related to biosolids recycling have come to light in the recent years. Some of these have arisen because of the detection of additional toxic chemicals in sewage or biosolids. Others are due to new evidence indicating potential adverse effects for certain substances that could be present in sewage. Lack of adequate knowledge, such as the effect of low level exposure to endocrine disruptors, also creates concern. Odour, a long-standing issue, may affect public acceptance of pellet use because of the lack of prediction of potential impact.

This study briefly examined some of these issues, including:

- Odour;
- Polybrominated diphenyl ethers;
- Phthalates;
- Alkylphenol ethoxylates;
- Endocrine disruptors;
- Linear Alkylbenzene Sulphonates;
- Pharmaceuticals; and
- Radionuclides.

Odour detection is very subjective. Although biosolids pellets would be at the low end of a subjective measurement scale of odour unpleasantness, individual tolerance and sensitivity to odours will dictate public acceptance.



The characterization of chemicals identified is not well developed for biosolids and pellets. In some cases, the analytical methods to reliably measure these chemicals are still under development. For this reason, these chemicals are not included in the routine biosolids monitoring program. To reduce the risk from exposure to these chemicals from beneficial use of biosolids, Toronto restricts the discharge of many of these chemicals, including radionuclides, into the sewer system under its sewer use by-law. Besides setting strict discharge limits for many known endocrine disruptors including phthalates, nonylphenol and ethoxylates, the by-law also requires institutions and industries that discharge these chemicals to submit pollution prevention plans to the City. Health Canada, which is responsible for regulating pharmaceuticals, is considering development of a cradle to grave approach to dealing with pharmaceuticals.



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GLOSSARY

ABTP	Ashbridges Bay Treatment Plant
As	Arsenic
BAF	Bioaccumulation Factor
BUC	Biosolids Utilization Committee
BW	Body Weight
Cancer	A disease characterized by malignant, uncontrolled invasive growth of body tissue cells.
Cancer Slope Factor (CSF)	An upper bound estimate of the cancer risk associated with a specified chronic exposure or dose.
Cancer Unit Risk (UR)	An upper bound estimate of the cancer risk associated with a specified exposure point concentration.
Carcinogen	A chemical or substance known or suspected of being of capable producing cancer in living organisms.
CCME	Canadian Council of Ministers of the Environment.
Cd	Cadmium
CDI	Chronic Daily Intake
Chronic exposure	Long-term, low-level exposure to substances, i.e., the repeated exposure to a substance over a long period of time.
CFIA	Canadian Food Inspection Agency
Chronic daily intake (CDI)	The average daily intake of a substance, expressed in weight per kg body weight per day, averaged over a long period of time.
Co	Cobalt
Concentration	A quantitative measure of the amount of a substance present in a specified amount of sample (e.g. mg of a substance per kg).



GLOSSARY

Conservatism	The tendency towards caution or protection. Conservative assumptions made in a risk assessment are designed so as to not under-predict the actual risks.
Cr	Chromium
Cu	Copper
Dose	That amount of a substance absorbed into the body of an exposed receptor.
Dose-response	The quantitative relationship between the dose of a substance and observed health effect caused by exposure to such substance.
dw	Dry weight
EoPC	Entity of Potential Concern.
Ecological risk	The likelihood (or probability) that a given exposure, or series of exposures, to a hazardous substance will cause adverse health or other response impacts on individual receptors (for species of special status) or populations experiencing the exposures.
Effect	The response observed in the receptor due to exposure to a substance (e.g., decreased body weight).
EPC	Exposure Point Concentration. The calculated concentration of a substance that is representative of the concentration at the point of exposure (e.g., the concentration of a substance in soil, water or air that is carried forward in the risk assessment calculations for a particular exposure pathway). An entity that is carried forward into a risk assessment.
Exposure	Receiving a dose of a substance; or coming in contact with a hazard.
Exposure assessment	The exposure assessment includes the identification of the receptors of interest, the identification of the relevant exposure pathways, and the quantification of the exposures from each pathway.
Exposure pathway	The mechanism by which a receptor can be exposed to a chemical hazard, such as ingestion of contaminated soil or inhalation of contaminated air.



GLOSSARY

ERA	Ecological Risk Assessment
fw	Fresh weight
Groundwater	The water contained in interconnected pores in soil and bedrock located below the water table.
Guidelines	Guidelines for environmental quality are defined by regulators for many substances to quickly and easily identify the concentration of a substance where no further investigation or study is required. If the concentration of a sample exceeds an established guideline, then further investigation is carried out to determine if a potential risk exists and whether action might be required.
ha	Hectare. A unit of land area equivalent to 100 m x 100 m.
Hazard	The inherent toxic potency of a substance independent of level of exposure.
Hazard identification	The first step in a risk assessment, used to identify environmental hazards (e.g., EoPC) that may pose a health or environmental risk. The hazards at a site are identified based on the results of data reviewed and field investigations, as well as an understanding of the toxicology of the chemicals of potential concern.
Hazard index (HI)	Sum of the EoPC – specific hazard quotients for an exposure scenario.
Hg	Mercury
HHERA	Human Health and Ecological Risk Assessment
HHRA	Human Health Risk Assessment
HQ	Hazard Quotient. The ratio between the calculated potential dose of a substance and the toxicity reference value for that substance.
HTP	Humber Treatment Plant
Human health risk	The likelihood (or probability) that a given exposure or series of exposures to a hazardous substance will cause adverse health impacts on individual receptors experiencing the exposures.



GLOSSARY

ILCR	Incremental lifetime cancer risk. An upper-bound estimate of the excess potential cancer risk, expressed as a probability of cancer incidence for an exposed individual over a lifetime.
Ingestion	Exposure to a substance through the mouth and into the gastrointestinal system.
Inhalation	Exposure to a substance through the respiratory tract system.
Intake	The amount of material taken into the body (e.g., inhaled, or ingested) during a specified time period. (i.e., a measure of exposure, often expressed in mg EOPC /kg BW-day).
IR	Ingestion (or intake) Rate
Jacques Whitford	Jacques Whitford Limited
LADI	Lifetime Average Daily Intake
LCLM	Lower Confidence Limit of the Mean
Lifetime average daily dose	The average dose of a substance over a lifetime, expressed as a mass of a substance per unit body weight per unit time.
Modeling	Use of mathematical algorithms to simulate and predict real events and processes.
MOE	Ontario Ministry of the Environment
NEBRA	New England Biosolids and Residual Association
Ni	Nickel
NMA	Nutrient Management Act
NTTP	North Toronto Treatment Plant
OMAF	Ontario Ministry of Agriculture and Food
OTR	The typical range of concentrations of a compound in Ontario soils.



GLOSSARY

OTR₉₈	The 98 th percentile concentration of the Ontario Typical Range
Pb	Lead
PCBs	Polychlorinated biphenyls
PCDD/F	Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), commonly referred to as PCDD/F
PhATE	Pharmaceutical Assessment and Transport Evaluation model
PhRMA	Pharmaceutical Research and Manufacturers Association
Potency	A measure of the relative toxicity of a substance.
Receptor	Refers to members of a potentially exposed population, e.g., persons or organisms that are potentially exposed to a particular substance.
Risk assessment	The determination of the potential adverse health or environmental effects due to exposure to substances that may cause harm.
Risk management	The steps and processes taken to reduce, abate, or eliminate unacceptable risks that have been identified by a risk assessment.
Risk	The probability or likelihood of an adverse consequence from a hazardous situation or hazard, or the potential for the realization of undesirable adverse consequences from impending events.
RME	Reasonable Maximum Exposure
SAS	Surfers Against Sewage
Se	Selenium
SEM	Standard Error Mean
SF	Slope factor
Slope factor	A plausible upper-bound probability estimate of a response per unit intake of a substance over a lifetime. It is used to estimate an upper bound probability of an individual developing cancer as a result of a lifetime of exposure to a particular level of a potential carcinogen.



GLOSSARY

Stddev	Standard deviation
Surface Water	Water from lakes, rivers and streams.
TDI	Tolerable Daily Intake
TEQ	Toxic Equivalent Quotient
Threshold	The lowest dose or exposure of a substance at which a specified measurable effect is observed and below which such effect is not observed.
Tolerable Daily Intake	The estimate of lifetime daily exposure of a non-carcinogenic substance for the general human population that appears to be without an appreciable risk of deleterious effects
Toxicity	The harmful effects produced by a substance; the quality or degree of being poisonous or harmful to human or ecological receptors.
TPH	Toronto Public Health
TR	Target Risk
TRV	Toxicity Reference Value
UCLM	Upper Confidence Limit of the Mean
Uncertainty	Lack of surety in the estimate of a variable's magnitude or probability of occurrence.
Uncertainty factor	Refers to a factor that is used to provide a margin of safety when extrapolating toxicity reference values from experimental or epidemiological data.
UF	Uptake Factor
US EPA	United States Environmental Protection Agency
US FDA	United States Federal Drug Agency
WEAO	Water Environment Association of Ontario



GLOSSARY

WES	Works and Emergency Services, City of Toronto
WHO	World Health Organization
Zn	Zinc



1. INTRODUCTION

Jacques Whitford Limited (Jacques Whitford) was contracted by Toronto Public Health (TPH) to conduct a Biosolids Pellet Review Study. To this end Jacques Whitford has conducted a Human Health and Ecological Risk Assessment (HHERA) for various application scenarios of biosolids pellets (pellets) produced up until 2003 by the Ashbridges Bay Treatment Plant (ABTP) in the City of Toronto.

The initial contract and scope of work awarded to Jacques Whitford included a review and risk assessment of the land application of biosolids cake product produced at the ABTP and spread on nearby agricultural land. During December 2003, the focus of the project was altered by TPH to include only a review and HHERA on the application of pellets, formerly produced at ABTP, to be spread within the borders of the City of Toronto. The revised scope of work limited the number of entities of potential concern (EoPC) evaluated in the study.

This report provides a background on pellets produced at ABTP, the regulatory context involved with the spreading of pellets, data analysis of the EoPCs, available concentration data in ABTP biosolids cake and pellets, a human health risk assessment, an ecological risk assessment, discussion of emerging issues surrounding pellets, and recommendations on appropriate pellet uses.

1.1 Study Background

The application of biosolids on agricultural land and other types of land is a common biosolids management practice employed by municipalities in Ontario and across North America.

Conventional sewage treatment consists of a combination of physical, chemical and biological processes that separate solids from water in sewage. The solids are typically digested in an anaerobic digester resulting in stable organic matter. The solids remaining after the digestion process are further dewatered or processed, producing biosolids cake. Pellets are produced by further heating and dewatering of biosolids cake. Biosolids cake or pellets may be landfilled, incinerated or land applied.



In 1998, the City of Toronto decided to pursue a policy of 100% beneficial use of biosolids at Ashbridges Bay Treatment Plant (ABTP). A pelletization plant was constructed at the ABTP to convert 50% of the plant's biosolids into dry pellets, leaving 50% as dewatered cake. Both forms of biosolids could then be applied to land. The high nutrient and organic carbon content of biosolids makes them a potentially valuable resource as a fertilizer for land application. Land application of biosolids cake is regulated in Ontario through Regulation 347 of the Environmental Protection Act and the Ontario Ministry of Environment's (MOE, 1996a) *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land* (although biosolid pellets are essentially the same material as biosolid cakes, in terms of metal content and other contaminants). Regulation 347 exempts wastes that are sold; therefore, the City of Toronto pellets would then fall under the jurisdiction of the Federal Fertilizers Act.

Although biosolids are a potentially valuable resource, considerable public concern remains over their use. Public apprehension surrounding the levels of environmental contaminants (metals, organic compounds, pharmaceuticals, *etc.*) and pathogenic content of biosolids has led to concern that the spreading of biosolids may adversely impact both human and ecological health. The long-term application of pellets on land may also lead to accumulation of entities of potential concern (EoPCs) in soils.

Although the pelletizer plant was recently damaged in a fire at the ABTP, our understanding is that the plant will be repaired. It has been assumed that the quality of pellets produced by the new or refurbished plant will not differ significantly from what was previously produced.

1.2 Objectives

The focus of this study is on the use of pellets produced at Ashbridges Bay Treatment Plant (ABTP) as fertilizer within the City of Toronto limits or on City of Toronto owned lands. Pellets were considered to be used under three scenarios:

1. Use of pellets as a fertilizer on City of Toronto owned land (*e.g.* parks, golf courses).
2. Commercial sale of pellets to residents of the City of Toronto for application on their home lawns and gardens as a fertilizer.
3. Use of pellets as part of a landfill topdressing mixture applied as cover material by the City of Toronto. Topdressing is a material applied on top of soil without mixing it in.



The overall objectives of the study are to:

- Improve knowledge and understanding about biosolids pellets and related issues;
- Provide information to assist in developing appropriate management practices for pellet use in the City of Toronto; and,
- Provide practical and scientifically defensible information to address public concerns related to pellets.

1.3 Scope of Work

This study examines both chemical and biological hazards associated with the use of pellets on City of Toronto land within the relevant regulatory framework in Ontario and Canada. Chemical hazards, or EoPCs, were selected based on low volatility, persistence in the environment and, to a lesser extent, availability of analytical data. The study addresses only issues relevant to pellets formerly produced by the Ashbridges Bay Treatment Plant and their potential application on lands within the City of Toronto or on City of Toronto lands and potential impact on human and ecological health. The study does not address the use of pellets on agricultural lands, nor does the study address the land application of biosolids cake.

1.4 Organization of This Report

This report is presented in eleven sections:

Section 1 describes the study background, objectives, and scope of work.

Section 2 presents the approach to human health and ecological risk assessment in this study.

Section 3 provides background information on the City of Toronto Ashbridges Bay Treatment Plant (ABTP), biosolids characteristics and regulatory frameworks that govern biosolids management.

Section 4 provides a review of EoPC concentrations in pellets and cake produced at ABTP and provides the rationale for selection of EoPC concentrations to be used in the quantitative risk assessment.



Section 5 presents the results of the human health risk assessment.

Section 6 presents an overview of human health risks from biological agents.

Section 7 presents the results of the ecological risk assessment.

Section 8 presents a discussion on the emerging issues surrounding biosolids pellets.

Section 9 provides a summary of the results and conclusions of the assessment.

Section 10 contains a statement of limitations and closure for this assessment.

Section 11 provides a list of references.

Finally, supporting information is provided in appendices at the end of the report.



2. HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT APPROACH

The Human Health and Ecological Risk Assessment (HHERA) of the City of Toronto Biosolids Pellet Management Program was based on accepted risk assessment standards, including those published by Health Canada, the Ontario Ministry of the Environment (MOE), the Canadian Council of Ministers of the Environment (CCME), and the United States Environmental Protection Agency (US EPA). The foundation of the HHERA is based on the data retrieved from the City of Toronto-specific characterization of biosolids pellets and cake.

Figure 2-1 depicts a recognized and generic approach to risk assessment. The steps depicted in Figure 2-1 have been used to guide the development of tasks for the Biosolids Pellet Review Study.

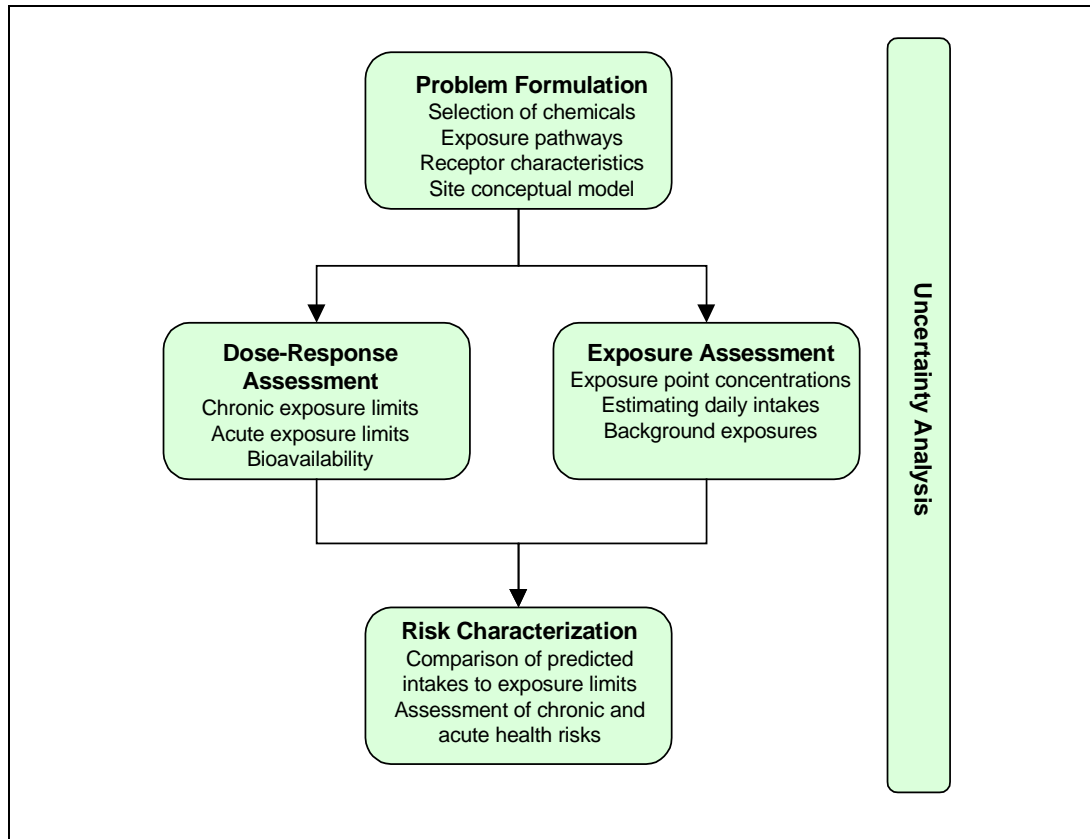
A deterministic risk assessment approach was adopted in this study. A deterministic approach involves generating a single estimate of exposure and risk based on user-defined assumptions that are usually reflective of reasonable maximum assumptions. When multiple reasonable maximum assumptions are made, a “worst-case scenario” often results. Deterministic risk assessments thus err on the side of conservatism and often over-estimate risk. Although the deterministic and other approaches have pros and cons, a deterministic approach was adopted as it is the most widely accepted form of risk assessment currently. Wherever applicable, acknowledgement of the uncertainty in certain phases of the risk assessment such as the hazard identification or exposure assessment stage, were discussed in the uncertainty section.

The reasonable maximum exposure (RME) concentration, using the 95% upper confidence limit on the arithmetic mean (UCLM) of the data set, was evaluated as the exposure point concentration (EPC) for each of the entities of potential concern (EoPCs).

The HHERA framework comprises the following major components:

1. **Literature Review and Data Collection:** Review of pertinent literature, regulatory framework and compilation of City of Toronto biosolids chemical data.
2. **Problem Formulation:** Identification of the environmental hazards that may pose a health or environmental risk (i.e. selection of EoPCs).
3. **Dose-Response Assessment:** Identification of published, scientifically reviewed toxicity reference values (TRVs) against which exposures or doses can be compared.

Figure 2-1: Human Health and Ecological Risk Assessment Framework



4. **Exposure Assessment:** Qualitative or quantitative evaluation of the likelihood or degree to which the receptors will be exposed to the hazard.
5. **Risk Characterization:** Quantitative assessment of the potential health risk of each hazard to each receptor, based on the degree of exposure.
6. **Uncertainty Assessment:** Review of the uncertainty associated with the risk estimation.
7. **Risk Management Conclusions and Recommendations**

The same approach was followed for both the human health and the ecological assessments.

A quantitative evaluation of human and ecological risks was conducted for those EoPCs for which the state of knowledge is such that a reasonable quantification of risks can be conducted. For other entities, a qualitative discussion of potential risks to human health is presented.

A qualitative discussion of potential risks to plants and soil organisms is also presented. Because the purpose of pellet use is as a soil nutrient containing supplement, a qualitative assessment of the potential risks to plants and soil organisms is considered the appropriate level of assessment. This is consistent with CCME (1996) guidance on ecological risk assessment.



3. BACKGROUND ON BIOSOLIDS PELLETS AND REGULATORY FRAMEWORK

3.1 Literature Review

Jacques Whitford has conducted a literature review specific to pellets only. The purpose of the literature review was to identify concerns related to land application of pellets. The literature review focused on studies prepared in the past 5 to 8 years.

The conducted review of data and literature on pellets included a review of the following documentation:

- Government documents (including appropriate US documents),
- Scientific (primary) literature, and
- Grey Literature (web sites or unpublished reports).

3.1.1 Review of Government Documents

No government documentation specific to pellets was retrieved during the literature review. The majority of the documents refer to the application of biosolids cake on agricultural land. Jacques Whitford reviewed the numerous reports produced for the City of Ottawa's Biosolids Management Plan as well as selected reports prepared by the Water Environment Research Foundation (WERF), the Ontario Ministry of Agriculture and Food (OMAF), the European Union/European countries, Agriculture Canada, and the World Health Organization (WHO). Finally, although the US EPA has spent considerable effort and resources to investigate issues surrounding the beneficial use of biosolids cake, no information specific to pellets was uncovered.

One document was provided by Toronto Public Health (TPH) on the probability of prions occurring in City of Toronto pellets. The TPH unpublished report titled *EMERGING ISSUES Prion Diseases: Can biosolids carry the pathogen that causes mad cow disease?* dated May 10, 2001 (Li-Muller, 2001), suggested that “[I]t is not clear how much prions a person has to ingest to develop prion disease and whether prions can survive the sewage treatment process”. Furthermore, the document states, “[t]o be prudent, it is best to ensure that the sewage treatment or pelletization processes provide the necessary condition that would deactivate any prions that



might find their way into the sewage system”. This issue is discussed further in Section 8.0 entitled Emerging Issues.

3.1.2 Review of Scientific Literature

A review of the primary (published) scientific literature related to pellets was undertaken. Several literature databases were searched and screened for relevant literature.

The search of primary literature revealed very few articles published specifically on pellets. The literature that was uncovered has been addressed throughout this report and appendices.

3.1.3 Review of Grey Literature

A limited web based search was conducted in order to gather “grey literature”. Grey literature is defined as that material which has not been published either in the scientific literature or by a government agency, as well as industry conferences. This search provided information regarding public concerns associated with the land application of biosolids in either the cake or pellet form.

In general, there appear to be numerous groups in North America that oppose spreading of biosolids cake on agricultural land. Jacques Whitford was not able to retrieve any information specific to the application of pellets on land. TPH’s qualitative survey of public concerns over biosolids land application, as reported by regional Ontario Ministry of the Environment (MOE) and local health units, was considered in the design and the evaluation of pellets, as well as throughout this report.

3.1.4 Summary

Overall very little information specific to pellets was uncovered during the literature review. It is apparent that the application of pellets on land has not been well studied or characterized. The majority of biosolids literature currently focuses on biosolids cake, possibly because the process of converting biosolids cake to pellets is not as common as the more traditional practices of land applying liquid biosolids or dewatered cake. However, much of the scientific literature on biosolids cake is likely relevant to the study of pellets.



For further information on biosolids cake literature, the reader should consult the following documentation:

- Apedaile, E., CH2M Hill Canada Limited, Cole, D. March 2002. Health Aspects of Biosolids Applied to Land. Prepared for the City of Ottawa.
- WEAO, 2001. Fate and Significance of Selected Contaminants in Sewage Biosolids Applied to Agricultural Land Through Literature and Consultation with Stakeholder Groups. Water Environment Association of Ontario.
- NRC, 2002. Biosolids Applied to Land: Advancing Standards and Practices. National Research Council.

3.2 Study Background on City of Toronto Pellets

3.2.1 Ashbridges Bay Waste Water Treatment Plant

The Ashbridges Bay Treatment Plant (ABTP) is the largest of four wastewater treatment plants serving the City of Toronto. The plant is designed to remove suspended and dissolved solids from the wastewater stream by physical screening, degritting, primary settling, activated sludge aeration, phosphorous removal and secondary settling.

Solids removed during primary and secondary settling are transferred to anaerobic digesters. Anaerobic digestion is used to stabilize the solids through decomposition of organic matter in the absence of oxygen (i.e. the solids are stable since they are no longer readily decomposed). Stabilization is a process used to reduce pathogens, and putrescible solids and to reduce odour, while destroying volatile solids. Organic material is biologically converted to methane and carbon dioxide by facultative and obligate anaerobic nonmethanogenic bacteria and by anaerobic methanogenic bacteria. The City of Toronto uses high rate anaerobic digesters with a minimum retention time of 15 days. While anaerobic digestion results in a significant pathogen reduction, digested biosolids are not pathogen free. Following digestion, a polymer solution is added to the solids, after which they are dewatered using high-speed centrifuges. The resulting biosolids are approximately 30 percent solids.



Historically, the City of Toronto incinerated biosolids at the ABTP using multiple hearth incinerators. In the 1990s they developed a beneficial use program that consisted of a central storage facility and land application on agricultural land in surrounding rural municipalities. The incinerators at the ABTP have subsequently been shut down. As a part of the City of Toronto's goal to eventually recycle 100 percent of their biosolids¹, a pelletizer was installed at ABTP. Currently, with the pelletizer out of service, a portion of the dewatered cake continues to be land applied while the majority is shipped to a landfill in Michigan.

3.2.2 Pelletizer Operations

The City of Toronto installed a Seghers HARDpelletizer plant at the ABTP in 2002. The pelletizer plant was in the process of being commissioned when it was damaged by fire in August of 2003.

The Seghers HARDpelletizer produces biosolids pellets by evaporating moisture from digested dewatered biosolids using indirect heat. The pelletizer shown in Figure 3-1 is enclosed. The pelletizer plant was designed to process up to 25,000 dry tonnes of biosolids per year, which is about half the total annual production of ABTP (includes solids from Humber and North Toronto Treatment Plants).

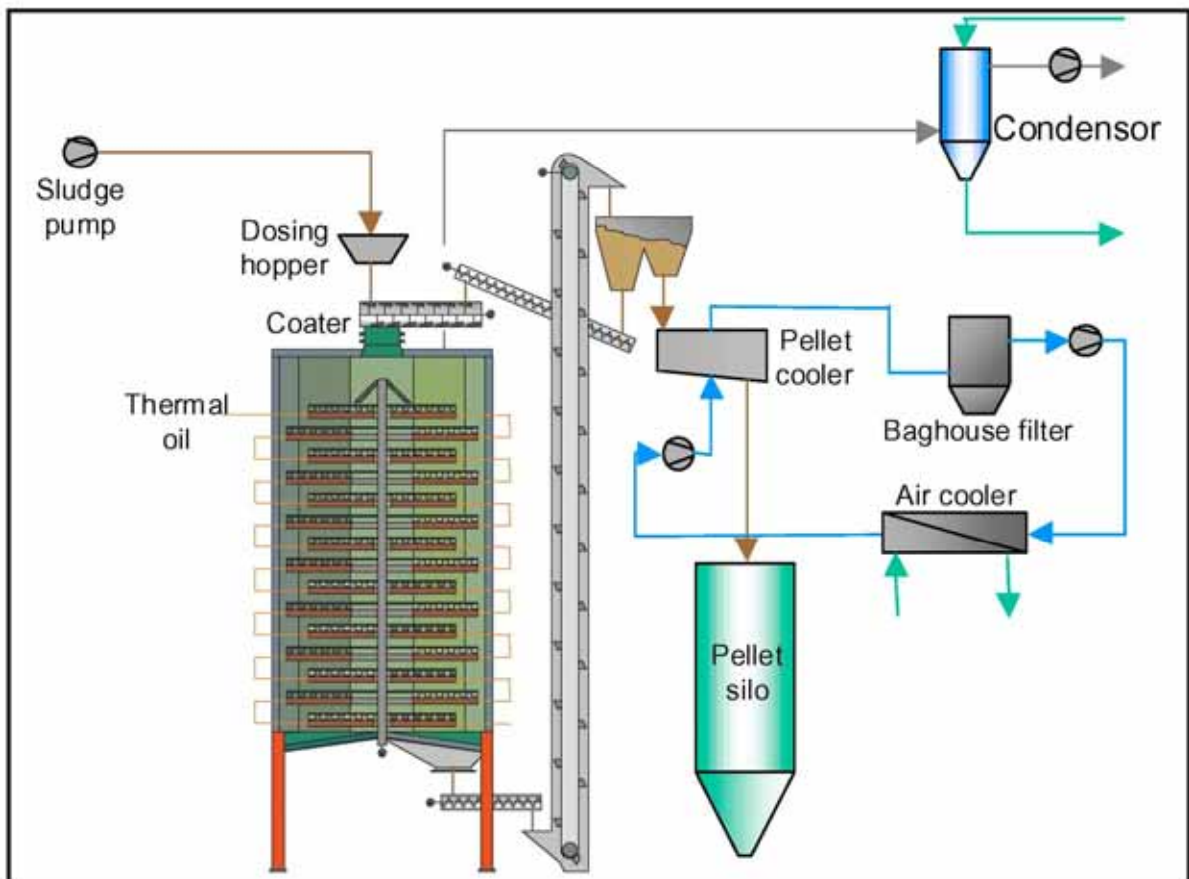
Biosolids cake is entered into the process as approximately 28 to 30% solids (70 to 72% water). The pellets are then produced by coating a nucleus of dry biosolids pellets with wet biosolids each time they are recycled through the dryer. Although the temperature within the dryer or pellets and the approximate pressure have not been confirmed within the ABTP pelletizer, a general idea of the pelletization process is offered by the manufacturer and summarized here. Within the dryer, each pellet is heated to a temperature of approximately 110 to 115 degrees Celsius (°C) at a pressure of 80 psi. The dryer consists of a series of 17 trays, each heated by thermal oil at a temperature of approximately 280°C. The heated oil is circulated in a closed loop through the trays. For each pass through the dryer (15 to 20 minutes), the pellets must pass over each tray before reaching the bottom. The pellets are recirculated in the dryer approximately 5 to 7 times prior to being sent to the cooler. Each pass is never less than 15 minutes, according to dryer specifications. The pelletizer can achieve pellets approximately 3 mm in diameter and approximately 97% solids and 3% water. Pellets collect at the bottom of

¹ ABTP biosolids includes biosolids from the North Toronto and Humber Treatment Plants, which are dewatered at ABTP. The Highland Creek Treatment Plant continues to incinerate biosolids.

the pelletizer and are transferred by a conveyor to a short term storage silo. The City of Toronto produced 4,416 tonnes of pellets in 2002.

The pelletization process may be considered advantageous because it promotes the destruction of pathogens with high temperature and retention time in the dryer. The resulting pellet is reported to be more than 99% pathogen free (Segher Keppel, not dated). During the initial testing of the pelletizer by the City of Toronto, analysis of the pellets found that fecal coliform was 1.8 Most Probable Number (MPN) per gram and the test for salmonella was below the limit of detection.

Figure 3-1: Segher Keppel's HARDpelletiser Process



The City of Toronto had entered into an agreement with US Filter to transport, store and market biosolids pellets. The City of Toronto’s Biosolids Advisory Group, a group made up of Works Committee members, City staff, union and community representatives, was convened to provide input to the City to assist in its negotiation with US Filter. There was unanimous agreement on a number of issues, including support for using pellets in golf courses, forests, remote parks, conservation areas, landfill rehabilitation and city parks. There was also an agreement that farmers should not be paid to use the biosolids pellets.

3.2.3 Potential Uses for Pellets in the City of Toronto

The fifteen elements essential for plant growth are indicated in Table 3-1 (Brady, 2002), divided into macronutrients and micronutrients. Macronutrients are nutrients that are required in relatively large quantities by plants. Micronutrients, while not less essential, are used in relatively small amounts. If the balance of essential nutrients are sufficient for plant growth, they are said to be in the sufficiency range. If nutrient availability is not sufficient then it is deficient, or if excessive nutrients are available, they may be toxic. The sufficiency range for macronutrients tends to be relatively wide. In the case of micronutrients, the sufficiency range tends to be quite narrow, which means that there is a fine balance between deficiency and toxicity.

Table 3-1: Fifteen Nutrients Considered Essential for Plant Growth

Macronutrients	Micronutrients
Nitrogen	Boron
Phosphorous	Chloride
Potassium	Copper
Calcium	Cobalt
Magnesium	Iron
Sulphur	Manganese
	Molybdenum
	Nickel
	Zinc

The City of Toronto pellets have not been analyzed for all fifteen essential nutrients. Based upon available data, the pellets contain appreciable concentrations of nitrogen and phosphorous, as well as boron, copper, cobalt, iron, manganese, molybdenum, nickel and zinc. The pellets also contain potassium, but not at an agronomically significant concentration.

Since the macronutrient content of the City of Toronto pellets is less than 24% by weight, under the Canadian Fertilizers Act they are classified as a low nutrient fertilizer (Fertilizers Regulation S10.1, 2003). A single application at the recommended rate of 2.7 tonnes per hectare (t/ha) (see Figure 3-1, City of Toronto Label for ABTP biosolids pellets) would provide approximately 22 kilograms of plant available nitrogen per hectare and 121 kilograms of phosphorous (P_2O_5) per hectare. The pellets contain a negligible amount of potassium. OMAF recommends up to 200 kilograms of available nitrogen and 200 kilograms of phosphoric acid per hectare per year for lawn turf, to be applied in three or four equal applications in the spring, summer and fall (OMAF, 2000). To be equivalent to existing general-purpose lawn fertilizers, the pellets could be blended with water-soluble nitrogen and potassium.

Because of the low soluble nitrogen and relatively high concentration of phosphorous, the pellets, blended with a source of potassium could also be used as a general-purpose garden fertilizer. Other jurisdictions, such as certain states in the United States and Australia produce pellets that are marketed domestically for home lawn and garden use.

The City of Toronto has also considered using the pellets as a component of landfill topdressing. Final landfill cover normally consists of a number of layers. The top or final layer is typically topsoil that is seeded to establish vegetative cover. The vegetation prevents wind and rain erosion and also provides aesthetic appeal to the covered landfill.

In order for biosolid pellets to be used as landfill topdressing, they would be blended with a carbon source, such as straw, and a base mineral material such as sand. The carbon source is required to adjust the carbon to nitrogen ratio of the resulting mixture. If the carbon to nitrogen ratio is too low, which would be the case if a carbon source was not added, organic nitrogen would be mineralized too quickly, releasing nitrogen to the soil solution faster than it could be used by the plants. Sand is added to increase the density of the resulting mixture. If the density is too low, the mixture would be susceptible to wind and water erosion, especially while the vegetative cover is being established.



A mixture of 1 part pellets to 2 parts straw and 20 parts sand would result in a mixture that does not exceed metals loading and soil concentration limits, has a relatively high C/N ratio and will result in a reasonable amount of available nitrogen, assuming a rate of between 15 and 20% mineralization.

3.2.4 Regulatory Framework

Sewage biosolids are defined as a processed organic waste by Regulation 347 of the Environmental Protection Act. The Environmental Protection Act and Regulation 347 regulate the production and use of biosolids in Ontario. Wastewater treatment plants that produce biosolids do so under a Certificate of Approval issued by the MOE. The Certificate of Approval specifies terms and conditions for design, operation and maintenance of the wastewater treatment plant.

While biosolids are considered to be a waste under the Environmental Protection Act, the key concept underpinning land application is that of beneficial use. Biosolids are applied to land to supplement fertilizer use at rates that do not exceed crop nutrient needs. Individual sites are licensed by a Provisional Certificate of Approval for an Organic Soil Conditioning Site. The Certificate of Approval contains terms and conditions for land application. General conditions for land application are contained in the *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land* (MOE, 1996a). General conditions include setbacks from surface water, wells and residences, maximum application rates and quality standards for biosolids applied to land. The Province of Ontario has recently passed the Nutrient Management Act and is currently phasing in Regulation 367/03, the Nutrient Management Regulation. The Nutrient Management Act regulates the production and land application of agricultural source (manure) and non-agricultural source (biosolids) nutrients that are not fertilizers. The Nutrient Management Act is jointly administered by OMAF and MOE (MOE, 2003).

The Ontario regulatory framework provides for non-agricultural uses of biosolids. However, under the regulations, land application is generally limited to agricultural land or, in some cases, as a component of landfill topdressing.

Fertilizers and soil supplements sold in Canada are regulated by the Canadian Fertilizers Act, which is administered by the Canadian Food Inspection Agency (CFIA). The Fertilizers Act enables regulations to be made and provides for enforcement and penalties. The Fertilizers Regulations set out standards for labelling, registration, and quality. The Regulations are supplemented by a series of Trade Memoranda.



3.2.4.1 Pellets: Biosolid or Fertilizer?

Biosolids pellets may be considered to be a fertilizer if:

- they are offered for sale in Canada as a fertilizer or soil supplement, and
- they meet the requirements of the Fertilizers Act.

The Certificate of Approval issued for the ABTP pelletizer indicates that if the pellets meet the standards of the Fertilizers Act. As a product, the non-agricultural use of the pellets is regulated by the Fertilizers Act. Because pellets produced at ABTP contain 10% or less of total nitrogen, available phosphorus and soluble potash, the pellets will be considered as “non-agricultural source material” under the Nutrient Management Act. The City of Toronto applied to the CFIA for a “letter of no objection”, which is a voluntary action. CFIA did not undertake a safety study of the pellets. The label for the pellets is illustrated in Figure 3-2.

3.2.5 Ontario Framework

The following review of the Ontario Guidelines and the Nutrient Management Act are provided for context and as background information. The Ontario regulations provide for both agricultural and non-agricultural source material. If the City of Toronto markets/uses their biosolids pellets as a fertilizer or soil supplement on agricultural land, provisions of the Nutrient Management Act will apply.

3.2.5.1 Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land (March 1996)

The Environmental Protection Act and Regulation 347 provide the authority to issue Certificates of Approval to land apply biosolids. The standards for biosolids production and land application are contained in the *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land* (the Guidelines) and are intended to supplement Regulation 347 (MOE, 1996a). The Guidelines contain criteria that must be met before biosolids may be applied to agricultural land. These criteria include maximum allowed metal concentrations.

