Health Canada Santé Canada

Canadian Handbook on Health Impact Assessment

Volume 4: Health Impacts by Industry Sector

Canada

CANADIAN HANDBOOK ON HEALTH IMPACT ASSESSMENT

VOLUME 4: HEALTH IMPACTS BY INDUSTRY SECTOR

NOVEMBER 2004

A Report of the Federal/Provincial/Territorial Committee on Environmental and Occupational Health

Our mission is to help the people of Canada maintain and improve their health.

Health Canada

Published by authority of the
Minister of Health

Également disponible en français sous le titre
Guide canadien d'évaluation des incidences sur la santé
Volume 4 : Impacts sur la santé par secteur industriel

This publication can be made available in/on computer diskette/
large print/audio-cassette/braille upon request.

Cat. H46-2/04-363E
ISBN 0-662-38011-8

ACKNOWLEDGMENTS

The *Canadian Handbook on Health Impact Assessment* has a long history, evolving over time with input from a significant number of individuals. Only some are specifically mentioned here, though the contributions of all were crucial to the finalization of the Handbook. The Handbook was prepared under the general guidance of the Health Impact Assessment Task Force reporting to the Federal/Provincial/Territorial Committee on Environmental and Occupational Health (CEOH). The CEOH had membership from all provinces, territories, and the federal government. Membership on the CEOH and Task Force represented environment, health, and labour sectors. The Task Force members included representatives of Health Canada and Labour Canada, as well as the following representatives of provincial government bodies:

- Mark Allan, Department of Health and Community Services, New Brunswick
- George Flynn, Alberta Health, Alberta
- Pierre Gosselin, WHO-PAHO Collaborating Centre on Environmental and Occupational Health Impact Assessment and Surveillance, Quebec City University Hospital, Public Health Institute and Public Health Agency, Quebec
- Jerry Spiegel, Department of Environment, Manitoba

The Handbook started as a discussion paper prepared under contract by Kate Davies and entitled *The National Health Guide for Environmental Assessment: A Discussion Paper*. Consultations on the discussion paper took place in 1995 at six multisectoral workshops held in Dartmouth, Nova Scotia; Montreal, Quebec; Toronto, Ontario; Winnipeg, Manitoba; Vancouver, British Columbia; and Ottawa, Ontario.

Based on input from the 1995 workshops, a draft Handbook was written with contributions from several authors. Special thanks go to staff of Health Canada's Environmental Health Assessment Services for coordinating the preparation of the 1998 draft Handbook. In 2000, multistakeholder consultations on the draft Handbook were held in Dartmouth, Nova Scotia; Montreal, Quebec; Toronto, Ontario; Regina, Saskatchewan; Vancouver, British Columbia; and Ottawa, Ontario.

For both the 1995 and 2000 workshops, numerous provincial government and Health Canada regional staff assisted in the planning and delivery of and reporting on the workshops.

The final version of the *Canadian Handbook on Health Impact Assessment* was prepared on the basis of discussions at the workshops held in 2000 and contributions from several authors. Special thanks go to staff of Environmental Health Assessment

Services of the Healthy Environments and Consumer Safety Branch (HECSB) of Health Canada for their efforts in coordinating input to the Handbook.

Individual authors were involved in the writing of the various chapters of the Handbook. Their input is greatly appreciated. Significant contributions were made by Reiner Banken, Ugis Bickis, Marci Burgess, Pierre Chevalier, Wesley Cragg, Kate Davies, Pierre Dubé, Alan Emery, Pierre Gosselin, Philippe Guerrier, Henry Lickers, Pascale Méra, Robert Rattle, and Alain Webster; Industrial Economics Inc. in Cambridge, Massachusetts; and Health Canada staff in the Department's Environmental Health Assessment Services, the Biostatistics and Epidemiology Division, and the HECSB Office of Policy Coordination and Economics.

Finally, special recognition is given to Pierre Gosselin for his efforts in coordinating input into and finalizing Volumes 2 and 4 of this Handbook.

EXECUTIVE SUMMARY

This fourth volume of the *Canadian Handbook on Health Impact Assessment* presents a discussion of the environmental and human health impacts associated with the implementation of development projects and activities in major sectors of the Canadian economy. The aim is to provide an integrated approach to the public health aspects within the framework of environmental assessment (EA).

Volume 4 applies the health impact assessment (HIA) concepts, techniques, and tools outlined in Volumes 1 and 2 of this Handbook to representative examples of EAs of development projects in each of eight Canadian economic sectors: energy, transportation and communications, forestry, mining, agriculture, waste management, wastewater and sludge management, and the manufacturing sector. It also incorporates the concepts and approaches presented in Volume 3 regarding the role of values in health and in EA, the inclusion of social impact assessment (SIA) and economic appraisal of projects, the nature and contribution of indigenous HIA, and the use of environmental epidemiological methods.

The EAs conducted in relation to the various sectors can vary considerably in scope, depending on the requirements of the provinces/territories and the federal government. This volume deals with the types of development projects that are likely to require the expertise of local or regional public health authorities and offers advice and guidance for conducting HIAs of projects such as those selected as illustrations in each sector.

The focus of the discussion of the impacts of implementing development projects is on effects on the biophysical environment and on human health, including psychosocial and socioeconomic impacts and quality of life. The broad range of potential impacts reflects the principles of sustainable development (SD), encompassing the ecosystem, the economy, and the social system. Health is a key component of SD, as the latter's focus is ultimately human health, which is dependent on social, economic, and environmental sustainability. Indeed, SD serves as a framework for integrating the risks and benefits to public health that may be associated with development projects. This approach also complements the broad concept of health as defined by the World Health Organization.

In the sector-by-sector discussion, the reader will notice that some environmental hazards and health impacts are common to several or most sectors; the range generally includes exposure to and effects of atmospheric emissions, water pollutants, and soil contaminants (e.g., heavy metals, organic compounds, infectious agents); noise, technological risks, emergencies, and disasters; and socioeconomic and psychosocial impacts. The salient aspects of the latter are particularly relevant to all sectors, and the main principles can be applied generally to similar types of projects and related activities in these sectors.

One of the very useful features of the information in this volume is the inclusion of a matrix of environmental and health impacts for major development projects in each of the eight economic sectors (e.g., in the energy sector (Chapter 2): hydro-electric dams, co-generation power plants, transportation and liquefaction of natural gas, and nuclear power generation). These matrices consist of a biophysical environment and a human health component and are a handy tool for organizing and analysing the wealth of technical information on environmental hazards and health impacts for any given project. Two detailed appendices are also provided: Appendix A, which is on air quality and related health effects; and Appendix B, which addresses occupational health and safety considerations for each economic sector.

The basic structure of each chapter of Volume 4 is similar and includes information on the Canadian context, a socioeconomic overview, and background information on the technical aspects of the sector and development projects of interest. Each chapter is rich in descriptive and technical detail; accordingly, this summary outlines the main points regarding the types of environmental and occupational hazards and health risks associated with projects in these sectors. Representative types of projects have been selected to illustrate the diversity of each sector within the context of EA and the wide range of health impacts that can arise.

The reader is referred to the main text of this volume for information on the more technical aspects of specific environmental hazards and health risks – for example, information on occupational health and safety regulations; standards and criteria regarding exposure to various hazards (e.g., guidelines for exposure to noise, maximum acceptable concentrations of contaminants in drinking water, acceptable daily intakes, etc.); and emergency response plan standards.

Volume 4 also provides extensive descriptions of the technical elements, processes, and activities of each sector and offers advice on mitigation measures for specific environmental or occupational hazards in a given sector.

The following are the major topic areas that comprise Volume 4, with a focus on the environmental, human health, and social impacts of representative types of development projects in each of the eight economic sectors of interest, within the context of EA:

- *Energy*: hydro-electric dams; co-generation power plants; transportation and liquefaction of natural gas; and nuclear power generation, including fuel and reactor wastes (Chapter 2).
- *Transportation and Communications*: road construction; high-voltage power transmission lines, including the effects of electromagnetic fields; maintenance of power line rights-of-way; and airport construction, expansion, and operation, including emergencies and disasters (Chapter 3).
- *Forestry*: the use of herbicides (e.g., glyphosate) and mechanical clearing in forest regeneration; and the use and effects of the bacterial insecticide *Bacillus thuringiensis* (Chapter 4).
- *Mining*: fundamentals of mining operations; gold mining (extraction methods, acid mine drainage, mine tailings); and uranium mining and human health concerns, particularly occupational risks (Chapter 5).
- *Agriculture*: hog production and associated wastes and pollution; and pesticide use in apple production (Chapter 6).
- *Waste Management*: landfilling, including the hazards and effects of biogas and leachate; and atmospheric emissions and solid wastes associated with waste incineration (Chapter 7).
- *Wastewater and Sludge Management*: wastewater treatment plant construction and operation; management of municipal wastewater treatment sludge, including incineration; agricultural and silvicultural use of sludge; and septic tank sludge (Chapter 8).
- *Manufacturing Industries*: atmospheric, liquid, and solid waste pollutants and related health effects of aluminum production and pulp and paper production (Chapter 9).