Figure 3-2: City of Toronto Approved Label for ABTP Produced Biosolids Pellets

11/12/01

NUTRI-PEL

Processed Sewage 3.5 – 5.0 – 0.0

Guaranteed Minimum Analysis

Total Nitrogen	(N)	-	3.5 %
3.25% Water insoluble Nitrogen (N)			
Available Phosphoric Acid	(P ₂ O ₅)	-	5.0 %
Iron	(Fe)	Actual	-
5.0 %			
Organic Matter		-	50 %
Maximum Moisture		-	10 %

Directions for Use:

This product is derived from digested municipal sewage that has been dried and pelletized at high heat.

The recommended rate of application for this product is dependent upon the crop it is applied to. This product should be used in accordance with all applicable fertilizer recommendations published by the Ontario Ministry of Agriculture Food Approximately 20% of the Total nitrogen is available in the 1st year of application.

Caution:

This fertilizer contains copper and should be used only as recommended. It may prove harmful when misused.
Do not exceed crop specific nutrient application rates as recommended in published OMAF fertilizer recommendations.
Do not exceed an application rate of 2.7 tonnes of product per Hectare per year.

Product Storage:

Store product in a dry location until application.

Weight:

Weight on Bill of Lading (attached)

Responsible Packager's Name and Address:

USF Canada Inc.
250 Royal Crest Court
Markham, Ontario, CANADA L3R3S1
Telephone: 800-663-2463



The basic criteria for a waste material to be considered as biosolids is that it must be beneficial to crop production and/or soil and must not degrade the natural environment. Approval to land apply a waste material is a two-phase process. First, the producer of the waste must obtain approval for the material, meaning that it may be considered beneficial to crop production and/or soil quality and that it will not degrade the natural environment. Once the material has been approved, each individual site must be approved to receive biosolids.

Approvals are granted in the form of a Provisional Certificate of Approval for an Organic Soil Conditioning Site under the Environmental Protection Act. The MOE may request that the Biosolids Utilization Committee (BUC) review applications. The BUC provides recommendations to the MOE regarding the suitability of the material for land application, application rates and special conditions for application. The BUC recommendations are normally included in any applicable system approvals as well as individual site approvals. The BUC is co-chaired by OMAF and MOE and includes representation from government, industry and academia.

The Guidelines currently are being updated. It is expected that the updated Guidelines will be harmonized with the Nutrient Management Regulation 267/03. The only expected difference between the two documents will be the stipulation of setbacks from residences and residential areas, based upon odour, within the Guidelines. It is understood that as waste water treatment plants are phased into the Nutrient Management Act, land application of solids generated at the plant will be moved from the Guidelines to the Nutrient Management Act regulations; however, setbacks from residences and residential areas will continue to fall under the Guidelines.

3.2.5.2 *Ontario Nutrient Management Act and Regulation 267/03*

The Government of Ontario started the process of developing the Nutrient Management Act in 1999. The goal of the original consultation process was to develop a plan that would both protect farmers' right to farm while not infringing on surrounding land uses. The Nutrient Management Act received Royal Assent on 27 June 2002. The Nutrient Management Regulations were enacted at the end of September 2003.

The Nutrient Management Act and the Nutrient Management Regulations deal primarily with livestock manure production, storage and land application, but they also have an impact upon biosolids management. While farms that do not generate nutrients and do not receive agricultural source materials currently are not required to have a nutrient management plan, facilities that produce non-agricultural source materials (biosolids) that are land applied will be



required to have an approved nutrient management strategy. The regulation also contains standards for sampling non-agricultural source materials, standards for regulated metals in non-agricultural source materials, sampling requirements for soil and soil standards for regulated metals, pH and phosphorous. The regulation prohibits the application of a non-agricultural source material to “the land of an established golf course or to land on which tobacco grow”.

For the most part, the standards in the Nutrient Management Regulations are similar to those in the Guidelines. The standards address application rates (per application based upon volume), waiting periods and separation distances from surface water, groundwater and wells. Separation distances from residences and residential areas are not addressed in the regulation because they are odour based, and odour is not addressed by the legislation. Since the majority of farms that receive biosolids are currently not required to have a nutrient management plan, land application will continue to be regulated through Provisional Certificates of Approval and the Guidelines. In the event that biosolids are applied to a farm and field that fall under an approved nutrient management plan, that application will be regulated through the Nutrient Management Act and Nutrient Management Regulations.

3.2.6 Federal Fertilizers Act and Regulations

The federal Fertilizers Act was enacted in 1985 with the most recent amendment in 2003. The Fertilizers Act prohibits the selling or importation of fertilizers or supplements unless they have been registered as prescribed, they conform to standards and they are packaged and labelled as required. It also enables regulations to be made and governs enforcement, offences and punishment.

The Act defines fertilizer as:

“any substance or mixture of substances, containing nitrogen, phosphorous, potassium or other plant food, manufactured, sold or represented as a plant nutrient”;

and a supplement as:

“any substance or mixture of substances, other than a fertilizer, that is manufactured, sold, or represented for use in the improvement of the physical condition of soils or to aid plant growth or crop yields”.



All products that are sold as a fertilizer or supplement must conform to the Fertilizers Act and regulations but not all fertilizers are required to be registered. Products made from sewage are generally exempt from registration. However, if pellets are sold as a fertilizer, then they must comply with the Fertilizers Act, which requires an approved label and minimum guaranteed nitrogen, phosphorous and potassium content.

Standards for fertilizers and supplements are outlined in a number of Trade Memoranda. Trade memoranda that apply to biosolids fertilizers are outline below.

3.2.6.1 T-4-93 Standards for metals in fertilizers and supplements

Metals standards were originally developed in 1979 and re-evaluated between 1993 and 1995. The standards were developed to minimize the risk of adverse effects from metal contamination. The Trade Memorandum on metals standards does not provide details on how the standards were derived, nor does it define adverse effects. There are two standards, the maximum acceptable cumulative metal addition to soil (Table 3-2) and the maximum acceptable metal concentration in processed sewage and sewage-based products offered for sale as fertilizers (Table 3-3). The former is the total permitted cumulative loading for each regulated element, whereas the latter is the maximum accepted concentration of each element in the biosolids being applied to land.

Table 3-2: T-4-93 Standards for Cumulative Metal Addition to Soil

Metal	Maximum Acceptable Cumulative Metal Addition to Soil (kg/ha)
Arsenic	15
Cadmium	4
Cobalt	30
Lead	100
Mercury	1
Molybdenum	4
Nickel	36
Selenium	2.8
Zinc	370



It is notable that these standards do not include chromium and copper, which are regulated in the Nutrient Management Act. The maximum acceptable metal concentration in processed sewage products are the same as the low metal standards of the Nutrient Management Act Regulation (O. Reg. 267/03 Part IX, Table 1 Column 2). The maximum cumulative metal addition to soil is more difficult to compare with the Nutrient Management Act regulation, since Regulation 267 provides for the maximum permissible metal addition to soil per five years and the maximum permissible metal concentration in soil receiving non-agricultural source materials (O. Reg. 267/03 Part IX, Table 1 Columns 4 and 5).

3.2.6.2 T-4-106 Organic Fertilizers under the Fertilizers Act

The organic fertilizers Trade Memorandum defines organic fertilizer as a product that is solely derived from organic matter and defines organic-based fertilizer as a product that contains at least 15% organic matter. Given that pellets would contain constituents other than organic matter, they meet the definition of an organic-based product. Products that are described as ‘environmentally beneficial’ must provide a rationale for the claim. If a product such as biosolids pellets contains 25% of a nutrient or several nutrients that are slowly released, such as organic nitrogen that is mineralized, then it may be indicated on the label along with a guarantee (such as percent total nitrogen and percent water insoluble). In the case of the City of Toronto pellets, the label provided by the City of Toronto Works and Emergency Services (WES) indicates 3.5 % total nitrogen and 3.25 % water insoluble. Statements that the product is completely safe and non-toxic are not permitted on the label.

3.2.6.3 T-4-112 Information Required for the Assessment of By-Products and Other “Waste” Materials Sold as Fertilizers or Supplements

The CFIA asks for specific information for the assessment of biosolids pellets to be sold as a fertilizer. This information includes:

- Description of the product (constituent materials);
- Description of the benefits of using the product, recommended rate and method of application;
- Description of the nutrients and other components that account for the described benefits;
- Description of the process by which the biosolids pellets are produced or generated. This would include a description of the source of raw sewage (*i.e.* municipal residential, commercial or industrial sewage), the process by which the solids are generated (*i.e.* primary and secondary activated sludge and anaerobic digestion) and a description of the pelletization process;

- Identification of contaminants that may occur in the product and the form in which they occur;
- Any analysis of the product that is available;
- Copies of scientific reports that support claims of effectiveness and safety of the product; and
- Information on whether the product or a similar product is currently used in agriculture or for other purposes.

3.2.6.4 T-4-113 Guidelines to Safety Assessments of Fertilizers and Supplements and to Information to be Submitted in Demonstrating Product Safety

The Trade Memoranda describe safety assessments conducted by the Fertilizer Section of the Plant Products Division of the CFIA and submissions submitted to the Plant Products Division to demonstrate product safety by the product proponent.

The Plant Products Division bases their assessment on information provided by a proponent to address food safety, human safety and environmental effects. The assessment is carried out with the assistance of Environment Canada and Health Canada.

The CFIA does not provide approvals; instead it is the CFIA's approach that if the requirements under the Federal Fertilizers Act are met, then the product can be sold. The CFIA will review operations after production has started and issue any orders deemed necessary without issuing approvals.

As previously mentioned, the City of Toronto applied to the CFIA for review of the pellets.

3.2.7 Other Jurisdictions

The following section summarizes how biosolids are regulated in other Canadian, American and European Union jurisdictions. Table 3-3 is a summary of the most stringent metals and pathogen standards for different jurisdictions. These are the standards that are or would be applied to relatively unrestricted use.

Table 3-3: Biosolids Regulations and Standards From Various Jurisdictions.

Parameter	Canadian Regulations and Standards (mg/kg dry weight)				USEPA Exceptional Quality ^e (mg/kg)	European Union ^f (mg/kg)	Western Australia C1 and P1 ^g (mg/kg) ^h
	Ontario ^a	British Columbia Biosolids Growing Medium ^b	Quebec Category C1P1 ^c	Standards for Metals in Fertilizers and Supplements ^d			
Arsenic	170	13	13	75	41		20
Cadmium	34	1.5	3.0	20	39	10	3
Chromium	2800	100	210			1000	100
Cobalt	340	34	34	150			
Copper	1700	150	100		1500	1000	100
Lead	1100	150	150	500	300	750	150
Mercury	11	0.8	0.8	5	17	10	1
Molybdenum	94	5	5.0	20			
Nickel	420	62	62	180	420	300	60
Selenium	34	2	2.0	14	100		3
Zinc	4200	150	500	1850	2800	2500	200
PCBs							0.3
Pathogens		<1000 fecal coliform MPN	<1000 MPN/g fecal coliform <u>and</u> <3 MPN/4 g salmonella		<1000 MPN/g fecal coliform <u>or</u> <3 MPN/4 g salmonella		Salmonella: <1 count per 50 g of dry product <u>and</u> Thermo-tolerant coliforms: <100 counts per gram of dry product

Notes:

- a. Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land (MOE, 1996a) Table 1 Column 4 – Present Requirements for Anaerobic, Dewatered and Dried Biosolids and Other Wastes
- b. BC Reg. 18/2002 – Schedule 4 - Quality Criteria, Biosolids Growing Medium
- c. Interim Criteria for the Reclamation of Fertilizing Residuals Quebec 2002, Table 3.4
- d. CFIA Trade Memorandum T-4-93
- e. 40 CFR Ch. I Part 503.13 Table 3 – Pollutant Concentrations
- f. Working Document on Sludge 3rd Draft April 2000 Annex III – Proposed Limit Values for Concentrations of heavy metals in sludge for use on land.
- g. Western Australia’s Guidelines for Direct Land Application of Biosolids and Biosolids Products, February 2002 (draft).
- h. Based on dry weight



3.2.7.1 Canadian Provinces

Available biosolids regulations from Canadian provinces were reviewed. Of the provinces reviewed, British Columbia, Alberta, Quebec, Nova Scotia and New Brunswick have regulations and guidelines specific to land application of biosolids. Manitoba issues licenses under the Manitoba Environment Act, but does not have regulation specific to beneficial use or disposal of biosolids. There was no information available on biosolids disposal and/or reuse from Saskatchewan, Newfoundland and Prince Edward Island. According to the websites for the Cities of Regina and Saskatoon, biosolids are recycled on agricultural land, but no further information was available. Regulations in British Columbia and Quebec address non-agricultural uses for high quality biosolids products.

British Columbia

The British Columbia *Organic Matter Recycling Regulation* provides for diversion of organic matter from disposal towards recycling such as land application (McDougall *et al.*, 2002). Managed organic matter under the act includes agricultural waste, biosolids, compost and yard waste [BC OMRR]. The regulation defines two classes of biosolids as well as “biosolids growing medium”. The pellets produced at the ABTP are similar to Class A biosolids under the regulation. The requirements for Class A biosolids include pathogen reduction, vector attraction reduction and other quality criteria equivalent to those of the CFIA *Standards for Metals in Fertilizers and Supplements* (Trade Memorandum T-4-93). Class A biosolids may be sold or distributed in volumes of less than 5 m³ without further approvals. If the volume is greater than 5 m³, then a ‘Land Application Plan’ must be prepared and approved.

Biosolids growing medium is a retail grade product that is produced by blending Class A biosolids with other material to make a topsoil like product which may be distributed without restriction. Biosolids growing medium has to meet the same criteria as Class A biosolids, with the exception of cadmium, copper, mercury, and zinc, where the criteria is lower. If class A biosolids or biosolids growing medium is marketed and sold as a fertilizer or a supplement, then it would have to meet the requirements of the Canada Fertilizers Act.

Currently there are no wastewater treatment plants in British Columbia that produce pelletized biosolids.

Quebec

The Province of Quebec defines fertilizing residuals as:

...objects that are “expired, rejected or otherwise considered waste and that can be used to maintain or improve, separately or simultaneously, plant nutrition, as well as the physical and chemical properties and biological activity of soils.” [Interim Criteria for Reclamation of Fertilizing Materials].

The reclamation and use of fertilizing materials is regulated by the Quebec *Environmental Quality Act*. The *Criteria for Reclamation of Fertilizer Materials* cover a wide range of organic material, including sewage biosolids, for a wide range of potential uses. The Criteria specifically addresses the use of fertilizing residuals both for horticultural applications as well as for the manufacture of soil mixes. Residuals are classified according to contaminants and pathogen content, as well as by odour. Contaminant levels for Category 1 residuals are similar to those for biosolids growing medium in British Columbia. Currently in Quebec, the cities of Gatineau and Montreal produce biosolids pellets.

3.2.7.2 *United States Environmental Protection Agency*

In the United States, the US EPA has a mandate to protect human health and to safeguard the natural environment. Unlike Canada, the United States has national biosolids standards that are the responsibility of the US EPA. The standards are contained in Part 503 of Chapter 40 of the Code of Federal Regulations, which became effective in 1993. The regulation includes standards for pollution limits, management practices, monitoring requirements, operational standards record keeping and reporting.

The US regulations have three general criteria for biosolids quality. The quality of the biosolids determines the level of restrictions placed on the use of the biosolids. These categories are:

- Ceiling pollutant concentration,
- Pathogen content (Class A and B), and
- Process control criteria to control vector attraction.

Biosolids that meet the strictest level of all three categories are called ‘exceptional quality’ and have no restrictions placed on their use and distribution under the regulation. Biosolids that are not ‘exceptional quality’ have restriction placed on use and distribution, depending upon where they rank in each category.

The United States regulates nine inorganic elements, namely, arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium and zinc, compared to the eleven regulated by Ontario (Ontario regulates the same metals, as well as cobalt and chromium). Compared to the Ontario standards, the US standards for pollutant metals are mostly higher (*i.e.* less stringent).

In October 2003, the US EPA announced a decision not to regulate dioxins in land applied sewage biosolids. Their decision was based upon an observed declining trend in dioxin levels in sewage biosolids and on the determination that the concentrations of dioxins do not pose a significant risk to human or environmental health.

To be qualified for Class A designation, biosolids must meet specific process, pathogen content and monitoring requirements. Fecal coliforms (indicator bacteria) and *Salmonella* must be measured at the time the biosolids are used or disposed, or prepared for distribution. Class A biosolids must meet one of two requirements: either less than 1,000 MPN fecal coliforms or less than 3 MPN *Salmonella sp.* bacteria per 4 grams total solids (dry weight basis). Processes that involve heat treatment must also meet specific time-temperature requirements.

Based upon available data, the ABTP pellets are consistent with the US EPA's requirements for the exceptional quality classification.

3.2.7.3 European Union

Like the United States, the European Union has a central standard for use of sewage biosolids. If member states decide to reuse biosolids, they must meet the minimum standards or they may set more stringent standards. Member states are not obliged to reuse biosolids and may opt to otherwise dispose of them. Standards for sewage sludge used in agriculture are contained in Council Directive 86/278/EEC. The purpose of Objective 86/278 is to regulate the use of sewage sludge in agriculture to prevent harmful effects on soil, vegetation, animals and man. The Directive is a framework for regulation of biosolids in member states. The current directive does not contemplate the use of biosolids for anything other than agriculture. However, the European Union has issued the third draft of a working document on sludge that suggests broadening the current scope of the regulations to include the use of biosolids in silviculture, green areas and reclaimed land. Where biosolids are to be used without restriction, such as for green spaces and for horticulture, advanced treatment, with a similar outcome to pelletization, would be required.



3.2.7.4 *Western Australia*

The Department of Environment for Western Australia (2002) has produced working draft guidelines for the *Direct Land Application of Biosolids and Biosolids Products*. The main objective of the guideline is to “provide a means of minimising public health risks and environmental harm”.

The guideline applies to “the reuse of biosolids in direct land application”, where direct application is confined to large tracts of land and defines biosolids as “stabilised organic solids produced by treatment of sewage or septage that can be beneficially reused”. The guidelines further define pellets as “small compressed balls or granular like product dried to greater than 90% total solids”. These biosolids and biosolid products are given a grade based on contaminant (from C1 to C3, with C1 being of highest quality) concentrations and the levels of treatment to reduce pathogens, vector attraction and odour (P1 to P4 with P1 being the highest quality). Biosolids are assigned the lowest grade of any one contaminant. The guidelines grade inorganic contaminants arsenic, cadmium, total chromium, copper, lead, mercury, nickel, selenium and zinc as well as some organics such as DDT/DDD/DDE, aldrin, chlordane, heptachlor, HCB, lindane, PHC and PCBs. Therefore, if most contaminants are graded C1 but, for example, PCBs are graded C3 then the biosolids are graded C3.

The contaminant grading is based on the comparison of the “biosolids adjusted contaminant concentration” or BACC with the “Contaminant Acceptance Concentration Thresholds”. The BACC is calculated by adding the mean of all samples with the standard deviation. There are no thresholds for C3, instead if a contaminant exceeds the C2 threshold, then it automatically is graded C3.

For pathogen grading, the guidelines provides several treatment methods such as “digested and then composted in a vessel, heated at >55°C for a 3 day period” that typically achieve required pathogen levels in each grade.

The possible end use of the biosolids according to classification is provided in Table 3-4.

Table 3-4: Western Australia’s Classification and End Uses of Biosolids

Biosolids Classification	Minimum Pathogen Grade	Minimum Contaminant Grade
Unrestricted – suitable for public sale and distribution	P1	C1
Urban landscaping(not household use)	P2	C2
Horticulture	P2	C2
Agricultural direct land application (root crops)	P2	C2
Agricultural direct land application (not root crops)	P3	C2
Forestry direct land application	P3	C2
Mine-site rehabilitation	P3	C2
Municipal landfill disposal	P4	C3
Secure landfill	P4	C3
Thermal processing (incineration, oil extraction, metal smelting or use in building products)	P4	C3

3.2.7.5 Summary

Regulation in Canada, Western Australia and the United States permit the use of biosolids products outside of agriculture. Biosolids become a product when they are sold. Biosolids products sold as a fertilizer or soil supplement are regulated by the Canada Fertilizers Act. If they are given away, they come under the same regulations as biosolids cake. In the United States and Western Australia, biosolids that meet exceptional quality criteria may be distributed and used without restriction. Although Europe is currently considering wider use of biosolids, use outside of agriculture is currently not permitted.



4. PELLET QUALITY DATA

4.1 City of Toronto's Monitoring Program

The City of Toronto collects and analyzes samples of biosolids cake biweekly. Samples are collected from the discharge chute of an in-service centrifuge. The biosolids cake is analyzed for the eleven regulated metals, nutrients and total solids. This monitoring is mandated by the Ashbridges Bay Treatment Plant (ABTP) Certificate of Approval. Biosolids pellets were also sampled when the pelletizer was in operation. Pellet samples were analyzed for a similar set of parameters to biosolids cake.

In addition to biweekly monitoring, the City performs annual plant performance evaluations, which consist of hourly sampling over a 22-hour period. The time of year that the evaluation is carried out varies from year to year. The set of parameters is extensive and includes polychlorinated biphenyl (PCB), polychlorinated dibenzo-p-dioxin (PCDD), polychlorinated dibenzofurans (PCDF) and volatile organics in addition to nutrients, metals and general chemistry.

4.2 Risk Assessment Data Set

Data on the eleven Ontario regulated elements in ABTP biosolids cake for the past 14 years were available from April 1989. There were also data available from 1978 for cadmium, chromium, copper, nickel, lead and zinc.

Because the cake data set was more complete than the pellet data set, it was used to determine input values for the risk assessment. The concentrations of metals and other elements are not expected to change substantially with pelletization. Data from 1996 to 2003 were used to be most representative of the current biosolids quality. Older data are likely not representative given improvements in treatment efficiency and the introduction of greater controls over discharges to the sewer. The complete data set is found in Appendix E of this report, with statistical justification for the use of cake data set provided in Appendix F.



The upper and lower confidence limits of the mean (UCLM and LCLM) are the 95% confidence interval surrounding the mean. The confidence interval is calculated as:

$$95\%CI = mean \pm 1.96 \times \frac{s}{\sqrt{n}},$$

where 's' is the sample standard deviation and 'n' is the number of observations.

In addition, Jacques Whitford selected the cake data set since the former pelletizer at ABTP is not currently in use and the cake data represents the potential concentrations of entities of potential concern (EoPCs) that may eventually end up in pellet concentrations in the future. Although there was some variance in concentration between the cake and the pellet data sets in EoPC concentrations, it was not believed to be a significant factor in the conduct of the Human Health and Ecological Risk Assessment (HHERA) (see Appendix F).

Table 4-1 presents the analytical data and soil loadings for trace organics in ABTP biosolids. There were only limited data available for the trace organic compounds in the City of Toronto's biosolids, one value in the case of PCBs and only five observations for PCDD/PCDF toxic equivalent quotients (TEQ). Jacques Whitford approached the MOE to attempt to establish whether or not these values were consistent with organic EoPC concentrations found in other municipal biosolids in Ontario. After review of the trace organics data, the MOE provided comment that the limited data on concentrations measured in the ABTP biosolids cake data were approximately two times higher than those found in other sewage treatment plants in Ontario (pers comm., Kleywegt, 2004). Since there were limited data for trace organics, it was felt that these selected organic compounds could be carried forward in the quantitative risk assessment without underestimating potential risks.



Table 4-1: Analytical Data for Trace Organics in Biosolids Cake from 1996 to 2003, Used as the Pellet Concentration

Descriptive Statistics	PCBs	PCDD/PCDF TEQ
Mean Concentration (ng/kg)	170	11
Standard Deviation	NA	4.15
SEM ^a	NA	1.86
95% UCLM ^b	NA	15
95% LCLM ^c	NA	7.5
Number of observations	1	5
Loading 5.4 dry t/ha (ng/ha)	890,000	80,000
OTR ^d Mean Background Concentration (ng/kg)	10 500	1.73

Notes:

- a. SEM – Standard error on the mean.
- b. UCLM – upper confidence limit on the mean.
- c. LCLM – lower confidence limit on the mean.
- d. MOE, 1993. Ontario Typical Range of Chemical Parameters in Soil, Vegetation, Moss Bags and Snow. Old Urban Parkland Land Use.
- e. NA: Not Applicable

Table 4-2 summarizes analytical data for the inorganics in ABTP biosolids. The inorganic element data set was comprised of 174 sample concentrations providing sufficient data to conduct the risk assessment.

No data on chromium speciation was available, which significantly limits the ability to quantitatively evaluate chromium risks.

Table 4-2: Analytical Data for Inorganic Chemicals in Biosolids Cake^a from 1996 to 2003, Used as the Pellet Concentration

Descriptive Statistics	Inorganic Chemical										
	Arsenic (As)	Cadmium (Cd)	Cobalt (Co)	Chromium (Cr)	Copper (Cu)	Mercury (Hg)	Molybdenum (Mo)	Nickel (Ni)	Lead (Pb)	Selenium (Se)	Zinc (Zn)
Mean Concentration (mg/kg)	7.3	4.6	2.9	150	1100	1.6	12	36	88	2.9	880
Standard Deviation	5.9	3.5	2.4	51	120	0.80	5.5	14	34	1.3	130
SEM ^b	0.45	0.27	0.18	3.9	9.2	0.061	0.42	1.1	2.6	0.096	10
95% UCLM ^c	8.1	5.1	3.3	160	1200	1.7	13	39	93	3.1	900
95% LCLM ^d	6.4	4.1	2.6	140	1100	1.5	11	34	83	2.8	860
95th percentile	14	11	6.3	250	1300	2.7	19	63	140	5.3	1100
Number of Observations	174	174	174	174	174	174	174	174	174	174	174
Loading 5.4 dry t/ha (mg/ha)	44,000	28,000	18,000	860,000	6,300,000	9,300	68,000	210,000	500,000	17,000	4,800,000
OTR ^e Mean Background Concentration (mg/kg)	2.4 ^f	0.3	7.7	26	30	0.8	0.25	15	35	0.48	75

Notes:

- Based on dry weight
- SEM – Standard error on the mean.
- UCLM – upper confidence limit on the mean.
- LCLM – lower confidence limit on the mean.
- MOE, 1993. Ontario Typical Range of Chemical Parameters in Soil, Vegetation, Moss Bags and Snow. Old Urban Parkland Land Use.
- City of Toronto background concentration in parks (Ursitti *et al.*, in press). This arsenic concentration was used for comparison instead of the OTR mean concentration because background arsenic concentrations as being more typical of Southern Ontario.



4.3 Evaluation of Pellet Integrity

To evaluate the physical fate of land applied pellets, 10 grams of pellets were spread on a rectangle of felt 29.5 by 23 centimetres that was tacked to bare (not covered by sod or grass) soil (Figure 4-1). An average of 11 pellets weighed 121 mg. A second rectangle of felt was placed ovetop. The second layer was used to prevent the pellets from moving off the felt when water was applied and to simulate the humid microenvironment in grass foliage.

Figure 4-1: Pellets Spread on Felt

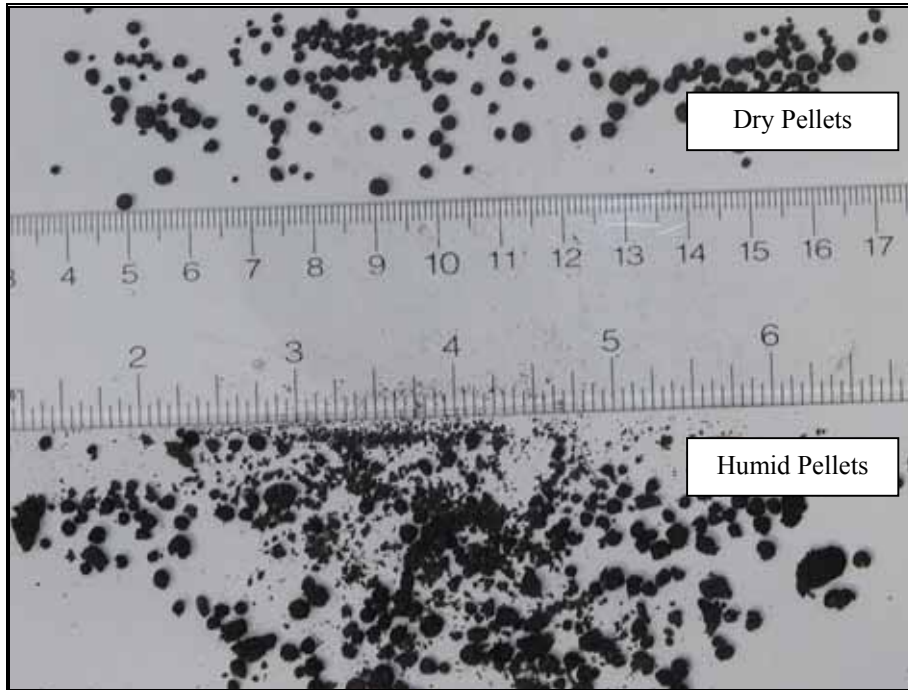


The felt was watered twice per day using a watering can until the surface of the felt was saturated. The soil was well drained and dry beneath the felt.

After 5 days, the pellets had swelled and became friable (Figure 4-2). Once the pellets become friable, they lose their structural integrity and crumble, becoming integrated into the humic layer of the soil. It should be noted that this trial was carried out under controlled simulated natural conditions, to informally test whether the pellets would breakdown. Like any other granular fertilizer, biosolids will likely not dissolve on the soil surface under sustained dry conditions. However, it should also be noted that, once applied, the pellets will migrate down through the grass foliage to the surface of the soil or thatch layer, and will thus not be readily available for children to pick-up and ingest.

In this study, pellets are assumed to be readily available for children to ingest throughout the growing season. The results of the pellet experiment demonstrate that this assumption is likely to overestimate potential exposure to children.

Figure 4-2: Dry and Humid Pellet Sizes



Initially, this experiment was attempted on a section of lawn; however, the pellets disappeared into the thatch layer of the sod and further observations were not practical.

5. HUMAN HEALTH RISK FROM CHEMICAL EXPOSURE

The following sections detail the results of the quantitative human health risk assessment (HHRA) for exposure to chemicals in biosolids pellets.

5.1 Hazard Identification

The hazard identification stage of the HHRA approach determines the entities of potential concern (EoPCs) that will be further assessed.

5.1.1 Selection of Entities of Potential Concern

The EoPCs in pellets (derived from cake concentrations, see Section 4.0) that could be quantitatively assessed based on availability of sufficient data included 11 inorganic elements:

- Arsenic (As),
- Cadmium (Cd),
- Cobalt (Co),
- Chromium III (Cr III),
- Copper (Cu),
- Mercury (Hg),
- Molybdenum (Mo),
- Nickel (Ni),
- Lead (Pb),
- Selenium (Se), and
- Zinc (Zn).

The inorganic EoPCs were selected based on current standards and regulations, their contribution to plant growth and data quality. Regulations and standards considered include the MOE's (1996a) *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land* (which provides criteria for all eleven inorganic elements), Trade Memorandum T-4-93 (which regulates As, Cd, Co, Pb, Hg, Mo, No, Se and Zn), and the Nutrient Management Act (which regulates Cr and Cu). Details of these standards and regulations are provided in Chapter 3.0. There are 15 inorganic elements considered essential plant nutrients, as detailed in Section 3.2.3. Of these 15, Co, Cu, Mo, Ni and Zn were selected as EoPCs. Finally, based on the previous selection considerations, the available data was reviewed and found that there was sufficient data

available for the statistical analysis of inorganic elements to determine a reasonable maximum concentration in pellets.

Total chromium was measured by the City of Toronto. Chromium is a naturally occurring element that is most commonly found as chromium III and chromium VI (hexavalent chromium) forms in the environment (ATSDR, 2000). Chromium III can persist and accumulate in soils because of its association with relatively inert phases while chromium VI, however, is more soluble and is not readily adsorbed onto particulate matter. Although little literature exists on the species of chromium present in soils, it is believed that nearly all the chromium in soils (excluding those contaminated with chromium VI) is likely present as chromium III (Environment Canada and Health Canada, 1994; ATSDR, 2000). This conclusion is based on limited sample data and the environmental fate of chromium III and chromium VI.

As well, the following trace organics were selected as EoPCs:

- Polychlorinated biphenyls (PCBs),
- Dioxins (PCDDs), and
- Furans (PCDFs).

Dioxins and furans are generic terms used to refer to two classes of organic chemical compounds classified as polyhalogenated aromatic hydrocarbons. This group includes polychlorinated dibenzo-dioxin (PCDDs) and polychlorinated dibenzo-furan (PCDF) together referred to as PCDD/Fs. In this assessment, dioxins and furans are referred to generically as PCDD/Fs.

PCBs and dioxins/furans were selected as EoPCs due to public concerns regarding the potential adverse health effects associated with these trace organics. Information on the toxicological effects that could result from exposure sufficiently high levels of these EoPCs is summarized in Tables 5-1 and 5-2.

Although other entities may exist in pellets, data on these compounds are limited, introducing a high degree of uncertainty into the assessment of these compounds. Even data on the selected organic compounds are limited; however, the larger base of information on these chemicals in biosolids, other than specific to the City of Toronto, makes the evaluation of these chemicals more practical. Furthermore, although data on volatile organic compounds (VOCs) exist, based on volatility and persistence, they were not evaluated in this assessment. For the purposes of this study only the listed inorganic elements and trace organics were evaluated.



5.2 Dose-Response Assessment

Previous review studies of whether or not epidemiological evidence of health effects exist resulting from biosolids, and particularly in pellet form, use on land have yielded mixed results. Differences in study methodologies, the range of components of biosolids, methods of application, and health outcomes of relevance have resulted in a broad range of findings that may not be comparable, and which may not be applicable to the current pellet study.

The Health Aspects of Biosolids Land Application report for the City of Ottawa provides a summary and review of epidemiological studies with comparison populations of either sewage treatment plant workers or farm or resident populations within range of exposure (Apedaile *et al.* 2002).

This summary and comparison found that most studies were either unable to demonstrate increased human health effects, or found certain health effects to be somewhat increased, but not significantly so. Some studies did, however, find a significantly higher prevalence of gastroenteritis, gastrointestinal symptoms or headaches in sewage treatment plant workers (Khuder, *et al.*, 1998; Lundholm and Rylander, 1983).

Likewise, most studies of farm and resident populations did not find significant increases in health effects for populations living with range of exposure. However, some studies yielded mixed results, finding slightly higher rates of viral infections or coxsackie, but also weak associations between exposure and specific viral infection, or associations for echoviruses (Caman *et al.*, 1985; Northrop *et al.*, 1980).

The challenge of determining the potential health effects of biosolids pellet application based on existing literature resulted in the decision to undertake a human health and ecological risk assessment of the application of biosolids pellets on City of Toronto property. The dose-response assessment involved the selection of appropriate toxicity reference values and corresponding bioavailabilities for each EoPC. The following sections present summaries of the selected toxicity information with a detailed toxicological profile provided in Appendix A.

5.2.1 Toxicity Reference Values

An essential part of the risk assessment is the identification of appropriate toxicity reference values (TRVs). This is typically done by a literature review of toxicological assessments published by several agencies including Health Canada, the US Environmental Protection Agency (US EPA), the Ontario Ministry of the Environment (MOE) and other selected sources. Preference has been given to the most scientifically defensible recent TRVs in the readily available references from Health Canada, the US EPA and the MOE.

5.2.1.1 Non-carcinogenic EoPC TRVs

Summaries of the non-carcinogenic TRVs selected for inclusion in the risk assessment are provided in Table 5-1 and detailed rationales for each of the toxicity values are provided in Appendix A.

Table 5-1: Toxicity Reference Values for Non-Carcinogenic Substances

EoPC	Route of Exposure	Exposure Limit (mg/kg-d) ^a	Toxicological Basis	Source Agency
As	Ingestion	3.0 x 10 ⁻⁴	Blackfoot disease, keratosis, hyper-pigmentation and skin disease in humans	US EPA, 1993a
	Inhalation	NA		
Cd	Ingestion	5.0 x 10 ⁻⁴	Proteinuria in humans	US EPA, 1994
	Inhalation	NA		
Cr III	Ingestion	1.5	Reduced weight of livers and spleens of rats	US EPA, 1998a
	Inhalation	NA		
Co	Ingestion	0.020	Upper range of average intake in diet of children	US EPA, 2001
	Inhalation	5.0 x 10 ⁻⁶	Respiratory effects in rats	US EPA Region III, 1995
Cu	Ingestion	0.030 – adult 0.10 - toddler	Protection from liver damage	CCME, 1999
	Inhalation	NA		

EoPC	Route of Exposure	Exposure Limit (mg/kg-d) ^a	Toxicological Basis	Source Agency
Pb	Ingestion	0.0036	Effects on the central nervous system and blood (e.g. neurobehavioural effects, and anemia)	Health Canada, 1996a
	Inhalation	NA		
Hg	Ingestion	3.0×10^{-4}	Liver damage	US EPA, 1995
	Inhalation	3.0×10^{-4} mg/m ³	Neurological effects in humans	US EPA, 1995
Mo	Ingestion	0.0050	Depleted copper stores in the body	US EPA, 1993b
	Inhalation	NA		
Ni	Ingestion	0.020	Decreased body weight and organ weights in rats	US EPA, 1996a
	Inhalation	NA		
Se	Ingestion	0.005	Lowered hemoglobin levels, central nervous system abnormalities, gastrointestinal abnormalities	US EPA, 1991
	Inhalation	NA		
Zn	Ingestion	0.30	Decreased erythrocyte superoxide dismutase (ESOD) levels in women. ESOD is a blood enzyme that protects against cell injury from active peroxide species and indicator of copper balance in the body.	US EPA, 1992
	Inhalation	NA		
2,3,7,8-TCCD TEQ	Ingestion	2.0×10^{-9}	Developmental and reproductive effect	Health Canada, 2003a
	Inhalation	NA		
PCBs	Ingestion	2×10^{-5}	immunological effects in monkeys	US EPA, 1996b
	Inhalation	NA		

Note:

- a. Units are in mg/kg-day, unless otherwise indicated.
b. NA: Not Available

5.2.1.2 Carcinogenic EoPC TRVs

Arsenic, cadmium, nickel, PCBs, dioxins and furans are known or probable carcinogens. Summaries of the carcinogenic toxicity reference values selected for inclusion in the risk assessment are provided in Table 5-2.

Table 5-2: Toxicity Values for Carcinogenic Substances

EoPC	Route of Exposure	Exposure Limit	Toxicological Basis	Source Agency
As	Ingestion	1.5 (mg/kg-d) ⁻¹	Skin cancer	US EPA, 1998b
	Inhalation	0.0043 (µg/m ³) ⁻¹	Lung cancer	
Cd	Ingestion	NA		
	Inhalation	9.8 (mg/m ³) ⁻¹	Lung and upper respiratory tract cancers.	Health Canada, 2003a
Ni	Ingestion	NA		
	Inhalation	0.24 (mg/m ³) ⁻¹	Lung and nasal tumours	US EPA, 1996a
2,3,7,8-TCCD TEQ	Ingestion	1.5x10 ⁵ (mg/kg-d) ⁻¹	Respiratory tumours in rats	US EPA, 1994
	Inhalation	3.4x10 ⁴ (mg/m ³) ⁻¹	Based on oral	
PCBs	Ingestion	2.0 (mg/kg-d) ⁻¹	Liver tumours in rats	US EPA, 1997a
	Inhalation	1 x 10 ⁻⁴ (µg/m ³) ⁻¹	Similar to oral exposure	

5.2.2 Bioavailability

Bioavailability refers to “the fraction of the total amount of material in contact with a body portal-of-entry (lung, gut, skin) that enters the blood”. Relative bioavailability is the amount of a substance entering the blood via a particular route of exposure (*e.g.* gastrointestinal) relative to the study used to derive the TRV. For instance, a relative bioavailability factor of 0.5 indicates that 50% of the administered (*e.g.* ingested) chemical is absorbed into the bloodstream compared to the absorption in the TRV study. Relative bioavailability via inhalation exposure was assumed to be 100%.

Dermal relative absorption (bioavailability) factors for inorganic elements were obtained primarily from Health Canada (Health Canada, 2003a). Table 5-3 provides the oral and dermal bioavailability factors used in this assessment. Rationale supporting the selection of each of the values recommended for use in this assessment is provided in Appendix A. The selected values are based on a conservative selection from the ranges of values in the literature. The actual form of metals in the biosolids may have lower bioavailabilities.

Table 5-3: Selected Relative Bioavailability Factors

EoPC	Oral Bioavailability	Inhalation Bioavailability	Relative Dermal Bioavailability Factor
As	0.24 (soil) 0.70 (food)	1	0.030
Cd	1	1	0.140
Cr	1	1	0.040
Co	0.003 (soil)	1	0.100
Cu	1	1	0.100
Pb	0.57 (soil)	1	0.006
Hg	1	1	0.050
Mo	1	1	0.100
Ni	1	1	0.350
Se	1	1	0.002
Zn	1	1	0.020
PCDD/PCDF	1	1	0.06
PCB	1	1	0.067

5.2.3 Dermal Toxicity

There are limited TRVs available for the dermal pathway. As a result, dermal exposures are added to the oral dose after being adjusted for relative bioavailability or absorption (Health Canada, 2003b). By applying the adjustment bioavailability as described in Section 5.2.2, the dermal dose can be compared to the oral TRV. The selected dermal bioavailabilities outlined in Table 5-3 were used in the dermal exposure calculations for each corresponding EoPCs.

5.3 Exposure Assessment

The exposure assessment is a qualitative or quantitative evaluation of the likelihood or degree to which receptors will be exposed to the EoPCs previously identified in the hazard identification. A process is used to complete the exposure assessment beginning with the identification of the receptors. This is followed by a visualization of exposure scenarios that are illustrated by a conceptual model. The final step is an evaluation of the likelihood of these exposure pathways resulting in the selection of exposure pathways.

5.3.1 Exposure Pathways

The identification of exposure pathways assesses the likelihood and mechanisms of potential hazards coming into contact with the identified receptors. This includes identifying potential exposure mechanisms, followed by an evaluation of each mechanism. If the likelihood of the evaluated mechanism is limited, exclusion from the assessment may be an option.

5.3.2 Receptor Identification and Characteristics

The future application of pellets to land uses must first be identified followed by the identification of the most sensitive receptors likely to be present. Detailed receptor characteristics by age group are summarized in Appendix C. Receptor physical characteristics such as weight have been selected as representative of typical or average characteristics.

Carcinogenic and non-carcinogenic chemicals are evaluated differently with respect to life stages as illustrated in Table 5-4. Non-carcinogenic effects were evaluated by individual life stages while carcinogenic effects were evaluated over a lifetime. The life stages were selected to capture all likely exposure scenarios where the toddler was selected to be protective of all other life stages with similar exposures. The toddler life stage is considered to be from 6 months of age up to five years of age (i.e. 6 months to <5 years). The toddler is considered protective of all other receptors because toddlers have a lower body weight and higher ingestion rate (i.e. higher breathing rate and food ingestion rate per body mass) compared to other age groups, which make them more sensitive. Toddlers also tend to be the most exposed to soils and dirt.

Carcinogenic effects are evaluated based on probability of an individual developing cancer from a lifetime of exposure to a carcinogen. A composite receptor was chosen for modelling carcinogenic risk. A composite receptor is assumed to be exposed to pellet-amended soil in parks or on golf-courses or in home environments from birth to 75 years of age. This is considered conservative, and the combination of this assumption with average physical receptor characteristics is considered to be a reasonable maximum scenario. Conservative or reasonable maximum values were also selected for other lifestyle parameters, including pellet ingestion, soil ingestion, fraction of produce ingested from a backyard garden, exposure frequency and duration, and pellet application rate. The average daily exposure of a composite receptor is calculated from the average daily exposures experienced during each lifestage (i.e. infant, toddler, children, teenager, adult lifestages), weighted by the fraction of the total lifetime that each lifestage represents.

Table 5-4: Human Receptors considered in the Biosolids Pellet Study

EoPC	City Worker Scenarios	Recreational Use Scenario	Home Use Scenario
Non-Carcinogen	Adult exposed over 30 years.	Toddler aged six months up to five years old (i.e. 6 months to <5 years). Adult Golfer aged 20 to 75 years old.	Toddler aged six months up to five years old (i.e. 6 months to <5 years). Adult aged 20 to 75 years old.
Carcinogen	Adult exposed over 30 years.	Receptor assumed to grow up using the site from birth to 75 years lifetime. Exposures averaged over five age groups: <ul style="list-style-type: none"> • 0 to <6 months; • 6 months to <5 years; • 5 to <12 years; • 12 to <20 years; • 20 to <75 years. 	Receptor assumed to grow up using the site from birth to 75 years lifetime. Exposures averaged over five age groups: <ul style="list-style-type: none"> • 0 to <6 months; • 6 months to <5 years; • 5 to <12 years; • 12 to <20 years; • 20 to <75 years.

5.3.2.1 Potential Exposure Mechanisms

The mechanisms by which human receptors may be exposed to EoPCs include:

- inhalation of dust or vapours;
- ingestion of amended soils or pellets;
- dermal contact with amended soils or pellets; and
- ingestion of produce grown in amended soils.

The likelihood of exposure is considered and evaluated in terms of the following series of definitions, presented in Table 5-5.

Table 5-5: Exposure Definitions

Likelihood Of Exposure	Definition
Very Unlikely	Level of exposure that could result in adverse effects is not expected.
Unlikely	Level of exposure that could result in adverse effects would probably not occur.
Possible	Level of exposure that could result in adverse effects might be expected.
Likely	Level of exposure that could result in adverse effects is expected. Exceedance of this exposure level might be expected.

The likelihood of exposure includes consideration of the duration and frequency of exposure to each potential hazard and to the relative concentrations to which the receptor is likely to be exposed. Those hazard-exposure-receptor combinations considered to have the highest likelihood to contribute a health risk are carried forward for further quantitative analysis.

5.3.3 City Worker Scenarios

Two city worker scenarios were developed to address the likelihood of pellet application to City of Toronto parks and golf courses as well as the use of amended landfill topdressing. The following sections describe these scenarios further.

An indoor worker scenario was considered; however, concentrations of volatile chemicals in pellets are expected to be very low and other chemical risks quantitatively evaluated would not be expected to differ significantly between indoor and outdoor exposures. In addition, it is Jacques Whitford's understanding that Parks and Recreation is not considering use of pellets in greenhouses.

5.3.3.1 City Parks Worker

Table 5-6 qualitatively evaluates the likelihood of potential exposure mechanisms and determines which exposure pathways will be evaluated for the City Parks Worker Scenario.

Table 5-6: Potential Exposure Scenarios - City Parks Worker

Exposure Pathway Description	Likelihood of Exposure	Carried Forward for Quantitative Analysis?	Justification
Inadvertent ingestion of pellet material	Likely	Yes	City Parks Workers are assumed to spend the summer season applying pellets to city parkland and are expected to come into contact with pellets and pellet dust.
Dermal contact with pellets	Likely	Yes	
Ingestion/inhalation of pellets dust	Likely	Yes	
Inadvertent ingestion of amended soil	Possible	No	City Parks Workers are assumed to spend the summer season applying pellets to city parkland; the bulk of the exposure will be to pellets, moreover, the concentrations of EoPCs will be higher in the pellets than in amended soil.
Dermal contact with amended soil	Possible	No	
Ingestion/inhalation of amended soil dust	Possible	No	
Ingestion of surface water	Very Unlikely	No	City Parks Workers at the site are not expected to come in contact with the surface water or sediment within City parks impacted by pellets.
Dermal contact with surface water	Very Unlikely	No	
Dermal contact with sediment	Very Unlikely	No	City Parks Workers at the site are not expected to come in contact with the surface water or sediment within City parks impacted by pellets.
Ingestion of groundwater	Very Unlikely	No	Groundwater is not used as a drinking water source in Toronto.
Dermal contact with groundwater	Very Unlikely	No	It is unlikely that workers will have contact with groundwater for showering
Ingestion of garden produce	Very Unlikely	No	Garden produce will not be grown in the City parks.

Exposure Pathway Description	Likelihood of Exposure	Carried Forward for Quantitative Analysis?	Justification
Inhalation of outdoor vapours	Possible / Very Unlikely	Yes for organics No for Inorganics	PCBs and PCDD/Fs are semi-volatile and may produce low concentrations of vapours outdoors. Inorganic EoPCs are not volatile and thus not a relevant pathway.
Inhalation of indoor vapours	Very Unlikely	No	An indoor worker scenario was considered; however, concentrations of volatile chemicals in pellets are expected to be very low and other chemical risks quantitatively evaluated would not be expected to differ significantly between indoor and outdoor exposures.

An adult City Parks Worker was assumed to apply pellets to City of Toronto parks, golf courses and gardens for 4 hours/day, 180 days/year for 30 years. The scenario assesses the potential exposure of the City Parks Worker to non-carcinogenic EoPCs from the inadvertent ingestion and dermal contact of pellets, inhalation of outdoor vapours and inhalation of pellet dust. In this scenario 100% of the daily ingestion rate of soil was assumed to be from exposure to pellets.

A longer averaging time, using 75 years lifetime was evaluated for carcinogenic risks. The receptor characteristics of the City Parks Worker who applies pellets to parks, golf courses and gardens are summarized in Table 5-7 and the conceptual model is illustrated in Figure 5-1.

Table 5-7: City Parks Worker Characteristics

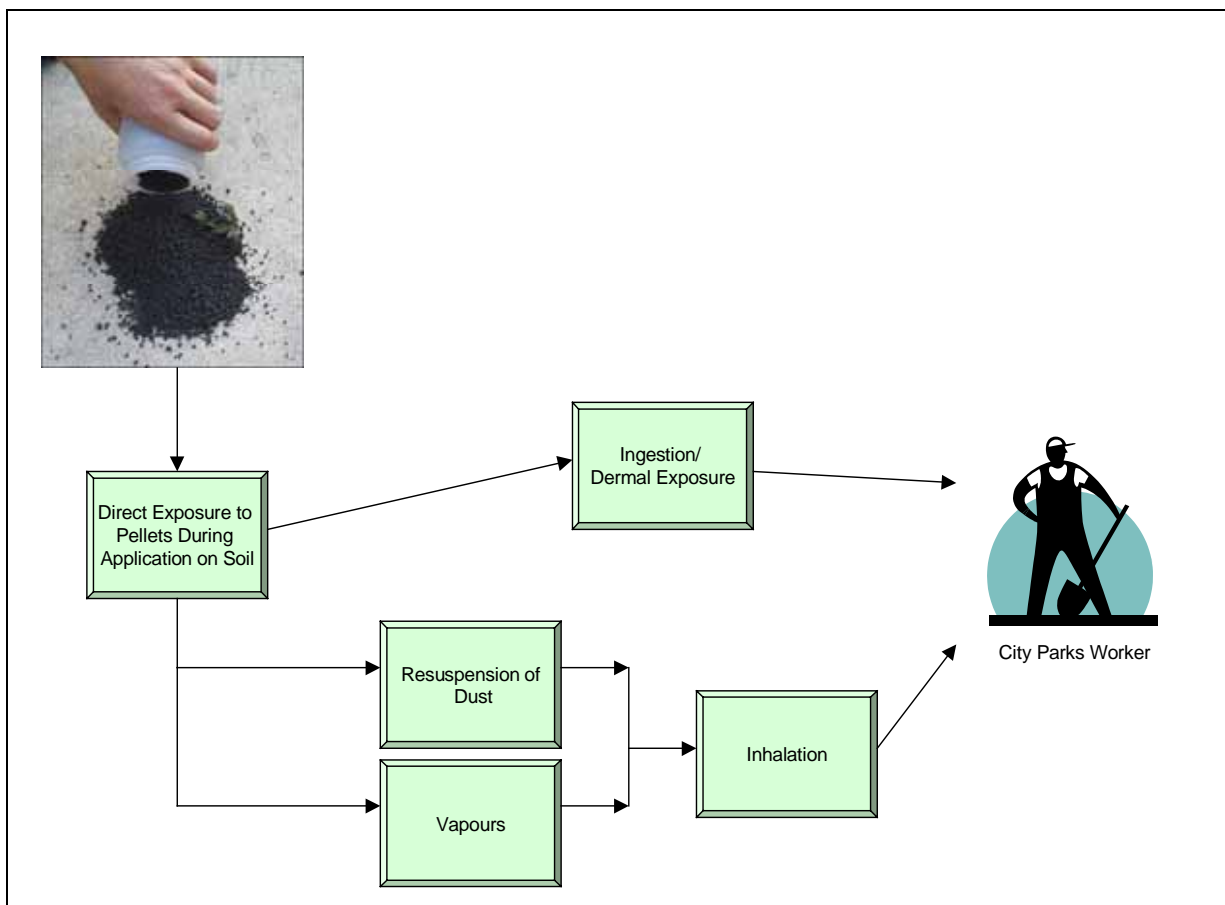
Characteristic		Units	City Parks Worker (Non-carcinogens) ^a	City Parks Worker (Carcinogens) ^b	Reference
Age	Age Range	years	20 to 55	20 to 55	
BW	Body Weight	kg	70.7	70.7	Richardson, 1997; CCME, 2000
SA _{soil}	Surface Area exposed to pellets	cm ²	2,140 ^c	2,140 ^c	Richardson, 1997
SAF _{soil}	Soil Adherence Factor	mg/cm ²	0.1	0.1	CCME, 2000
IR _{pellets}	Ingestion Rate of pellets ^d	mg/day	100	100	Richardson, 1997; CCME, 2000
IR _{air}	Inhalation Rate of pellet dust and vapours outdoors ^e	m ³ /hr	1.1 ^f	1.1 ^f	US EPA, 1997
ED	Exposure Duration	years	30	30	CCME, 2000

Characteristic		Units	City Parks Worker (Non-carcinogens) ^a	City Parks Worker (Carcinogens) ^b	Reference
EF _{soil}	Exposure Frequency for Pellet Application	days/year	180	180	Assumed application period
ET _{app}	Exposure Time spent applying pellets	hrs/day	4	4	Assumed
AT	Averaging Time	days	10,950	27,375	Calculated ^g

Notes:

- Non-carcinogens calculated for adult life stage.
- Carcinogens calculated for composite receptor characteristics averaged over 75 years.
- Exposed surface area based on total surface area of hands and lower arms.
- Assumes 100% of daily inadvertent soil ingestion occurs at while applying pellets.
- An indoor worker scenario was considered; however, concentrations of volatile chemicals in pellets are expected to be very low and other chemical risks quantitatively evaluated would not be expected to differ significantly between indoor and outdoor exposures.
- Hourly inhalation rate based upon light activity as defined in the Exposure Factors Handbook (US EPA, 1997c).
- Calculated for non-carcinogens as ED x 365 days/year, for carcinogens over lifetime exposure.
- Please see Appendix C: Human Receptor Characteristics for further details.

Figure 5-1: Conceptual Model for City Parks Worker Scenario



5.3.3.2 City Landfill Worker

Table 5-8 qualitatively evaluates the likelihood of potential exposure mechanisms and determines which exposure pathways will be evaluated for the City Landfill Worker scenario.

Table 5-8: Potential Exposure Scenarios - City Landfill Worker

Exposure Pathway Description	Likelihood of Exposure	Carried Forward for Quantitative Analysis?	Justification
Inadvertent ingestion of amended topdressing	Likely	Yes	City Landfill Workers are assumed to spend the summer season applying landfill topdressing, and are expected to come into contact with amended topdressing dust.
Dermal contact with amended topdressing	Likely	Yes	
Ingestion/inhalation of dust from amended topdressing	Likely	Yes	
Ingestion of surface water	Very Unlikely	No	City Landfill Workers at the site are not expected to come in contact with the surface water or sediment within City landfills impacted by pellets.
Dermal contact with surface water	Very Unlikely	No	
Dermal contact with sediment	Very Unlikely	No	City Landfill Workers at the site are not expected to come in contact with the surface water or sediment within City landfills impacted by pellets.
Ingestion of groundwater	Very Unlikely	No	Groundwater is not used as a drinking water source in Toronto.
Dermal contact with groundwater	Very Unlikely	No	It is unlikely that workers will have contact with groundwater for showering
Ingestion of garden produce	Very Unlikely	No	Garden produce will not be grown on landfills.
Inhalation of outdoor vapours	Possible / Very Unlikely	Yes for organics No for Inorganics	PCBs and PCDD/Fs are semi-volatile and may produce low concentrations of vapours outdoors. Inorganic EoPCs are not volatile and thus not a relevant pathway.
Inhalation of indoor vapours	Very Unlikely	No	Landfill workers will not be working indoors.

An adult City Landfill Worker was assumed to apply pellet amended landfill topdressing to City of Toronto landfills for 8 hours/day, 180 days/year for 30 years. The scenario assesses the potential exposure of the City Landfill Worker to non-carcinogenic EoPCs from the inadvertent ingestion and dermal contact of pellets, inhalation of outdoor vapours and inhalation of pellet dust. In this scenario 100% of the daily ingestion rate of soil was assumed to be from exposure to pellet amended topdressing.

A longer averaging time, using 75 years lifetime was evaluated for carcinogenic risks. The receptor characteristics of the City Landfill Worker who applies apply pellet amended landfill topdressing and composite receptors are summarized in Table 5-9.

Table 5-9: City Landfill Worker Characteristics

Characteristic		Units	City Landfill Worker ^a	Composite ^b	Reference
Age	Age Range	years	20 to 55	0 to 75	
BW	Body Weight	kg	70.7	70.7	Richardson, 1997; CCME, 2000
SA _{soil}	Surface Area exposed to pellets	cm ²	2,140 ^c	2,140 ^c	Richardson, 1997
SAF _{soil}	Soil Adherence Factor	mg/cm ²	0.1	0.1	CCME, 2000
IR _{soil}	Ingestion Rate of pellets	mg/day	100	100	Richardson, 1997; CCME, 2000
IR _{air}	Inhalation Rate of pellet dust and vapours outdoors ^e	m ³ /hr	1.1 ^f	1.1 ^f	US EPA, 1997
ED	Exposure Duration	years	30	75	CCME, 2000
EF _{soil}	Exposure Frequency for Pellet Application	days/year	180	180	Assumed application period
ET _{app}	Exposure Time spent applying pellets	hrs/day	8	8	Assumed
AT	Averaging Time	days	10,950	27,375	Calculated ^g

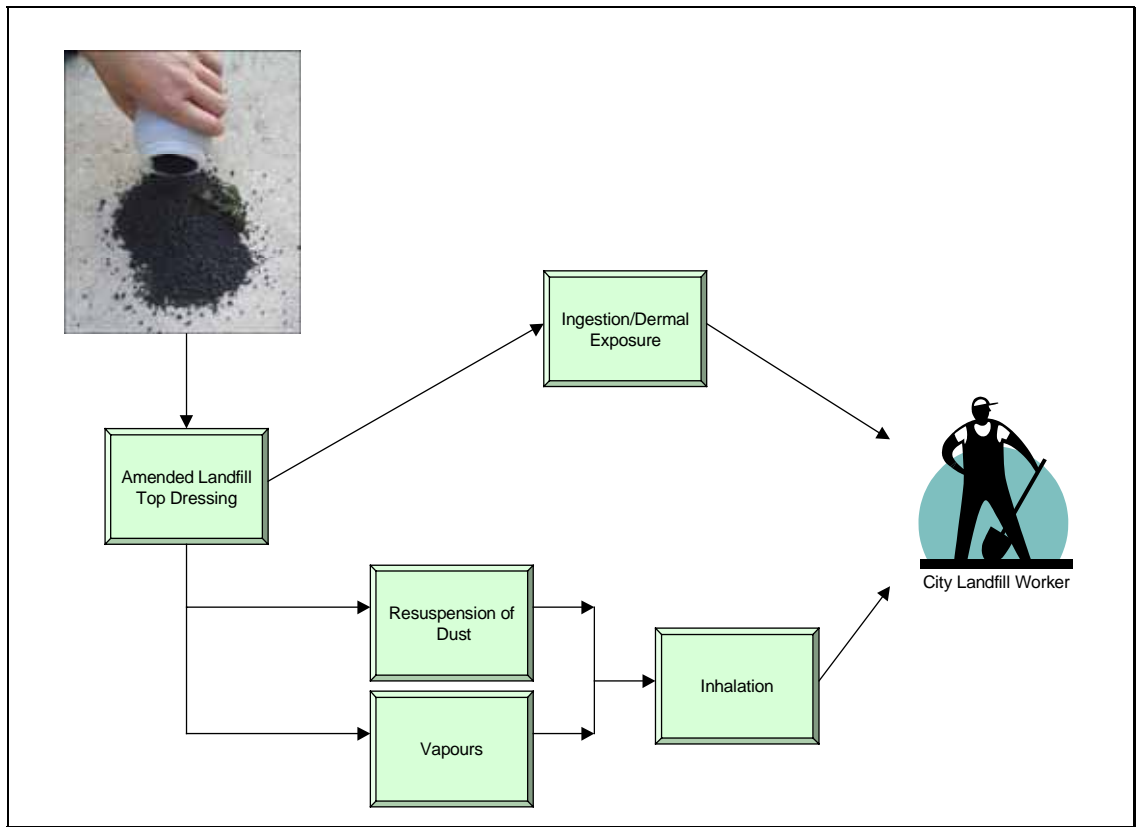
Notes:

- a. Non-carcinogens calculated for adult life stage.
- b. Carcinogens calculated for composite receptor characteristics averaged over 75 years.
- c. Exposed surface area based on total surface area of hands and lower arms.
- d. Assumes 100% of daily incidental soil ingestion occurs at the golf course.
- e. An indoor worker scenario was considered; however, concentrations of volatile chemicals in pellets are expected to be very low and other chemical risks quantitatively evaluated would not be expected to differ significantly between indoor and outdoor exposures.
- f. Hourly inhalation rate based upon light activity as defined in the *Exposure Factors Handbook* (US EPA, 1997c).
- g. Calculated by: ED x 365 days/year.
- h. Please see Appendix C: Human Receptor Characteristics for further details.



The conceptual model for City Landfill Worker is presented in Figure 5-2.

Figure 5-2: Conceptual Model for City Landfill Worker Scenario



5.3.4 Recreational Use Scenario

A Recreational Use Scenario was developed to address the likelihood of amended soil exposure at City of Toronto parks and golf courses. Based upon the qualitative evaluation, three receptors have been identified for the Recreational Use Scenario: toddler, composite receptor and adult golfer.

5.3.4.1 Toddler and Composite Receptors

Table 5-10 qualitatively evaluates the likelihood of potential exposure mechanisms and determines which exposure pathways will be evaluated for the recreational toddler.

Table 5-10: Potential Exposure Routes for Recreational Use Scenario - Toddler and Composite Receptors

Exposure Pathway Description	Likelihood of Exposure	Carried Forward for Quantitative Analysis?	Justification
Ingestion of soil	Possible	Yes	Toddlers may come into contact with amended soils and pellets while using City of Toronto parks.
Ingestion of pellets	Possible	Yes	
Dermal contact with soil	Possible	Yes	
Ingestion/inhalation of dust	Possible	Yes	
Ingestion of surface water	Very Unlikely	No	Recreational users of the site are not expected to come into contact with pellet impacted surface water or sediment in City parks.
Dermal contact with surface water	Very Unlikely	No	
Dermal contact with sediment	Very Unlikely	No	
Ingestion of groundwater	Very Unlikely	No	Groundwater is assumed to not be used as a drinking water source in Toronto parks.
Dermal contact with groundwater	Very Unlikely	No	It is unlikely that residents will have contact with groundwater during park use.
Ingestion of garden produce	Very Unlikely	No	Garden produce will not be grown in City parks.
Inhalation of outdoor vapours	Possible / Very Unlikely	Yes for organics No for Inorganics	PCBs and PCDD/Fs are semi-volatile and may produce low concentrations of vapours outdoors. Inorganic EoPCs are not volatile and thus not a relevant pathway.
Inhalation of indoor vapours	Very Unlikely	No	Not applicable to parks.

A toddler was assumed to visit a City of Toronto park from the age of 6 months up to 5 years (i.e. 6 months to <5 years). The scenario assesses the potential exposure of the toddler to non-carcinogenic EoPCs from the ingestion and dermal contact of amended soils, inhalation of outdoor vapours and inhalation of dust for 1.5 hours/day, 208 days/year for the entire duration of this life stage. In this scenario 100% of the daily ingestion rate of soil was assumed to be from exposure to pellet amended soil (80%) and to direct ingestion of pellets themselves (20%). The rationale for splitting the toddler's ingestion rate between amended soil and pellets is to capture the potential scenario where a toddler visiting a City of Toronto park may discover a pellet and decide to ingest it. The 20% contribution to the daily ingestion rate was assigned based on the assumption that the majority of the daily ingestion rate of soil would be amended soil. The pellets were found to crumble after five days in humid conditions. Once the pellets crumble, they become integrated onto the humic layer of the soil. Therefore, out of an estimated 100 mg/day

of inadvertent soil ingestion, a toddler was assumed to ingest 80 mg/day of amended soil and 20 mg/day of pellets.

A longer duration exposure of 75 years was evaluated for carcinogenic risks as a composite receptor visiting the park over a lifetime from 0 to 75 years. This assumes that the receptor visits the park every year over a 75 year period and exposed to EoPCs. The receptor characteristics of the toddler and composite receptor are summarized in Table 5-11.

Table 5-11: Toddler and Composite Receptor Characteristics

Characteristic		Units	Toddler ^a	Composite ^b	Reference
Age	Age Range	years	0.5 to 5	0 to 75	
BW	Body Weight	kg	16.5	62.3	Richardson, 1997; CCME, 2000
SA _{soil}	Surface Area exposed to soil	cm ²	1,720 ^c	4,514 ^c	Richardson, 1997
SAF _{soil}	Soil Adherence Factor	mg/cm ²	0.1	0.1	CCME, 2000
IR _{soil/pel}	Ingestion Rate of total soil and pellets	mg/day	100 ^d	25 ^d	Richardson, 1997; CCME, 2000
IR _{soil}	Ingestion Rate of total soil	mg/day	80	NA	Assumed
IR _{pellet}	Ingestion Rate of total pellets	mg/day	20	NA	Assumed
IR _{air}	Inhalation Rate of particulates outdoors	M ³ /hr	1.0 ^e	1.0 ^e	US EPA, 2000
ED	Exposure Duration	years	4.5	75	CCME, 2000
EF _{soil}	Exposure Frequency for Amended Soil	days/year	208	208	Non-snow covered days ^f
ET _{out}	Exposure Time spent Outdoors	hrs/day	1.5	1.5	Health Canada, 2003
AT	Averaging Time	days	1,643	27,375	Calculated ^g

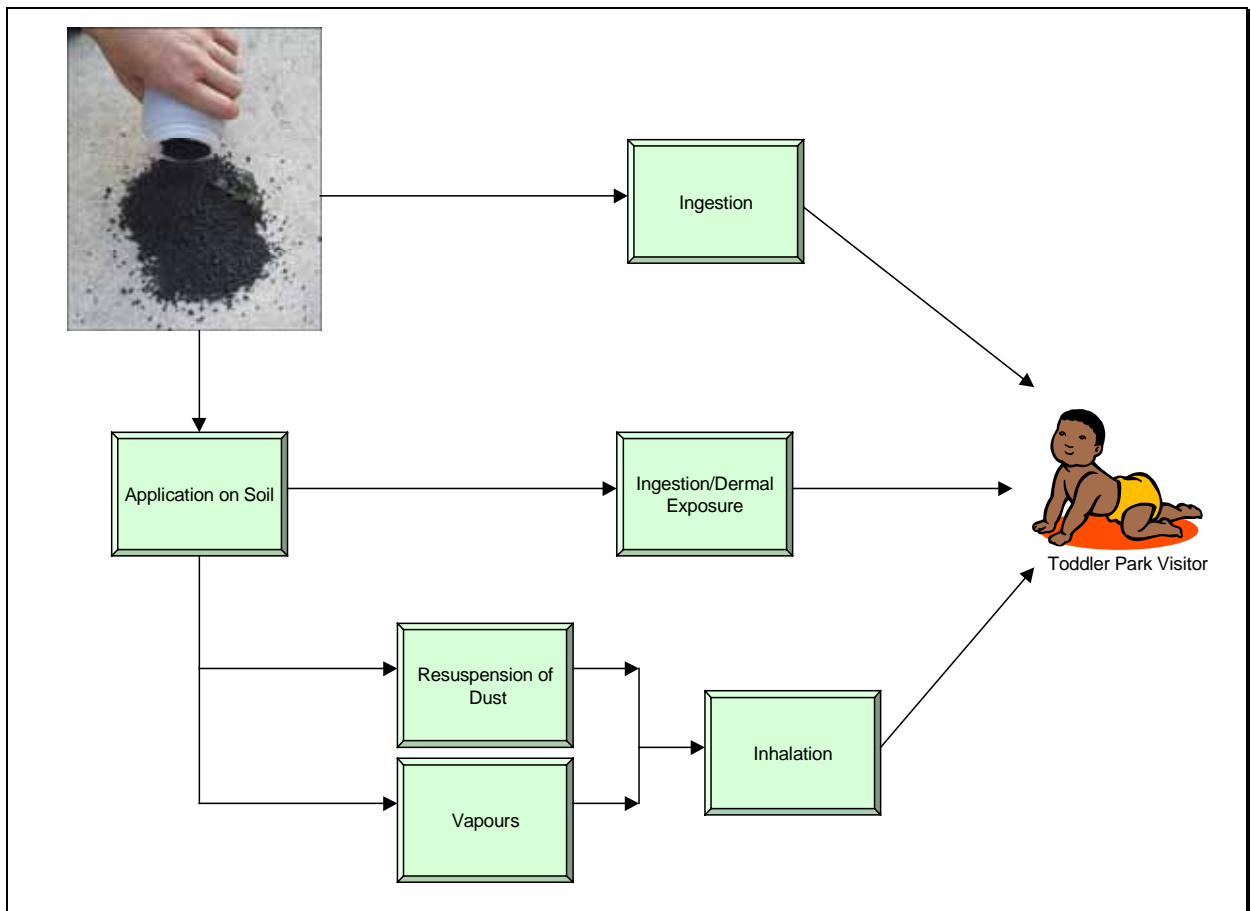
Notes:

- a. Non-carcinogens calculated for toddler life stage (i.e. 6 months to <5 years).
- b. Carcinogens calculated for composite receptor characteristics averaged over 75 years.
- c. Exposed surface area based on total surface area of hands, lower arms and lower legs.
- d. Assumes 100% of daily incidental soil ingestion occurs at recreational park and is composed of 80% amended soil (5 cm) and 20% pellets.
- e. Hourly inhalation rate based upon light activity as defined in the *Child-Specific Exposure Factors Handbook* (US EPA, 2000). The inhalation rate for the composite receptor was calculated as a weighted averaged over a lifetime from ages 0 to 75.
- f. Based on 30-year climate normals for Toronto.
- g. Calculated by: ED x 365 days/year.
- h. Please see Appendix C: Human Receptor Characteristics for further details.

The conceptual model for the toddler for the Recreational Use Scenario is illustrated in Figure 5-3.



Figure 5-3: Conceptual Model for Toddler for Recreational Use Scenario



5.3.4.2 Adult Golfer

Table 5-12 shows a qualitative evaluation of potential exposure mechanisms and pathways for evaluation for the adult golfer.

Table 5-12: Potential Exposures for Adult Golfer - Recreational Use Scenario

Exposure Pathway Description	Likelihood of Exposure	Carried Forward for Quantitative Analysis?	Justification
Ingestion of soil	Possible	Yes	Golfers may come into contact with amended soils while using City of Toronto golf courses.
Dermal contact with soil	Possible	Yes	
Ingestion/inhalation of dust	Possible	Yes	
Ingestion of surface water	Very Unlikely	No	Recreational users of the site are not expected to come into contact with pellet impacted surface water or sediment in City golf courses.
Dermal contact with surface water	Very Unlikely	No	
Dermal contact with sediment	Very Unlikely	No	
Ingestion of groundwater	Very Unlikely	No	Groundwater is assumed to not be used as a drinking water source in Toronto.
Dermal contact with groundwater	Very Unlikely	No	It is unlikely that golfers will have contact with groundwater for showering
Ingestion of garden produce	Very Unlikely	No	Not applicable to golf courses.
Inhalation of outdoor vapours	Possible / Very Unlikely	Yes for organics No for Inorganics	PCBs and PCDD/Fs are semi-volatile and may produce low concentrations of vapours outdoors. Inorganic EoPCs are not volatile and thus not a relevant pathway.
Inhalation of indoor vapours	Very Unlikely	No	Not applicable to golf courses.

An adult was assumed to visit a City of Toronto golf course from the ages of 20 to 75 years. The scenario assesses the potential exposure of the adult to non-carcinogenic EoPCs from the ingestion and dermal contact of amended soils, inhalation of outdoor vapours and inhalation of dust for 4 hours/day, 208 days/year for the entire duration of this life stage.

A longer averaging time, using 75 years lifetime was evaluated for carcinogenic risks. The receptor characteristics of the adult golfer and composite receptor are summarized in Table 5-13.

Table 5-13: Adult Golfer Characteristics

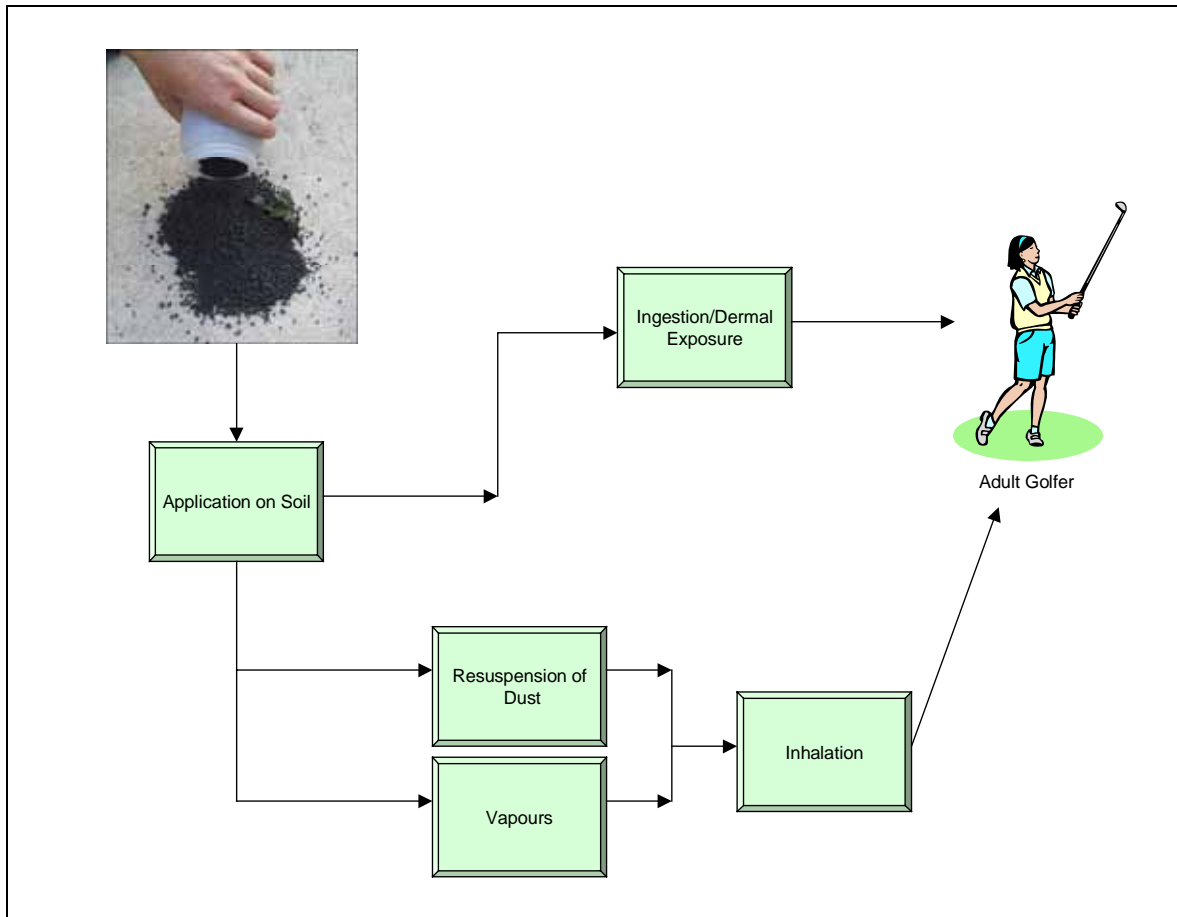
Characteristic		Units	Adult Golfer a	Reference
Age	Age Range	years	20 to 75	
BW	Body Weight	Kg	70.7	Richardson, 1997; CCME, 2000
SA _{soil}	Surface Area exposed to soil	cm ²	5,000 ^b	Richardson, 1997
SAF _{soil}	Soil Adherence Factor	mg/cm ²	0.1	CCME, 2000
IR _{soil}	Ingestion Rate of soil	mg/day	20 ^c	Richardson, 1997; CCME, 2000
IR _{air}	Inhalation Rate of particulates outdoors	m ³ /hr	1.0 ^d	US EPA, 1997
ED	Exposure Duration	years	55	CCME, 2000
EF _{soil}	Exposure Frequency for Amended Soil	days/year	208	Non-snow covered days ^e
ET _{out}	Exposure Time spent Outdoors	Hrs/day	4	Assumed
AT	Averaging Time	days	20,075	Calculated ^f

Notes:

- a. Non-carcinogens calculated for adult life stage.
- b. Exposed surface area based on total surface area of hands, lower arms and lower legs.
- c. Assumes 100% of daily incidental soil ingestion occurs at the golf course.
- d. Hourly inhalation rate based upon light activity as defined in the *Exposure Factors Handbook* (US EPA, 1997c).
- e. Based on 30-year climate normals for Toronto, conservatively applied as the golfing season.
- f. Calculated by: ED x 365 days/year.
- g. Please see Appendix C: Human Receptor Characteristics for further details.