The illustrations of HIAs in each of the above sectors addressed in Volume 4 of the *Canadian Handbook on Health Impact Assessment* encapsulate an integrated approach to the public health aspects of development projects within the framework of EA and serve as a useful resource for health professionals involved in such assessments.

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1 INTRODUCTION

This fourth volume of the *Canadian Handbook on Health Impact Assessment* presents a discussion of the environmental and human health impacts associated with activities in major sectors of the Canadian economy. The aim is to provide an integrated approach to the public health aspects within the framework of environmental assessment (EA).

This volume and the two preceding volumes are practical extensions of the first volume, which presented the rationale for the necessary presence of the health sector in the field of EA, as well as a summary of current practices in Canada and other countries.

Volume 4 outlines the impacts of implementing development projects in each of Canada's major economic sectors. These include effects on the biophysical environment and on human health (including psychosocial impacts and quality of life), as well as socioeconomic impacts. Though not all of the environmental hazards discussed in this document are common to all economic sectors, the range of hazards generally includes atmospheric emissions, food and water pollution, and soil pollution; emergencies and disasters; and technological hazards, among others.

The EAs conducted in relation to these various sectors can vary considerably in scope, depending on the requirements of the provinces/territories and the federal government. The present volume deals with the types of projects that are likely to require the expertise of local or regional public health authorities. It also presents guidance for conducting health impact assessments (HIAs) and examples of the application of HIA to development projects in the various economic sectors.

This volume comprises eight chapters that address the environmental, human health, and social impacts of projects undertaken in the following Canadian economic sectors:

- *the energy sector*: hydro-electric dams, co-generation power plants, transportation and liquefaction of natural gas, and nuclear power generation (Chapter 2);
- *the transportation and communications sectors*: road construction, power transmission lines, and airport construction, expansion, and operation (Chapter 3);
- *forestry*: the use of herbicides and mechanical clearing in forest regeneration and the use of the bacterial insecticide *Bacillus thuringiensis* (Chapter 4);
- *the mining sector*: mining operations, gold mining, and uranium mining (Chapter 5);
- *the agricultural sector*: hog production and pesticide use in apple production (Chapter 6);
- *waste management*: landfilling and incineration (Chapter 7);
- *wastewater and sludge management*: wastewater treatment plant construction and operation, management of municipal wastewater treatment sludge, and septic tank sludge (Chapter 8); and
- *manufacturing industries*: aluminum production and pulp and paper production (Chapter 9).

2 ENERGY

2.1 Canadian Context

Canadian energy sources include oil, natural gas, hydro-electricity, coal, and nuclear power. Coal is used mainly as a primary energy source for the production of electricity, while nuclear energy is used exclusively to generate electricity (see below).

Energy consumption can be measured using a number of units, such as barrels of oil, kilowatt-hours, BTUs (British thermal units), joules, cubic metres (gas), etc. In order to compare the energy output from the various sources listed above, in this document we have chosen tonnes of oil equivalent (TOE), the thermal unit from the metric system of the Organisation for Economic Co-operation and Development (OECD). One TOE is equal to 6.75 barrels of crude oil or 1163 kilowatt-hours.

In 1998, Canadian energy consumption totalled 1.66 million TOE, which can be broken down as follows: 41.4% from oil, 31.4% from natural gas, 24.7% from electricity, and 2.6% from coal. Oil represents between 35% and 71% of the energy used by any one province; it is the main energy source in all provinces except Saskatchewan and Alberta. In these two provinces, natural gas is the primary source of energy, accounting for 49% and 48% of total energy consumption, respectively. In Quebec, natural gas accounts for only 16% of the province's energy consumption, while in other provinces this proportion ranges between 30% and 35%. In Quebec, electricity is the main energy source, representing 41% of consumption, while in the other provinces this figure ranges from 16% to 25%. Coal is a minor energy source, accounting for less than 1% of the provinces' energy consumption, except in Ontario, where it represents 6% of energy used directly.

The data above must be clarified, however, because coal is largely used as a primary energy source to produce electricity, which then becomes a secondary source. Therefore, in Alberta and Saskatchewan, coal represents 20% and 24%, respectively, of total primary energy consumption because it is used in thermal power plants to produce electricity. This aspect is important to the assessment of pollution caused by an energy source; electricity generated by a coal-fired power plant does not produce the same pollutants as electricity generated by a dam or by nuclear power.

For nuclear power generation in Canada, the CANDU (**Can**adian **D**euterium **U**ranium) nuclear reactors use natural uranium that is bombarded with neutrons moderated by heavy water. The heat generated by the nuclear reactions is used to produce steam, which in turn drives turbines to generate electricity. As of 2001, there were 21 CANDU nuclear power reactors operating in Canada. These are distributed as follows: 19 in Ontario and one each in Quebec and New Brunswick, representing 61%, 3%, and 33% of each province's electricity generation, respectively. In 1994, 19% of Canada's electricity was generated by nuclear power, but by 1996 this figure had declined to 16%.

Like most industrialized countries, Canada's energy consumption is very high – 5.5 TOE per person in 1997. Canada has the highest per capita energy consumption in the world, exceeding even the United States (5.14 TOE). In Europe, annual energy consumption ranges between 2.4 and 3.7 TOE per person, slightly over 50% of Canadian consumption. In Canada, the provinces of Alberta and Saskatchewan have the highest energy consumption, at 9.5 TOE per person and 8.4 TOE per person, respectively (1998 data). Energy consumption in other provinces is lower than the Canadian average.

Various forecasting models predict that energy demand will increase moderately until 2010, but at a slower rate than during the past three decades. The forecasting models also indicate that the energy market share of each of these energy sources will stabilize. Oil will therefore continue to play an important role, while new energy sources (e.g., solar, biomass, and wind power) are not expected to make significant inroads.

Given the energy consumption patterns of Canadians and the fact that energy production plays a key role in the Canadian economy, representing nearly 8% of gross domestic product (GDP), new projects (hydro-electric dams, oil and gas development, etc.) can be expected to be constantly subjected to public scrutiny. A number of projects will likely be planned for the northern regions of the country, where the natural and social environments are especially vulnerable. Particular attention should be paid to these projects.

2.2 Hydro-electric Dams

In this section, we will limit our discussion to what are called "large dams," permanent water-retaining structures that are 15 m in height or more. Dams between 5 and 15 m in height that have a reservoir capacity of at least 3 million cubic metres are also classified as large dams. There are more than 45 000 large dams in the world, 19% of which are used to produce hydro-electricity. The remaining dams generate water reserves for irrigation purposes. There are slightly over 600 large dams in Canada, with Quebec accounting for a disproportionate share (189), followed by Ontario, British Columbia, and Newfoundland and Labrador, each of which has about 80 dams.

In 1995, 61% of Canadian electricity was generated by hydro-electric power plants, the majority of which rely on dams. However, there are a few run-of-river plants whose turbines are turned by the natural flow of the river alone. There are also a few tidal power plants, located at the mouths of rivers near the ocean, which are operated by the ebb and flow of the tide. In Newfoundland and Labrador, Quebec, Manitoba, and British Columbia, more than 85% of the electricity produced comes from plants connected to dams; in Nova Scotia and Alberta, this proportion is less than 10%, as electricity in these two provinces comes from coal-, oil-, or gas-fired thermal power plants.

2.2.1 Construction Phase

2.2.1.1 Environmental Impacts and Human Health Risks

The creation of temporary and permanent roads, operation of heavy trucks, and blasting are the types of activities likely to generate particulates that pollute the environment. Other problems include noise, vibrations (from blasting), and the aesthetic deterioration of the environment. Secondary consequences can also occur, since the presence of roads leading to dams provides access to previously inaccessible areas. These consequences include destruction of wildlife or waterfowl habitats, overuse of some areas, pollution from garbage and motor vehicles, unusual disturbance of wildlife, etc.

From an occupational health and safety standpoint, the construction activities of most large projects can be divided into two categories/sequences:

1) site preparation/excavation; and

2) fabrication/erection of superstructure.

[Note: There is also “deconstruction,” i.e., as part of the (eventual/ultimate) decommissioning phase, which has the additional and often dominant risk factors associated with the materials processed/produced during the life of the facility (e.g., toxic and/or explosive chemicals, radionuclides), as well as the potentially decreased structural integrity due to renovations and/or wear and tear. However, this is very much a hazard-specific consideration (epitomized by nuclear and biological warfare and pharmaceutical industries) and will not be specifically considered here.]