The conceptual model for the golfer in the Recreational Use Scenario is presented in Figure 5-4.

Figure 5-4: Conceptual Model for Adult - Recreational Use Scenario



5.3.5 Home Use Scenario

A Home Use Scenario was developed to address the likelihood of pellet application to residential homes within the City of Toronto limits. Based upon a qualitative evaluation, the following Home Use Scenarios have been assessed in this study: a toddler who resides on a property with amended soil and pellets, an adult who is exposed to amended soils while gardening and an adult who applies pellets to their lawn or gardens.

5.3.5.1 Residential Toddler

Table 5-14 qualitatively evaluates the likelihood of potential exposure mechanisms and determines which exposure pathways will be evaluated.

Table 5-14: Potential Toddler Exposure - Home Use Scenario

Exposure Pathway Description	Likelihood of Exposure	Carried Forward for Quantitative Analysis?	Justification
Ingestion of amended soil	Possible	Yes	Toddlers are expected to come into contact with amended soils in their yards (lawns and gardens).
Dermal contact with soil	Possible	Yes	
Ingestion/inhalation of dust	Possible	Yes	
Inadvertent ingestion of pellet material	Possible	Yes	Toddlers are expected to come into contact with pellets once applied to yards (lawns and gardens).
Dermal contact with pellets	Possible	Yes	
Ingestion/inhalation of pellet dust	Possible	Yes	
Ingestion of surface water	Very Unlikely	No	Residential users are not expected to come in contact with pellet impacted surface water or sediment.
Dermal contact with surface water	Very Unlikely	No	
Dermal contact with sediment	Very Unlikely	No	
Ingestion of groundwater	Very Unlikely	No	Groundwater is not used as a drinking water source in Toronto.
Dermal contact with groundwater	Very Unlikely	No	It is unlikely that residents will have contact with groundwater for showering
Ingestion of garden produce	Likely	Yes	Garden produce may be grown in backyards in amended soils.
Inhalation of outdoor vapours	Possible / Very Unlikely	Yes for organics No for Inorganics	PCBs and PCDD/Fs are semi-volatile and may produce low concentrations of vapours outdoors. Inorganic EoPCs are not volatile and thus not a relevant pathway.
Inhalation of indoor vapours	Very Unlikely	No	An indoor use scenario was considered; however, concentrations of volatile chemicals in pellets are expected to be very low and other chemical risks quantitatively evaluated would not be expected to differ significantly between indoor and outdoor exposures.

A toddler was assumed to live on a property with amended lawn and garden surface soils from the age of 6 months up to 5 years old (i.e. 6 months to <5 years). The scenario assesses the potential exposure of the toddler to non-carcinogenic EoPCs from the ingestion of amended soils and pellets, dermal contact of amended soils, ingestion of produce grown in amended soil, inhalation of outdoor vapours and inhalation of dust for 1.5 hours/day, 208 days/year for the entire duration of this life stage. In this scenario 100% of the daily ingestion rate of soil was assumed to be from exposure to pellet amended soil (80%) and to direct ingestion of pellets themselves (20%). The rationale for splitting the toddler's ingestion rate between amended soil and pellets is to capture the potential scenario where a toddler may discover a pellet and decide to ingest it. The 20% contribution to the daily ingestion rate was assigned based on the assumption that the majority of the daily ingestion rate of soil would be amended soil. Therefore, out of an estimated 100 mg/day of inadvertent soil ingestion, a toddler is assumed to ingest 80 mg/day of amended soil and 20 mg/day of pellets.

A longer duration exposure of 75 years was evaluated for carcinogenic risks as a composite receptor from 0 to 75 years. In addition, residential adults were exposed to pellet amended soil, garden amended soil and pellets themselves during lawn application. The receptor characteristics of the toddler and composite receptor are summarized in Table 5-15.

Table 5-15: Residential Toddler and Composite Receptor Characteristics

Characteristic		Units	Toddler ^a	Composite ^b	Reference
Age	Age Range	years	0.5 to <5	0 to 75	
BW	Body Weight	Kg	16.5	62.3	Richardson, 1997; CCME, 2000
SA _{soil}	Surface Area exposed to soil	cm ²	1,720 ^c	4,514 ^c	Richardson, 1997
SAF _{soil}	Soil Adherence Factor	mg/cm ²	0.1	0.1	CCME, 2000
IR _{soil/pel}	Ingestion Rate of total soil and pellets	mg/day	100 ^d	25 ^d	Richardson, 1997; CCME, 2000
IR _{soil}	Ingestion Rate of total soil	mg/day	80	NA	Assumed
IR _{pellets}	Ingestion Rate of total pellets	mg/day	20	NA	Assumed
IR _{air}	Inhalation Rate of particulates outdoors	m ³ /hr	1.0 ^e	1.0 ^e	US EPA, 2000
IR _{fruit}	Ingestion Rate of fruit	g/day	189	184	Health Canada, 1995
IR _{rootveg}	Ingestion Rate of Root Vegetables	g/day	105	184	Health Canada, 2003



Characteristic		Units	Toddler ^a	Composite ^b	Reference
IR _{ag(veg)}	Ingestion Rate of Vegetables grown Above Ground	g/day	67	127	Health Canada, 2003
ED	Exposure Duration	years	4.5	75	CCME, 2000
EF _{soil}	Exposure Frequency for Amended Soil	days/year	208	208	Non-snow covered days ^f
ET _{out}	Exposure Time spent Outdoors	Hrs/day	1.5	1.5	Health Canada, 2003
AT	Averaging Time	days	1,643	27,375	Calculated ^g

Notes:

- a. Non-carcinogens calculated for toddler life stage (i.e. 6 months to <5 years).
- b. Carcinogens calculated for composite receptor characteristics averaged over 75 years.
- c. Exposed surface area based on total surface area of hands, lower arms and lower legs.
- d. Assumes 80% of daily incidental soil ingestion and 20% of pellet ingestion occurs at residence.
- e. Hourly inhalation rate based upon light activity as defined in the *Child-Specific Exposure Factors Handbook* (US EPA, 2000). The inhalation rate for the composite receptor was calculated as a weighted averaged over a lifetime from ages 0 to 75.
- f. Based on 30-year climate normals for Toronto.
- g. Calculated by: ED x 365 days/year.
- h. Please see Appendix C: Human Receptor Characteristics for further details.

The conceptual model for the residential toddler exposure is presented in Figure 5-5.

5.3.5.2 Residential Adult

Table 5-16 summarizes a qualitative screening of pathways for the residential adult's exposure to chemicals in pellets.

Figure 5-5: Conceptual Model for Toddler - Home Use Scenario

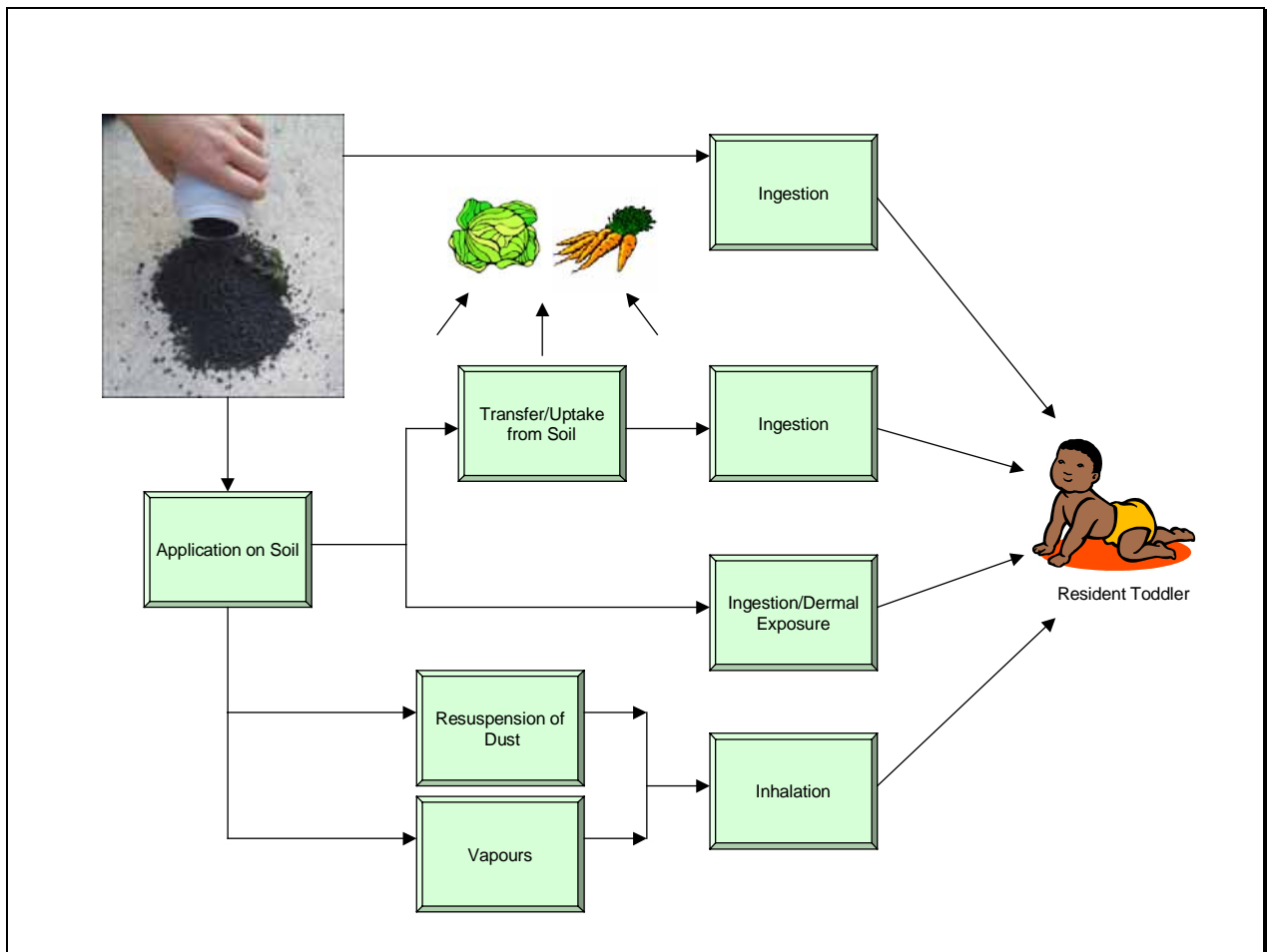


Table 5-16: Potential Adult Exposure - Home Use Scenario

Exposure Pathway Description	Likelihood of Exposure	Carried Forward for Quantitative Analysis?	Justification
Ingestion of amended soil (5 cm and 15 cm depth)	Possible	Yes	Adults are expected to come into contact with amended soils in their yards (lawns and gardens).
Dermal contact with soil (5 cm and 15 cm depth)	Possible	Yes	
Ingestion/inhalation of dust	Possible	Yes	
Inadvertent ingestion of pellet material	Possible	Yes	Residential users are expected to come into contact with pellets when applying pellets to their yards (lawns and gardens).
Dermal contact with pellets	Possible	Yes	
Ingestion/inhalation of pellet dust	Possible	Yes	
Ingestion of surface water	Very Unlikely	No	Residential users are not expected to come in contact with pellet impacted surface water or sediment.
Dermal contact with surface water	Very Unlikely	No	
Dermal contact with sediment	Very Unlikely	No	
Ingestion of groundwater	Very Unlikely	No	Groundwater is not used as a drinking water source in Toronto.
Dermal contact with groundwater	Very Unlikely	No	It is unlikely that residents will have contact with groundwater for showering
Ingestion of garden produce	Likely	Yes	Garden produce may be grown in backyards in amended soils.
Inhalation of outdoor vapours	Possible / Very Unlikely	Yes for organics No for Inorganics	PCBs and PCDD/Fs are semi-volatile and may produce low concentrations of vapours outdoors. Inorganic EoPCs are not volatile and thus not a relevant pathway.
Inhalation of indoor vapours	Very Unlikely	No	An indoor use scenario was considered; however, concentrations of volatile chemicals in pellets are expected to be very low and other chemical risks quantitatively evaluated would not be expected to differ significantly between indoor and outdoor exposures.

An adult was assumed to live on a property with amended lawn and garden surface soils from the age of 20 to 75 years. The scenario assesses the potential exposure of the adult to non-carcinogenic EoPCs from the ingestion of, dermal contact with and inhalation of particulates from amended surface soil (5 cm), amended garden soil (15 cm) and pellets, as well as the inhalation of vapours arising from surface soil. The scenario assumes 1.5 hours/day spent



outdoors and 1 hour/day spent gardening for 208 days/year, as well as 1 hour/day spent applying pellets for 4 days/year for the entire duration of this life stage. In this scenario the daily ingestion rate of soil was weighted by the time spent outdoors engaged in activities.

The receptor characteristics of the adult receptor are summarized in Table 5-17.

Table 5-17: Residential Adult Characteristics

Characteristic		Units	Adult ^A	Reference
Age	Age Range	years	20 to 75	
BW	Body Weight	kg	70.7	Richardson, 1997; CCME, 2000
SA _{soil}	Surface Area exposed to soil	cm ²	5,000 ^b	Richardson, 1997
SAF _{soil}	Soil Adherence Factor	mg/cm ²	0.1	CCME, 2000
IR _{soil}	Ingestion Rate of total soil and pellets	mg/day	20 ^c	Richardson, 1997; CCME, 2000
IR _{air}	Inhalation Rate of particulates outdoors	m ³ /hr	1.0 ^d	US EPA, 1997
IR _{fruit}	Ingestion Rate of fruit	g/day	186	Health Canada, 1995
IR _{rootveg}	Ingestion Rate of Root Vegetables	g/day	188	Health Canada, 2003
IR _{ag(veg)}	Ingestion Rate of Vegetables grown Above Ground	g/day	137	Health Canada, 2003
ED	Exposure Duration	years	55	CCME, 2000
EF _{soil}	Exposure Frequency for Amended Soil (5 and 15 cm)	days/year	208	Non-snow covered days ^e
EF _{pellets}	Exposure Frequency for Pellets	days/year	4	Calculated ^f
ET _{out}	Exposure Time spent Outdoors	hrs/day	1.5	Health Canada, 2003
ET _{garden}	Exposure Time spent gardening	hrs/day	1	US EPA, 1997c
ET _{pellet}	Exposure Time spent applying pellets	hrs/day	1	Calculated ^f
AT	Averaging Time	days	20,075	Calculated ^g

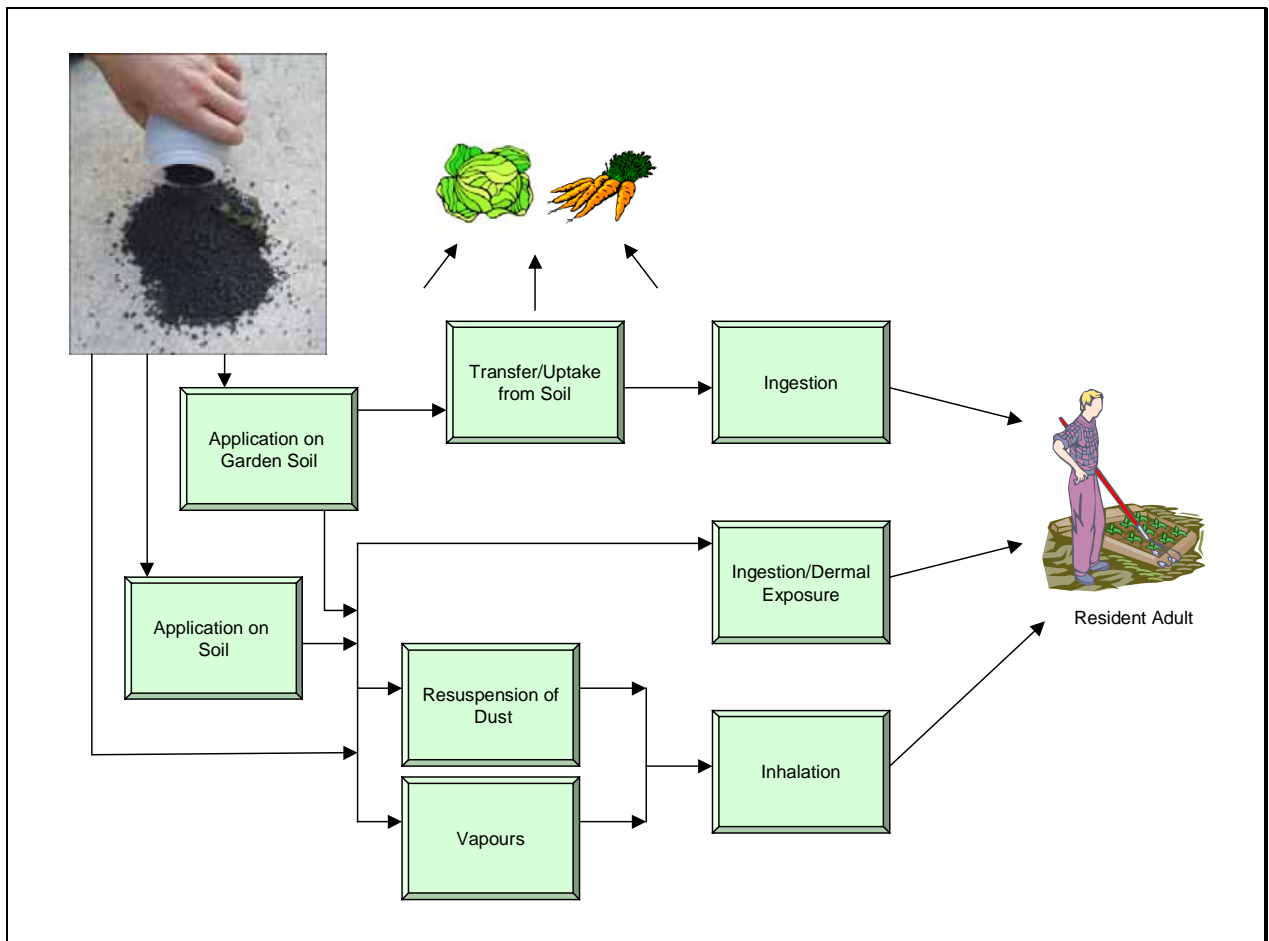
Notes:

- Non-carcinogens calculated for toddler life stage (i.e. 6 months to <5 years).
- Exposed surface area based on total surface area of hands, lower arms and lower legs.
- Ingestion rate of soil was time weighted based upon time spent outdoors, time spent gardening and time spent applying pellets and used with corresponding ETs.
- Hourly inhalation rate based upon light activity as defined in the *Exposure Factors Handbook* (US EPA, 1997c). Inhalation rate was time weighted based upon time spent outdoors, time spent gardening and time spent applying pellets.
- Based on 30-year climate normals for Toronto.
- Based on recommended application rate.
- Calculated by: ED x 365 days/year.
- Please see Appendix C: Human Receptor Characteristics for further details.

The conceptual model for adult residential exposure is presented in Figure 5-6.



Figure 5-6: Conceptual Model for Adult - Home Use Scenario



5.3.6 Summary of Exposure Assessment

Table 5-18 summarizes the selected scenarios, receptors and exposure pathways and presents an integrated conceptual model for all potential pathways and receptors.

Table 5-18: Summary of Receptors and Exposure Pathways

Scenario	Receptor(s)	Exposure Pathways
City Parks Worker	City Worker Parks, Golf Courses and Gardens Pellet Application	<ul style="list-style-type: none"> • Inadvertent Pellet Ingestion • Dermal Contact with Pellets • Ambient Air Inhalation (Dust & Vapours)
City Landfill Worker	City Worker Landfill Topdressing Application	<ul style="list-style-type: none"> • Amended Soil Ingestion • Dermal Contact with Amended Soil • Ambient Air Inhalation (Dust & Vapours)
Recreational Use	Toddler	<ul style="list-style-type: none"> • Amended Soil Ingestion • Pellet Ingestion • Dermal Contact with Amended Soil • Ambient Air Inhalation (Dust & Vapours)
	Composite Receptor	<ul style="list-style-type: none"> • Amended Soil Ingestion • Pellet Ingestion • Dermal Contact with Amended Soil • Ambient Air Inhalation (Dust & Vapours)
	Golfer (Adult)	<ul style="list-style-type: none"> • Amended Soil Ingestion • Dermal Contact with Amended Soil • Ambient Air Inhalation (Dust & Vapours)
Home Use	Toddler	<ul style="list-style-type: none"> • Amended Soil Ingestion • Pellet Ingestion • Dermal Contact with Amended Soil • Ambient Air Inhalation (Dust & Vapours) • Garden Produce Ingestion
	Composite Receptor	<ul style="list-style-type: none"> • Amended Soil Ingestion (5 and 15 cm) • Pellet Ingestion • Dermal Contact with Amended Soil (5 and 15 cm) • Ambient Air Inhalation (Dust & Vapours) • Garden Produce Ingestion
	Adult (Pellet Application)	<ul style="list-style-type: none"> • Inadvertent Pellet and Amended Soil (5 cm and 15 cm) Ingestion • Dermal Contact with Pellets and Amended Soil (5 cm and 15 cm) • Ambient Air Inhalation (Dust & Vapours) • Garden Produce Ingestion

5.3.7 Concentrations of EoPCs

5.3.7.1 Concentration in Amended Soils

Exposure point concentrations (EPCs) of EoPCs in pellet amended soil and pellets were calculated for use in the risk assessment. Four different pathways through which people could be exposed to EoPCs in soil and pellets were identified as:

- **Pellets:** assumes the 95% Upper Confidence Limit of the Mean (UCLM) of the cake data set.
- **Amended Soil Concentration Assuming 5 cm depth:** assumes application of pellets on sod (lawn) and that pellet EoPC concentrations would be restricted to the top 5 cm of soil.
- **Amended Soil Concentration Assuming 15 cm depth:** assumes incorporation of pellets in to top 15 cm of soil. These concentrations represent the concentrations of EoPCs in soil used for gardening, where the applied pellets would be incorporated into garden soils to a depth of 15 cm.
- **Landfill Topdressing:** Assumes mixing of pellets into landfill topdressing.

The EoPC pellet concentrations were derived from the 95% UCLM concentration of the 1996 to 2003 cake data set. The recommended pellet application rate on the Ashbridges Bay Treatment Plant (ABTP) biosolids approved label (Figure 3-1) is 2.7 wet weight tonnes per hectare per year. The surface (5 cm) and garden (15 cm) amended soil EoPC concentrations were estimated by conservatively using twice the recommended application rate or 5.4 tonnes per hectare per year. Furthermore, the 5.4 tonnes per hectare per year application rate assumed dry weight concentrations. Given that the label indicates a maximum moisture content of 10%, converting 5.4 dry tonnes per hectare would be equivalent to 6.0 tonnes wet weight per hectare per year.

The resulting loadings based on a spreading rate of 5.4 dry t/ha year, using the 95% UCLM concentration of EoPCs in pellets were then used to derive the concentration of EoPCs that would occur in both pellets spread on lawns (5 cm mixing depth) or incorporated into gardens (15 cm mixing depth). The calculated soil amended concentrations were added to the mean Ontario Typical Range (OTR) background concentration of inorganic elements and trace organics in urban parkland soil. The Ontario Ministry of the Environment (MOE) undertook a detailed study of OTRs in 1993. The mean concentrations reported in this report were used to estimate the existing concentrations of inorganic elements in City of Toronto urban soils (MOE, 1993).

A surface soil mixing depth of 5 cm was selected to be consistent with the derivation of the OTR₉₈ developed by the Ontario Ministry of the Environment. Soil samples were collected throughout Ontario at 0 to 5 cm depth for all areas except gardens or tillage, where 0 to 15 cm depth was considered (MOE, 1993).



EoPC concentrations in landfill cover were estimated at an appropriate ratio of biosolids pellets in a landfill cover topdressing mixture. Two main factors were considered in estimating an appropriate concentration of biosolids pellets in a soil mixture intended to be used as a component of landfill cover. The first factor is that the resulting mixture should not exceed maximum permissible metals loading levels or maximum permissible metal soil concentrations. The second factor is the total nitrogen application rate coupled with the nitrogen mineralization rate should not result in excessive mineral nitrogen. Practically all of the nitrogen in biosolids pellets is present in an organic form, which means that the nitrogen is present in organic compounds and is relatively immobile and not plant available. Organic nitrogen becomes available through the process of mineralization, which results in nitrogen being released into the soil solution as ammonium, which is then converted into nitrate. Nitrate is plant available, but is also very mobile. If there is more nitrate available in the soil than can be used by plants growing in the soil, it may be lost through leaching or through the process of denitrification. Typical rates of mineralization for anaerobic biosolids pellets are not well established. Rates between 30 and 50 percent for liquid anaerobic biosolids have been quoted in the literature (Adegbidi and Briggs, 2003), although it was under optimal conditions. The rate of mineralization for pellets under sub-optimal field conditions would be considerably less.

A mixture of 1 part pellets to 2 parts straw and 20 parts sand would result in a mixture that does not exceed metals loading and soil concentration limits, has a relatively high C/N ratio and will result in a reasonable amount of available nitrogen, assuming a rate of between 15 and 20% mineralization.

Table 5-19: Assumed Landfill Topdressing Components

	% Carbon	% Nitrogen	Density (kg/m ³)
Pellets	31	3.5	630 ^a
Sand	0	0	1500 ^b
Straw	38	0.5	100 ^b

Note:

- a. Moss, *et al.*, 2002
- b. Bradey, N.C and R.R. Weil, 2002



In one cubic metre of final product, there will be 29 kilograms of pellets. If the topdressing layer is assumed to be 15 cm thick, the volume of the layer over 1 hectare would be calculated by multiplying the area of 1 hectare (10,000 m²) by the thickness of the layer (0.15 metres), resulting in a volume of 1500 m³. One cubic metre of the topdressing mixture contains 29 kilograms of pellets; therefore, the effective pellet application rate is 43 tonnes of pellets per hectare. Assuming that the pellets are 90% solids, then the dry weight application rate is 39 tonnes of pellets per hectare. This value was used to calculate the loadings and concentrations of the EoPCs in landfill cover.

It should be noted that the soil mixture described above is a very general estimate of what could be an appropriate topdressing mixture using the Toronto biosolids pellets. There are many other sources of carbon that could be used instead of straw and other sources of mineral material besides sand. The purpose of the present exercise was to look at a possible topdressing mixture in order to examine possible concentration of EoPCs. It is not intended as a recommendation for mixture components and ratios.

In order to better understand the impact of amending soil with pellets over a twenty-five year period, the following is a breakdown of the relative contribution of EoPCs from pellets in amended soil at a depth of 5 cm:

- <25% cobalt, PCBs
- >25% to <50% arsenic, mercury, nickel, lead
- >50% to <75% chromium, selenium, zinc, PCDD/Fs
- >75% copper, cadmium, molybdenum

The relative loading of EoPCs to soil from pellet amendment was a function of both pellet concentration and the naturally occurring concentration of EoPCs in Ontario soils.



Table 5-20: Exposure Point Concentrations of EoPCs in Amended Soil Over 25 years Based on a 5.4 t/ha annual application rate.

Soil Concentration	As	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Se	Zn	PCB	PCDD/F
Pellet Concentration													
From Cake data (mg/kg)	8.1	5.1	3.3	160	1200	1.7	13	39	93	3.1	900	1.7E-04	1.5E-05
OTR													
OTR Mean Background Concentration (mg/kg)	2.4 ^a	0.3	7.7	26	30	0.8	0.25	15	35	0.48	75	0.011	1.73E-06
Pellet Amended Soil Concentration Assuming 5 cm depth													
1 year (mg/kg)	2.5	0.34	7.7	27	39	0.81	0.35	15	36	0.51	82	0.011	1.8E-06
10 year (mg/kg)	3.1	0.72	8.0	39	120	0.94	1.3	18	43	0.73	150	0.011	2.9E-06
25 year (mg/kg)	4.1	1.3	8.4	58	260	1.1	2.8	23	54	1.1	260	0.011	4.7E-06
Pellet Amended Soil Concentration Assuming 15 cm depth													
1 year (mg/kg)	2.4	0.31	7.7	26	33	0.80	0.28	15	35	0.49	77	0.011	1.8E-06
10 year (mg/kg)	2.6	0.44	7.8	30	61	0.85	0.59	16	38	0.56	99	0.011	2.1E-06
25 year (mg/kg)	3.0	0.65	7.9	37	110	0.92	1.1	18	41	0.69	140	0.011	2.7E-06
Landfill Topdressing													
Per application (mg/kg)	0.32	0.20	0.13	6.2	45	0.067	0.50	1.5	3.6	0.12	35	6.5E-06	5.8E-07

Notes:

a. City of Toronto background in parks (Ursitti *et al*, in press)

At a soil amendment depth of 15 cm, 10 of the 13 EoPCs had relative contributions of pellets to the overall soil concentration used in the risk assessment of less than 50%. This is important as the concentration of EoPCs in garden vegetables were derived from this soil depth.

- <25% arsenic, cobalt, mercury, nickel, lead, PCBs
- >25% to <50% chromium, selenium, zinc, PCDD/Fs
- >50% to <75% cadmium, copper
- >75% molybdenum

It should also be noted that the pellet amended soil concentrations do not take into account leaching or other physical and chemical transport mechanisms that would be present in the environment.

5.3.7.2 *Concentration of EoPCs in Garden Vegetables*

Calculation of EoPC concentrations in garden produce consisted of determining uptakes to fruit and vegetables for human ingestion of the leafy, fruit, and tuber portions of the plant. Since differences exist in uptake mechanisms, consideration of indirect produce exposure was separated into two broad categories – above-ground and below ground produce. In addition, above-ground produce was further subdivided into vegetables and fruit.

The total EoPC concentration in exposed produce (dry weight) was calculated based on all routes of soil to plant transfer from pellet amended soil at a depth of 15 cm. Routes of soil to plant transfer factors include soil particles adhered to the broad leaves as a result of resuspension of soil particles in air and rain-splash. Soil to plant bioconcentration (B_r) factors for inorganic transfer to root vegetables and fruit were taken from Baes *et al.* (1984). For all inorganic compounds, above-ground vegetable bioconcentration (B_v) factors were either constants taken from Baes *et al.* (1984), or calculated using linear regression and input parameters from Efroymson *et al.* (2001).

Note that plant uptake of inorganic chemicals from biosolids is expected to be less than from soils, so the use of literature uptake factors (UFs) is considered conservative. Because the pH of biosolids is about 7 compared to about 6 or less for natural soils, the inorganic constituents in biosolids are less bioavailable for plant uptake. Soils in Southern Ontario do not have low pH which would affect the uptake of EoPCs by plants. The 97.5th percentile Ontario Typical Range (OTR₉₈) pH for soils, as reported by the MOE (1993), is 7.5 for Old Urban/Parkland. The Water



Environment Research Foundation (WERF, 2002) report lists some general factors and their relative impact on metals leachability, in descending order of importance. These include:

1. Water solubility
2. Exchangability
3. Presence of metal ions bound to carbonate
4. Organic binding of metals
5. Binding of metals with oxides

For biosolids, Camp, Dresser and McKee (1998) compared forms of metals in compost, a heat-dried product and an alkaline stabilized product. They reported that most metals measured were organically bound or in less bioavailable forms for plant uptake in the heat dried or composted biosolids.

For organic chemicals, soil to plant transfer factors were estimated as:

$$\log BAF_{plant} = 1.588 - 0.578 \log K_{ow} \text{ (Travis and Arms, 1988)}$$

A summary of physical-chemical parameters used in this evaluation is given in Table 5-21.

Table 5-21: Summary of Physical-Chemical Parameters

EoPC	Parameter	Value	Reference
PCBs Aroclor 1254	Log K _{ow}	6.21	US EPA, 1999
PCDD/Fs	Log K _{ow}	6.64	US EPA 1998

Soil to food type bioconcentration factors for EoPCs are presented in Table 5-22.

Table 5-22: Bioconcentration Factors from Soil to Food Type

EoPC	Bioaccumulation Factor from Soil to Food Type (BAF) (kg/kg dw)			
	Food Type (BAF=B _v or B _r)	Values	Notes	Reference
As	Above-ground Plants (B _v)	0.059	Simple regression ^a B0 = -1.99 B1 = 0.56	Efroymson <i>et al.</i> , 2001
	Root vegetables and fruit (B _r) ^b	0.0060	Constant	Baes <i>et al.</i> , 1984
Cd	Above-ground Vegetative portion of plants (B _v)	0.75	Simple regression ^a B0 = -0.48 B1 = 0.55	Efroymson <i>et al.</i> , 2001
	Root vegetables and fruit (B _r) ^b	0.15	Constant	Baes <i>et al.</i> , 1984
Co	Above-ground Vegetative portion of plants (B _v) ^c	0.020	Constant	Baes <i>et al.</i> , 1984
	Root vegetables and fruit (B _r) ^b	0.0070	Constant	Baes <i>et al.</i> , 1984
Cr	Above-ground Vegetative portion of plants (B _v) ⁽³⁾	0.0075	Constant	Baes <i>et al.</i> , 1984
	Root vegetables and fruit (B _r) ⁽²⁾	0.0045	Constant	Baes <i>et al.</i> , 1984
Cu	Above-ground Vegetative portion of plants (B _v)	0.11	Simple regression ^a B0 = 0.67 B1 = 0.39	Efroymson <i>et al.</i> , 2001
	Root vegetables and fruit (B _r) ^b	0.25	Constant	Baes <i>et al.</i> , 1984
Hg	Above-ground Vegetative portion of plants (B _v)	0.38	Simple regression ^a B0 = -1.00 B1 = 0.54	Efroymson <i>et al.</i> , 2001
	Root vegetables and fruit (B _r) ^b	0.20	Constant	Baes <i>et al.</i> , 1984
Mo	Above-ground Vegetative portion of plants (B _v) ^c	0.25	Constant	Baes <i>et al.</i> , 1984
	Root vegetables and fruit (B _r) ^b	0.060	Constant	Baes <i>et al.</i> , 1984
Ni	Above-ground Vegetative portion of plants (B _v)	0.053	Simple regression ^a B0 = -2.22 B1 = 0.75	Efroymson <i>et al.</i> , 2001
	Root vegetables and fruit (B _r) ^b	0.060	Constant	Baes <i>et al.</i> , 1984
Pb	Above-ground Vegetative portion of plants (B _v)	0.051	Simple regression ^a B0 = -1.33 B1 = 0.56	Efroymson <i>et al.</i> , 2001
	Root vegetables and fruit (B _r) ^b	0.0090	Constant	Baes <i>et al.</i> , 1984
Se	Above-ground Vegetative portion of plants (B _v)	0.49	Simple regression ^a B0 = -0.68 B1 = 1.10	Efroymson <i>et al.</i> , 2001
	Root vegetables and fruit (B _r) ^b	0.025	Constant	Baes <i>et al.</i> , 1984

EoPC	Bioaccumulation Factor from Soil to Food Type (BAF) (kg/kg dw)			
	Food Type (BAF=B _v or B _r)	Values	Notes	Reference
Zn	Above-ground Vegetative portion of plants (B _v)	0.56	Simple regression ^a B0 = 1.58 B1 = 0.56	Efroymsen <i>et al.</i> , 2001
	Root vegetables and fruit (B _r) ^b	0.90	Constant	Baes <i>et al.</i> , 1984
PCB	Plants (B _v , B _r) ^{b, c}	0.010	Calculated	Based on Travis and Arms, 1988
PCDD/Fs	Plants (B _v , B _r) ^{b, c}	0.0056	Calculated	Based on Travis and Arms, 1988

Notes:

- a. Simple regression, where $BAF_{above-ground\ vegetables} = B_v = \frac{e^{(B0+B1 \cdot \ln C_{soil})}}{C_{soil}}$
- b. $BAF_{root\ vegetables\ and\ fruits} = B_r$
- c. $BAF_{above-ground\ vegetables} = B_v$

To estimate the chemical concentrations in the edible portions of the produce, the concentration of each EoPC in the amended garden soil (pellets incorporated to a depth of 15 cm) was then multiplied by the appropriate BAF. In addition, the bioconcentration factors are presented as dry weight soil to dry weight plant. Given that the exposure calculations for ingestion of produce are in wet weight (ww) plants, the resulting concentrations were all multiplied by a factor of 19% (0.19) to convert from dry weight plant concentration to wet weight plant concentration (Efroymsen *et al.*, 2001).