The risks inherent in site preparation/excavation may depend to a large extent on the local geology and are in turn shared with projects such as mining (see Chapter 5 of this volume).

Generally, injuries/fatalities may arise due to activities such as blasting and the use of heavy equipment. These risks are compounded in areas of confinement (e.g., tunnels, trenches), due to physical constraints, reduced visibility, the potential for rockfalls/trenchslides, etc.

In areas composed of "hard rock" (e.g., granite), there is a need to involve more blasting, leading to a potential for exposure; and the dust generated is more toxic by virtue of its silica content (as compared with areas where the excavation may be in, for example, limestone). Even in the 1990s, there were U.S. worker deaths (e.g., in sandblasting occupations) due to "progressive massive fibrosis." The U.S. National Institute for Occupational Safety and Health (NIOSH, 1996) and two United Nations agencies, the International Labour Organization (ILO) and the World Health Organization (WHO), have undertaken a major initiative targeting the global elimination of silicosis. NIOSH (1996) cautions that exposure to respirable crystalline silica dust during construction activities can cause serious or fatal respiratory disease. (See Chapter 7 of Volume 3 for more details on occupational health.)

Noise and vibration overexposures are prevalent in the construction trades, as are various repetitive motions that may lead to repetitive strain injuries. It is not uncommon for task noise exposures (e.g., breaking concrete pavement with a pneumatic drill) to be well in excess of 100 decibels (dB) – i.e., levels that should preclude work durations (with unprotected ears) of more than a few minutes (or less) per day.

There may also be a variety of chemical exposures – e.g., to fuel combustion products, cement and other caustics, and isocyanates (lung sensitizers).

Of course, exposure to climatic factors (solar ultraviolet radiation, heat, biting insects, and "ambient" air contaminants such as ground-level ozone/smog) is greater for all outdoor workers in an exposed (particularly summertime, urban) situation (similar factors would also apply to tree planting in, for example, clear-cut zones). With respect to biting insects, they are of interest particularly since the concern about West Nile virus, and similar diseases with insect vectors, has emerged even in the Canadian climate (see section 4.4.1.2 for details on biting insects). Outdoor levels of ozone, another climatic factor, may episodically (multiple days over the summer) exceed the limits set to protect worker health, particularly for "heavy work."

The following web sites (ranging from provincial to global in intended application) are recommended for further information:

- Construction Safety Association of Ontario: http://www.csao.org/; Content: Erecting and dismantling frame shoring towers; masonry scaffold erection procedures; health risks for heavy equipment operators; musculoskeletal injuries in the masonry trade; cement hazards and controls; carbon monoxide (CO) poisoning alert; heat stress, etc.
- U.S. National Institute for Occupational Safety and Health (NIOSH): http://www.cdc.gov/niosh/elcosh.html; Electronic Library of Construction Safety and Health.
- International Labour Organization (ILO): http://www.ilo.org/public/english/protection/safework; SafeWork.

An example of a common health and safety concern associated with construction, the operation of a heavy truck, is provided in Box 2.1.

Box 2.1
Health and Safety Concerns Associated with Heavy Truck Operation

From the ILO web site (http://www.ilo.org/public/english/protection/safework) is drawn this listing of the health and safety concerns that may be associated with the operation of a heavy truck; this is to serve as an example of one worker category that would be found in construction and operation of many projects.

Accident Hazards:

- Slips, trips, and falls from a tall cabin, cabin ladder, or trailer
- Overturning of heavily loaded truck due to mechanical failure, difficult road conditions and/or excessive speed, head-on collisions, etc., with resulting life-threatening trapping of driver inside cabin or under the truck
- Injuries due to accidental bumping into unguarded rigid parts of truck or cargo
- Injuries while performing various functions of a heavy truck driver (e.g., field repair-work, tire change, unfastening tight bands and ropes, etc.)
- Danger of being crushed between tractor and trailer, or between trailers, while trying to disengage one from another
- Accidents caused by uncoupling the locking device securing the tractor to the trailer
- Traumas, such as hernia rupture, due to physical overexertion (changing tires, moving heavy pieces of cargo, fastening ropes, etc.)
- Explosions, chemical burns, acute intoxication by dangerous chemicals, etc., caused by hazardous cargo, such as explosives and flammables, strong chemicals, toxic substances, and dust-forming bulk solids
- Acute poisoning by exhaust gases, including carbon monoxide
- Increased risk of road accidents due to lengthy driving periods (especially for long-haul truck drivers), including at night, in bad weather and with poor road conditions, and through traffic jams (risk is increased by fatigue due to long driving hours, short rest periods, drowsiness, hunger and thirst, use of alcohol, and driving at high speeds due to the bonus wages system)
- Fire hazards from spills and leaks of inflammables (usually in tank-trucks) that may ignite on contact with open flame, hot surfaces, electric sparks, atmospheric or electrostatic discharges, or as a result of mechanical shock following collision, etc.
- Explosion of over-inflated tires, car battery

Physical Hazards:

- Exposure to prolonged engine noise of high amplitude (>80 dBA) and/or low frequency, resulting in early (severe headache) or delayed (e.g., hearing loss) detrimental effects
- Exposure to ionizing radiation while transporting radioisotopes (frequently kept, for security reasons, inside the driver's cabin)

- Exposure to direct and reflected ultraviolet (solar) radiation
- Exposure to potentially health-detrimental climatic factors, such as extreme cold or heat, or combinations of temperature, humidity and wind, resulting in frostbite or heat stroke
- Exposure to sudden ambient temperature changes when leaving and entering the climatic-conditioned cabin, resulting in colds and/or rheumatic effects
- Whole-body vibrations that may impair functions of the chest, abdominal organs, and musculoskeletal system, contribute to driver's fatigue and decrease his/her [concentration]

Chemical Hazards:

- Exposure to various toxic substances (in solid, liquid, or gaseous state) while transporting hazardous cargo
- Skin diseases/conditions (dermatitis, skin sensitization, eczema, etc.) caused by chemicals (cleaning compounds, antifreeze, brake fluids, gasoline, diesel oil, oils, etc.)
- Chronic effects caused by inhalation of gasoline, diesel-fuel fumes and other exhaust fumes containing carbon monoxide, nitrogen oxides (NO_x), hydrocarbons, etc.
- Exposure to dust (especially on desert roads, etc.)
- Exposure to various automobile fluids (e.g., battery fluid, brake fluid)

Biological Hazards:

- Contamination and infection caused by exposure to biologically hazardous cargo

Ergonomic, Psychosocial, and Organizational Factors:

- Pains in the low back and in the joints (of legs and hands/arms) caused by prolonged driving – sometimes over bumpy roads – and/or inadequate seat
- Overexertion while moving or otherwise handling bulky and heavy loads, equipment, etc.
- Digestive tract disorders caused by irregular eating, bad diet habits, and stress
- Hypnotic hallucinations during periods of drowsiness, and psychotic disorders caused by mental and emotional stress factors
- Smoking inside cabin, contributing to health deterioration
- Visual discomfort and eye problems caused by inadequate illumination and eyestrain (especially when driving at dark times on interurban roads)
- Exposure to peer violence (e.g., in roadside cafeterias, etc.) and to petty and gang (including organized) crime attracted by valuable cargo
- Development of lumbago due to poor vehicle suspension, uncomfortable seat, etc.
- Psychological discomfort, as a result of possible control by cellular phone or radio communication equipment

Atmospheric Impact

Although hydro-electricity is usually described as a clean energy source, the submergence of vast areas when reservoirs are filled contributes to greenhouse gas emissions. The decomposition of vegetation in flooded areas produces carbon dioxide (CO_2) and methane (CH_4) emissions. In addition, the disappearance of vegetation constitutes a net loss of what is known as a carbon sink, i.e., growing trees that absorb CO_2. According to an assessment by the World Commission on Dams, artificial reservoirs could represent between 1% and 28% of the global warming potential attributable to humans; in Canada, greenhouse gases originating from dams total between 500 g and 1500 g of CO_2/m^2 per year. (See Appendix A for a description of CO_2 and CH_4 and their health effects.)

Terrestrial Impact

The first impact of the initial filling of a reservoir is the loss of terrestrial wildlife habitat and the destruction of plant resources. Riparian vegetation is most affected, and for a number of years after an artificial reservoir is filled, the new banks often remain barren of this type of plant life because of occasionally significant fluctuations in the reservoir's water level.