Concentrations of EoPCs in ingested plants were estimated as:

$$C_k = C_{soil} \cdot BAF_k \cdot MC$$

where,

BAF_k = Bioaccumulation factor for the kth food type (kg/kg dw)

MC = Adjustment for moisture content from dry to fresh weight

The estimated concentrations in garden produce are shown in Table 5-23.

Table 5-23: Summary of Estimated Soil and Plant Concentrations

EoPC	Concentrations (mg/kg)			
	Amended Soil Assuming 15 cm Mixing depth	Fruit ^a	Root Vegetables ^a	Above Ground Vegetables ^a
As	3.0	0.0034	0.0034	0.033
Cd	0.65	0.018	0.018	0.092
Co	7.9	0.011	0.011	0.030
Cr	37	0.031	0.031	0.052
Cu	110	5.1	5.1	2.3
Hg	0.92	0.035	0.035	0.066
Mo	1.1	0.013	0.013	0.053
Ni	18	0.20	0.20	0.18
Pb	41	0.071	0.071	0.40
Se	0.69	0.0033	0.0033	0.064
Zn	140	23	23	14
PCBs	0.011	2.0E-05	2.0E-05	2.0E-05
PCDD/Fs	2.7E-06	2.9E-09	2.9E-09	2.9E-09

Note:

a. Wet weight

5.3.7.3 Concentrations of EoPCs in Air

Concentrations of EoPCs in air were estimated based on dust particulate suspension and volatilization of semi-volatile EoPCs from soil. The results are summarized in Table 5-24 with calculations shown in Appendix B.

Table 5-24: Summary of Estimated Air Concentrations

EoPC	Concentration of EoPCs in Air (mg/m ³)		
	Based on Pellet 95% UCLM	Based on 5 cm Soil 25 year	Based on 15 cm Soil 25 year
Dust Particulate			
As	6.2E-07	3.1E-07	2.2E-07
Cd	3.9E-07	1.0E-07	4.9E-08
Co	2.5E-07	6.4E-07	6.0E-07
Cr	1.2E-05	4.4E-06	2.8E-06
Cu	8.8E-05	2.0E-05	8.2E-06
Hg	1.3E-07	8.7E-08	7.0E-08
Mo	9.6E-07	2.1E-07	8.4E-08
Ni	2.9E-06	1.7E-06	1.3E-06
Pb	7.1E-06	4.1E-06	3.1E-06
Se	2.4E-07	8.5E-08	5.3E-08
Zn	6.8E-05	2.0E-05	1.0E-05
PCBs	1.3E-11	8.0E-10	8.0E-10
PCDD/Fs	1.1E-12	3.6E-13	2.1E-13
Vapours			
PCBs	NA	1.3E-09	NA
PCDD/Fs	NA	8.5E-14	NA

5.3.8 Chronic Daily Intake and Lifetime Averaged Daily Intake of EoPCs

Media exposure concentrations and combined (total) intakes from all selected pathways were evaluated, as appropriate, for each receptor and exposure scenario. All calculations are thoroughly documented and provided in Appendix B. The non-carcinogenic intakes are expressed as chronic daily intakes (CDI), while the intake of carcinogenic EoPCs are expressed as lifetime averaged daily intakes (LADI).

5.3.8.1 City Parks Worker Pellet Application Daily Intakes of EoPCs

The estimated CDI from inadvertent soil ingestion, dermal absorption and inhalation of dust particles are summarized in Table 5-25. In the case of the City Parks Worker who applies pellets to lands, the estimated exposure by the inadvertent soil ingestion pathway was always at least one order of magnitude greater than the other exposure pathways.

Table 5-25: City Parks Worker Chronic Daily Intake and Lifetime Averaged Daily Intake

EoPC	Chronic Daily Intake		Lifetime Averaged Daily Intake	
	Total Non-Cancer Ingestion/Dermal (mg/kg-d)	Non-Cancer Inhalation ^a (mg/m ³)	Total Cancer Ingestion/Dermal (mg/kg-d)	Cancer Inhalation ^a (mg/m ³)
As	1.4E-6	NA ^b	5.7E-7	1.0E-7
Cd	3.7E-6	NA ^b	NA ^d	6.5E-8
Co	9.0E-8	4.2E-8	NA ^d	NA ^d
Cr	1.1E-4	NA ^c	NA ^d	NA ^d
Cu	8.4E-4	NA ^c	NA ^d	NA ^d
Hg	1.2E-6	2.2E-8	NA ^d	NA ^d
Mo	9.2E-6	NA ^c	NA ^d	NA ^d
Ni	3.0E-5	NA ^b	NA ^d	4.9E-7
Pb	3.7E-5	NA ^c	NA ^d	NA ^d
Se	2.2E-6	NA ^c	NA ^d	NA ^d
Zn	6.3E-4	NA ^c	NA ^d	NA ^d
PCBs	1.2E-10	NA ^c	4.7E-11	1.3E-09
PCDD/Fs	1.1E-11	NA ^c	4.2E-12	2.7E-13

Note:

- a. Concentration in air evaluated as airborne particulate from amended soil at 5 cm depth.
- b. Not Applicable: EoPC evaluated as a carcinogen following inhalation.
- c. Not Applicable: Inhalation CDI not evaluated because there are no applicable inhalation Reference Concentrations (RfCs) for the corresponding EoPC.
- d. Not Applicable: Not evaluated as a carcinogen for this route of exposure.

Table 5-26 lists the CDI and LADI for EoPC exposure for a City Landfill Worker applying pellet amended landfill topdressing. Overall both the non-carcinogenic CDI exposures and LADI carcinogenic intakes were orders of magnitude less than those calculated for City Parks Workers exposed directly to pellets during parkland application. This was a function of the amended landfill topdressing EoPC concentrations being orders of magnitude less than those calculated for pellets.

Table 5-26: City Landfill Worker Chronic Daily Intake and Lifetime Averaged Daily Intake

EoPC	Chronic Daily Intake		Lifetime Averaged Daily Intake	
	Total Non-Cancer Ingestion/Dermal (mg/kg-d)	Non-Cancer Inhalation ^a (mg/m ³)	Total Cancer Ingestion/Dermal (mg/kg-d)	Cancer Inhalation ^a (mg/m ³)
As	5.8E-08	NA ^b	2.3E-08	8.1E-09
Cd	1.5E-07	NA ^b	NA ^d	5.1E-09
Co	6.7E-09	3.3E-09	NA ^d	NA ^d
Cr	4.5E-06	NA ^c	NA ^d	NA ^d
Cu	3.4E-05	NA ^c	NA ^d	NA ^d
Hg	4.9E-08	1.7E-09	NA ^d	NA ^d
Mo	3.7E-07	NA ^c	NA ^d	NA ^d
Ni	1.3E-06	NA ^b	NA ^d	3.8E-08
Pb	1.5E-06	NA ^c	NA ^d	NA ^d
Se	8.6E-08	NA ^c	NA ^d	NA ^d
Zn	2.5E-05	NA ^c	NA ^d	NA ^d
PCBs	4.7E-12	NA ^c	1.9E-12	1.3E-09
PCDD/Fs	4.2E-13	NA ^c	1.7E-13	1.0E-13

Note:

- a. Concentration in air evaluated as airborne particulate from amended soil at 5 cm depth.
- b. Not Applicable: EoPC evaluated as a carcinogen following inhalation.
- c. Not Applicable: Inhalation CDI not evaluated because there are no applicable inhalation RfC for the corresponding EoPC.
- d. Not Applicable: Not evaluated as a carcinogen for this route of exposure.

5.3.8.2 Recreational Daily Intakes of EoPCs

The CDI and LADI calculated intake of EoPCs for the toddler and composite receptors for the Recreational Use Scenario are presented in Table 5-27. The greatest contribution of EoPCs to toddlers using the recreational parks was via inadvertent ingestion of a pellet, followed by dermal and inhalation. In the case of the composite receptor exposure to arsenic, PCBs and PCDD/Fs the ingestion and dermal carcinogenic intakes were an order of magnitude greater than those calculated for the inhalation pathway.

Table 5-27: Recreational Toddler Chronic Daily Intake and Composite Receptor Average Daily Intake

EoPC	Toddler Chronic Daily Intake		Composite Lifetime Averaged Daily Intake	
	Total Non-Cancer Ingestion/Dermal (mg/kg-d)	Non-Cancer Inhalation ^a (mg/m ³)	Total Cancer Ingestion/Dermal (mg/kg-d)	Cancer Inhalation ^a (mg/m ³)
As	8.4E-6	NA ^b	7.1E-7	1.9E-8
Cd	7.3E-6	NA ^b	NA ^d	6.6E-9
Co	3.9E-7	4.0E-8	NA ^d	NA ^d
Cr	2.7E-4	NA ^c	NA ^d	NA ^d
Cu	0.0015	NA ^c	NA ^d	NA ^d
Hg	4.4E-6	5.5E-9	NA ^d	NA ^d
Mo	1.7E-5	NA ^c	NA ^d	NA ^d
Ni	9.3E-5	NA ^b	NA ^d	1.1E-7
Pb	1.2E-4	NA ^c	NA ^d	NA ^d
Se	5.2E-6	NA ^c	NA ^d	NA ^d
Zn	0.0013	NA ^c	NA ^d	NA ^d
PCBs	2.9E-8	NA ^c	3.8E-9	1.3E-09
PCDD/Fs	2.3E-11	NA ^c	2.3E-12	1.1E-13

Note:

- a. Concentration in air evaluated as airborne particulate from amended soil at 5 cm depth.
- b. Not Applicable: EoPC evaluated as a carcinogen following inhalation.
- c. Not Applicable: Inhalation CDI not evaluated because there are no applicable inhalation RfC for the corresponding EoPC.
- d. Not Applicable: Not evaluated as a carcinogen for this route of exposure.

The CDI calculation results for the golfer for the Recreational Use Scenario are presented in Table 5-28. Similar to the park users greatest contribution of EoPCs to golfers was via inadvertent ingestion of a pellet, followed by dermal and inhalation. Both the CDI and LADI estimated intakes for all EoPCs were less than that calculated for the parkland users, as a result of less time spent on site.

Table 5-28: Golfer Chronic Daily Intake and Lifetime Averaged Daily Intake

EoPC	Chronic Daily Intake		Lifetime Averaged Daily Intake	
	Total Non-Cancer Ingestion/Dermal (mg/kg-d)	Non-Cancer Inhalation ^a (mg/m ³)	Total Cancer Ingestion/Dermal (mg/kg-d)	Cancer Inhalation ^a (mg/m ³)
As	2.4E-7	NA ^b	1.8E-7	5.1E-8
Cd	3.4E-7	NA ^b	NA ^d	1.7E-8
Co	5.7E-7	1.1E-7	NA ^d	NA ^d
Cr	1.1E-5	NA ^c	NA ^d	NA ^d
Cu	6.1E-5	NA ^c	NA ^d	NA ^d
Hg	2.2E-7	1.5E-8	NA ^d	NA ^d
Mo	6.5E-7	NA ^c	NA ^d	NA ^d
Ni	9.1E-6	NA ^b	NA ^d	2.9E-7
Pb	5.3E-6	NA ^c	NA ^d	NA ^d
Se	1.8E-7	NA ^c	NA ^d	NA ^d
Zn	4.5E-5	NA ^c	NA ^d	NA ^d
PCBs	2.2E-9	NA ^c	1.6E-9	1.4E-09
PCDD/Fs	9.5E-13	NA ^c	7.0E-13	1.0E-13

Note:

- a. Concentration in air evaluated as airborne particulate from amended soil at 5 cm depth.
- b. Not Applicable: EoPC evaluated as a carcinogen following inhalation.
- c. Not Applicable: Inhalation CDI not evaluated because there are no applicable inhalation RfC for the corresponding EoPC.
- d. Not Applicable: Not evaluated as a carcinogen for this route of exposure.

5.3.8.3 Residential Daily Intakes of EoPCs

Estimated chronic daily intakes of EoPCs for toddlers and LADI for composite receptors in the Home Use Scenario are presented in Tables 5-29. The consumption of vegetables and fruits had a significant impact on the total ingestion exposure for residential receptors for both CDI and LADI daily intakes. In many cases the total exposure of EoPCs, to which the toddlers were exposed was similar between the inadvertent soil ingestion pathway, and the ingestion of garden produce and garden fruits. The backyard garden produce and fruit ingestion rates were estimated to be 7% of the total ingestion of these foodstuffs for 208 days per year. This ingestion rate of backyard produce is considered a conservative estimate since it represents a reasonable maximum exposure that assumes that an individual with a garden, who applies pellets at twice the recommend rate, consumes garden produce (7% of their total diet for each vegetables and fruit) over the entire growing season. This also assumes that pellets are applied to gardens even though the label recommends application specifically to lawns.



The current study assumes that 7% of a residential receptor's total diet is comprised of garden-grown root vegetables, above-ground vegetables and fruit. In a recent survey of close to 400 homes in Port Colborne, Ontario (Jacques Whitford, 2004), it was found that most fruits and vegetables that make up the diet are not grown in backyard gardens. Although the fraction from gardens is higher for some items, as a fraction of total dietary fruits and vegetables (which includes oranges, juices, etc.), the home-grown fraction is quite small and the 7% assumed is thus considered conservative for the City of Toronto.

Exposure via the inhalation pathway resulted in daily intakes, both CDI and LADI, were orders of magnitude less than those calculated for the ingestion/dermal exposure pathways. Overall the LADI intakes were approximately three times less than those calculated for the toddler, non-carcinogenic chronic daily intakes. This is a function of the exposure to EoPCs being averaged over all five lifestages and a 75 year period.

Table 5-29: Residential Toddler Chronic Daily Intake and Lifetime Averaged Daily Intake

EoPC	Toddler Chronic Daily Intake		Lifetime Averaged Daily Intake	
	Total Non-Cancer Ingestion/Dermal (mg/kg-d)	Non-Cancer Inhalation ^a (mg/m ³)	Total Cancer Ingestion/Dermal (mg/kg-d)	Cancer Inhalation ^a (mg/m ³)
As	9.5E-6	NA ^b	3.4E-6	2.7E-8
Cd	3.5E-5	NA ^b	NA ^d	8.3E-9
Co	1.3E-5	4.0E-8	NA ^d	NA ^d
Cr	3.0E-4	NA ^c	NA ^d	NA ^d
Cu	0.0056	NA ^c	NA ^d	NA ^d
Hg	4.0E-5	5.5E-9	NA ^d	NA ^d
Mo	3.4E-5	NA ^c	NA ^d	NA ^d
Ni	2.6E-4	NA ^b	NA ^d	1.5E-7
Pb	2.4E-4	NA ^c	NA ^d	NA ^d
Se	1.8E-5	NA ^c	NA ^d	NA ^d
Zn	0.020	NA ^c	NA ^d	NA ^d
PCBs	4.7E-8	NA ^c	1.1E-8	1.4E-09
PCDD/Fs	2.6E-11	NA ^c	3.3E-12	1.2E-11

Note:

- Concentration in air evaluated as airborne particulate from amended soil at 5 cm depth.
- Not Applicable: EoPC evaluated as a carcinogen following inhalation.
- Not Applicable: Inhalation CDI not evaluated because there are no applicable inhalation RfC for the corresponding EoPC.
- Not Applicable: Not evaluated as a carcinogen for this route of exposure.

Table 5-30 presents chronic daily intakes for adults in the residential scenario.



Table 5-30: Residential Adult Chronic Daily Intake

EoPC	Adult Chronic Daily Intake	
	Total Non-Cancer Ingestion/Dermal (mg/kg-d)	Non-Cancer Inhalation ^a (mg/m ³)
As	2.5E-6	NA ^b
Cd	1.1E-5	NA ^b
Co	4.9E-6	6.5E-8
Cr	2.0E-5	NA ^c
Cu	0.0013	NA ^c
Hg	1.3E-5	8.5E-9
Mo	7.2E-6	NA ^c
Ni	6.3E-5	NA ^b
Pb	5.1E-5	NA ^c
Se	5.8E-6	NA ^c
Zn	0.0060	NA ^c
PCBs	7.7E-9	NA ^c
PCDD/Fs	1.6E-12	NA ^c

Note:

- Concentration in air evaluated as airborne particulate from amended soil at 5 cm depth.
- Not Applicable: EoPC evaluated as a carcinogen following inhalation.
- Not Applicable: Inhalation CDI not evaluated because there are no applicable inhalation RfC for the corresponding EoPC.
- Not Applicable: Not evaluated as a carcinogen for this route of exposure.

5.4 Risk Characterization

The potential hazards associated with exposures to non-carcinogenic (threshold acting) substances are assessed differently than the potential risks associated with exposures to carcinogenic (non-threshold acting) substances. For threshold acting substances, it is assumed that there is a dose (or concentration) of the chemical of concern that does not produce any adverse effect.

A Tolerable Daily Intake (TDI) is an estimate of a chemical intake that is unlikely to cause an increased incidence of deleterious health effects during a lifetime of exposure. TDIs are specifically developed to be protective for chronic exposure to a chemical. For the purposes of deriving site-specific threshold levels, a chronic daily intake (CDI) is calculated for the exposed individual and compared to the TDI. If the ratio of CDI to TDI (*i.e.* CDI/TDI) is greater than 0.2, then there is the potential for adverse health effects and further assessment would be required.

For EoPCs for which the critical effect is assumed to have no threshold (*i.e.* carcinogens), it is assumed that there is some probability of harm to human health at any level of exposure. A linear dose-response relationship is assumed to convert estimated daily intakes averaged over a lifetime of exposure directly to an incremental risk of an individual developing cancer. For the purposes of deriving site-specific soil quality guidelines, Health Canada considers that a single increased case of cancer in an exposed population of 100,000 merits action (Health Canada, 2003). The MOE considers that a single increased case of cancer in an exposed population of 1,000,000 merits action (MOE, 1996c).

5.4.1 Non-carcinogenic Risk Assessment Approach and Methodology

The potential health effects associated with non-carcinogenic chemicals are assessed differently than those for carcinogenic chemicals. Non-carcinogenic chemicals are generally considered to act through a threshold mechanism where it is assumed that there is a dose (or concentration) that does not produce any adverse effect. As the dose or concentration increases to the point where the body can no longer process or excrete the chemical to repair the damage, and/or the body's defense mechanism is overwhelmed, an adverse effect may occur. This point is termed the *threshold* response level and is different for every chemical.

For risk characterization of non-carcinogenic EoPCs, individual Hazard Quotients (HQs) were derived for each of the compounds for the inadvertent ingestion, dermal contact, and produce ingestion pathways by dividing the CDI by the TDI.

$$HQ = \frac{CDI}{TDI}$$

Where:

- HQ = Hazard Quotient
- CDI = Chronic Daily Intake
- TDI = Tolerable Daily Intake

A target HQ of 0.2 was used for all EoPCs for each exposure pathway as this risk assessment has not addressed all potential pathways of exposure, including background exposure from items such as supermarket foods. If the HQ is less than 0.2 then the intake of EoPC from pellet exposure does not exceed the benchmark level and no adverse health effects are expected.



Where TDIs exist specifically for inhalation exposure (cobalt and mercury) HQs for inhalation of amended soil and pellet particles for each of the EoPCs were calculated by dividing the concentration of the EoPC in the air by the inhalation RfC.

$$HQ = \frac{C_{air}}{RfC}$$

Where:

- C_{air} = Concentration of EoPC in air (mg/m^3) = $C_{soil/pel}$ (mg/kg) x Particulate concentration in air ($7.6E-8 \text{ kg}/m^3$; Health Canada, 2003); and
- $C_{soil/pel}$ = Concentration of EoPC in soil or pellet (mg/kg)
- RfC = Reference Concentration (mg/m^3)

5.4.2 Carcinogenic Risk Assessment Approach and Methodology

As previously discussed, the characterization of potential hazards associated with carcinogenic and non-carcinogenic exposures is assessed separately, based on the differences in the way these two types of chemicals may produce effects in the body.

Carcinogenic risks are expressed as Exposure Ratios in this study. Exposure ratios are determined using the following equation:

$$ER = \frac{LADI \text{ or } C_{air}}{Exposure \text{ limit}}$$

Where:

- ER = Exposure Ratio (unitless)
- LADI = Lifetime Averaged Daily Intake ($mg/kg-d$);
- C_{air} = Concentration of EoPC in air (mg/m^3) = $C_{soil/pel}$ (mg/kg) x Particulate concentration in air ($7.6E-8 \text{ kg}/m^3$; Health Canada, 2003); and
- Exposure limit = Reference Exposure Limit expressed as a dose rate ($mg/kg-d$) or air concentration (mg/m^3)

Note that the dose rate or concentration and the exposure limit are expressed using the same units. An Exposure Ratio of 1.0 can be used as a benchmark for non-threshold acting chemicals.

The exposure limit for non-threshold acting chemicals is calculated from a cancer slope factor (*i.e.*, a cancer risk expressed as risk per exposure rate) or a cancer unit risk (*i.e.*, a cancer risk expressed as risk per airborne concentration) for a specific level of cancer risk considered acceptable as follows:

$$\text{exposure limit} = \frac{\text{tolerable cancer risk}}{SF \text{ or } UR}$$

Where:

Exposure Limit	=	reference exposure limit expressed as a dose rate (mg/kg-d) or air concentration (mg/m ³)
Tolerable Cancer Risk	=	1E-05 (Health Canada benchmark) or 1E-06 (MOE benchmark)
SF	=	Cancer slope factor (mg/kg-d) ⁻¹
UR	=	Cancer unit risk (mg/m ³) ⁻¹

An incremental cancer risk greater than one case in one hundred thousand to one in one million was used as a reference range to ascertain whether or not the incremental risk in developing cancer from an EoPC is acceptable based on Health Canada and MOE guidance.

5.4.3 Risk Characterization Results for City Parks Worker

Hazard quotients and exposure ratios for City Parks Workers applying pellets to parks and other city lands are presented in Table 5-31. All hazard quotients and exposure ratios are below their respective benchmarks of 0.2 and 1.0.



Table 5-31: Risk Characterization for City Parks Worker Scenario

EoPC	Hazard Quotients		Exposure Ratios			
	Total Ingestion/Dermal	Inhalation ^a	Total Ingestion/Dermal Cancer Risk ER		Inhalation ^a Cancer Risk ER	
			1E-05	1E-06	1E-05	1E-06
As	0.005	NA ^b	0.09	0.9	0.04	0.4
Cd	0.007	NA ^b	NA ^d	NA ^d	0.06	0.6
Co	4E-06	0.002	NA ^d	NA ^d	NA ^d	NA ^d
Cr	8E-05	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Cu	0.03	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Hg	0.004	7E-05	NA ^d	NA ^d	NA ^d	NA ^d
Mo	0.002	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Ni	0.002	NA ^b	NA ^d	NA ^d	0.01	0.1
Pb	0.01	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Se	4E-04	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Zn	0.002	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
PCBs	6E-06	NA ^c	9E-06	9E-05	1E-05	1E-04
PCDD/Fs	0.005	NA ^c	0.06	0.6	9E-04	0.009

Note:

- a. Concentration in air evaluated as airborne particulate from amended soil at 5 cm depth.
- b. Not Applicable: EoPC evaluated as a carcinogen following inhalation.
- c. Not Applicable: Inhalation HQ not evaluated because there are no applicable inhalation RfC for the corresponding EoPC.
- d. Not Applicable: Not evaluated as a carcinogen for this route of exposure.

HQs for City Landfill Workers applying pellet amended landfill topdressing are presented in Table 5-32. In the City Landfill Worker Scenario, the exposure to EoPC concentrations resulted in HQs at least an order of magnitude below the MOE's acceptable benchmark of 0.2. All carcinogenic exposure ratios were also well below the benchmark of 1.0 for both risk levels evaluated.

Table 5-32: Risk Characterization for City Landfill Worker Scenario

EoPC	Hazard Quotients		Exposure Ratios			
	Total Ingestion/Dermal	Inhalation ^a	Total Ingestion/Dermal Cancer Risk ER		Inhalation ^a Cancer Risk ER	
			1E-05	1E-06	1E-05	1E-06
As	2E-04	NA ^b	0.003	0.03	0.003	0.03
Cd	3E-04	NA ^b	NA ^d	NA ^d	0.005	0.05
Co	3E-07	1E-04	NA ^d	NA ^d	NA ^d	NA ^d
Cr	3E-06	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Cu	0.001	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Hg	2E-04	6E-06	NA ^d	NA ^d	NA ^d	NA ^d
Mo	7E-05	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Ni	7E-05	NA ^b	NA ^d	NA ^d	9E-04	0.009
Pb	4E-04	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Se	2E-05	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Zn	8E-05	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
PCBs	2E-07	NA ^c	4E-07	4E-06	1E-05	1E-04
PCDD/Fs	2E-04	NA ^c	0.003	0.03	3E-04	0.003

Note:

- Concentration in air evaluated as airborne particulate from amended soil at 5 cm depth.
- Not Applicable: EoPC evaluated as a carcinogen following inhalation.
- Not Applicable: Inhalation HQ not evaluated because there are no applicable inhalation RfC for the corresponding EoPC.
- Not Applicable: Not evaluated as a carcinogen for this route of exposure.

5.4.4 Risk Assessment Results for Recreational Exposure

Hazard quotients for a toddler who visits recreational parks and are exposed to EoPCs are presented in Table 5-33. Individual HQ for all non-carcinogenic EoPC compounds were less than 0.2, and in most cases by at least an order of magnitude, thus there was no exceedance of MOE guideline risk targets. No cancer exposure ratios exceeded either benchmark evaluated.



Table 5-33: Risk Characterization for Toddler and Composite Receptor - Recreational Use Scenario

EoPC	Hazard Quotients		Exposure Ratios			
	Total Ingestion/Dermal	Inhalation ^a	Total Ingestion/Dermal Cancer Risk ER		Inhalation ^a Cancer Risk ER	
			1E-05	1E-06	1E-05	1E-06
As	0.03	NA ^b	0.07	0.7	0.008	0.08
Cd	0.01	NA ^b	NA ^d	NA ^d	0.006	0.06
Co	2E-05	0.002	NA ^d	NA ^d	NA ^d	NA ^d
Cr	2E-04	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Cu	0.02	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Hg	0.01	2E-05	NA ^d	NA ^d	NA ^d	NA ^d
Mo	0.003	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Ni	0.005	NA ^b	NA ^d	NA ^d	0.003	0.03
Pb	0.03	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Se	0.001	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Zn	0.004	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
PCBs	0.001	NA ^c	8E-04	0.008	1E-05	1E-04
PCDD/Fs	0.01	NA ^c	0.03	0.3	4E-04	0.004

Note:

- a. Concentration in air evaluated as airborne particulate from amended soil at 5 cm depth.
- b. Not Applicable: EoPC evaluated as a carcinogen following inhalation.
- c. Not Applicable: Inhalation HQ not evaluated because there are no applicable inhalation RfC for the corresponding EoPC.
- d. Not Applicable: Not evaluated as a carcinogen for this route of exposure.

Hazard quotients for golfers derived using 95% UCLM amended soil (5 cm depth) EoPC concentration values are presented in Table 5-34. Individual HQs for all non-carcinogenic EoPC compounds were orders of magnitude less than 0.2. No cancer exposure ratios exceeded either benchmark of acceptable risk evaluated.

Table 5-34: Risk Characterization for Golfer - Recreational Use Scenario

EoPC	Hazard Quotients		Exposure Ratios			
	Total Ingestion/Dermal	Inhalation ^a	Total Ingestion/Dermal Cancer Risk ER		Inhalation ^a Cancer Risk ER	
			1E-05	1E-06	1E-05	1E-06
As	8E-04	NA ^b	0.03	0.3	0.02	0.2
Cd	7E-04	NA ^b	NA ^d	NA ^d	0.02	0.2
Co	3E-05	0.005	NA ^d	NA ^d	NA ^d	NA ^d
Cr	7E-06	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Cu	0.002	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Hg	7E-04	5E-05	NA ^d	NA ^d	NA ^d	NA ^d
Mo	1E-04	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Ni	5E-04	NA ^b	NA ^d	NA ^d	0.007	0.07
Pb	0.001	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Se	4E-05	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Zn	2E-04	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
PCBs	1E-04	NA ^c	3E-04	0.003	1E-05	1E-04
PCDD/Fs	5E-04	NA ^c	0.01	0.1	5E-04	0.005

Note:

- a. Concentration in air evaluated as airborne particulate from amended soil at 5 cm depth.
- b. Not Applicable: EoPC evaluated as a carcinogen following inhalation.
- c. Not Applicable: Inhalation HQ not evaluated because there are no applicable inhalation RfC for the corresponding EoPC.
- d. Not Applicable: Not evaluated as a carcinogen for this route of exposure.

5.4.5 Risk Assessment Results for Home Use

HQs for residential pellet users were derived for receptors exposed to amended soils following the application of pellets to lawns, for receptors exposed directly to pellets during pellet application, and for receptors exposed to amended garden soils during gardening activities and via ingestion of backyard garden vegetables. Individual HQs for all EoPC compounds with non-carcinogenic effects were less than 0.2 as shown in Table 5-35 and Table 5-36. Given that the most sensitive life stage, a toddler aged 6 months up to 5 years old (i.e. 6 months to <5 years) was modeled, a potential non-carcinogenic risk is not anticipated for any other life stage. A toddler in the Home Use Scenario, that is separate from the toddler in the Recreational Use Scenario, was created to allow maximization of the amount of time spent outdoors estimated by Health Canada (2003a and 2003b) in each location.

For the composite receptor, the exposure ratio for arsenic exceeded one for the MOE cancer benchmark, but was less than one for the Health Canada cancer benchmark.



Table 5-35: Risk Characterization for Toddler and Composite Receptor - Home Use Scenario

EoPC	Hazard Quotients		Exposure Ratios			
	Total Ingestion/Dermal	Inhalation ^a	Total Ingestion/Dermal Cancer Risk ER		Inhalation ^a Cancer Risk ER	
			1E-05	1E-06	1E-05	1E-06
As	0.03	NA ^b	0.5	5	0.01	0.1
Cd	0.07	NA ^b	NA ^d	NA ^d	0.008	0.08
Co	6E-04	0.002	NA ^d	NA ^d	NA ^d	NA ^d
Cr	2E-04	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Cu	0.06	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Hg	0.1	2E-05	NA ^d	NA ^d	NA ^d	NA ^d
Mo	0.007	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Ni	0.01	NA ^b	NA ^d	NA ^d	0.004	0.04
Pb	0.07	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Se	0.004	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
Zn	0.07	NA ^c	NA ^d	NA ^d	NA ^d	NA ^d
PCBs	0.002	NA ^c	0.002	0.02	1E-05	1E-04
PCDD/Fs	0.01	NA ^c	0.05	0.5	4E-04	0.004

Note:

- Concentration in air evaluated as airborne particulate from amended soil at 5 cm depth.
- Not Applicable: EoPC evaluated as a carcinogen following inhalation.
- Not Applicable: Inhalation HQ not evaluated because there are no applicable inhalation RfC for the corresponding EoPC.
- Not Applicable: Not evaluated as a carcinogen for this route of exposure.

Table 5-36: Risk Characterization for Adult - Home Use Scenario

EoPC	Hazard Quotients	
	Total Ingestion/Dermal	Inhalation ^a
As	0.008	NA ^b
Cd	0.02	NA ^b
Co	2E-04	0.003
Cr	1E-05	NA ^c
Cu	0.04	NA ^c
Hg	0.04	3E-05
Mo	0.001	NA ^c
Ni	0.003	NA ^b
Pb	0.01	NA ^c
Se	0.001	NA ^c
Zn	0.02	NA ^c
PCBs	4E-04	NA ^c
PCDD/Fs	8E-04	NA ^c

Note:

- Concentration in air evaluated as airborne particulate from amended soil at 5 cm depth.
- Not Applicable: EoPC evaluated as a carcinogen following inhalation.
- Not Applicable: Inhalation HQ not evaluated because there are no applicable inhalation RfC for the corresponding EoPC.

5.4.6 Summary of the Risk Characterization of the Non-Carcinogens

No unacceptable levels of non-cancer risk, as defined by the MOE, were found from exposure to pellets or to amended soils for any receptor in any scenario. The HQs for all EoPCs in all scenarios were less than 0.2.

Of the inadvertent ingestion, dermal contact, and ingestion of garden produce exposure pathways considered in this assessment, the toddler in the Home Use Scenario has the overall highest potential exposure to non-cancer effects from exposure to amended soils on their lawn and garden, followed by the toddler in the Recreational Use Scenario exposed to amended turf soils. The lowest HQs were found for the City Workers and the adult for the Recreational Use Scenario. However, the HQs for all EoPCs for both scenarios are less than 0.2, indicating adverse non-cancer health effects are not expected.



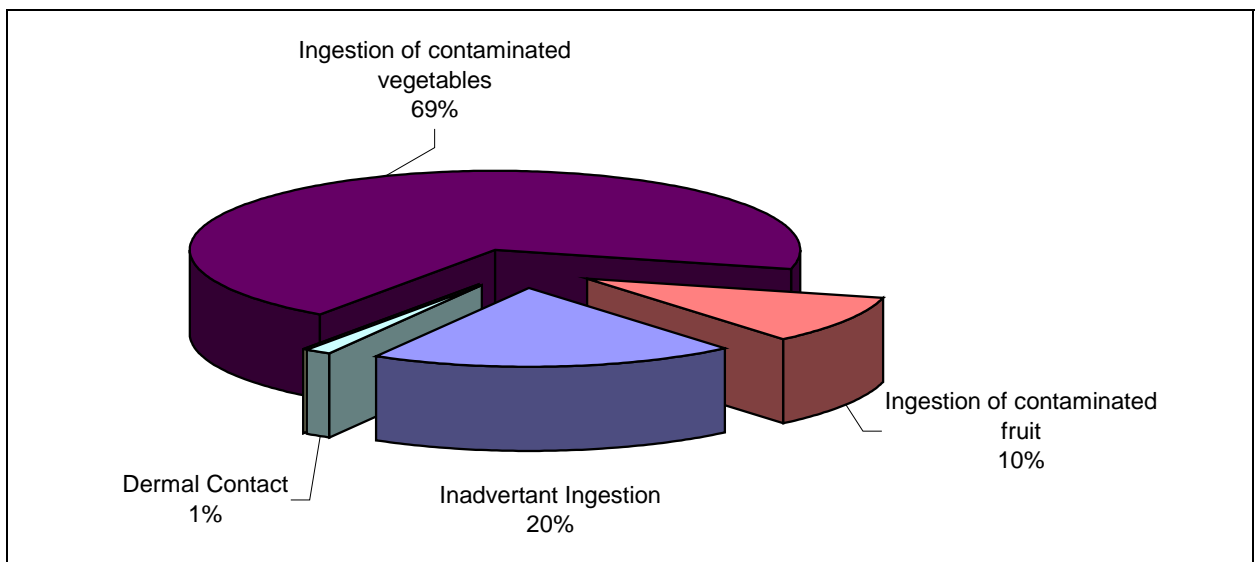
For all carcinogenic endpoint EoPCs, with the exception of arsenic, there was no increased lifetime cancer risk found above the MOE's (1996c) benchmark of 1×10^{-6} . Therefore, in the case of the carcinogenic effects of cadmium, nickel, PCBs and PCDD/F the concentrations in pellets and the amended soil scenarios described in this risk assessment would not pose an increased cancer risk above the MOE or Health Canada guidelines.

5.4.7 Discussion on Potential Carcinogenic Risk from Exposure to Arsenic from Pellets

Risks from arsenic did not exceed either the Health Canada or MOE benchmarks for acceptable risk for the City Landfill Worker, City Parks Worker and Recreational Use Scenarios. This indicates that there are no unacceptable risks to these receptors, based on the Health Canada and MOE definitions of acceptability.

The cancer exposure ratio for arsenic exceeded one for the MOE benchmark but was less than one for the Health Canada benchmark for the Residential Scenario. This indicates that the risk is acceptable based on the Health Canada definition of acceptability, but not the MOE definition. Figure 5-7 provides a graphical illustration of the contribution of each ingestion/dermal pathway to the overall cancer risk for the Residential Scenario.

Figure 5-7: Percent Contribution of Each Ingestion/Dermal Exposure Pathway to Residential Composite Receptor Cancer Risk



The estimated concentration of arsenic in pellets of 8.1 mg/kg (based on cake data) is less than the MOE (2004) reported full-depth background concentration of arsenic in soils at 17 mg/kg. This concentration is considered representative of upper limits of typical province-wide background arsenic concentrations in soils that are not contaminated by point sources. Based on the results of the arsenic characterization, it can be assumed that exposure to background soils would result in a greater risk than pellets. Therefore, the Residential and Recreational scenarios carcinogenic risks, as defined by the MOE benchmark, are less than the risk associated with exposure to background concentrations of arsenic in Ontario soil.

5.5 Uncertainty Analysis

Risk estimates normally include an element of uncertainty, and generally these uncertainties are addressed by incorporating conservative assumptions in the analysis. As a result, risk assessments tend to overstate the actual risk. Although many factors are considered in preparation of a risk analysis, the results are generally only sensitive to very few of these factors. The uncertainty analysis is included to demonstrate that assumptions used are conservative, or that analysis results are not sensitive to the key assumptions.

A risk assessment containing a high degree of confidence will be based on:

- conditions where the problem is defined with a high level of certainty based on data and physical observations;
- an acceptable and reasonable level of conservatism in assumptions that will ensure that risks are overstated; or
- an appreciation of the bounds and limitations of the final solution.

The exposure assessment performed as part of this assessment was based on:

- available data to describe existing surface soil conditions and EoPC distributions;
- sound conservative assumptions for certain parameters, as required; and
- well-understood and generally accepted methods for risk prediction.