Aquatic Impact

The aquatic environment is the most affected by the initial filling of a reservoir. What was once a river becomes a lacustrine (lake-like) environment upstream of the dam, with greatly altered physical and chemical parameters. The flooding of vegetation produces large concentrations of organic matter, which is broken down by microorganisms. There is an increase in the biological oxygen demand (BOD), resulting in a reduction in dissolved oxygen saturation. At the same time, decomposition of the organic material leads to an increased amount of nutrients (nitrogen and phosphorus), which promote the growth of phytoplankton and eutrophication.

The environment downstream of the dam is also highly disturbed by the major changes to the river. A loss of biodiversity occurs because a number of species cannot adapt to the new environment. The change in the water regime to an almost constant annual flow prevents certain species from spawning or reproducing during periods when the water level and flow would normally have been higher. According to data from the World Commission on Dams, large dam construction is responsible for the disappearance of nearly 75% of aquatic species living in harnessed rivers.

Dams are also impassable barriers for migratory species such as salmon and eels. The most common situation is that of anadromous species in the area, such as salmon, which are prevented from swimming upriver to spawn. Fish passes can be built to allow fish to swim upriver, but this type of structure has limitations, particularly when dams are a few dozen metres high.

Another effect of dams is that they hold sediment back in the reservoir, preventing it from travelling further downstream. When a dam is built on a river that empties into the ocean through a delta, sediment retention can have serious consequences. The flood plain in the area of the delta may disappear, leading to a decrease in the normally high biological productivity of such an environment.

The environmental changes caused by dams can have major repercussions for humans. One of the most serious consequences of changes in the water regime is a decrease in fishery capacity; the construction of certain dams is believed to have reduced fish catches by 80%. The people affected by such situations must change their eating habits, which can sometimes be harmful to their health. It has also been observed that reservoirs are often breeding grounds for insects carrying infectious diseases. Although this situation is common in tropical and subtropical regions, the possibility cannot be ruled out in temperate and northern regions. The recent outbreak of the West Nile virus in eastern North America and the northward spread of malaria are examples of infectious tropical diseases that may spread more readily because of the presence of lakes and reservoirs that foster the breeding of insect vectors.

Mercury

A major health problem stemming from flooding is the conversion of inorganic mercury, naturally present in the soil, into organic mercury (primarily methylmercury), which can be biologically accumulated by aquatic organisms. The presence of water and decaying matter favours the microbial activity that promotes this conversion. The contamination of aquatic life by mercury has a significant social and economic impact because it means that local communities must limit their fish consumption.

Contamination of fish tissue varies depending on the species, but in all cases it is a gradual process, occurring over several years. In the La Grande 2 reservoir in Quebec, for example, the concentration of mercury in northern sucker and lake whitefish tissue reached 0.5 mg/kg five years after the reservoir was first filled and remained stable until at least the ninth year. In the case of the carnivorous species walleye and northern pike, tissue mercury concentrations increased steadily until the ninth year, when they reached 3 mg/kg. It is difficult to predict how long fish tissue mercury concentrations remain high, but a minimum of 15-30 years is considered realistic.

Mercury levels in fish are typically assessed from a human health perspective on a case-by-case basis. The levels of mercury found, as well as the nutritional benefits[1] of consuming fish, are taken into consideration. Specific sectors of the population are also taken into consideration such as Aboriginal communities, subsistence consumers of fish, and young children and women of child-bearing age. Where, necessary, consumption advisories for the consumption of the tissue(s) of specific species of fish are recommended. These advisories fall under the mandate of provincial authorities and are provided for certain watersheds.

Health Canada has established a guideline level of 0.5 mg/kg mercury in the edible flesh of commercial fish. This guideline is enforced by the Canadian Food Inspection Agency (CFIA). In addition, Health Canada has issued consumer advisories recommending limits to the consumption of shark, swordfish, and fresh and frozen tuna (not canned tuna), for example, in the 1999 Health Canada publication Nutrition for Healthy Pregnancy.

For more information, visit the websites for Health Canada and the Canadian Food Inspection Agency at:

http://www.hc-sc.gc.ca/english/protection/warnings/2002/2002_41e.htm

http//www.inspection.gc.ca/english/corpaffr/foodfacts/mercurye.shtml

2.2.1.2 Social Impact

Dam construction projects create many jobs that do not require specific skills or knowledge and can provide work for the local population and improve their well-being. (See Appendix B regarding occupational health risks.) However, this is only a temporary effect; once the construction is finished, there are significantly fewer jobs, and the remaining jobs are limited to maintenance work.

The creation of a reservoir can involve the permanent displacement of communities, villages, and even entire towns, to the detriment of the lifestyle, work, and, in some cases, the very survival of the people displaced. This phenomenon has not occurred often in Canada, but on an international scale it is estimated that 40 million to 80 million people have been displaced by dam construction, including 10 million people in China. Within Canada, the social impacts are most often experienced by Aboriginal populations. In addition to losing the use of harnessed rivers and land that has been flooded, they often face a threat to their cultural, spiritual, and social heritage. Submersion of archaeological, burial, and prayer sites is another important sociocultural effect associated with hydro-electric dams.

[1] Fish are an excellent source of high-quality protein, and are low in saturdated fat, which makes them a healthy food choice.

Because a number of animal species play a major role in Aboriginal diets, changes imposed on plant and animal habitats, including outright habitat destruction, can have a negative impact on the health of Aboriginal populations that rely on these plant and animal food sources. Changes in eating habits resulting from the use of non-conventional foods are also possible and, in the past, have often had adverse effects. Even when they appear minor, changes in traditional diets can lead to various health problems; one of the most common health problems among northern Aboriginal populations is diabetes.

Dam construction can also have an impact on migratory waterfowl and non-migratory birds by destroying habitats (forest clearing) and causing nest abandonment. Ungulates (e.g., caribou, moose, deer) are likely to be disturbed by the presence of various machines during construction, while the very existence of the dam and reservoir can change the migratory habits of certain species, such as northern caribou.

2.2.2 Operational Phase

Some of the specific health ("physical") and safety factors to be considered in hydro-electric generating station operations include (respectively):

- high magnetic fields, noise, and heat; and
- confined spaces, drowning, electrocution, etc.

There is ongoing concern regarding the numbers of workers injured/killed by contact with electricity in all industrial sectors. Further information is provided at http://www.eusa.on.ca.

Dam Failure

Dam failure is the most catastrophic event that could occur in the operation of a dam. It involves a sudden break in the structure and the rapid, uncontrolled release of the impounded water, resulting in a flood wave that inundates the valley downstream of the dam. The most serious consequences are loss of life and major property damage in downstream areas. In Canada, the Dam Safety Interest Group is composed of organizations and businesses that promote improved dam safety. The main aspects that should be taken into consideration when monitoring dam safety are damage caused to dams by erosion, internal hydraulic leaks, and static pressure from ice and earthquakes.

Table 2.1a
Hydro-electric Dam Structure[1]: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations
Technological Disaster	dam failure	destruction of terrestrial and aquatic habitats	downstream from the dam (up to tens of kilometres away)	regular dam inspections; preparation of evacuation plan	provincial laws where applicable
Gas Emissions or Emissions to Air	CO_2 and CH_4 (decomposition of vegetation)	greenhouse effect	global	none	Rio (1992) and Kyoto (1997) commitments
Liquid Emissions or Emissions to Water	organic mercury (methylmercury)	contamination of aquatic organisms	upstream and downstream from the reservoir	none	methylmercury: 0.47 µg/kg body weight per day for adults (PTDI)[2] methylmercury: 0.2 µg/kg body weight per day for young children and women of child-bearing age (PTDI) inorganic mercury: 0.71 µg/kg body weight per day (PTDI) mercury: 0.5 ppm (mg/kg) mercury in the edible flesh of commercial fish (Health Canada)
	decomposing organic material	water pollution, reduction in dissolved oxygen	reservoir	recovery of vegetation prior to priming reservoir	none
	floating debris	water pollution, unhealthy conditions, aesthetics	reservoir	recovery of vegetation prior to priming reservoir	none
Solid Emissions or Emissions to Soil	varied construction debris (rock, sand, etc.)	pollution, unhealthy conditions, aesthetics	construction site vicinity and access roads	recovery of waste materials; restoration of sites	none
Nuisances	upstream flooding	destruction of terrestrial habitats	reservoir area	none	none
	downstream drying	destruction of aquatic habitats (affecting fish)	riverbed downstream	fishways	none
	noise, dust (during construction)	unhealthy conditions	construction area	dust control, mitigation measures	L_{eq}[3] 55 dBA (day) and 45 dBA (night) (WHO guidelines)

[1] Applies to the construction of a concrete or rockfill dam that creates a reservoir flooding terrestrial habitats.

[2] PTDI = provisional tolerable daily intake. These toxicity reference values, currently employed for human health risk assessments by Health Canada, are subject to change in the event of the availability of new toxicological information. Information on toxicity reference values (TRVs) such as these recommended PTDIs is available in Volume 3, Chapter 8 of this Handbook.

[3] L_{eq} = equivalent sound pressure level.

Table 2.1b
Hydro-electric Dam Structure[1]: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	dam failure	injury, trauma, death	communities downstream from the dam, particularly those on the banks	very rare	public safety reports; regular inspections
Gas Emissions or Emissions to Air	CO_2 and CH_4 (decomposition of vegetation)	climate change	global	frequent	atmospheric CO_2 and CH_4 concentrations
Liquid Emissions or Emissions to Water	organic mercury (methylmercury)	poisoning (behavioural and neurological disorders)	consumers of large quantities of fish	rare to frequent	mercury levels in blood and hair (15-30 mg/kg in hair[2])
	decomposing organic material	N/A	N/A	N/A	N/A
	floating debris	unhealthy conditions, quality of life	neighbouring communities, people using the area	occasional	visual appearance of the area
Solid Emissions or Emissions to Soil	varied construction debris (rock, sand, etc.)	N/A	N/A	N/A	N/A
Nuisances	upstream flooding	quality of life	local communities	occasional to frequent	complaints/perception
	downstream drying	quality of life	local communities	occasional to frequent	complaints/perception
	noise, dust (during construction)	quality of life	local communities	occasional	complaints/perception

[1] Applies to the construction of a concrete or rockfill dam that creates a reservoir flooding terrestrial habitats.

[2] This concentration is three times the limit recommended by WHO, which is impossible to apply to Quebec Aboriginal communities for whom fish is the dietary mainstay.

2.3 Co-generation Power Plants

Co-generation means the simultaneous production of two types of energy, usually electricity and steam. Co-generation itself relies on one or more energy sources, with natural gas being the most common (90% of inputs); combustion of various bio-masses (forest residues, for example) or waste can also be used as a secondary energy source. In reality, most developers have chosen to use declassified heavy oil or # 2 oil as the alternative or back-up fuel in the case of an interruption in the natural gas supply.

Natural gas and fossil fuel sources are used to drive the turbines that power the electricity-producing generators. The hot gases recovered from the turbines then drive the steam turbines. The steam can be used by various industrial clients or to drive another electricity-producing generator. There are several possible combinations, which each developer assesses according to potential client needs.

2.3.1 Atmospheric Emissions

Environmental constraints associated with the operation of co-generation plants relate mainly to the atmosphere. Even when the plant uses only natural gas, the full range of the main atmospheric pollutants is emitted:

- CO_2;
- carbon monoxide (CO);
- nitrogen oxides (NO_x);
- nitrous oxide (N_2O);
- volatile organic compounds (VOCs);
- suspended particulates; and
- sulphur dioxide (SO_2).

While emissions of these substances are minimal when natural gas is burned, they increase markedly when fossil fuels are used. Burning heavy oil or fossil fuel can also cause the release of polycyclic aromatic hydrocarbons (PAHs). (See Appendix A for a description of CO_2, CO, NO_x, N_2O, VOCs, suspended particulates, and SO_2 and their health effects.)

Vapour plumes also occur, as the result of the condensation of hot gases emanating from chimneys. These plumes, which become fog at ground level, can affect visibility and contribute to the formation of ice on roadways in winter. In both cases, road safety can be jeopardized.

It should be noted that co-generation plants generally do not produce foul odours, except where large quantities of fossil fuels must be used because of problems with the gas system. In this case, the potential sources of odours would be NO_x and SO_2.

2.3.2 Wastewater

Wastewater discharged into the environment by co-generation plants usually comes from routine purges of the boilers and residual steam condensers. A certain amount of wastewater is also generated when machinery or piping is cleaned. Generally, this wastewater contains few pollutants, although the presence of some biocides used to prevent the growth of bacteria in the machinery may give liquid effluent toxic properties.

2.3.3 Socioeconomic Impact

Although construction of a co-generation plant has the potential to be an economic stimulus through job creation and the expansion of industrial and commercial activity, it can also have negative social and economic impacts. Such impacts stem from the fear that some form of pollution, or the mere presence of the plant, will harm the natural and human environment, or even cause the depreciation of residential properties in the area.

Table 2.2a
Co-generation Power Plant: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations[1]
Technological Disaster	fires, explosions	deposits, smoke, destruction	site and perimeter	containment, collection	CSA Z731-95, emergency measures planning, and NFPA 850
Gas Emissions or Emissions to Air	suspended particles	photosynthesis inhibition (deposits on leaves)	site and perimeter	dust collector	EQG, 24- hr (CCME) in µg/m^3: 25 (PM_{10}), 15 ($PM_{2.5}$)
	NO_x	ground-level ozone formation with VOCs	regional	catalytic reduction	NO_2: 200 µg/m^3 (24-h MAC, NAAQO Canada)
	VOCs	ground-level ozone formation with NO_x	regional	collection (biofiltration)	benzene, 15 mg/m^3 (Health Canada, tumour-producing effects)
	$CO_2 + CH_4$	greenhouse effect	global	reduction of combustion	Rio (1992) and Kyoto (1997) commitments re greenhouse gases
	SO_2	acid rain, toxic to vegetation	local and regional	collection and absorption	30-60 µg/m^3 (annual EQG in Canada)
	CO	pollution	site and perimeter	collection	15 mg/m^3 (8-h MAL, NAAQO Canada)
	PAHs	air pollution	local, regional, and continental	collection	0.001 µg/m^3 for 87 excess cancers/million over 70 years (WHO-Europe)
Liquid Emissions or Emissions to Water	suspended solids	unhealthy conditions, disturbance of aquatic life	receiving watercourses	holding and sedimentation tank	500 mg/L (Canada aesthetic objective)
	anticorrosive substances and biocides (cooling water)	toxicity to aquatic organisms	receiving watercourses	none	none
Solid Emissions or Emissions to Soil	N/A	N/A	N/A	N/A	N/A
Nuisances	noise and vibrations	health conditions	vicinity	buffer zone, better technology	L_{eq} 45 dBA (night) and 55 dBA (day) (WHO guidelines)
	vapour plume	health conditions, visibility, safety	site and perimeter	condensation inside stack	none
	odours	health conditions	vicinity	filtration	municipal by-laws

[1] CSA = Canadian Standards Association; NFPA = National Fire Protection Association; EQG = environmental quality guideline; CCME = Canadian Council of Ministers of the Environment; PM_x = particulate matter ≤ × µm in diameter; MAC = maximum acceptable concentration; NAAQO = national ambient air quality objectives; MAL = maximum acceptable level; L_{eq} = equivalent sound pressure level.

Table 2.2b
Co-generation Power Plant: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	fires, explosions	respiratory irritation, burns	workers and vicinity	very rare	public safety reports; regular inspections
Gas Emissions or Emissions to Air	suspended particles	irritation of respiratory tract, asthma	vicinity (especially asthmatics)	rare	epidemiological monitoring, level of atmospheric particulate matter
	NO_x	respiratory tract irritants	vicinity	rare	level of atmospheric NO_x
	VOCs	none at predicted concentrations	N/A	N/A	mass of VOC emissions
	$CO_2 + CH_4$	climate change	global	frequent	determination of CO_2 emissions
	SO_2	respiratory problems	vicinity (especially asthmatics)	rare	concentration of atmospheric SO_2; monitoring of hospital admissions for asthma
	CO	none at predicted concentrations	N/A	N/A	N/A
	PAHs	possibility of cancer	vicinity	very rare	level of benzo[a]pyrene and other ambient air PAHs
Liquid Emissions or Emissions to Water	suspended solids	unhealthy conditions, no direct effects	users of polluted water (swimmers, boaters, etc.)	rare	suspended solids measurements
	anticorrosive substances and biocides (cooling water)	unknown	N/A	N/A	N/A
Solid Emissions or Emissions to Soil	N/A	N/A	N/A	N/A	N/A
Nuisances	noise and vibrations	quality of life and sleep, stress	vicinity	unknown	complaints, ambient noise measurements
	vapour plume	quality of life	vicinity	unknown	complaints
	odours	quality of life	vicinity	unknown	complaints

2.4 Transportation and Liquefaction of Natural Gas

[Note: The information used to prepare this section was drawn mainly from the impact assessment of the PAC-RIM LNG project presented in British Columbia in 1995. The main purpose of the project was to export liquefied natural gas (LNG) to Asia in LNG tankers. This project was selected as a primary source of information because it combined a number of components related to this activity – i.e., transportation of natural gas via a pipeline, liquefaction of natural gas, and its trans-shipment in a deep-water seaport. Additional information was obtained from: (1) the Sable Island gas pipeline project (off the coast of Nova Scotia), aimed at bringing gas through Nova Scotia, New Brunswick, and Quebec as far as Montreal, and (2) the Gazoduc TQM project for the construction of a gas pipeline between Portland, Maine, and Montreal.]