5.5.1 Uncertainties in Hazard Assessment Assumptions

The hazard assessment included a number of assumptions to produce a risk assessment that was a conservative estimate of EoPC exposure. Uncertainties in the hazard assumption include the use of cake data instead of the limited pellet data available, using the 95% UCLM concentrations and assuming an application rate that is twice the recommended application rate. These uncertainties are summarized and further discussed in Table 5-45.

As introduced in Section 5.1, the hazard assessment assumes that the measured total chromium concentrations are chromium III only. This assumption is justified given the dominant prevalence of chromium III in soil over chromium VI and what is known about their environmental chemistry and fate. Although chromium VI is more toxic than chromium III and in general is more easily absorbed by the body, once inside the body chromium VI can be reduced to chromium III (IARC, 1990; ATSDR, 2000). Studies have shown that the absorption of ingested chromium VI is less than 5% (US EPA, 1998) while the Canadian Environmental Protection Act (1994) reports up to 10% of chromium VI absorption via ingestion.

To address the uncertainty associated with the species of chromium present in pellets, a quantitative analysis of uncertainty was conducted by assuming that 3.5% of the total measured chromium concentration was chromium VI. Although the ratio of chromium VI to III in the environment is not well known, the MOE (2004) Table 1: Full Depth Background Site Conditions Standards, reports total chromium in soil as 71 µg/g and chromium VI at 2.5 µg/g. Using these background concentrations, the percentage contribution of chromium VI to total chromium is 3.5% which yields the concentrations in Table 5-37. The assumption that 100% of the measured total chromium is chromium VI would grossly overestimate risk.

Table 5-37: Estimated Chromium VI Concentrations

Media Concentrations	Total Chromium (mg/kg)	Chromium VI (mg/kg)
Pellet Concentration	159	5.60
Pellet Amended Soil Concentration Assuming 5 cm Depth	59	2.07
Pellet Amended Soil Concentration Assuming 15 cm Depth ^a	37	1.30
Landfill Topdressing	0.016	5.8E-4

Note:

- a. The plant bioconcentration factors applied to the 15 cm depth concentration were the same that were used for total chromium.

The following TRVs in Table 5-38 and bioavailabilities in Table 5-39 were selected.

Table 5-38: Selected Toxicity Reference Values for Chromium VI

Route of Exposure	TRV	Toxicological Basis	Source Agency
Non-Cancer Effects			
Ingestion	0.003 mg/kg-day	No critical effect listed	US EPA, 1998
Inhalation (CrVI particulates)	1E-4 mg/m ³	Lactate dehydrogenase in bronchioaveolar lavage fluid	US EPA, 1998
Cancer Effects			
Ingestion	NA	NA	NA
Inhalation	0.012 (µg/m ³) ⁻¹	Lung cancer	US EPA, 1998

NA – Not Applicable

Table 5-39: Selected Relative Bioavailabilities for Chromium VI

Route of Exposure	Relative Bioavailability	Reference
Ingestion	0.10	Environment Canada and Health Canada, 1994
Inhalation	1.0	Assumed
Dermal	0.090	Health Canada, 2003

Table 5-40: Chromium VI Uncertainty Assessment

Exposure Scenario	Receptor	Hazard Quotients		Exposure Ratios ^a	
		Total Ingestion/Dermal	Inhalation	Inhalation Cancer Risk	
				1E-05	1E-06
City Parks	Adult Worker	2E-04	0.004	0.5	5
Landfill	Adult Worker	2E-08	4E-07	5E-05	5 E-04
Residential	Toddler	7E-04	0.002	NA	NA
	Adult	2E-04	0.007	NA	NA
	Composite	NA	NA	0.8	8
Recreational	Toddler	3E-04	0.002	NA	NA
	Adult	5E-05	0.002	NA	NA
	Composite	NA	NA	0.2	2

Note:

- Total Ingestion/Dermal cancer risk not applicable and therefore not included in this table.
- NA = Not Applicable
- Bolded Hazard Quotients and Exposure Ratios indicate an exceedance of the tolerable benchmark.

The total ingestion/dermal and inhalation HQs for Chromium VI were several orders of magnitude less than the benchmark of 0.2. All of the cancer inhalation exposure ratios were less than 1 for the Health Canada tolerable benchmark. The landfill City worker inhalation exposure ratio did not exceed the MOE tolerable benchmark. The remaining scenarios (city parks worker, residential and recreational composite) exceeded the MOE tolerable benchmark for inhalation cancer risk. This indicates that the risk is acceptable based on the Health Canada definition of acceptability, but not the MOE definition. Furthermore, since the Chromium VI concentrations were based on 3.5% of the total chromium concentration the assumption that 100% of the pellets is chromium VI would grossly overestimate risk.

This quantitative uncertainty analysis of potential exposures to Chromium VI addresses the uncertainty associated with the relative contribution of different species within the measured total chromium. It shows, based on the percentage of background chromium VI to total chromium concentration, that the risk estimates for chromium VI meet the non-carcinogenic risk benchmarks and the Health Canada tolerable inhalation cancer risk benchmarks. The exceedances of the MOE benchmark suggest a potential for risk but does not by itself indicate a risk, given the complete lack of monitoring data on chromium VI.

The inhalation slope factor that was adopted for the uncertainty analysis was based on an epidemiological study of people exposed to chromium particulates occupationally (Mancuso, 1975). Occupational exposure to a mixture of trivalent and hexavalent chromium resulted in an increased incidence of deaths from lung cancer. According to the US EPA (1998), Mancuso (1975) reported that these lung cancer deaths were related to insoluble (trivalent), soluble (hexavalent), and total chromium exposure. The specific form of chromium that was responsible for the lung cancers was uncertain. Based on the carcinogenic potential of chromium VI and an extrapolative model by the US EPA, a slope factor of $1.2 (\mu\text{g}/\text{m}^3)^{-1}$ was derived. A follow-up cohort by Mancuso in 1997, found a clear relationship between increased incidence of lung cancer and total chromium exposure. The relationship to chromium III and chromium VI, however, was less clearly understood. In their discussion of confidence, the US EPA notes that the assumed ratio of chromium III to chromium VI may underestimate risk, however overall risks may be overestimated due to lifestyle assumptions made about the workers and lack of species-specific data.

In order to ascertain actual risk from chromium VI exposure, speciation of pellet and cake is recommended.



5.5.2 Uncertainties in Toxicological Information

There is a limited amount of toxicological information on the effects associated with human exposures to low levels of chemicals in the environment. What human information is available is generally based on epidemiological studies of occupationally exposed workers. These studies are generally limited in scope and provide results that may not be applicable to chronic or continuous exposures to low levels of chemicals. Because human toxicological information is limited, reference doses and cancer potency estimates for many compounds are based on the results of dose-response assessment studies using animals.

The use of experimental animal data to estimate potential biological effects in humans introduces uncertainties into the evaluation of potential human health effects. These estimations require that a number of assumptions be made:

- The toxicological effect reported in animals is relevant and could occur in humans.
- The assumption that extrapolation from high-dose studies to low-dose environmental exposures adequately represents the shape of the dose-response curve in the low-dose exposure range.
- Short-term exposures used in animal studies can be extrapolated to chronic or long-term exposures in humans.
- The uptake of a compound from a test vehicle (drinking water, food, etc.) in animals must be extrapolated to estimate the uptake of the chemical from environmental media (soil, sediment, air-borne particulate matter) in humans.
- The pharmacokinetic processes that occur in the test animals also occur in humans.

There are clearly a number of uncertainties associated with extrapolating from experimental animal data to humans. To address these weaknesses, regulatory agencies, such as the Health Canada and the US EPA, incorporate a large number of conservative assumptions to try and account for the uncertainties associated with this process. The uncertainties are accounted for by the use of *Uncertainty Factors* that are used to lower the reference dose well below the level at which adverse health effects have been reported in the test species. Uncertainty factors are generally applied by factors of 10 and are used to account for the following types of uncertainties:

- Variation within the population (protection of sensitive members of the population).
- Differences between humans and the test species.
- Limitations in the available toxicological information.



The magnitude of the uncertainty factors applied by the various regulatory agencies provides an indication of the level of confidence that should be placed in the reference value. Uncertainty factors typically range between 100 and 10,000, although some can be lower than 10. The latter values are found for a few chemicals where sound and substantial human toxicological information is available to enable the setting of toxicological end-point solely on the basis of human epidemiological information.

The application of uncertainty factors is intended to introduce a high degree of conservatism into the risk assessment process and to ensure, as far as possible, that limited exposures that exceed the reference concentrations will not result in adverse human health effects. Because risk assessments that use these regulatory limits incorporate the conservatism used in the development of the toxicological information, the results can generally be viewed as being extremely conservative.

5.5.3 Uncertainties in Exposure Parameters

There exists great variation in exposure parameters between individuals and ages. Exposure parameters commonly used in risk assessments include soil ingestion rates, inhalation rates, body weights, and body surface area. Numerous studies have been conducted in Canada and the United States with varying results due to population differences and factors such as lifestyles and temperature differences.

Most notable, soil ingestion rates are highly variable due to climate differences and behaviour. A behaviour, referred to as pica behaviour in children, and some adults has been demonstrated in several individuals. Pica behaviour is characterized by the deliberate ingestion of “non-nutritive substance” or, in the case of this risk assessment, soil. Given the relative rarity of this behaviour, pica individuals are not typically modelled in risk assessments.

5.5.3.1 Body Surface Area

The exposed body surface area was based on the forearms and lower legs as recommended by the US EPA (1997) that 25% of the body’s total body surface should be considered exposed during the summer. Health Canada recommends a total body surface area of 3010 cm² for toddlers and 9110 cm² for adults and construction workers based on the total surface area of hands, lower and upper arms and lower and upper legs. This leaves the trunk of the body and feet as the only unexposed areas. It is unlikely that city workers will conduct work with so much exposed skin and that adults and toddlers will be outside for 208 days in this manner as well.



Although there may be days when residential adults and toddlers wear only bathing suits to work or play outside during the summer, this is unlikely during the colder, non-snow covered days. Furthermore, the US EPA (1997) recommended skin surface area that would come in contact with soil outdoors for adults is 5000 cm², which is the same surface area that was selected in this study. Therefore, the body surface area selected is considered appropriate.

5.5.3.2 Arsenic Concentration without Background

A semi-quantitative uncertainty analysis was conducted to determine the effect of OTR contribution to risk. For arsenic, the mean background concentration from Toronto parks, as reported by the City of Toronto, was included in the HHRA. The results of the arsenic analysis found that the residential composite adult exposure ratio of 5 for total ingestion/dermal exceeded the MOE one in a million tolerable benchmark but did not exceed the Health Canada benchmark. The uncertainty analysis calculated exposure ratios by assuming no additional contribution by the background concentration. This yielded the arsenic concentrations listed in Table 5-41.

Table 5-41: Comparison of Arsenic Concentrations With and Without Background

Arsenic Concentration (mg/kg)	HHRA Analysis (with Background)	Uncertainty Analysis (without Background)	Percentage Difference
Pellet ^a	8.1	8.1	NA
Amended Soil 5 cm Depth	4.1	1.7	41
Amended Soil 15 cm Depth	3.0	0.55	69

Note:

- a. The calculation of the pellet concentration did not take into consideration the OTR₉₈ value. Please see Appendix E for calculation details.

Using the arsenic concentrations without the OTR added yielded significantly different results, as summarized in Table 5-42.

Table 5-42: Arsenic Exposure Ratio Comparison

Residential Composite Receptor Scenario	As with OTR Added	As without OTR Added
Total Dose (mg/kg-day)	3.1E-06	7.2E-07
Exposure Ratio ^a	5	1

Note:

- a. Exposure ratio based on MOE's benchmark of 10⁻⁶.



The exposure ratio of one for incremental risks from arsenic based on comparison to the MOE benchmark indicates that the risk is acceptable based on MOE criteria.

Using the amended soil concentrations without the background contribution found a decrease in all exposure ratios. Most notably, the exposure ratios for the total ingestion/dermal pathway for the residential composite decreased from 5 to 1 and the recreational composite receptor was reduced from 1 to 0.7. Therefore, the significant contribution of background arsenic in soil produces elevated risk.

5.5.3.3 *Mixing Depth of Surface Soil*

A surface soil depth of 5 cm was adopted in the HHERA. The 5 cm depth was chosen, as previously explained, to be consistent with OTR soil depths. Adopting a shallower mixing depth, however, could have impacts on the EoPC concentrations in amended surface soil. A semi-quantitative analysis was conducted to determine the effect of mixing depth on risk characterization. Table 5-43 compares the calculated 2 cm depth amended soil EoPC concentrations to the 5 cm depth concentrations adopted in the assessment.

Table 5-43: EoPC Concentrations Assuming 2 cm Mixing Depth

EoPC	Pellet Concentration (mg/kg)	Assuming 5 cm depth	Assuming 2 cm Depth	Percentage Difference
As	8.1	4.1	6.5	23%
Cd	5.1	1.3	2.9	37%
Co	3.3	8.4	9.4	6%
Cr	160	58	110	29%
Cu	1,200	260	620	40%
Hg	1.7	1.1	1.7	19%
Mo	13	2.8	6.7	41%
Ni	39	23	35	20%
Pb	93	54	82	21%
Se	3.1	1.1	2.1	30%
Zn	900	260	530	35%

An exposure assessment and risk characterization were conducted for the EoPC with the greatest percentage difference and cancer risk. The selected EoPCs were molybdenum and arsenic.



Table 5-44: Surface Soil Mixing Depth Uncertainty Analysis

Residential Toddler Scenario	As		Mo
	HQ Total Ingestion/Dermal	Exposure Ratio (10 ⁻⁶ Target Risk)	HQ Total Ingestion/Dermal
2 cm	0.04	5	0.009
5 cm	0.03	5	0.007
Percentage Difference	14%	0	13%

As demonstrated in Table 5-44, although there are increases in the hazard quotients the values are still below the benchmark of 0.2. For the exposure ratio, however, there was no influence on the risk estimates. Therefore, based on the OTR soil depths and the uncertainty analysis, a surface soil mixing depth of 5 cm is considered appropriate for this assessment.

5.5.4 Modelling Assumptions

Table 5-45 contains a summary of the major assumptions used in this risk analysis, provides an evaluation for each assumption and an opinion as to whether the assumption is acceptable.

Table 5-45: Evaluation of Assumptions in the Risk Analysis

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk ?	Acceptable Assumption?
Hazard Identification			
EoPC concentrations based on biosolid cake data from 1996 – 2003 and not the limited pellet dataset.	Details of statistical analysis and justification for use of cake dataset instead of the limited pellet dataset to establish EoPC concentrations is found in Appendix F. Only cake data set was analyzed for organic EoPC concentrations, while inorganic element concentrations were higher in the cake than the pellets, with the exception of Co and Cu. Given the relatively low temperature used in the pelletization process (280°C), it is unlikely that metal concentrations would change, although it is possible that concentration of organic EoPCs could be somewhat decreased in the pellets.	Over-estimate / Neutral	Yes
Exposure to EoPCs in pellets based on the 95% UCLM concentration applied to defined exposure areas.	This methodology is the accepted approach by Health Canada, MOE, and the US EPA. Decisions are not driven by outliers, or by a few high concentrations, or hot spots, but represent a reasonable estimate of exposure applied to the subject area. Decisions based upon the 95 th percentile would be influenced by outliers and therefore, would not be representative of EoPC concentrations in pellets.	Neutral	Yes
Exposure to EoPCs in amended soil based on the 95% UCLM concentration of twice the recommended application rate.	In order to maintain the conservative nature of the risk assessment it was assumed that twice the recommended application rate of biosolid pellets on land would be used. Twice the application rate takes into consideration those individuals who do not read the labels and may apply more than is recommended. This assumption also compensates for cutting off the evaluation of risk at 25 years.	Over-estimate/ Neutral	Yes
Use of limited data on concentrations of trace organics.	The MOE indicated that the limited data show concentrations roughly twice the average. Risks would therefore not be underestimated by the use of the small data set.	Over-estimate / Neutral	Yes
Exposure to EoPCs in amended soil based on dry weight application rates.	The recommended application rate of pellets is based on a wet weight. The derived concentrations were based upon dry weight concentrations. Assuming 10% maximum moisture content, the effective application rate of pellets is 6.0 tonnes wet weight per hectare or 5.4 tonnes dry weight per hectare.	Over estimate	Yes



Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk ?	Acceptable Assumption?
Exposure to EoPCs in amended surface soil based on 5 cm mixing depth.	The 5 cm surface soil mixing depth was selected to be consistent with the derivation of the OTR. Soil samples were collected throughout Ontario at a depth of 0 to 5 cm to establish a typical range of concentrations in the surface soil. Using a shallower mixing depth, such as 2 cm, would increase the EoPC concentrations but not significantly increase the risk.	Neutral	Yes
Exposure to EoPCs in amended garden soil based on 15 cm mixing depth.	The 5 cm surface soil mixing depth was selected to be consistent with the derivation of the OTR. Soil samples were collected throughout Ontario at a depth of 0 to 15 cm to establish a typical range of concentrations in garden or tillage soil. Most other studies assume 15 cm for gardening activities. Selecting a mixing depth less than 15 cm would not allow comparison to published studies or guidelines.	Neutral	Yes
Exposure Assessment			
Receptor characteristics were selected to represent reasonable maximum exposure scenarios.	Receptor characteristics such as soil ingestion rate and inhalation rate were selected based on recommended values by various agencies including Health Canada and the US EPA. Conservative assumptions, such as increased direct ingestion of pellets by toddlers and city parks workers, have been adopted to represent reasonable maximum exposure scenario. Adopting higher receptor characteristic values such as values representing 95 th percentiles would grossly overestimate exposures and provide unrealistic scenarios.	Neutral	Yes
Both City Worker Scenarios do not consider the use of biosolids pellets application at home; combined effect of adult Home Use Scenario with City Worker Scenarios.	The separation of the City Worker and Home Use Scenarios, allows for the most likely scenarios to be evaluated. A combined effect can be estimated semi-quantitatively by comparing the adult in the Home Use Scenario with each City Worker Scenario, therefore if the risk evaluation yields results well below the target risk value in both scenarios, it may be assumed that the additive results would also be below the target risk.	Neutral	Yes

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk ?	Acceptable Assumption?
Infant, Child and Teen lifestages were not considered to ingest pellets in addition to soil ingestion rates in the lifetime carcinogenic risk calculations.	It is considered unlikely that other lifestages will ingest pellets primarily because their exposure to pellets is reduced compared to toddlers and adults. Toddlers were assumed to ingest pellets because of mouthing behaviour exhibited by most toddlers. Mouthing behaviour involves placing a foreign object into their mouths, a behaviour that is rarely seen outside of this lifestage. Adults were assumed to ingest pellets because of exposure via handling during land application. By assuming that toddlers consume 20 mg/day of pellets for 4.5 years and that adults ingest pellets for their entire lifestage compensates for infants, children and teens.	Over-estimate	Yes
For analysis of non-carcinogenic exposure to the public accessing the parkland, and residents exposed to amended soils from their lawns, a toddler (0.5 up to 5 years old, i.e. 6 months to <5 years) was chosen as the receptor.	Young children are the most sensitive age group, potentially with the greatest exposure, for assessing non-carcinogenic effects. This approach is in accordance with accepted Health Canada, MOE and US EPA practice.	Neutral for young children but will over-estimate risks for other life stages.	Yes
For analysis of potential carcinogenic effects to the public accessing the parkland, and residents exposed to amended soils from their lawns, a lifetime average intake was used representing exposure living in Toronto and accessing the pathway and parkland daily from birth to 75 years old.	For carcinogenic chemicals this is the most protective approach. In contrast, CCME only model adult exposure (20 to 70 years old) and US EPA only model exposure for 25 years (0 to 25 years old) averaged over a lifetime.	Neutral	Yes
For the analysis of potential carcinogenic effects for adult City Workers, an averaging time of 75 years was taken into consideration.	Health Canada recommends an averaging time of 56 years for adult workers exposed to carcinogens. Using the 56 years would increase the total ingestion/dermal dose and exposure ratio by a percentage difference of approximately 14%. Inhalation effects are unaffected since averaging time is not considered in the calculation. Based on a quantitative analysis of dioxins/furans and PCBs, the exposure ratios did not exceed the MOE or Health Canada tolerable benchmark for both City Worker scenarios. For arsenic, the exposure ratios were also below the tolerable benchmarks except for the City Parks Worker that had an exposure ratio of 1 for the MOE benchmark.	Under-estimate	Yes

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk ?	Acceptable Assumption?
For the Recreational Use Scenario, both potential receptors (toddler and lifetime) assumed to be present on the property for 208 days with a maximum temperature above 10°C per year. For the City Worker Scenarios, the receptor is assumed to be exposed to pellets on-site 180 days per year for 30 year.	These are reasonable maximum values based on 30-year climate normals for temperatures in Toronto and reasonably anticipated site usage, providing a reasonable maximum exposure estimate for a toddler but likely overestimating lifetime exposure.	Over-estimate	Yes
For the Home Use Scenarios, both potential receptors (toddler and lifetime) assumed to be outdoors on the property for 1.5 hours per day, 208 days with a maximum temperature above 10°C per year.	These are reasonable maximum values based on 30-year climate normals for temperatures in Toronto and reasonably anticipated site usage, providing a reasonable maximum exposure estimate for a toddler but likely overestimating lifetime exposure.	Over-estimate.	Yes
Separate toddler scenarios were provided for time spent at the park and time spent at home.	<p>The assumption for time duration spent in the park or in the home backyard for the toddler is based on a survey of how much time Canadians spend outdoors. The full duration for time spent outdoor is used in the calculation for each of the two scenarios.</p> <p>For the toddler Home Use Scenario, consideration of pathways is considered to be inclusive of all pathways experienced at the park with the addition of garden produce consumption. Therefore, since the concentrations remain unchanged and the total time spent outdoors remains unchanged, a combined scenario does not need to be considered.</p>	Neutral	Yes
For the residential scenarios, an adult receptor was used, and was assumed to be exposed throughout their adult life. Pellet application is assumed to last 4 hours and take place 4 times per year. Gardening activities are assumed to be undertaken for 1 hour per day for 208 days.	These are reasonable maximum values based on recommended pellet applications and 30-year climate norms for temperatures in Toronto and reasonably anticipated site usage, providing a reasonable maximum exposure estimate for an adult.	Over-estimate	Yes

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk ?	Acceptable Assumption?
For the residential adult scenario, a vegetarian home gardener was not considered; 7% of total fruit, total root vegetable and total other vegetable intakes were from homegrown produce.	It was assumed that the residential adult and residential toddler consume 7% of garden-grown vegetables and 7% of garden-grown fruits based on Health Canada's <i>Investigating Human Exposure to Contaminants in the Environment: A Handbook for Exposure Calculations</i> (1995). Although no fractions are recommended for a vegetarian home gardener, it was assumed in this study that 7% of root vegetables and other vegetables (each) were home produced, therefore doubling the recommended vegetable intake which takes into consideration above average ingestion of garden vegetables. Since homegrown vegetables are the most commonly consumed in greater amounts than other homegrown produce (US EPA, 1997), this assumption was considered acceptable.	Neutral	Yes
An additional 20 mg/day pellet ingestion rate was added to the CCME default of 80 mg/day soil ingestion rate for toddlers.	CCME employed a soil ingestion rate of 80 mg/day for toddlers when it developed the 1999 soil quality guidelines. However, increased exposure to pellets was modeled in this assessment.	Over-estimate	Yes
The selected toddler soil ingestion rate of 100 mg/day is less than the US EPA recommended soil ingestion rate.	The selected rate of 80 mg/day was based on CCME guidance. The CCME guidance, in turn, was based on values estimated by Richardson, 1997. Richardson statistically analyzed measured soil ingestion rates of Canadians. The additional 20 mg/day ingestion of pellets for toddlers adopted in this assessment conservatively acknowledges the potential EoPC intake from amended soil and an additional daily intake from direct pellet ingestion.	Over-estimate	Yes
Pellets were assumed to be available for toddlers to ingest throughout the growing season.	A test of pellet integrity indicated that pellets swell and start to crumble after five days. As the time from spreading increases, it becomes increasingly unlikely that pellets remain available to be picked up and ingested.	Over-estimate	Yes
For the Home Use Scenario, receptors were also assumed to ingest fruit, vegetable and root vegetables grown in amended soil. Receptors were assumed to ingest garden produce for 208 days per year. Seven percent of the produce consumed was assumed to come from a home garden.	These are conservative assumptions based on 30-year climate norms for temperatures in Toronto. Produce would not be available during the beginning of the growing season, however some produce may be kept or canned for later consumption. Health Canada (1995) states that 7% of produce consumed can be assumed to come from a home garden in a non-agricultural setting.	Over-estimate	Yes



Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk ?	Acceptable Assumption?
Plant uptake of EoPCs in pellets was assumed to be similar to uptake from soils.	This is conservative since the literature indicates that metals in biosolids are generally less bioavailable than those in soil and plant uptake of metals is thus reduced.	Over-estimate	Yes
Plant uptake values for EoPCs were assumed to be constant.	Plant uptake values are affected by variables such as soil pH, climatic conditions and soil types. The selected uptake values were considered the most applicable for that EoPC. It is unlikely that plant uptake factors will be affected by soil pH (OTR ₉₈ pH = 7.5) and therefore are not considered to greatly affect uptake values. Plant uptake of inorganic chemicals from biosolids is expected to be less than from soils, so the use of literature uptake factors (Ufs) is considered conservative. Because the pH of biosolids is about 7 compared to about 6 or less for natural soils, the inorganic constituents in biosolids are less bioavailable for plant uptake.	Over-estimate	Yes
Toxicity Information			
Most current toxicity information available from Health Canada and the US EPA IRIS database was employed.	This approach is in accordance with standard practice and provides the most recent scientific basis for toxicity values. All values are extensively peer reviewed and accepted by Health Canada, the US EPA or the MOE.	Neutral	Yes
Uncertainty in toxicity reference values	Unit risks and slope factors are upper bound estimates of risks. Reference doses and reference concentrations have factors of uncertainty built into them. Often these factors are the largest source of uncertainty in the assessment.	Over-Estimate	Yes
Uncertainty in bioavailability	Bioavailability reflects the amount of a contaminant that enters the blood through contact with the body. Studies are often based on absolute bioavailability (<i>i.e.</i> ingestion studies) and therefore, relative bioavailability (<i>i.e.</i> extrapolation to dermal absorption) must be determined. Peer reviewed studies were evaluated in the assessment.	Over-estimate	Yes
Adopted oral bioavailabilities are based on the ingestion of soil not pellets.	The bioavailability of metals and trace organics in biosolids pellets is unknown. However, since the fraction organic carbon is likely high in pellets (given they are primarily organic matter), the oral bioavailability of pellets will likely also be high.	Underestimate for pellets	Yes

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk ?	Acceptable Assumption?
Risk Characterization			
Target risk set at 1 in 10 ⁻⁵ to 10 ⁻⁶ .	MOE accepts 10 ⁻⁶ . US EPA accepts range of 10 ⁻⁴ to 10 ⁻⁶ . Health Canada accepts 10 ⁻⁵ .	Neutral	Yes
Target Hazard Quotient = 0.2	This approach for EoPCs recognizes the contributions from all sources and provides the best estimate of total daily exposure. CCME guidelines assume that guidelines may also have to be established for other contaminated media at a site (e.g., water) and therefore only apportion 20% of the allowable daily intake to soil exposure. Broadly accepted by the MOE, Health Canada, and the World Health Organization.	Over-estimate	Yes
Deterministic risk assessment approach adopted.	The deterministic approach was taken as an initial step towards determining possible risk resulting from exposure to pellets and amended soil. A probabilistic approach provides a range of risk which takes into consideration the quantification of uncertainty. Often, a deterministic approach in risk assessment adopts upper bound variables, resulting in a more conservative assumption. Although the deterministic approach may yield a risk that is unlikely if adopted variables are extreme values (i.e. adopting 99 th percentile values), adopting reasonable maximum exposure values would yield risk estimates that err on the side of conservatism.	Over-estimate	Yes

6. HUMAN HEALTH RISK FROM EXPOSURE TO BIOLOGICAL AGENTS

Sewage sludge and biosolids potentially contain a wide range of pathogens at various times. The sewage sludge and biosolids partially reflect the infections present within the community served by the sewage treatment plant and therefore combinations of pathogens present may vary seasonally. The following section presents a literature review of biological issues relevant to the City of Toronto pellets. This section is intended to provide a general summary of the full review conducted by Springthorpe and Sattar (2004). The reader is referred to Appendix G for further details.

There are well-developed guidelines for conducting chemical risk assessments and guidance on acceptability of risk for both human and ecological receptors; however, there are no well-defined guidelines for assessing risk from environmental exposure to biological agents and no clear definition for acceptability. The science of assessing such risks is under development at the present time; therefore, this section and Appendix G are focussed on the effectiveness of the pelletization process to destroy biological agents of potential concern but does not explicitly assess risk to biological agents.

It is assumed that the pelletization technology used by the City of Toronto produces biosolids pellets by evaporating moisture from digested dewatered biosolids cakes using indirect heat. The wet biosolids cake enters the enclosed dryer from the top onto a heated tray and passes over each of the 17 trays before reaching the bottom. The dried biosolids nuclei are coated with wet biosolids each time they are recycled through the dryer. Each pass takes at least 15 minutes and the pellets are recirculated in the dryer approximately 5 to 7 times prior to being sent to the cooler.

6.1 Limitations of the Study

The literature was bound by several limitations which must be taken into consideration while reading the review. The following section outlines these limitations.

The overriding limitation of this study to assess the effectiveness of the pelletization process to destroy biological agents is that the actual temperature of the pellets has not been measured and is therefore not known precisely. Drying by itself will not necessarily inactivate pathogens. Microbial inactivation is usually achieved by a time and temperature combination, and in order to judge the potential for reduction of pathogens in the biosolids pellets, it is necessary to understand the holding time at the highest temperature achieved or an appropriate integration



over the time it takes for biosolids to pass through the pelletizer system. The stated temperature that the process achieves is 110-115 °C. However, it is not known when during the cycle this temperature is met. Does it occur for the whole of the drying process due to the increased pressure in the system, or is that temperature only achieved for a part of the process? Also, where is that temperature measured? Where is the temperature monitor placed in the system? It may not be the temperature that is reached inside each pellet as it would be quite difficult to measure. It is therefore difficult to assess the true exposure to temperature the biosolids receive.

The key issue becomes, to what extent the drying occurs in relation to the temperature achieved in the system. In other words, do the pellets experience moist or dry heat? Although dry heat is applied, because the process is enclosed, humidity is reported to be high in the pelletizer. No information was identified with which to confirm whether this is the case or not. Follow-up monitoring of the pelletizer or a similar design pelletizer in operation should be used to ascertain the humidity and confirm the effectiveness of the process.

Biosolids research has limited knowledge of the individual types of strains of microbes present in biosolids. Furthermore, the pathogenic or toxigenic potentials of these strains are poorly understood.

Finally, available literature was limited. The review included moist heat conditions. The University of Ottawa authors caution on the extrapolation of moist heat condition studies to dry heat application. The destruction of microbial cells by heat is a function of their water content (Pflug *et al.*, 2001). Dry heat inactivation is well recognized to require much higher temperatures than moist heat inactivation. The pelletization process seems to be a potentially suitable decontamination technology to make biosolids safe to use and satisfies the US EPA's process requirements for biosolids they define as Class A.

The following summary focuses on the types of pathogenic organisms shed in faeces and that may be present in sewage. This represents a range of pathogen classes including bacteria, fungi, viruses, protozoa and helminths.

6.2 Vegetative Bacteria and Enveloped Viruses

Vegetative bacterial cells and enveloped viruses are relatively sensitive to heat. The lipid bi-layer membranes that function to keep the organism intact tend to lose integrity at elevated temperatures ranging from 75 to 80°C over minutes to an hour in liquid matrices. This would



apply to many respiratory and enteric pathogens. The SARS coronavirus has been shown to be rendered non-infectious after 30, 60 and 90 minutes on surfaces at 75, 67 or 56 °C, respectively.

Vegetative bacteria are used in the United States to classify Class A biosolids with fecal coliforms of <1000 MPN (most probable number) per gram of total solids or salmonellae of <3 MPN per 4 grams of total solids. According to a study by Mocé-Llivina *et al.* (2003), a temperature of 80°C for 30 to 60 minutes would probably qualify the biosolids product as Class A according to the specified criteria. Although enterococci are not mentioned in the regulations, they are important and a 90 minute period at 80°C is considered more appropriate.

6.3 Bacterial Spores

C. perfringens is ubiquitous and the most widely spread pathogen in nature growing in short generation times of 8 to 10 minutes. *C. perfringens* causes mainly wound infections and food poisoning (Lichtigfeld, 1967; Hatheway, 1990; Bryant *et al.*, 2002). The minimal infectious dose is high (about one billion) and this is likely strain specific.

One could consider if a process was designed to inactivate *C. perfringens* then the product would most likely be free of virtually all pathogens. Strains of *C. perfringens* can be classified according to heat resistance. A liquid solution containing 10 million high heat resistant spores may need to be 100 °C for more than one hour for all of the spores to become non-viable.

6.4 Human Enteric Viruses

Human enteric viruses cannot multiply in the environment and will only decline in number in sludges and soils, however, they may survive for months or years in soils. The most important enteric viruses are hepatitis A virus (HAV), adenoviruses, calciviruses and enteroviruses which are more resistant to heating than vegetative bacteria. Human enteric viruses are not enveloped and have varying resistance to heat. The density of enteric virus in a Class A biosolid (as defined by the US EPA) after treatment must be less than 1 PFU (plaque forming unit) per 4 grams once they are shown to be present before treatment. Class A treatment at 80°C should reduce viruses by >99.99%. Although virus numbers in pellets are likely to be small, if present at all, the minimal infectious dose is extremely small and may be a single infectious virus particle (virion).

Routine enteric virus detection in biosolids is impractical because it is difficult and expensive. If the objective is to produce biosolids equivalent to the US EPA's class A, phages may be suitable indicators for the presence of human enteric viruses and as process indicators for bacteria.



6.5 Protozoan Parasites

Although numbers of organisms such as *Cryptosporidium* are known to be reduced by approximately 2 orders of magnitude in conventional anaerobic digestion, there are still many pathogenic protozoa present in sewage sludge (Chauret *et al.*, 1999).

The two most common protozoan parasites related to water are *Cryptosporidium* and *Giardia*. Others that can be found in sewage sludge include *Toxoplasma*, *Acanthamoeba*, *Naegleria*, and *Entamoeba* (Bose *et al.*, 1990).

Protozoan parasites are renowned more for their resistance to chemicals than to heat, yet information on protozoan parasites, other than *Cryptosporidium*, is limited in its availability. In water, *Cryptosporidium* oocysts were inactivated rapidly at 55 to 70°C (Fayer, 1994; Fujino *et al.*, 2002) and in milk undergoing flash pasteurization (Harp *et al.*, 1996). There is no information on dry-heat inactivation of *Cryptosporidium*.

The numbers of protozoan parasites in Class A biosolids are currently not regulated by the US EPA.

6.6 Helminths

Helminth eggs are widely distributed in digested sludges. The eggs of *Ascaris* are used as an indicator. Although they are very chemical resistant, they have been found to be inactivated at temperatures of 55°C and above (Plym-Forsell, 1995; Kato *et al.*, 2003). They are also rapidly inactivated (a few seconds) by steam cleaning when dried onto surfaces (Haas *et al.* 1998); therefore, it is reasonable to expect that temperatures that are necessary to control other organisms are adequate to inactivate *Ascaris* eggs.

6.7 Prions

Prions are infectious protein agents that are thought to cause diseases such as bovine spongiform encephalopathy (BSE) or “mad cow” disease, which is a condition of the same type as Creutzfeldt-Jakob disease (CJD) in humans. A prion is a modified form of a normal cellular protein (Prusiner, 2000). The possibility of prion disease agents replicating in the natural environment is unknown and probably remote (Gale *et al.*, 1998).



Recommendations on prions, specifically transmissible spongiform encephalopathies (TSE), have not been included because of various reasons including virtually nothing is known about the occurrence of these agents in North America. These agents are unlikely to be present in Toronto's municipal waste and if present, the risks from human exposure are unknown. Based on information on TSE, it is suggested that the pelletization process may not be suitable for prion inactivation. Furthermore, lipids that are likely present in Toronto biosolids, greatly enhance the stability of prion proteins at lower temperatures (Appel *et al.*, 1994).

There is currently no known outbreak of prion disease such as BSE in the Toronto area. The diseases are extremely rare and no "outbreak" of TSE has occurred among the Canadian human population. Transmission through feces has not been demonstrated (Tan *et al.* 1999); however, the discovery that prion diseases can be transmitted through ingestion (Heaphy, 2000) and the presence of infectivity in blood components during both the incubation and the clinical phases of the diseases (Brown, *et al.* 1999, 2001) could be a potential concern should a future outbreak of prion related disease occur in the Toronto area.

Should prion disease become a concern in Ontario in the future, precautionary measures may prevent biosolids recycling from becoming a conduit for transmission of prion disease from animals to humans or from humans to humans. Since it is not possible to ascertain if sewage treatment and pelletization processes can deactivate prions, it would be prudent to prevent entry of prions into the sewer system, such as by restricting discharge of untreated blood or blood products into the sewer systems or introducing policies similar to those in the United Kingdom regarding abattoir operation. In the United Kingdom, protective measures include

- animals that are symptomatic are subject to testing. If found to be positive, they are incinerated rather than being slaughtered;
- the brain, skull, spleen and spinal cord are banned from being disposed of into the sewer system; and,
- fine screens are installed across drains in abattoirs to prevent larger particles from entering the sewers.