2.4.1 Introduction

Natural gas is usually transported by pipelines that measure nearly a metre in diameter and can extend for distances exceeding 1000 km and transport several million cubic metres of natural gas each day. The pipeline, a tubular steel structure, can be buried or above ground and is installed within a permanent right-of-way ranging between 15 m and 25 m wide. The right-of-way is deforested and kept clear of trees by means of herbicides or manual cutting of vegetation (see section 3.2 on transportation of electricity). When crossing rivers, the pipeline must usually be buried at least 1.5 m beneath the riverbed. The operation of a natural gas transportation system also requires the construction of above-ground structures, such as compressor stations, measuring stations, and block valves. Signs should be posted along the entire length of the right-of-way indicating the presence of the pipeline; they are generally placed near roads, railway tracks, and rivers, at every lot line, and near large agricultural drainage ditches.

A gas liquefaction plant that produces LNG, such as the PAC-RIM LNG project plant, can have a capacity of several million tonnes per year and usually liquefies gas by cooling it in a cryogenic tower at -160ºC. Liquefying natural gas reduces it to 1/625 of its original volume, which allows it to be transported by LNG tankers. The transformation process involves removal of the CO_2 dissolved in the natural gas, followed by dehydration (removal of the water contained in the gas). Liquefaction is achieved by cooling the gas with compressed propane gas and a mixture of pressurized methane, ethylene, and propane. The smooth operation of the refrigeration systems requires cooling of the compressed gases by means of water, which is used in the PAC-RIM LNG project at the rate of 300 000 L/min. After liquefaction, natural gas is stored at a temperature of -160ºC in pressurized, double-walled reservoirs with a volume of several tens of thousands of cubic metres each.

A deep-water port must be built in order to trans-ship the LNG in tankers that have pressurized, double-walled holds and a capacity of 125 000 – 135 000 m^3 each. For the PAC-RIM LNG project, it was anticipated that each year, 60 ships would be loaded with LNG destined for Asian countries such as Korea and Japan.

2.4.2 Impacts of Pipeline Construction and Operation

A pipeline has little impact on air quality unless there is a leak. However, gas pumping stations that operate with the use of fossil fuels are likely to release into the atmosphere low levels of combustion gases, such as CO_2, CO, NO_x, and VOCs. (See Appendix A for the description of the effects of these pollutants.)

The pipeline right-of-way, which ranges from 15 m to 25 m wide, has an impact on the biotic components of the environment (vegetation, aquatic and terrestrial wildlife) and on agricultural and forestry activities, where applicable. Destruction of riverbanks and drainage of wetland constitute major disturbances. In addition, suspended particulates and petroleum products could be introduced into the water during construction, thereby contaminating the ground water. The greatest effect of these water disturbances would be felt by fish, particularly salmonids, but the deterioration of ground water quality could also have an impact on drinking water wells.

Pipeline construction also affects migratory and non-migratory birds by destroying habitats (i.e., forest clearing) and causing nest abandonment. Ungulates (e.g., caribou, moose, and deer) are likely to be disturbed by the presence of various machines during construction, while the very existence of the pipeline can change the migratory habits of certain species, such as northern caribou.

The crossing of Aboriginal land is one of the most controversial aspects of the social and economic consequences. As noted above, there can be negative impacts on the health of Aboriginal populations as a result of changes imposed on wildlife habitats. Increased hunting pressure on wildlife resources from non-Aboriginal hunters as a result of intrusion by outside parties could disrupt traditional ways of life. It is considered that the creation of construction jobs could improve the quality of life of local populations. However, the number of permanent jobs created is generally low, which means that the economic expansion experienced during construction may not continue. In more urbanized areas, however, the presence of a pipeline can lead to the establishment of businesses that use natural gas for fuel, thus contributing to local and regional economic development.

The health of Aboriginal populations could also be adversely affected through contamination of their food sources (plant or animal) by petroleum products spilled during construction or pipeline maintenance or by the application of herbicides to keep the right-of-way clear. Recall from the discussion of the health and social impacts of hydro-electric dam construction (previous section) that adverse health effects, particularly diabetes in northern Aboriginal populations, can result from shifting from traditional diets to the use of non-conventional foods.

The presence of archaeological and heritage resources and historical sites should be taken into account during establishment of the pipeline right-of-way. Whether they are Aboriginal artifacts and sites or areas dating back to European colonization, their presence should be considered and the path of the pipeline right-of-way modified, if necessary. In the case of Aboriginal communities, developers generally agree to halt work and consult the community involved.

In inhabited areas, i.e., southern regions, disadvantages associated with the presence of the right-of-way and its accesses (easements) should be noted. Hunters, snowmobilers, and all-terrain vehicle users invade the area, often resulting in increased conflict with private property owners adjacent to the pipeline right-of-way. As a result, the peacefulness of the area and its enjoyment by residents living along the right-of-way are diminished. Such access causes some people to fear trespassers and to feel unsafe. This in turn leads to decreased property values near the pipeline, and it can cause significant depreciation in the assessed value of buildings.

With regard to impact on services and infrastructures, the main requirements during the construction phase include appropriate medical and security services, temporary accommodations, and transportation (mainly ensuring that the local road network is not overloaded or damaged). Once the pipeline has been constructed, some municipalities may have to obtain additional emergency response equipment for explosions or fires; in some cases, these measures can be quite costly. However, a potential increased demand for services (education and health) is often considered positive because it can protect existing services against workforce reduction or closures.

If a pipeline is used to transport natural gas, there is a possibility of a break in the pipeline, followed by ignition of spilled natural gas. Since natural gas is highly flammable, the heat generated as the natural gas is forced out through the break can be enough to start a fire.

2.4.3 Impacts Associated with the Construction and Operation of a Natural Gas Liquefaction Plant

An oil or natural gas complex is always associated with the possibility of a technological disaster resulting from a leak followed by an explosion. The greatest risk in the current situation would be a leak of natural gas or LNG, which is flammable in the atmosphere at concentrations between 6% and 13%. Depending on the size of the leak and the direction and strength of the wind, the natural gas plume could travel towards inhabited areas in flammable concentrations.

Several pollutant gases would be released into the atmosphere by operation of the plant. Most of the air pollution is caused by CO_2 removal and the use of burners (gas flares) to dispose of surplus CH_4. The burners, as well as minor leaks from the numerous valves, can release the following pollutants: CO, NO_x, and VOCs. (See Appendix A for a description of CO_2, CH_4, CO, NO_x, and VOCs and their health effects.)

The construction and operation of a liquefaction plant are likely to cause noise nuisances that can disturb animals and humans living near the site. The main problems that can be attributed to noise exposure are:

- sleep interference;
- communication difficulties;
- effects on the performance and behaviour of students; and
- a feeling of annoyance that undermines quality of life.

Box 2.2

Noise Measurement and World Health Organization Guidelines

Noise is the environmental nuisance most likely to be harmful to public health. Noise is generally defined as any acoustic energy capable of altering the physical or psychological well-being of individuals. The measurement most often used is the average equivalent sound pressure level (L_{eq}) per unit time (e.g., 24 hours). A logarithmic decibel scale is used for this measurement; in other words, the noise intensity doubles with any increase of 3 decibels (dB).

The WHO recommends that residential indoor noise levels be limited to less than 45 dBA during the day and 35 dBA at night in the interest of a restful sleep. The WHO recommends an outdoor noise limit of 55 dBA L_{eq} during the day and 45 dBA L_{eq} during the night. A nuisance sound level above 55 dBA in a residential area is considered to be seriously annoying. However, in industrial areas or work environments, a level of 75 dBA L_{eq} (8 hours) is considered acceptable.

In addition, chronic exposure can cause an increase in blood pressure.

The space required for a liquefaction plant and its surrounding area results in the destruction of the habitats of plants (particularly medicinal plants) and animals that may be used as food resources, particularly in areas frequented by Aboriginal peoples. Accidental spillage of petroleum products (during construction) or chemicals during operation of the plant could contaminate land and water resources in a larger area if storage facilities and protective dikes around reservoirs and pipelines are inadequate.

2.4.4 Impacts Associated with the Construction and Operation of a Deep-water Trans-shipment Port

The construction of a deep-water port would increase water turbidity in the port, and ship movements would increase turbidity within an area of a few hundred metres from the dock. Benthic fauna, particularly crustaceans and molluscs, would be affected by turbidity and the disturbance of the seabed as a result of turbulence created by ship propellers. Sediment in the water also creates various problems for fish by burying bottom habitats and interfering with respiration and occasionally reproduction. Spillage of LNG or oil products used as tanker fuel could also have a major impact, depending on the extent of the spill. Bird life is generally the most severely affected, as has been shown by numerous oil spills that have occurred since the 1960s.

Human health is not directly compromised by the construction and presence of a deep-water port. However, the nature of the product being transported (i.e., LNG) poses a risk if a leak were to produce an explosion. Port area workers face the greatest risk of potential injuries and death. Human health would be indirectly affected by point source discharges of petroleum products.

Table 2.3a
Natural Gas Transmission and Liquefaction: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations[1]
Technological Disaster	rupture in pipeline, conduits, or tanks; explosion, fire	destruction of terrestrial, aquatic, and marine habitats	primarily site and perimeter	regular inspections, emergency measures planning, spill containment	appropriate CSA standards, such as Z184 and Z276-M1994
Gas Emissions or Emissions to Air	$CO_2 + CH_4$	greenhouse effect	global	collection of CO_2 extracted from natural gas; prevention of leaks	none
	NO_x	toxicity, formation of smog and ozone at ground level	local and regional	antipollution systems	NO_2: 200 µg/m^3 (24-h MAC, NAAQO Canada)
	VOCs	toxicity, formation of smog and ozone at ground level	local and regional	collection or increase in combustion performance	benzene: 15 mg/m^3 (Health Canada, tumour-producing effects)
Liquid Emissions or Emissions to Water	suspended solids	unhealthy conditions, disturbance of aquatic life	watercourses downstream or marine perimeter	preventive measures, but difficult to monitor	all pollutants: *Fisheries Act* (Canada); *Canadian Environmental Assessment Act*; applicable provincial/territorial statutes
	hydrocarbons	unhealthy conditions, toxicity to aquatic life	watercourses downstream or marine perimeter	containment, but difficult to monitor	
	diversion or drainage of watercourses and wetlands	destruction of wildlife habitats	watercourses or wetlands, site and perimeter	mitigation measures, rehabilitation	
Solid Emissions or Emissions to Soil	destruction of forests and terrestrial habitats	loss of wildlife habitats, disturbance of wildlife	site and perimeter	reduction of areal extent of destruction, appropriate mitigation measures	*Migratory Birds Convention Act* (Canada); federal and provincial/territorial statutes on EA
	hydrocarbon spills	aesthetics, toxicity to animals	site and perimeter	prevention and containment	
Nuisances	noise and dust	disturbance of wildlife, unhealthy conditions	site and perimeter	noise reduction measures and dust control	L_{eq} 45 dBA (night) and 55 dBA (day) (WHO guidelines); federal and provincial/territorial statutes on EA (Box 2.2)

[1] CSA = Canadian Standards Association; MAC = maximum acceptable concentration; NAAQO = national ambient air quality objective.

Table 2.3b
Natural Gas Transmission and Liquefaction: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	rupture in pipeline, conduits, or tanks; explosion, fire	respiratory irritation, burns, trauma, death	primarily workers, also population inhabiting the perimeter	very rare, around 10^{-7} to 10^{-2} deaths per year	reports on incidents, morbidity, and mortality; CH_4 explosibility
Gas Emissions or Emissions to Air	$CO_2 + CH_4$	climate change	global (CO_2, CH_4); urban area residents (CH_4, asphyxia)	frequent	CO_2 and CH_4 ambient air measurements
	NO_x	irritation of respiratory tract, inflammation caused by smog	local and regional	occasional during hot summer periods	NO_x ambient air measurements
	VOCs	irritation of respiratory tract, inflammation caused by smog; some carcinogenic VOCs	primarily on the perimeter	occasional during hot summer periods	VOC ambient air measurements, including benzene
Liquid Emissions or Emissions to Water	suspended solids	unhealthy conditions, effects on drinking water production	water users	unknown	suspended solids measurements
	hydrocarbons	toxicity, potentially carcinogenic if PAHs present	consumers of drinking water	rare or unknown	measurements of concentration in water
	diversion or drainage of watercourses and wetlands	no direct effects on health	N/A	N/A	N/A
Solid Emissions or Emissions to Soil	destruction of forests and terrestrial habitats	N/A	N/A	N/A	N/A
	hydrocarbon spills	potential toxic effects	workers handling soil	rare or unknown	measurements of concentration in soil
Nuisances	noise and dust	quality of life, sleep disturbance, stress, aggressiveness, hypertension	workers and perimeter residents	rare to frequent	measurements of exterior and interior noise, complaints, medical monitoring

2.5 Nuclear Power

To a greater or lesser degree, the biophysical and socioeconomic health impacts of nuclear power generation and spent fuel storage/disposal on both workers and the general public are caused by the same parameters and involve the same considerations. The biophysical components include the impact of radionuclides and heavy metals on the food chain by their release into the atmosphere, water, or ground; and consequential effects on fish, wildlife, vegetation, and country foods and, ultimately, on humans. In the case of external radiation exposure, the impact on humans is direct. Socioeconomic impacts include effects on public health, the social fabric, Aboriginal/other cultures and lifestyles; reduced business opportunities; unemployment and boom-and-bust cycles; and general stress factors associated with the dangers, perceived or real, from radioactivity.

2.5.1 Nuclear Power Generation

Operators at the 21 nuclear CANDU power stations in Canada have now had many years of experience, and the short-term adverse environmental impacts of nuclear power generation are well known. These are generally limited to inadvertent releases of radioactive gases to the atmosphere and of tritium to adjacent rivers or lakes.

No formal environmental impact reviews were conducted prior to the construction of the existing nuclear power stations in Canada, as construction occurred before the formalization of EA in Canada. Strict regulations are in place to prevent both catastrophic and chronic occurrences at Canada's nuclear power stations. The Canadian Nuclear Safety Commission (CNSC) regulates nuclear power generation, including mining and spent fuel storage, and sets limits of radiation exposure for both the general public and workers. Not only must these limits not be exceeded, but also exposure levels must be kept **a**s **l**ow **a**s **r**easonably **a**chievable by means of the ALARA concept. Canada also subscribes to the recommendations of the International Atomic Energy Agency, which sets standards for operation of nuclear power reactors, and of the International Commission on Radiological Protection.

The socioeconomic impacts of nuclear power generation are seen to be generally positive. The environmental impact review for the reopening of a nuclear power reactor at the Pickering Generating Station in Ontario looked at a number of factors considered to be important. These included population growth, employment, economic activity, housing, community services, and community satisfaction. Existing conditions were reviewed and compared with anticipated effects likely to be caused by the reopening of the Pickering A station, particularly those that were adverse. The review considered both local and regional concerns and included extensive consultations with the people potentially affected. Project and environmental interactions were screened to determine those interactions for which environmental impacts were likely. Those for which such impacts were not likely were accorded no further consideration. The important factors were limited to:

- population;
- business;
- property;
- services, including health services, recreation, and education;
- community satisfaction; and
- culture. Extensive consideration was given to the Aboriginal groups in the study area.

It was concluded that the residual effects after mitigation would be positive except in the areas of personal security and community satisfaction. There was some feeling that health, safety, and well-being might be affected by the return of the nuclear facility to service and the possibility of malfunctions. Mitigation measures were deemed necessary to address these areas for a number of people in the community. Implementation of Ontario Power Generation's public education, communication, and consultation strategy will therefore continue both for the period of return to service and for the duration of the Pickering A reactor's operation. The significance of the positive residual effects included an increased population base to help contribute to and maintain the community's social fabric; increased employment, income, and quality of life; and increased business activity and a stronger economic base. Because of the distance of the native reserves from the generating station, the return to service was not expected to have an impact on Aboriginal activities.

2.5.2 Fuel and Reactor Wastes

Reprocessing of spent nuclear fuel is carried out in a number of countries, including France, the United Kingdom, and the United States. One reason for reprocessing is to recover valuable materials such as plutonium and uranium to be reused for further production of electricity. There are currently no economic incentives for reprocessing in Canada, due in part to the relatively low cost and abundance of natural uranium. If reprocessing were to be chosen in the future, reprocessing technologies would remain to be determined, with ensuing uncertainty in benefits and risks for Canada. It is important to note that the quantities of radionuclides in used fuel are not changed by reprocessing, and thus reprocessing alone would not reduce the amount of waste.

2.5.2.1 Dry Storage of Spent Nuclear Fuel

In Canada, when fuel is no longer useful in a reactor, it is moved to a swimming pool-type wet storage facility at the same reactor site for 6-10 years. When the radioactivity and rate of heat generation have decreased sufficiently, the fuel is moved to dry storage in concrete canisters. Dry storage has a number of advantages over wet storage, including:

- reduced amounts of radioactive waste;
- less contamination of the storage facility;
- little or no corrosion of the fuel sheaths; and
- less radiation exposure of workers.