6.8 Summary of Biological Issues

The pelletizer specifications include the application of dry heat at 110 to 115 °C. Because there is a continuous flow through, the precise number of cycles that pellets will take through the pelletizer is highly variable. The approximate 5 to 7 cycles that pellets take through the pelletizer is highly variable so that any one pellet may travel only one cycle through the dryer, or may cycle many times. Although the heat applied is dry heat, the pellets begin with a high moisture content and humidity is reported to potentially be near 100% in the pelletizer. This



makes the conditions difficult to assess in terms of effectiveness when dry and moist heat deactivation of pathogens vary substantially. Because the design temperature is based on heat applied rather than the internal pellet temperature, effectiveness of the process should be verified in terms of temperatures and/or effectiveness.

The literature data suggest a minimum process time of 60 to 90 minutes at a temperature of 80°C in order to achieve the destruction of most pathogens. The pellets should not be rushed through the process (i.e. the design number of passes should be maintained without attempting to hasten production). The 80 °C temperature is the internal pellet temperature required (as opposed to the applied heat temperature).

Although the inactivation of human enteric viruses is substantial (>99.99%) at the temperatures expected, a single virus can cause infection. Although the pelletization process appears to provide the conditions for effective destruction of micro-organisms, additional monitoring would be needed to confirm this capability. This can be done by routine monitoring for selected bacteria and phages. Phages may be suitable indicators for the presence of human enteric viruses in particular, and as process indicators for bacteria. The pellets should be routinely monitored for selected bacteria and phages by measuring reductions during treatment until a sufficient history of the process confirms the value of only parametric monitoring.

The pelletizer manufacturer asserts that the process meets the requirements of the US EPA for Class A biosolids. The available information seems to support this assertion; however, some biological entities in the biosolids pellets may not be deactivated by the pelletization process. Exposures to such entities increase with frequency and duration of handling, as well as quantities used and therefore would be greater for workers than for residents. Because of the increased contact time for workers routinely handling large quantities of pellets, some degree of care to minimize potential exposures to trace biological entities during handling would be reasonable until the effectiveness of the process is verified.

This review has not dealt with storage of biosolids pellets, but if they are exposed to water/moisture there may be a potential for the pellets themselves to become more friable and as a result generate more dust upon handling. Proper and consistent performance of the pelletization process is necessary in order to ensure that dehydration occurs in accordance with design specifications. Too high a moisture content in the pellets could lead to some pathogen regrowth, smouldering or fires. Complete rehydration of the pellets, if it occurs prior to land spreading, could also permit some pathogen regrowth to occur. Dry storage conditions would prevent this type of problem. Pathogen regrowth has also been demonstrated following land application.



Although pathogen content originally decreased below detection limits, pathogen content was found to increase following rainfall (NRC, 2002).

One potential risk from 'biosolids' aerosols is the possibility of pyrogenic reactions upon contact with bacterial endotoxins. This has received some interest since it is consistent with some of the anecdotal reports of effects, and the effect of endotoxins exposure may predispose tissues to infection. Depyrogenation of endotoxin-contaminated materials is relatively well understood in conjunction with 'clean' surfaces (Hecker *et al.*, 1994) but there is no information available on depyrogenation of sewage sludge. However it is anticipated that temperature(s) between 200 and 300°C would be needed for greater than one hour. It would seem unlikely that a low temperature process adequate to produce Class A biosolids would make a significant difference in the quantity of endotoxins present in pellets.

In the United Kingdom, restrictions are in place to help reduce the potential for BSE prions to enter the sewage system from abattoirs. Restrictions on abattoirs and other dischargers of blood products in quantity (e.g. mortuaries) may be considered if an outbreak of prion related disease was to occur in the Toronto area or in Canadian beef cattle.



7. ECOLOGICAL RISK ASSESSMENT

Ecological risk assessment (ERA) is a process that evaluates the likelihood that adverse environmental effects may occur, or are occurring, because of exposure to one or more stressors (Suter, 1993).

The objective of the ecological risk assessment of pellets was to determine if the use of pellets as fertilizer within the City of Toronto or as a soil amendment for landfill topdressing would pose any risk to ecological receptors for the potential usage scenarios under consideration.

The scenarios considered for the ecological risk assessment include:

1. Application to City of Toronto owned lands (e.g. parks, golf courses, landfills), with the pellets being incorporated into the surface 5-cm soil layer.
2. Commercial sale of pellets to residents of the City of Toronto for application on their lawns as a fertilizer, with the pellets being incorporated into the surface 5 cm soil layer. Note that for ecological receptors, this scenario is essentially the same as scenario (1) and does not require separate evaluation.
3. Amendment of soils used as landfill topdressing.

Application of pellets onto gardens was not considered as a scenario for ecological receptors for two reasons:

1. Pellets applied to gardens would be incorporated into a greater depth of soil, effectively reducing concentrations and making the scenario of application to lawns more conservative.
2. Pellet application to gardens would be limited due to the limited fraction of residential yards that are devoted to gardens and would thus not form a large or continuous habitat for ecological receptors.

The concentrations of entities of potential concern (EoPCs) evaluated in soils were summarized previously in Table 5-20 for the evaluated scenarios.

This ERA has been conducted according to principles laid out in Canadian guidance documents (CCME, 1996, 1997). The ERA is intended to:



- Qualitatively characterize representative ecological receptors or valued ecological components (VECs) that might be expected to be present in terrestrial habitats associated with the scenarios evaluated.
- Assess potential exposures of ecological receptors to EoPCs from pellets, following an extended period of application to soils or application of amended landfill topdressing.
- Characterize the risks associated with exposures of ecological receptors to EoPCs based upon exposure to soils and soil-based food chain pathways, following an extended period of pellet application or application of amended landfill topdressing.
- If unacceptable risks are identified for some scenarios, make recommendations for appropriate pellet uses.

This ERA uses a general framework similar in concept to the approach used for the human health risk assessment, but is distinctive in its emphasis in three main ways.

- There is no single set of ecological values or resources to be protected that can be generally applied to every site; therefore, the VECs are selected on the basis of their habits and life history to be highly exposed to EoPCs from a variety of pathways. VECs are assumed to be conservative compared to or representative of other biota that could potentially be exposed.
- For pets, the ERA considers effects on individuals. The TRVs selected for pets were considered appropriate to the protection of pets as individuals.
- For all other animals, the ERA does not consider effects on individuals of a single species, but instead is based on a consideration of chronic threshold effect levels (lowest observed adverse effect levels) based on reproductive effects for mammals and birds. This philosophy is intended to be protective of exposed biota at the population level. Therefore, although the TRVs selected for all other animals may be the same as those selected for pets, the TRVs applied for wildlife are considered protective of the species on a population basis.

A qualitative discussion of potential risks to plants and soil organisms is presented. Because the purpose of pellet use is as a soil nutrient containing supplement, a qualitative assessment of the potential risks to plants and soil organisms is considered the appropriate level of assessment. A preliminary quantitative assessment was carried out for birds and mammals. This is consistent with Canadian Council of Ministers of the Environment (CCME, 1996) guidance on ecological risk assessment.



7.1 Preliminary Qualitative Assessment of Plant Toxicity

A preliminary screening of the EoPC concentrations in pellet-amended soils with Ontario Ministry of the Environment (MOE) and CCME Ecotoxicity values was undertaken to screen the amended soil concentrations after 1 year, 10 years and 25 years. This was undertaken to assess the potential for impacts on plant life and soil micro-organisms. MOE and CCME ecotoxicity based criteria components, based on the most protective of either plant or soil invertebrate life forms, were used in this screening. The results of the comparison are presented in Table 7-1.

The majority of EoPC concentrations remain less than the relevant MOE and CCME ecotoxicity criteria even after 25 years of application. However, the concentrations of copper, selenium and zinc in soils amended with pellets down to 5 cm depth after 25 years of application are greater than either one or both of the guideline criteria, indicating that these concentrations may become a problem for plants or soil invertebrates growing in amended soils. Similarly, the concentration of copper in soils amended with pellets to a depth of 15 cm depth after 25 years of application is greater than that of both guideline criteria.

Although these long-term concentrations are greater than the ecotoxicity guideline criteria, firm conclusions cannot be reached from the preliminary evaluation. The species that determines the guideline value may not be normally found in the urban park and home environments. A more comprehensive review should be undertaken and may consider factors such as bioavailability of the form of copper or other EoPCs in pellets and potential for exposure to sensitive plant species normally grown in urban park and home environments.

7.2 Receptor Characterization

Potential ecological receptors or valued ecological components (VECs) were identified based on a review of the intended and likely uses of pellets on private and public property in the City of Toronto or on landfills, and a review of the biota typically found in the Toronto area. Only soil and soil-based pathways are assessed.

VECs in the context of the ERA are defined as resources or environmental features important to human populations, have economic or social value, or have intrinsic ecological significance. These components also provide a baseline from which the impacts of development can be evaluated, including changes in management or regulatory policies.



Table 7-1: Ecotoxicity of Soil Based on Plants or Invertebrates

Soil Concentration	As	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Se	Zn	PCB	PCDD/F
MOE ¹ Ecotoxicity Criteria													
(mg/kg)	20	12	40	750	225	10	40	150	nv	10	600	nv	nv
CCME ² Ecotoxicity Criteria													
(mg/kg)	17	10	nv	64	63	12	nv	50	300	1	200	1.3	nv
Pellet Amended Soil Concentration Assuming 5 cm depth (Lawns)													
1 year (mg/kg)	2.5	0.34	7.7	27	39	0.81	0.35	15	36	0.51	82	0.011	1.8E-06
10 year (mg/kg)	3.1	0.72	8.0	39	120	0.94	1.3	18	43	0.73	150	0.011	2.9E-06
25 year (mg/kg)	4.1	1.3	8.4	58	260	1.1	2.8	23	54	1.1	260	0.011	4.7E-06
Pellet Amended Soil Concentration Assuming 15 cm depth (Gardens)													
1 year (mg/kg)	2.4	0.31	7.7	26	33	0.80	0.28	15	35	0.49	77	0.011	1.8E-06
10 year (mg/kg)	2.6	0.44	7.8	30	61	0.85	0.59	16	38	0.56	99	0.011	2.1E-06
25 year (mg/kg)	3.0	0.65	7.9	37	110	0.92	1.1	18	41	0.69	140	0.011	2.7E-06

Notes:

1. MOE Rationale for the Development and Application of Generic Soil, Groundwater and Sediment Criteria for the Use at Contaminated Sites in Ontario, May 1996, Appendix A.2.2 Table B, coarse texture, residential parkland land use – ecological based criteria

2. CCME, Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health, 1999, rev. 2002, residential/parkland land use, soil quality guideline for protection of environmental health.

nv = no published value

Values in **BOLD** are greater than one or both criteria.



The following mammalian and avian VECs were selected for assessment on the basis of modelling their exposure and chemical dose for each of the EoPCs:

VECs that were identified included domestic pets, wild animals and birds. Plants and soil invertebrates were also identified for a preliminary qualitative assessment. The following VECs were selected as representative:

- Masked Shrew (*Sorex cinerus*). This is a small shrew, widely distributed in Canada from Newfoundland to Alberta. It is common in moist forests, open country, and brush, but can be found in virtually any habitat, urban or rural, where it's able to find food and burrow. It feeds primarily on soil invertebrates, and is consumed by predators such as hawks and foxes.
- Meadow Vole (*Microtus pennsylvanicus*). This is a small herbivorous vole which makes its burrows along open areas in grasses or other herbaceous vegetation. It is the most widely distributed small herbivore in North America, inhabiting grassy fields, marshes and bogs, including moist to wet habitats, as well as urban areas. It is a major prey item for predators such as hawks and foxes. Meadow voles and masked shrews are small burrowing animals. These particular species were selected rather than moles or mice because they are common in the area and their small size combined with the fact that they burrow make them the most sensitive small mammals.
- Red Fox (*Vulpes vulpes*). The red fox is present throughout Canada, and is something of a generalist in its feeding habits. Foxes prey heavily on mice and voles, and to a lesser extent on shrews, but will also consume insects, birds, and occasionally fruits, berries and seeds. They are also noted scavengers and are common in urban areas.
- Raccoon (*Procyon lotor*). The raccoon is the most abundant and widespread medium-sized omnivore in North America. Raccoons have adapted well to the urban environment, and frequently raid garbage cans. Their key habitat requirements are a permanent water supply, and suitable den sites. Raccoons are opportunistic omnivores, feeding on crayfish, invertebrates, reptiles and amphibians, small mammals, and fish, as well as on fruits, berries, nuts and grains.
- American Robin (*Turdus migratorius*). The American Robin is a medium sized bird that eats earthworms, insects and fruit. It occurs throughout most of Canada during the breeding season, and is increasingly being found over winter in milder portions of Canada. Access to fresh water, protected nesting habitat, and foraging areas are important to the robin. Nesting habitat includes moist forest, swamps, open woodlands, or parkland. The American Robin was selected both because of its prevalence in the area and because of its consumption of worms. The latter makes robins more sensitive to soil treatments than other species that are prevalent in the City.
- Red-tailed Hawk (*Buteo jamaicensis*). The Red-tailed Hawk is a common soaring hawk that inhabits open or semi-open areas. It is widely distributed in Canada, with the exception of Newfoundland. They prefer a mixed landscape containing old fields, wetlands, and pastures, interspersed with groves of woodland, bluffs, or streamside trees

for perching and nesting. They hunt primarily from an elevated perch, feeding on mice, voles, shrews, rabbits and squirrels.

- Domestic Dog (*Canis lupus familiaris*). Although body weight differences may cause a smaller dog to be at somewhat higher risk, very small dogs (e.g. toy dogs) would be expected to spend less time outdoors than other dogs, thus reducing their potential for exposure. An average sized dog was evaluated in this assessment. Since domestic dogs are notorious scavengers, they may occasionally catch and consume live prey including small mammals, and soil invertebrates and/or insects. Domestic dogs also consume some terrestrial plant material in the diet. The balance of the diet was assumed to be food provided by a human caregiver. The domestic dog is assumed to be fully exposed to potentially contaminated soils, and soil ingestion is assumed to comprise 2% of the total dry-weight food intake. The total dry-weight food intake for the domestic dog is based on the intake by the red fox, where the US EPA (1993) Wildlife Exposures Handbooks recommends 2% of food intake is soil.
- Domestic Cat (*Felis catus*). The domestic house cat was evaluated as a typical size house cat. Since domestic cats can be aggressive hunters, it was assumed that they consume small mammals, and soil invertebrates and/or insects. The balance of the diet is assumed to be food provided by a human caregiver. The domestic cat was assumed to be fully exposed to potentially contaminated soils, and soil ingestion was assumed to comprise 2% of the total dry-weight food intake. The total dry-weight food intake for the domestic cat is based on the intake by the red fox, where the US EPA (1993) Wildlife Exposures Handbooks recommends 2% of food intake is soil.

Because the pellets are formed from biosolids, chemicals in them are by their very nature not highly soluble. More soluble chemicals are removed from waste water by the process of flocculation, which makes them less soluble in the sewage sludge and biosolids. Aquatic effects resulting from dissolution of chemicals from pellets on lawns or gardens being transported to water courses via surface runoff are considered to be of lesser potential than more direct effects to terrestrial receptors and aquatic receptors were therefore not evaluated in this assessment.

Table 7-2 summarizes the VECs selected for this assessment. Receptors were characterized as spending all of their time (while outdoors) in areas where pellets had been spread.

Receptor characteristics were obtained largely from the US EPA (1993) *Wildlife Exposure Factors Handbook*. Detailed VEC characteristics selected are summarized in Appendix E.



Table 7-2: Summary of VECs Selected

Receptor Type	Selected VEC
Plants and soil invertebrates	Screening assessment only
Domestic pet – Carnivore	House cat
Domestic pet - Omnivore	Dog
Mammal - Herbivore	Meadow vole
Mammal – Carnivore	Masked shrew
Mammal – Omnivore	Raccoon
Mammal – Carnivore	Red fox
Fowl – Carnivore	American Robin
Fowl – Carnivore	Red-tailed hawk

The study area is assumed to be an area of parkland or property that is large enough for each of the modelled receptors to occupy for all, or a substantial part of their lifespan. This scenario is considered to be conservative for all but the smallest of receptors (such as the masked shrew or meadow vole), which are likely to occupy home ranges that will include areas of habitat that are not amended with the pellets. For the small receptors, this scenario will be realistic. This scenario is also conservative for smaller and/or discontinuous areas of potentially affected habitat, such as the application of pellets in private gardens.

7.3 Exposure Assessment

In order for chemicals to have deleterious effects, they need to gain access to the organism or receptor. The route by which this occurs is referred to as an exposure pathway, and is dependent on the nature of both the chemical and receptor. A complete exposure pathway is one that meets the following four criteria (US EPA, 1989):

- A source of constituents of concern must be present;
- Release and transport mechanisms and media must be available to move the chemicals from the source to the ecological receptors;
- An opportunity must exist for the ecological receptors to contact the affected media; and
- A means must exist by which the chemical is taken up by ecological receptors, such as ingestion, inhalation, or direct contact.

The sources of the constituents of concern for this study are:

- Biosolids pellets may be deposited onto the soil surface as a soil amendment in urban parklands or residential areas.
- Biosolids pellets may be mixed with soil as an amendment, prior to placement as landfill topdressing material.

An exposure route is the mechanism by which a receptor species might be exposed to a chemical from a source medium. For surface soils and terrestrial receptors, including mammals and birds, exposure to EoPCs may occur through the following routes:

- dermal contact with soils;
- incidental ingestion of soil (e.g., as a result of feeding or grooming);
- ingestion of plants or prey species that have accumulated chemicals from the soil; or
- inhalation of volatile chemicals or dust migrating from the soil to ambient air.

The inhalation pathway is typically of negligible importance for wildlife and pet receptors in open air situations. Methodologies for evaluating this pathway to VECs are consequently not well developed. In addition, the EoPCs considered in this assessment are either non-volatile, and/or have very low volatility and partition strongly to the solid phase present in the soil. Therefore, inhalation has not been considered a significant exposure pathway.

Dermal contact is not considered explicitly in this ERA, which is based upon oral ingestion pathways. However, for most inorganic substances, dermal absorption rates are low. The presence of fur or feathers will also tend to mitigate against dermal absorption of most soil-bound contaminants. In addition, soil ingestion (from grooming, as well as with ingested food) has been included as a pathway. All of the contaminant ingested with soil or food is assumed to be bioavailable, and would be absorbed by the organism. This conservative assumption compensates for any minor underestimation of exposure associated with omitting the dermal absorption pathway.

Exposures of VECs to EoPCs were calculated following methods consistent with CCME (1997) guidance. The potential average daily dose is considered to be equivalent to the combined doses from consumption of water, soil and diet as follows:

$$ADD_{pot} = ADD_{water} + ADD_{diet} + ADD_{soil} + ADD_{sed}$$



Where:

ADD_{pot}	=	Potential average daily dose (mg/kg-day)
ADD_{water}	=	Average daily dose from water (mg/kg-day)
ADD_{diet}	=	Average daily dose from dietary food intake (mg/kg-day)
ADD_{soil}	=	Average daily dose from soil ingestion (mg/kg-day)
ADD_{sed}	=	Average daily dose from sediment ingestion (mg/kg-day)

In the current evaluation, water and sediment were not considered as sources of EoPC exposure and were therefore set to zero. The average daily dose from dietary intake (which in general may include terrestrial and/or aquatic pathways) was calculated using the following equation:

$$ADD_{diet} = \sum (C_k \cdot FR \cdot DF_k \cdot NIR)$$

Where:

C_k	=	Average EoPC concentration in the k^{th} type of food (mg/kg fresh weight)
FR	=	Fraction of total diet ingested from the contaminated food source (unitless)
DF_k	=	Fraction of total diet accounted for by the k^{th} food group (unitless)
NIR	=	normalized ingestion rate of food on a weight to weight basis (kg/kg-day fw)

Note that in the current ERA, only ingestion of soil, and soil-based foodstuffs (terrestrial invertebrates, plants, and small animals) have been considered. The equations describing these ingestion pathways are described below.

The average daily dose from ingestion of soil was calculated according to the following:

$$ADD_{soil} = \frac{C_{soil} \cdot FS \cdot IR \cdot FR}{BW}$$

Where:

- C_{soil} = Average EoPC concentration in soil (mg/kg dw)
 FS = Fraction of soil in diet (kg/kg dw)
 IR = Food ingestion rate on a dry weight basis (kg/day)
 FR = Fraction of total soil intake from the contaminated foraging area (unitless)
 BW = Average body weight of an adult of the species (kg)

Concentrations of EoPCs in ingested plants, worms, mammals and birds were estimated as:

$$C_k = C_{soil} \bullet UF_k$$

Where:

- UF_k = Uptake factor for the kth food type (kg/kg fw)

Table 7-3 summarizes factors for the inorganic EoPCs, for each food type.

Table 7-3: Uptake Factors from Soil to Food Type (UF) (kg/kg fw)

EoPC	Food Type	Value or Equation for UF	Reference
As	Earthworm ^a	$UF_{worm} = \left(\frac{0.16 \times e^{(-1.421+0.706 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998a)
	Above-ground plant tissue ^b	$UF_{plant} = \left(\frac{0.19 \times e^{(-1.99+0.56 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Bechtel Jacobs Company (1998)
	Small animals ^c	$UF_{animal} = \left(\frac{0.32 \times e^{(-4.847+0.819 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998b)
Cd	Earthworm ^a	$UF_{worm} = \left(\frac{0.16 \times e^{(2.114+0.795 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998a)
	Above-ground plant tissue ^b	$UF_{plant} = \left(\frac{0.19 \times e^{(-0.48+0.55 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Bechtel Jacobs Company (1998)
	Small animals ^c	$UF_{animal} = \left(\frac{0.32 \times e^{(-0.431+0.487 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998b)

Table 7-3: Uptake Factors from Soil to Food Type (UF) (kg/kg fw)

EoPC	Food Type	Value or Equation for UF	Reference
Co	Earthworm ^a	$UF_{worm} = 0.122 \times 0.16 = 0.0195$	Sample <i>et al.</i> (1998a)
	Above-ground plant tissue ^b	$UF_{plant} = 0.02 \times 0.19 = 0.0038$	Baes (1984)
	Small animals ^c	$UF_{animal} = 0.020 \times 0.32 = 0.0064$	Sample <i>et al.</i> (1998b), median
Cr	Earthworm ^a	$UF_{worm} = 3.162 \times 0.16 = 0.51$	Sample <i>et al.</i> (1998a), 90 th percentile
	Above-ground plant tissue ^b	$UF_{plant} = 0.0075 \times 0.19 = 0.0014$	Baes (1984)
	Small animals ^c	$UF_{animal} = \left(\frac{0.32 \times e^{(-1.460+0.734 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998b)
Cu	Earthworm ^a	$UF_{worm} = \left(\frac{0.16 \times e^{(1.675+0.264 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998a)
	Above-ground plant tissue ^b	$UF_{plant} = \left(\frac{0.19 \times e^{(0.67+0.39 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Bechtel Jacobs Company (1998)
	Small animals ^c	$UF_{animal} = \left(\frac{0.32 \times e^{(2.042+0.144 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998b)
Hg	Earthworm ^a	$UF_{worm} = \left(\frac{0.16 \times e^{(-0.781+0.3369 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998a), regression based on model data
	Above-ground plant tissue ^b	$UF_{plant} = \left(\frac{0.19 \times e^{(-1.00+0.54 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Bechtel Jacobs Company (1998)
	Small animals ^c	$UF_{animal} = 0.054 \times 0.32 = 0.017$	Sample <i>et al.</i> (1998b), median
Mo	Earthworm ^a	$UF_{worm} = 0.953 \times 0.16 = 0.15$	Sample <i>et al.</i> (1998a), median
	Above-ground plant tissue ^b	$UF_{plant} = 0.25 \times 0.19 = 0.048$	IAEA 1994
	Small animals ^c	$UF_{animal} = 0.05 \times 0.32 = 0.016$	Derived – see text.

Table 7-3: Uptake Factors from Soil to Food Type (UF) (kg/kg fw)

EoPC	Food Type	Value or Equation for UF	Reference
Pb	Earthworm ^a	$UF_{worm} = \left(\frac{0.16 \times e^{(-0.218+0.807 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998a)
	Above-ground plant tissue ^b	$UF_{plant} = \left(\frac{0.19 \times e^{(-1.33+0.56 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Bechtel Jacobs Company (1998)
	Small animals ^c	$UF_{animal} = \left(\frac{0.32 \times e^{(0.076+0.442 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998b)
Ni	Earthworm ^a	$UF_{worm} = 1.656 \times 0.16 = 0.26$	Sample <i>et al.</i> (1998a), mean ⁴
	Above-ground plant tissue ^b	$UF_{plant} = \left(\frac{0.19 \times e^{(-2.22+0.75 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Bechtel Jacobs Company (1998)
	Small animals ^c	$UF_{animal} = \left(\frac{0.32 \times e^{(-0.246+0.466 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998b)
Se	Earthworm ^a	$UF_{worm} = \left(\frac{0.16 \times e^{(-0.075+0.733 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998a), regression, outlier removed
	Above-ground plant tissue ^b	$UF_{plant} = \left(\frac{0.19 \times e^{(-0.68+1.10 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Bechtel Jacobs Company (1998)
	Small animals ^c	$UF_{animal} = \left(\frac{0.32 \times e^{(-0.416+0.376 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998b)
Zn	Earthworm ^a	$UF_{worm} = \left(\frac{0.16 \times e^{(4.449+0.328 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998a)
	Above-ground plant tissue ^b	$UF_{plant} = \left(\frac{0.19 \times e^{(1.58+0.56 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Bechtel Jacobs Company (1998)
	Small animals ^c	$UF_{animal} = \left(\frac{0.32 \times e^{(4.471+0.074 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998b)

Table 7-3: Uptake Factors from Soil to Food Type (UF) (kg/kg fw)

EoPC	Food Type	Value or Equation for UF	Reference
PCB	Earthworm ^a	$UF_{worm} = \left(\frac{0.16 \times e^{(1.410+1.361 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998a)
	Above-ground plant tissue ^b	$UF_{plant} = 0.01 \times 0.19 = 0.0019$	Based on Travis and Arms (1988)
	Small animals ^c	$UF_{animal} = 0.000182 \times 0.32 = 0.000058$	U.S. EPA (1999)
Dioxin/ Furan	Earthworm ^a	$UF_{worm} = \left(\frac{0.16 \times e^{(3.533+1.182 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998a)
	Above-ground plant tissue ^b	$UF_{plant} = 0.0056 \times 0.19 = 0.0011$	Based on Travis and Arms (1988)
	Small animals ^c	$UF_{animal} = \left(\frac{0.32 \times e^{(0.8113+1.099 \times \ln(C_{soil}))}}{C_{soil}} \right)$	Sample <i>et al.</i> (1998b)

Notes:

- A dry-weight to wet-weight conversion factor of 0.16 is used for earthworms, based on Sample *et al.* (1998a).
- A dry-weight to wet-weight conversion factor of 0.19 is used for fresh above-ground plant tissues, based on values for dicot leaves and fruit U.S. EPA (1993)
- A dry-weight to wet-weight conversion factor of 0.32 is used for small mammal tissues, based on Sample *et al.* (1998b).
- The mean UF, while not explicitly recommended by Sample *et al.* (1998a), is an unbiased estimate of the true UF, and is the best available statistic.

A summary of chemical specific physical-chemical parameters used in this evaluation is given in Table 7-4.

Table 7-4: Summary of Physical-Chemical Parameters

EoPC	Parameter	Value	Reference
PCBs (Arochlor 1254)	Log K _{ow}	6.21	U.S. EPA (1999)
Dioxin/Furans (TCDD)	Log K _{ow}	6.64	U.S. EPA (1999)

7.4 Hazard Assessment

Assessment endpoints are explicit expressions of environmental values or characteristics to be protected at a site, and reflect societal and ecological values (Suter, 1993). Societal values address the need to protect species that are endangered, threatened, or of special interest, important as game or commercial species, or widely recognized as having aesthetic value. Ecological relevance refers to importance of the species to the function of the ecosystem. Therefore, evaluation of potential for adverse effects at the population level is used to infer potential for adverse effects at higher levels of organization, such as communities and ecosystems.

Based on the conceptual model for each ecological habitat, the following assessment endpoints are identified for the ERA:

- Assessment Endpoint: Populations of birds or mammals that may be reduced as a result of increased mortality or decreased reproduction because of the presence of constituents of concern in soils.

The information needed to deal directly with the assessment endpoints is difficult to generate and rarely available; thus measure of effects are used to bridge the gap. Measure of effects are measurable responses to stressors related to assessment endpoints, and are intended to provide a basis for assessing risk potential for the assessment endpoint. They may be defined in terms of an unacceptable level of impact to ecological receptors, such as a certain relative percent decrease in survival, growth or reproduction of ecological populations (Suter, 1993). As part of a weight-of-evidence approach, one or more measure of effects may be used for each assessment endpoint. Choice of measure of effects for each interaction between a VEC and a compound of concern is typically limited by available toxicity data. Those most commonly used to quantify the survival, growth and reproduction of mammals and birds in bioassays include the Lowest Observable Adverse Effect Level (LOAEL); and the No-observable Adverse Effect Level (NOAEL).

The measure of effects for each ecological habitat type in this assessment are as follows.

- Whether observed concentrations of constituents of concern in soils are expected to result in increased mortality or decreased reproduction in mammalian or avian wildlife receptors, after chronic exposure.
- Whether observed concentrations of constituents of concern in soils are expected to result in health effects in domestic dogs or cats, after chronic exposure.

The dose-response relationships that have been incorporated into this ERA are based upon Lowest Observed Adverse Effect Levels, in relation to survival or reproduction of birds and mammals after chronic exposure to the EoPCs. These relationships are expressed in terms of the daily ingested dose, normalized to body weight of the test organism (i.e., the toxicity reference value or TRV expressed as mg substance ingested / kg body weight–day). Where the LOAEL was based on a severe effect (e.g. significant mortality in the test population), the NOAEL was selected as a more appropriate measure of effect. Where such data were not available, LOAEL values were estimated from other endpoints including the NOAEL. The selection of TRVs is detailed in Appendix A and summarized in Table 7-5. For domestic dogs and cats, the NOAEL was used as the endpoint to respect the special relationship between humans and their pets.

Table 7-5: Summary of Selected TRVs for Ecological Receptors

EoPC	VEC	TRV (mg/kg-day)	Test Species (Body Weight, kg)	Reference
As	Birds	5.14	Mallard Ducks	Sample <i>et al.</i> 1996 based on US Fish and Wildlife Study (1964)
	Mammals	1.26	Mice	Sample <i>et al.</i> 1996 based on Schroeder and Mitchner (1971)
	Pets	0.126	Mice	Sample <i>et al.</i> 1996 based on Schroeder and Mitchner (1971)
Cd	Birds	20	Mallard Ducks	Sample <i>et al.</i> 1996 based on White and Finley (1978)
	Mammals	10	Rats	Sample <i>et al.</i> 1996 based on Sutou <i>et al.</i> (1980)
	Pets	1	Rats	Sample <i>et al.</i> 1996 based on Sutou <i>et al.</i> (1980)
Co	Birds	21	Broiler Chickens	Diaz <i>et al.</i> (1994)
	Mammals	13.25	Rats	Mollenhauer <i>et al.</i>
	Pets	1.325	Rats	Mollenhauer <i>et al.</i>
Cr	Birds	5	American Black Duck	Sample <i>et al.</i> 1996 based on study of reproduction and duckling survival
	Mammals	2737	Rats	Sample <i>et al.</i> 1996 based on Ivankovic and Preussmann (1975)
	Pets	2737	Rats	Sample <i>et al.</i> 1996 based on Ivankovic and Preussmann (1975)
Cu	Birds	47	Old Chicks	Sample <i>et al.</i> 1996 based on Mehring <i>et al.</i> (1960)
	Mammals	10	Minks	Aulerich <i>et al.</i> (1982)
	Pets	10	Minks	Aulerich <i>et al.</i> (1982)

EoPC	VEC	TRV (mg/kg-day)	Test Species (Body Weight, kg)	Reference
Hg	Birds	0.9	Japanese Quail	Sample <i>et al.</i> 1996 based on Hill Schaffner (1976)
	Mammals	1.0	Minks	Sample <i>et al.</i> 1996 based on Bleavins and Aulerich (1981)
	Pets	1.0	Minks	Sample <i>et al.</i> 1996 based on Bleavins and Aulerich (1981)
Mo	Birds	35.3	Chickens	Sample <i>et al.</i> 1996 based on Lepore and Miller (1965)
	Mammals	2.6	Mice	Sample <i>et al.</i> 1996 based on Schroeder and Mitchner (1971)
	Pets	0.26	Mice	Sample <i>et al.</i> 1996 based on Schroeder and Mitchner (1971)
Pb	Birds	11.3	Japanese Quail	Sample <i>et al.</i> 1996 based on Edens <i>et al.</i> (1976)
	Mammals	80	Rats	Sample <i>et al.</i> 1996 based on Azar <i>et al.</i> (1973)
	Pets	8	Rats	Sample <i>et al.</i> 1996 based on Azar <i>et al.</i> (1973)
Ni	Birds	77	Mallard Ducks	Sample <i>et al.</i> 1996 based on Cain and Pafford (1981)
	Mammals	30	Rats	Springborn Laboratories (2000a and 2000b)
	Pets	3	Rats	Springborn Laboratories (2000a and 2000b)
Se	Birds	1	Mallard Duck	Sample <i>et al.</i> 1996 based on Heinz <i>et al.</i> (1987)
	Mammals	0.33	Rats	Sample <i>et al.</i> 1996 based on Rosenfeld and Beath (1954)
	Pets	0.20	Rats	Sample <i>et al.</i> 1996 based on Rosenfeld and Beath (1954)
Zn	Birds	131	White Leghorn Hens	Sample <i>et al.</i> 1996 based on Stahel <i>et al.</i> (1990)
	Mammals	320	Rats	Sample <i>et al.</i> 1996 based on Schlicker and Cox (1968)
	Pets	160	Rats	Sample <i>et al.</i> 1996 based on Schlicker and Cox (1968)
PCBs	Birds	1.8	Ring-necked Pheasant	Sample <i>et al.</i> 1996 based on Dahlgren <i>et al.</i> (1972)
	Mammals	0.68	Mink	Sample <i>et al.</i> 1996 based on Aulerich and Ringer (1977)
	Pets	0.068	Mink	Sample <i>et al.</i> 1996 based on Aulerich and Ringer (1977)
PCDD/Fs	Birds	0.00014	Ring Necked Pheasant	Sample <i>et al.</i> 1996 based on Nosek <i>et al.</i> 1992
	Mammals	0.00001	Rats	Sample <i>et al.</i> 1996 based on Murray <i>et al.</i> (1996)
	Pets	0.000001	Rats	Sample <i>et al.</i> 1996 based on Murray <i>et al.</i> (1996)

If data for the specific representative mammalian or avian receptors was not available, then a scaling factor based on body weight was used to adjust the test species TRV to a wildlife species TRV based on Sample and Arenal (1999):

$$A_w = A_t \left(\frac{BW_t}{BW_w} \right)^{1-b}$$

Where:

- A_w = TRV for VEC species
- A_t = TRV for test species
- BW_w = Mean body weight for VEC species
- BW_t = Mean body weight for test species
- b = Allometric scaling factor

Body weights for test species (BW_t) and allometric scaling factors (b) selected are summarized in Table 7-6.

Table 7-6: Summary of Factors for Body Weight Scaling of TRVs

EoPC	Test Species	Body Weight (kg)	Reference	Allometric Scaling Factor (Sample and Arenal 1999)
As	Mallard Ducks	1	Sample <i>et al.</i> 1996 based on US Fish and Wildlife Study (1964)	2.080
	Mice	0.03	Sample <i>et al.</i> 1996 based on Schroeder and Mitchner (1971)	0.94
Cd	Mallard Ducks	1.153	Sample <i>et al.</i> 1996 based on White and Finley (1978)	1.2
	Rats	0.303	Sample <i>et al.</i> 1996 based on Sutou <i>et al.</i> (1980)	0.44
Co	Broiler Chickens	0.146	Diaz <i>et al.</i> (1994)	1.2
	Rats	0.35	Mollenhauer <i>et al.</i>	0.94
Cr	American Black Duck	1.25	Sample <i>et al.</i> 1996 based on study of reproduction and duckling survival	1.2
	Rats	0.35	Sample <i>et al.</i> 1996 based on Ivankovic and Preussmann (1975)	0.94
Cu	Old Chicks	0.534	Sample <i>et al.</i> 1996 based on Mehring <i>et al.</i> (1960)	1.2
	Minks	1	Aulerich <i>et al.</i> (1982)	0.94

EoPC	Test Species	Body Weight (kg)	Reference	Allometric Scaling Factor (Sample and Arenal 1999)
Hg	Japanese Quail	0.15	Sample <i>et al.</i> 1996 based on Hill Schaffner (1976)	1.2
	Minks	1	Sample <i>et al.</i> 1996 based on Bleavins and Aulerich (1981)	0.983
Mo	Chickens	1.5	Sample <i>et al.</i> 1996 based on Lepore and Miller (1965)	1.2
	Mice	0.03	Sample <i>et al.</i> 1996 based on Schroeder and Mitchner (1971)	0.94
Ni	Mallard Ducks	0.782	Sample <i>et al.</i> 1996 based on Cain and Pafford (1981)	1.2
	Rats	0.35	Springborn Laboratories (2000a and 2000b)	0.94
Pb	Japanese Quail	0.15	Sample <i>et al.</i> 1996 based on Edens <i>et al.</i> (1976)	1.2
	Rats	0.35	Sample <i>et al.</i> 1996 based on Azar <i>et al.</i> (1973)	0.94
Se	Mallard Duck	1	Sample <i>et al.</i> 1996 based on Heinz <i>et al.</i> (1987)	1.2
	Rats	0.35	Sample <i>et al.</i> 1996 based on Rosenfeld and Beath (1954)	0.94
Zn	White Leghorn Hens	1.766	Sample <i>et al.</i> 1996 based on Stahel <i>et al.</i> (1990)	1.2
	Rats	0.35	Sample <i>et al.</i> 1996 based on Schlicker and Cox (1968)	0.94
PCBs	Ring-necked Pheasant	1	Sample <i>et al.</i> 1996 based on Dahlgren <i>et al.</i> (1972)	1.2
	Mink	1	Sample <i>et al.</i> 1996 based on Aulerich and Ringer (1977)	0.94
PCDD/Fs	Ring Necked Pheasant	1	Sample <i>et al.</i> 1996 based on Nosek <i>et al.</i> 1992	1.2
	Rats	0.35	Sample <i>et al.</i> 1996 based on Murray <i>et al.</i> (1996)	0.537

7.5 Risk Characterization

Risk characterization is the final step of an ERA. It includes a quantification of the potential nature and magnitude of adverse effects that may occur to receptor species due to presence of chemicals in identified ecological habitats at the site. In this step, characterization of exposure and characterization of ecological effects for each chemical, is integrated into quantitative estimates (ecological hazard quotients or EHQ values) of the potential for adverse effects to ecological receptors.

7.5.1 Approach

For this assessment, EHQ values were calculated by dividing exposure (as the EPC or total ingested dose values) derived for each receptor by their appropriate TRV, as follows:

$$EHQ = \frac{ADD_{Pot}}{TRV_k}$$

Where,

EHQ	=	Ecological Hazard Quotient (dimensionless)
ADD _{Pot}	=	Potential average daily dose (mg/kg-day)
TRV _k	=	Toxicity Reference Value for species k (mg/kg-day)

As outlined in Section 7.3, the TRVs are adjusted for each species based on body weight scaling.

An EHQ value of less than 1 indicates the exposure concentration is less than the threshold for adverse effects, and a low probability exists that adverse effects might occur based on the assessment endpoint selected. Given the overall tendency to introduce conservatism (through the use of data or assumptions that are likely to overstate, rather than understate risk) into risk assessments, it is likely no adverse effect would occur based on the selected assessment endpoint. Alternatively, an EHQ value of greater than one does not automatically indicate that there is a risk. An EHQ value greater than one indicates that a risk cannot be ruled out based on the analysis performed. As a result, EHQ values greater than one should be examined carefully, and further more focused investigations may be required to reduce conservatism and provide a more realistic assessment of the actual risk level.

7.5.2 Results

Tables 7-7 and 7-8 summarize the calculated EHQs for ecological risk based on the Home or Recreational Use and Landfill Use Scenarios, respectively.

Table 7-7: Summary of Ecological HQs for Home or Recreational Use Scenario

EoPC	Masked Shrew	Meadow Vole	House Cat	Raccoon	American Robin	Red-Tailed Hawk	Pet Dog	Red Fox
As	0.08	0.06	1	0.1	0.02	0.006	1	0.06
Cd	0.01	0.005	0.4	0.3	0.05	0.01	0.4	0.1
Co	0.01	0.005	0.2	0.02	0.006	0.005	0.2	0.01
Cr	0.001	5E-05	8E-04	9E-04	3	0.4	7E-04	2E-04
Cu	0.3	0.4	0.9	0.7	0.1	0.1	0.8	0.8
Hg	0.07	0.08	0.03	0.07	0.09	0.03	0.03	0.04
Mo	0.1	0.06	0.4	0.1	0.008	0.002	0.4	0.05
Ni	0.1	0.01	0.3	0.09	0.04	0.02	0.2	0.05
Pb	0.03	0.008	0.3	0.03	0.2	0.2	0.2	0.03
Se	0.4	0.3	0.4	0.4	0.1	0.2	0.2	0.7
Zn	0.2	0.06	0.1	0.1	0.4	0.3	0.05	0.2
PCBs ^a	0.001	1E-04	0.004	9E-04	4E-04	4E-05	0.005	2E-04
PCDD/F ^b	0.03	0.002	1	0.4	0.01	0.007	0.9	0.3

Notes:

- a. Total PCBs based on Aroclor 1254
- b. PCDD/F based on 2,3,7,8-TCDD Equivalent
- c. Values in **Bold** indicate that the exposure ratio is greater than the threshold of adverse effects.



Table 7-8: Summary of Ecological HQs for Landfill Use Scenario

EoPC	Masked Shrew	Meadow Vole	House Cat	Raccoon	American Robin	Red-Tailed Hawk	Pet Dog	Red Fox
As	0.01	0.01	0.09	0.02	0.003	6E-04	0.1	0.007
Cd	0.003	0.001	0.1	0.07	0.01	0.005	0.06	0.04
Co	2E-04	7E-05	0.003	2E-04	1E-04	8E-05	0.003	2E-04
Cr	2E-04	5E-06	1E-04	1E-04	0.3	0.06	7E-05	3E-05
Cu	0.2	0.2	0.2	0.2	0.05	0.09	0.1	0.4
Hg	0.03	0.02	0.002	0.02	0.03	0.002	0.002	0.006
Mo	0.02	0.01	0.08	0.02	0.001	3E-04	0.07	0.009
Ni	0.009	0.001	0.04	0.007	0.003	0.004	0.02	0.01
Pb	0.003	0.001	0.03	0.003	0.02	0.05	0.01	0.008
Se	0.07	0.03	0.1	0.07	0.02	0.09	0.02	0.3
Zn	0.09	0.02	0.06	0.07	0.2	0.3	0.008	0.1
PCBs ^a	8E-08	5E-08	3E-06	2E-07	3E-08	2E-08	3E-06	9E-08
PCDD/F ^b	0.003	2E-04	0.1	0.03	9E-04	7E-04	0.1	0.03

Notes:

- Total PCBs based on Aroclor 1254
- PCDD/F based on 2,3,7,8-TCDD Equivalent
- Values in **Bold** indicate that the exposure ratio is greater than the threshold of adverse effects.

As shown for the Home or Recreational Use scenarios, a hazard quotient greater than 1 is estimated for the American robin exposure to chromium. The majority of remaining hazard quotients are less than 1, indicating that no risk to these receptors is expected.

Hazard quotients of one are estimated for house cat exposure to arsenic and dioxins and furans, and for pet dog exposure to arsenic. The TRVs for both arsenic and dioxins and furans exposure to house cats and arsenic exposure to dogs are based on NOAELs for chronic effects (reproduction effects over 3 generations). Hazard quotients of one are within the range of uncertainty of the assessment performed. Since the NOAELs are set at 10 times more conservative values than the LOAELs, EHQ values of 1 are considered to indicate no expected risk.

For the Landfill Use Scenario, all hazard quotients are less than 1 indicating that no risk to receptors evaluated is expected.

The hazard quotient of 3 for exposure of robins to chromium for the Home or Recreational Use scenarios indicate that some degree of risk cannot be ruled out based on the analysis performed. The amount by which the estimated hazard quotients are slightly greater than 1 is within the range of uncertainty of the assessment performed. The analysis performed does not account for migration or portions of the home ranges of robins that may not have pellets applied. If the robin is considered to migrate out of the Toronto area for approximately half of each year, unless pellets are applied to more than 60% of the robin population's home range the hazard quotient can be considered to be less than one and hence no effects to robins would be expected.

The American Robin is considered to be more sensitive for this assessment than other bird species in Toronto because of its consumption of worms. Uptake of soil (and hence chemicals in pellets) by worms is very high because the worm eats by taking soil into its body then extracting the unusable dirt. When ingested by robins, not only the worm is ingested, but also the soil within the worm, making the robin's ingestion of soil and hence pellet chemicals, very high compared to other species. For this reason, the elevated EHQ of 3 estimated for the American Robin is not expected to indicate a potential risk to other species of birds.

Further discussion of uncertainties in the assessment can be found in the next section.

7.6 Uncertainty Analysis

Many of the uncertainties in the ecological risk assessment are similar to those in the human health risk assessment since initial assumptions regarding the pellet characterization, application rates, etc. are the same for both the human health and ecological risk assessments. Table 7-9 outlines additional sources of uncertainty considered in the ecological risk assessment.



Table 7-9: Evaluation of Assumptions in Ecological Risk Analysis

Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk ?	Acceptable Assumption?
Hazard Identification			
Application onto gardens not evaluated	Pellets applied to gardens are incorporated to greater depths, decreasing concentrations.	Over estimate	Yes
VEC selection	The VECs selected encompass a range of trophic levels and both birds and mammals. The selection included common species as well as VECs likely to be the most exposed or most sensitive. Although deer and rabbits may be exposed in the Greater Toronto Area, they were not considered VECs in the evaluation.	Neutral	Yes
All VECs evaluated were assumed to be continuously exposed to amended soils.	Because the home range of most VECs is likely to extend beyond soil amended areas, this is conservative. For migrating birds in particular, only a portion of the year will be spent in the area of amended soils and the assumption is quite conservative. As described in Section 4.3, pellets swelled and became friable after 5 days of watering (twice a day). The availability of pellets to wildlife for consumption is believed to be limited.	Over estimate	May be overly conservative
Exposure Assessment			
Dermal contact and inhalation were not evaluated for ecological VECs.	The inhalation pathway is considered to be of negligible importance to wildlife in open air. Methodologies for evaluating this pathway and dermal exposure for wildlife are not well developed. Dermal exposure rates of inorganic substances are low.	Under estimate	Yes
Plant uptake of EoPCs in pellets was assumed to be similar to uptake from soils.	This is conservative since the literature indicates that some metals in biosolids are generally less bioavailable than those in biosolids. The pelletization process may serve to further reduce this bioavailability.	Over-estimate	Yes



Risk Analysis Study Factor/Assumption	Justification	Analysis Likely to Over/Under Estimate Risk ?	Acceptable Assumption?
Hazard Assessment			
Relative bioavailability of inorganic chemicals assumed to be 100%.	As discussed for human health, for some chemicals the relative bioavailability in soil or pellets is expected to be less than for the media on which the TRVs are based. The same holds true for ecological risk. The assumption of 100% may be quite conservative for some chemicals such as arsenic, cobalt and lead, as well as others.	Over estimate	May be overly conservative for some compounds
LOAELs were selected for VECs other than pets.	The selected values were based on non-serious endpoints and are thus considered appropriate for the evaluation of population effects.	Neutral	Yes
NOAELs were selected for pets.	The selected values were based on no observed adverse effects to test species, considering non-serious endpoints and are thus considered protective of individuals, reflecting the importance people place in their pets.	Over estimate	Yes
TRVs were adjusted based on body weights of test species versus VECs.	These methods are broadly used and considered appropriate in the absence of species specific data.	Neutral	Yes
Risk Characterization			
Target hazard quotient = 1.0	The target hazard quotient does not account for other potential sources of exposure but is generally accepted as appropriate for evaluation of population level effects based on non-severe endpoints.	Neutral	Yes

8. EMERGING ISSUES

The following section presents selected issues that may be encountered with the proposed use of biosolid pellets on City of Toronto lands. In general, concerns may be grouped and linked by a common factor: uncertainty. Given the broad topic area and associated uncertainties, concerns are perpetuated by that which is not understood, such as low level exposure to endocrine disruptors, and that which cannot be predicted, such as the intensity of potential odours.

Therefore, a number of emerging issues have been identified and discussed in this section but they are not meant to be an exclusive list of potential concerns.

8.1 Odour

The City of Toronto biosolids pellets are produced from drying digested and dewatered sewage sludge (biosolids) from the Ashbridges Bay Treatment Plant (ABTP). Given the origin of the pellets, their introduction to the public may be influenced by preconceived notions and public apprehension. The actual and perceived odours arising from pellet use may be a deterrent for residents residing near or on land with amended soils. Complaints about and apprehension towards biosolids application may affect public acceptance of pellet application and hinder marketability. Odour is a long-standing issue that surrounds biosolids acceptance, in that respect it is not an emerging issue. The quantification and measurement of odour, however, is a recent issue and thus, studies specific to odour quantification have been included in this section.

Rosenfeld *et al.* (2001) identified several characteristics that influence odour generation when three types of biosolids were applied to soil. The three types of biosolids included: biosolids dewatered on a belt press (pressed biosolids); biosolids dewatered by a centrifuge and flash dried at 190°C (dried biosolids); and biosolids dewatered by a centrifuge (spun biosolids). The pressed and spun biosolids were stabilized via mesophylic anaerobic digestion and dewatered mechanically to achieve a product that was 19 to 22% solids. The dried biosolids were produced from anaerobically digested biosolids that were dewatered and dried mechanically producing a sand-like product that was 55 to 70% solids. The characteristics that influence odour include initial substrate chemical composition, pH, moisture content, redox potential of soil, temperature, microbial activity and the physical and chemical properties of each volatile odorous compound. The main odour culprits that occur in biosolids, mainly on the drying bed and spreading on land, are sulphur compounds, nitrous compounds, acids, and organic compounds such as ketones and aldehydes (de Luca *et al.*, 1996). These compounds in biosolids may be stabilized with lime to reduce odours.



Murthy *et al.* (2003) conducted a study to evaluate the odour characteristics from wetted heat-dried biosolid pellets, the effect of storage time on odour, and the effect on odour following land application. The pellets were obtained from four wastewater treatment plants in Washington, D.C. where they were processed differently. The study was conducted under anaerobic conditions with nitrogen gas continuously flushing out the headspace.

An odour panel judged the following olfactometric parameters: intensity, described as a relative strength above the recognition threshold and expressed as parts per million butanol; persistence, described as the rate at which the odour decreases as it is diluted where a more negative slope indicates a less persistent odour; hedonic tone, described as a subjective measure of odour pleasantness or unpleasantness on a scale of -10 to +10; and descriptors which give descriptions of the odour such as fishy, earthy and so on. The study concluded that odour intensity decreased from lime-stabilized waste activated biosolids, all undigested, all primary digested-waste activated biosolids undigested, and all digested pellets but that the persistence of these odours was in the reverse order for dry pellets. For moistened pellets, all except undigested pellets had improved hedonic tone. Odour descriptions for the pellets with 33% moisture and soil inoculation are summarized in Table 8-1.

Table 8-1: Heat Dried Pellets with 33% Moisture Added and Soil Inoculation Odour Description

Sample	Typical Odour Description
All undigested	Earthy, rancid, garbage and sour
Primary digested-Waste activated biosolids undigested	Burnt, sour, earthy, rancid
Lime stabilized waste activated biosolids	Burnt, earthy, garbage, smoky
All digested	Vegetable, sour, burnt, earthy

The storage time for the pellets was 24 hours; the authors suggest a longer storage time in future studies to thoroughly characterize odour production.

Overall, subjectivity will play a major role in the accepted use of biosolid pellets and their application. Individual tolerance and sensitivity to odours will dictate public acceptance. If the City uses biosolids as a component of a fertilizer mix for parks, then the odour of the pellets may be masked somewhat by the other fertilizer materials, such as urea, in the mixture. Because the pellets would be manufactured from digested and stabilized biosolids, it is expected that they would be on the low end of the scale discussed by Murthy *et al.* (2003).



8.2 Polybrominated Diphenyl Ethers

Polybrominated diphenyl ethers (PBDEs), also referred to as polybrominated diphenyl oxides (PBDPOs), are a group of flame retardants that were first detected in the environment in 1979 (Alaee and Wenning, 2002). PBDEs are considered to be the most important class of brominated flame retardants due to their environmental persistence and occurrence in biotic and abiotic compartments (Haak and Letcher, 2003). There are 209 theoretical PBDE congeners, those congeners with less than four bromine atoms are often not found in commercial mixtures (ATSDR, 2002) because they lack stability and exhibit a tendency to debrominate (Birnbaum and Staskal, 2004).

Wenning (2002) reports that since 1987, several environmental monitoring programs have indicated increasing levels of PBDEs in sediments and wildlife. The three main commercial mixtures are decabromodiphenyl ether, octabromodiphenyl ether and pentabromodiphenyl ether (Hardy, 2001; Zhu and Hites, 2003; Hites, 2004). These commercial mixtures are used in polyurethane foams, phenolic resins, polyesters and epoxy resins, and polymers (Hale *et al.*, 2001; Alcock *et al.*, 2003; Sjödin *et al.*, 2003). Risk assessments of all three commercial mixtures have been conducted by the European Union, which lead to the conclusion that pentaBDE should be banned (Law *et al.*, 2003). PentaBDE is primarily used in North America and commonly detected in wildlife and humans.

The environmental distribution and eventual fates of PBDEs are largely dependent on their degree of bromination. PBDEs range from non- to semi- volatile with the volatility increasing as the degree of bromination decreases.

The solubility of PBDEs generally increases as the number of bromine atoms decreases however, even the least brominated compounds (dibromodiphenyl ether) are only sparingly soluble. Within aquatic systems lesser-brominated forms such as tetraBDE and pentaBDE will tend to bioaccumulate while the higher brominated PBDEs ($\text{Br} \geq 7$) will bind to sediment particles and remain essentially immobile. PBDEs are expected to enter aquatic systems by direct discharge of wastewater from manufacturing facilities, from landfill leachate, from wastewater treatment facilities and from the atmosphere by wet and dry deposition.

Current information strongly suggests that PBDEs are transported and distributed within the environment similar to polychlorinated biphenyls (PCBs). Consequently, they are most likely of little concern in terrestrial ecosystems but are a concern for aquatic ecosystems. The higher brominated compounds ($\text{Br} \geq 7$) do not bioaccumulate, despite their high $\text{Log } K_{ow}$ s, possibly due



to low uptake in organisms. TetraBDE and pentaBDE have been shown to be the primary forms of PBDE that bioaccumulate.

Norstrom *et al.* (2002) examined the temporal trend of BDE concentrations in herring gull eggs collected in the Great Lakes ecosystem from 1981 to 2000. A total of fifteen sampling sites were selected to present the geographical area of the Great Lakes. The temporal trend analysis found that total PBDE concentrations had increased at all three sites 20 to 75-fold from 1981 to 2000 with BDE-47, a pentaBDE, as the dominant congener at all sites.

In summary, PBDEs are lipophilic (ATSDR, 2002) and can be dissolved in organic solvents and broken down by UV light (Birnbaum and Staskal, 2004). The most bioaccumulative and toxic PBDEs are those containing 4 to 6 bromine atoms (Hale *et al.*, 2001) and have shown to target the thyroid gland. PBDE's physical and chemical similarity to PCBs, combined with increasing concentrations in animal and human tissues, and the uncertainty as to their carcinogenic potential, concerns have been raised. Furthermore, the 1973 Michigan incident when agricultural feed was accidentally replaced with another brominated flame retardant (polybrominated biphenyls) and led to the slaughter of thousands of livestock, may have heightened public concerns over the presence of brominated flame retardants in the environment.

PBDEs are deemed toxic as defined by CEPA (1999) because the amount entering the environment has harmful effects on ecological receptors (Environment Canada, 2004). However, after having completed a screening assessment, Health Canada (2004) considered an in-depth evaluation of PBDEs for human health to be a low priority since management of ecological risks is expected to be protective of human health.

8.3 Phthalates

Phthalates are a group of chemicals that are widely used as plasticizers to soften and increase the flexibility of plastics. They are often used in polyvinyl chloride (PVC) plastics, shower curtains, toys, raincoats and cosmetics. The annual world production of phthalates is approximately 2.7 million metric tons per year (van Wezel *et al.*, 2000). Up until the early 1980s, di-(2-ethylhexyl) phthalate (DEHP) was the predominant plasticizer produced and used in children's products containing PVC (Wilkinson and Lamb, 1999). Following concerns that DEHP could cause adverse health effects, and the US EPA's (1993a) B2 carcinogenicity classification, probable carcinogen, a voluntary phase out by toy manufacturers was introduced (Health Canada, 1998a; Wilkinson and Lamb, 1999). DEHP was replaced with diisononyl phthalate (DINP) which, in



1997, raised similar scrutiny as DEHP by Danish authorities (Wilkinson and Lamb, 1999). Soon, several countries were evaluating the use of DIHP in children's toys and products.

On 16 November 1998, Health Canada (1998b) issued an advisory warning alerting parents and caregivers of young children to dispose of soft vinyl teethingers and soft vinyl rattlers. The advisory warned children who weighed less than 8 kg could be at risk when sucking or chewing on the selected PVC items for 3 hours or more daily. Health Canada (1998a) estimated that dietary and other background sources of DINP were approximately 50 µg/kg-day resulting in a maximal acceptable ingestion of DINP from children's products at 242 µg/kg-day (for an overall provisional total daily intake of 292 µg/kg-day) for children aged 3 months to 1 year. DINP has been classified as D, not classifiable as a human carcinogen, by the US EPA (1993c).

Phthalates are not considered to be persistent chemicals given their several pathways of degradation including bacterial and photodegradation (van Wezel *et al.*, 2000). Bioaccumulation in the food chain is also considered to be limited given biotransformation.

Phthalates are suspected endocrine disruptors, specifically they are suspected to exhibit anti-estrogen or anti-androgen properties (van Wezel *et al.*, 2000). Van Wezel *et al.* (2000) reviewed ecotoxicity studies for DEHP only to find that the majority of studies had no effects at the highest administered concentration, furthermore in studies where a no-observed-effects-concentration (NOEC) was specified, the NOEC always exceeded the water solubility.

Despite advisories and warnings by regulatory agencies, researchers are still debating the risk of adverse health effects from phthalates.

8.4 Alkylphenol Ethoxylates

Alkylphenol ethoxylates refers to a family of nonionic surfactants commonly used in detergents, paints, herbicides and pesticides (White *et al.*, 1994; WEAO, 2001; WHO, 2002). The environmental concentrations of alkylphenol ethoxylates are generally low, found at trace amounts (WHO, 2002) most likely because alkylphenol ethoxylates are easily degraded into metabolites such as alkylphenols and ethoxylates (White *et al.*, 1994). Most data suggests that alkylphenol ethoxylates have a low to moderate potential for bioaccumulation and that some alkylphenol chemicals exhibit estrogenic characteristics.



8.4.1 Nonylphenol

Nonylphenol, a major degradation product of alkylphenol ethoxylates, is considered “toxic” under the Canadian Environmental Protection Act (CEPA) because of their levels in the environment and their impact on ecological receptors (Environment Canada, 2004). The major source of nonylphenol in Canada is considered to be municipal wastewater treatment plants and industrial discharge (Environment Canada, 2000). Nonylphenol concentrations obtained from municipal treatment systems across Canada ranged from <0.02 to 62.1 µg/L, from 0.12 to 4.79 µg/L and from <0.02 to 3.20 µg/L for primary, secondary and tertiary treatment systems, respectively (WHO, 2002). Since nonylphenol is hydrophobic, once discharged from the treatment plant it commonly remains in sewage biosolids and sediment (White *et al.*, 1994). By binding to sediment, nonylphenol may represent a potential risk to sediment biota (Environment Canada, 2000).

Nonylphenol is found to be relatively toxic to fish, invertebrates and algae (WHO, 2002; Environment Canada, 2000) with bioaccumulation in aquatic biota ranging from low to moderate (Environment Canada, 2000). Given this information, Environment Canada does not expect nonylphenol to cause significant effects to the aquatic environment following exposure to treated effluent (with the exception of primary treatment plants which require more investigation).

Nonylphenol is weakly estrogenic in fish, avian and mammalian cells (White *et al.*, 1994; Environment Canada, 2000), however the effects of nonylphenol on humans is unknown.

8.4.2 Ethoxylates

Nonylphenol ethoxylates are a class of alkylphenol ethoxylates and have been used as detergents, emulsifiers, wetting agents and dispersing agents for the past 40 years. The major concern surrounding ethoxylates is their potential role as endocrine disruptors.

8.5 Endocrine Disruptors

Following a workshop sponsored by the US EPA (1997b), an environmental endocrine disruptor was defined as:

An exogenous agent that interferes with the production, release, transport, metabolism, binding, action or elimination of natural hormones in the body responsible for the maintenance of homeostasis and the regulation of developmental processes.



This broad definition was intended to encompass the increasing knowledge base of the effects and interactions of endocrine disruptors with ecological and human systems as well as the several potential toxicities (Choi *et al.*, 2004). The workshop further defined endocrine disruptors as either indirect-acting or direct-acting endocrine disruptors. Indirect-acting endocrine disruptors affect the systemic target organ first and in turn affects the endocrine system to cause secondary neurotoxicity, reproductive toxicity, and/or immunotoxicity (Kavlock *et al.*, 1996). Direct-acting endocrine disruptors affect the endocrine system first and in turn affects the target organ (Kavlock *et al.*, 1996).

Given the broad category and the implications of endocrine disruptors, public attention has been heightened and awareness increased with literary works such as Rachel Carson's 1962 *Silent Spring* and *Our Stolen Future* (Colborn *et al.*, 1997). Furthermore, the effects of endocrine disruption have been witnessed in wildlife from gulls in the St. Lawrence to alligators in Lake Apopka in Florida (Schettler *et al.*, 1999), affecting public perception and concern.

Major concerns regarding endocrine disrupting compounds include timing, level and duration of exposure relative to the developmental stage of the organism (WHO, 2002). Given the number of chemicals which may be categorized as endocrine disruptors combined with the range of potential health effects at low level exposure, from cancer to interfering with the reproductive systems to neurobehavioural development, endocrine disruptors pose a concern to the public and researchers alike.

8.6 Linear Alkylbenzene Sulphonates

Linear alkylbenzene sulphonates (LAS) surfactants are major components of synthetic domestic and industrial detergents. LAS are degraded very slowly or not at all under anaerobic conditions (WEAO, 2001), however they are not persistent in aerobic soils. As a result, there is little evidence that LAS would pose a threat to terrestrial ecosystems. The WEAO (2001) also reports a study by de Wolf *et al.* (1998) that concluded, based on a worse case scenario, that there were no human health risks from indirect exposure to LAS. Understanding of the human health effects of LAS exposure is still premature.

8.7 Pharmaceuticals

The presence of pharmaceuticals in wastewater treatment plants has been a growing concern with respect to implications on the environment. There are two ways pharmaceuticals may enter the wastewater treatment stream, first via the excretion of mixtures of residues/metabolites in the



urine or faeces, unchanged or conjugated with an inactivating substance or via the disposal of unwanted or expired medicines (WEAO, 2001). The primary source of pharmaceuticals in the environment is believed to be via patient excretion following therapy and the least contributing factor is considered to be the flushing of medicines down the toilet (Anderson *et al.*, 2004). In a study by Kolpin *et al.* (2002), 139 streams in the United States that were considered susceptible to wastewater contamination were sampled and analyzed for organic wastewater contaminants. The study found a number of antibiotics, prescription and non-prescription drugs and as well as reproductive hormones. Non-prescription drugs were found at the greatest frequency.

The Pharmaceutical Research and Manufacturers of America (PhRMA) sponsored the development of pharmaceutical assessment and transport evaluation (PhATE) model to predict concentrations of pharmaceuticals in 11 US watersheds (Anderson *et al.*, 2004; Shanahan, 2004). The model predicts concentrations of active pharmaceutical ingredients that are defined as “a compound responsible for physiological or pharmacological action and used in the diagnosis, cure, mitigation, treatment or prevention of disease in humans” (Anderson *et al.*, 2004). Overall, the model is a useful screening tool in determining the concentrations of pharmaceuticals in the environment however, research has found that some advanced waste water treatment plants, such as membrane bioreactors or ozonation, can remove up to 90% of pharmaceuticals (McCann, 2004).

In Germany, acetaminophen and beta blockers found in heart medication have been identified in drinking water. Cholesterol-lowering drugs, antibiotics, analgesics and antiseptics have also been found in European drinking water supplies. Some estimates indicate that up to 90% of ingested drugs eventually end up in water supplies.

The implications of the presence of pharmaceuticals in wastewater and consequently, in the environment, present a risk to aquatic life and may pose drug-resistant strains of bacteria. Health Canada's Health Products and Foods Branch is considering development of a cradle to grave approach to dealing with pharmaceuticals.

8.8 Radionuclides

Radionuclides include both natural and synthetic compounds that emit alpha, beta, or gamma radiation. Half lives of radionuclides vary from a fraction of a second to thousands of years. Radionuclides are carcinogenic to humans. Radionuclides are known carcinogenics. The target organs vary depending on the radionuclide of concern.



A number of radionuclides are used in medical testing or pharmaceuticals (e.g. carbon, strontium) and can eventually end up in the waste water system and potentially, in the biosolids. Nuclear reactors and other nuclear equipment emit small amount of radioactive material that can enter the environment and potentially end up in small amounts in biosolids. Federal laws and local by-laws are in place, restricting the discharge of radioactive materials. Hospitals and laboratories are required to file pollution prevention plans with the City. Specific federal guidelines enforced by the Canadian Nuclear Safety Commission govern universities, pharmaceutical companies, laboratories and others that use radioactive chemicals. There are specific guidelines for the discharge and disposal of radioactive materials.

Some radionuclides are naturally occurring in the environment (e.g. radon gas, uranium, etc.). Groundwater passing through mineralized geologic deposits (e.g. the Canadian shield) can result in radionuclides in water supplies and ultimately in biosolids. Because of the geology in the Toronto area, this is likely to have a much lesser impact on biosolids quality than in many regions.



9. CONCLUSIONS

9.1 Study Overview

This report assessed the potential risks to people and to the environment associated with the use of biosolids pellets in the City of Toronto and landfill topdressing. The study considered the potential exposure to metals (i.e., arsenic, cadmium, cobalt, chromium III, copper, mercury, molybdenum, nickel, lead, selenium and zinc) and selected organic chemicals (polychlorinated biphenyls or PCBs, dioxins and furans) to people in Toronto under several conditions:

- Application of pellets to City-owned recreational areas such as parks and golf courses;
- Application of topdressing containing pellets to landfills to facilitate seeding; and,
- Home use of pellets by residents as fertilizer on lawns and gardens.

The potential for health effects resulting from the presence of micro-organisms and other biological agents in the pellets was qualitatively reviewed. A discussion was presented on emerging issues. As well, the assessment looked at the potential for adverse impacts on mammals including pets (cats and dogs) and wildlife and birds. Plants and soil micro-organisms were reviewed qualitatively.

Inherent to the risk assessment process, several assumptions were made which tend to overestimate risks. Multiple conservative assumptions in an assessment generally lead to estimates of risk that are conservative and may overstate the actual risk.

9.2 Summary of Findings

9.2.1 Human Health Risks from Non-Carcinogenic Effects

The study estimated potential exposures to metals and other pollutants and compared them with health benchmarks for non-cancer effects. In all scenarios considered the hazard quotient was less than the MOE's benchmark of 0.2. This indicates that potential exposures to these substances are below the health benchmark, and thus not expected to result in adverse non-cancer effects.



9.2.2 Human Health Risks from Carcinogenic Effects

The study assessed the potential human health risks from carcinogenic effects of those entities of potential concern that are known or probable carcinogens. Exposure ratios were calculated for Health Canada and Ontario Ministry of Environment (MOE) benchmarks of one in one hundred thousand and one in one million cancer risk levels, respectively. The results are as follows:

- All exposure ratios were below one for the City Parks Worker Scenario;
- All exposure ratios were below one for the City Landfill Worker Scenario;
- All exposure ratios were below one for the Recreational Use Scenario;
- Exposure ratios were below one for the Home Use Scenario for all chemicals except arsenic;
- The arsenic exposure ratio for the Home Use Scenario was below one for the Health Canada benchmark;
- The arsenic exposure ratio for the Home Use Scenario was greater than one for the MOE benchmark; and,
- When background concentrations of arsenic in soil are excluded from the calculation, the arsenic exposure ratio is equal to one, indicating an acceptable incremental risk from arsenic based on the MOE benchmark.

To understand the importance to health of the Home Use Scenario exposure ratio estimate, several factors should to be considered including the following:

- Many fertilizers contain traces of arsenic; the levels of arsenic in the biosolids pellets are below allowable limits for fertilizers.
- The concentration of arsenic in pellets was estimated to be below Ontario background soil concentrations.
- The calculated risk was within the range of uncertainty generally associated with risk assessments; the many assumptions used in the calculations tend to overestimate the risk, meaning the actual risk may be overstated.
- The MOE benchmark is based on incremental risk and the analysis excluding background thus demonstrates an acceptable level of risk based on the MOE benchmark.

9.2.3 Biological Agents

There are no well-developed guidelines available for conducting assessments of biological risks. In addition, quantified levels of biologics were not available for Toronto biosolids. There are also no available guidelines on the acceptability of different risk levels for environmental pathogens and the science of assessing such risks is underdevelopment; therefore, conclusions

regarding the acceptability of pellet use scenarios based on potential biological risks cannot be made. This assessment was therefore limited to examining the potential for biological entities to be present in biosolids or to be destroyed in the pelletization process. The major findings are as follows:

- The pelletizer manufacturer asserts that the pelletization process at ABTP is equivalent to that required by the US EPA for Class A biosolids.
- The process information and limited analytical data available indicate that the biosolids pellets from the ABTP pelletizer are likely of similar quality to those that meet the US EPA definition of Class A biosolids and exceptional quality biosolids which can be distributed in the United States without restriction.
- The literature data suggest a minimum process time of 60 to 90 minutes at a temperature of 80°C to effectively destroy most pathogens.
- Some biological entities in the biosolids pellets may not be deactivated by the pelletization process. Exposure to such entities increase with frequency and duration of handling, as well as quantities used and therefore exposure would be greater for workers than for residents.
- Confirmatory testing of pellet quality with respect to biological entities is limited.
- No confirmatory testing is known to have been undertaken to validate the temperature and residency times achieved by the pelletizer or the humidity within the pelletizer.
- Some biological entities may enter the sewage treatment system via the direct discharge of untreated blood products to the sewers which is currently permitted in the City of Toronto.
- There is currently no evidence of any outbreak of prion-related disease in Toronto and the diseases are extremely rare. Although the pelletization process may not effectively deactivate prions, the potential risk of exposure to these biological entities through biosolids pellets is very low.

9.3 Ecological Risks

A preliminary screening was done for potential ecological effects on plants and soil organisms. The levels that may accumulate in the top 5-cm of soil after 25 years of pellet application were compared to Canadian Council of the Ministers of the Environment (CCME) and Ministry of the Environment (MOE) ecotoxicity values for plants and soil organisms. The results included:

- No risks to plants or soil organisms were identified when pellets were used in landfill topdressing;
- No risks to plants or soil organisms were identified for arsenic, cadmium, cobalt, chromium III, mercury, molybdenum, nickel, lead, PCBs, dioxins and furans;

- The estimated concentrations of selenium and zinc were less than the corresponding MOE values but slightly higher than CCME ones. The results indicate that no risk to plants or soil organisms is expected due to selenium or zinc.
- Levels of copper were estimated slightly higher than the MOE toxicity value and about four times higher than the CCME ecotoxicity value. Copper levels were also higher than CCME ecotoxicity values when pellets were assumed to be mixed within the top 15-cm of soil.

The qualitative screening assessment performed for plants and soil organisms is considered sufficient to identify areas where closer analysis may be worthwhile and for what compounds it is not warranted. The analysis is not sufficient to conclude whether or not adverse effects on plants or soil organisms may actually occur. Further evaluation using toxicity values based on plants most commonly found in Toronto parks and gardens and considering the potential for reduced bioavailability of metals in biosolids-amended soils would be required to conclude whether or not plants or soil organisms may be at any risk from copper in pellets applied to lawns, gardens or City lands.

In looking at the potential impacts on wildlife, potential exposures to the meadow vole, masked shrew, racoon, red fox, American robin, and red-tailed hawk, were considered. After 25 years of use, when pellets were incorporated into the top 5-cm of the soil, the following hazard quotients were estimated:

- Hazard quotients were less than the benchmark of one for the meadow vole, masked shrew, racoon, red fox, and red-tailed hawk for all chemicals evaluated;
- Hazard quotients were less than one for the American robin exposure to arsenic, cadmium, cobalt, copper, mercury, molybdenum, nickel, lead, selenium, zinc, PCBs, dioxins and furans; and,
- The hazard quotient for the American robin exposure to chromium III was three, compared to the benchmark of one.

The assumptions used in the calculations tend to overestimate the levels of exposure and therefore overstate the potential risks. The hazard quotient greater than one does not imply a risk, but rather it indicates that a risk cannot be ruled out by the analysis performed. If the robin is considered to migrate out of the Toronto area for approximately half of each year, unless pellets are applied to more than 60% of the robin population's home range, the hazard quotient for chromium III can be considered to be less than one and hence no effects to robins would be expected.



Potential risks to pets as individuals were quantitatively evaluated. The results were as follows:

- Hazard quotients were less than the benchmark of one for cats and dogs exposed to cadmium, chromium III, cobalt, copper, mercury, molybdenum, nickel, lead, selenium, zinc, and PCBs;
- The hazard quotient was less than one for dogs exposed to dioxins and furans;
- The hazard quotient for cats exposed to dioxins and furans was estimated at one; and,
- The hazard quotient for cats and dogs exposed to arsenic was estimated at one.

Given that the evaluation of pets is based on the use of no observed adverse effects levels (NOAELs), no risk to pets is expected for a hazard quotient of one.



10. STATEMENT OF LIMITATIONS

This report has been prepared for the sole benefit of Toronto Public Health and the City of Toronto. The report may not be used by any other person or entity without the express written consent of Jacques Whitford, Toronto Public Health and the City of Toronto.

Any use which a third party makes of this report, or any reliance on decisions made based on it, are the responsibility of such third parties. Jacques Whitford accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this report.

Jacques Whitford makes no representation or warranty with respect to this report other than the work was undertaken by trained professional and technical staff in accordance with generally accepted engineering and scientific practices current at the time the work was performed. Any information or facts provided by others and referred to, or utilized in, the preparation of this report was assumed by Jacques Whitford to be accurate. Conclusions presented in this report should not be construed as legal advice.

This risk assessment was undertaken exclusively for the purpose outlined herein and was limited to those contaminants, exposure pathways, receptors, and related uncertainties specifically referenced in this report. This work was specific to the site conditions and land use considerations described herein. The report cannot be used for, or applied under, any circumstances to another location or situation or for any other purpose without further evaluation of the data and related limitations.

If any conditions become apparent that differ significantly from our understanding of conditions as presented in this report, we request that we be notified immediately to reassess the conclusions provided herein.



Respectfully submitted,

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ORIGINAL SIGNED

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