Concrete canisters are licensed for spent fuel storage by the CNSC at a number of sites, including nuclear stations on the Bruce peninsula in Ontario, Gentilly in Quebec, and Point Lepreau in New Brunswick; and Atomic Energy of Canada Limited (AECL) laboratories at Chalk River, Ontario, and Whiteshell, Manitoba. At the end of 1996, about 1.2 million used CANDU fuel bundles (weighing 29 400 tonnes) were stored at Canadian reactor sites. Studies suggest that dry storage can be effective for periods of at least 100 years, allowing easy retrieval if needed, but requiring continuous monitoring. About 87% of these wastes were produced by Ontario Hydro, 6% by New Brunswick Power, 5% by Hydro-Québec, and 2% by AECL.

Whether or not a dry storage site represents the final resting place of the spent nuclear fuel is currently the source of significant debate in Canada and elsewhere. AECL, at the request of the Canadian and Ontario governments, has developed a proposal that would see all spent nuclear fuel in Canada permanently disposed of deep in the Canadian Shield (see section 2.5.2.2).

Box 2.3
Dry Storage of Spent Nuclear Fuel

Dry storage is the currently favoured choice for long-term storage of spent nuclear fuel in Canada. Spent fuel bundles are stored in concrete canisters located at several nuclear power and research reactor sites. The United Kingdom, France, and Japan also use concrete dry storage containers.

This type of facility has been used safely in Canada for about 25 years without serious incident. The release of radioactivity and the radiation exposure of workers and the general public have been maintained well below regulatory limits. Safety analyses have shown that the release of radioactivity under accident conditions would also be well below regulatory limits.

Socioeconomic Impacts: The main socioeconomic impacts of a nuclear fuel dry storage facility occur during its construction. The noise from trucks going to and from the construction site, combined with the public's concern about potential adverse effects from radioactivity and radiation leakages, represent the main impacts.

It is not anticipated that dry storage will have any significant impact on infrastructure, health services, or education. If there are cases where new storage sites can be seen directly by the general public, concerns can be mitigated by erecting natural screens of bushes, trees, and mounds.

Aboriginal concerns will need to be solicited and addressed jointly in a cooperative manner. Any contamination of local water sources seems extremely unlikely but, if it occurs, would have a disproportionate effect on Aboriginals, particularly if they use the same water source for drinking water or for subsistence fishing. Whether or not there is such an occurrence, the stress caused by uncertainty in the minds of the members of the communities constitutes an adverse impact. This issue is potentially a major concern, and identification and extensive cooperative discussion of each issue are needed to allow for a resolution acceptable to all.

Technological Disaster: Studies conducted so far indicate that any accidents would result in radiation exposures and radioactivity releases that are either below detectable limits or significantly below regulatory limits.

Gaseous Emissions or Emissions to Air: No emissions to air are anticipated other than dust due to routine construction activities. Periodic air monitoring results should be compared with the National Ambient Air Quality Objectives (NAAQOs). It is not anticipated that air quality will be significantly affected.

Liquid Emissions or Emissions to Water: Experience at the Douglas Point Generating Station shows that dry storage would not have a significant effect on water or sediment quality. Drainage ditches may be necessary to control excavated areas during construction, and the water in these would need to be sampled to confirm that there is no radioactivity from the project. Storm water controls would need to be implemented to minimize water level fluctuations and any potential impacts on aquatic habitats.

Solid Emissions or Emissions to Soil: Other than the possible sediment deposits during storm runoffs mentioned above, there are no anticipated solid emissions or discharges into soil.

Indirect Impacts or Other Exposure: Where a dry storage facility is being expanded, the operators of the site should work closely with all concerned stakeholders to minimize any impact on sensitive sites.

Under normal conditions, there is no release of gaseous or liquid discharges to the environment. The only source of radiation to both workers and the general public is from spent nuclear fuel stored inside the concrete canisters. These are designed to be leak-tight and are monitored for contamination at the minimum detectable level. Precipitation can cause surface runoff into drainage ditches, which should therefore be monitored for radioactivity, as a safety precaution only.

2.5.2.2 High-level Waste Disposal Concept

In 1978, AECL was requested by the Canadian and Ontario governments to develop a concept proposal for the deep geological disposal of Canadian spent nuclear fuel. Other radioactive wastes, such as those from mining, were excluded. A time frame of 10 000 years was specified as the period for which environmental effects were to be considered. It is important to note that this was in concept only, and that no actual site was proposed.

Storage is different from disposal. Dry storage is perceived by the proponents of disposal to have two major disadvantages, in that perpetual long-term active monitoring is required, and an ever-increasing burden of responsibility is passed to future generations. Many others, however, claim that extended dry storage will allow new and better technical alternatives to be developed because of general scientific agreement that dry storage is safe for at least 100 years and permits an easy retrieval of the spent fuel, if required.

In the concept proposed by AECL to permanently dispose of spent radioactive fuel deep in the Canadian Shield at a depth of 500-1000 m, the proponents claim that continuous monitoring, while not precluded, is unnecessary, and that there is no burden to be passed to future generations. In its final report, the public panel reviewing the AECL proposed concept concluded that "From a technical perspective, the safety of the AECL concept has been on balance adequately demonstrated for a conceptual stage of development, but from a social perspective, it has not." The panel stated that, as it stands, the concept has not been shown to have broad public support and in its current form does not have the required level of acceptability to be adopted as Canada's approach for managing nuclear fuel wastes.

The disposal proposal considered several alternatives to deep geological disposal and rejected them as being less favourable. These included transmutation; disposal in outer space, on ice sheets, or at sea; and other than plutonic rock disposal. However, no formal EAs of these alternatives were conducted.

Possible environmental health effects of the concept were reviewed at the proposed siting, construction, operation, transportation, and decommissioning stages, and it was concluded by the scientific experts that radiological effects were the primary concern. Non-radiological, chemically toxic effects were considered, but were deemed not to be significant. Elements such as antimony, bromine, cadmium, cesium, chromium, molybdenum, samarium, and technetium – which could potentially accumulate through the food chain, resulting in elevated concentrations and significant human health effects – were also reviewed.

The Environmental Impact Statement of the proponents concluded that, under normal conditions, radiation doses to both the workers and members of the general public would be significantly below the maximum doses allowed under present regulations. Even under accident conditions, including transportation accidents, it was postulated that evacuation requirements would be unlikely. The environmental effects of any chemical contaminants released from a disposal facility were also expected to be small. It was anticipated that under normal conditions and with optimum procedures and systems design, radiation exposures of the public and workers would be virtually indistinguishable from the variations in natural background exposure.

Many serious community concerns, particularly those of Aboriginals, about radioactivity and transport and their impacts on health and lifestyles remain unresolved. These concerns will need to be addressed in a participatory manner by all the stakeholders involved on both sides of the issue.

The positive effects of a long-term waste disposal facility include:

- reducing risk and minimizing the burden of storage for future generations;
- increased employment opportunities;
- stimulation of the economy by increased wages and new marketplace demands; and
- improved infrastructure services such as roads, fire protection, education, and recreation.

Table 2.4
Nuclear Fuel Dry Storage: Matrix of Health Impacts: Biophysical Environment and Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations[1]	Effects on Health	Population at Risk	Probability of Occurrence	Biological/ Environmental Monitoring Indicators
Technological Disaster	containment failure or natural disaster	possible radioactive contamination of soil/ground water	site and local waterways	monitoring of canisters and ditches for radioactivity	Health Canada drinking water guidelines (1996); MMLE Regulations	none	site vicinity	very low	N/A
Gaseous Emissions or Emissions to Air	dust during construction	none	regional	air monitoring	NAAQO: 120 mg/m^3	none	site and region	very low	levels of radionuclides
	^{85}Kr and ^{3}H under accidental conditions, earthquakes, tornadoes, etc.	minimal	local	air monitoring	NAAQOs	none	site and region	very low	levels of radionuclides
Liquid Emissions or Emissions to Water	none	none	site	deep well and drainage ditch monitoring	MMLE Regulations; Health Canada drinking water guidelines (1996)	none	site	very low	levels of radionuclides in surface waters
Solid Emissions or Emissions to Soil	none	none	N/A	N/A	N/A	none	site	very low	N/A
Nuisances	noise during construction	quality of life; wildlife disturbance	local transportation routes	monitoring of noise levels	75 dBA	none	workers and public along transportation routes	high during construction	complaints
Indirect Impacts or Other Exposure	concern about Aboriginal food sources	changed lifestyle	region	monitoring of radioactivity in water, vegetation, fish, wildlife	CNSC regulations and Health Canada guidelines	probably none, but uncertain	region	low	health statistics

[1] MMLE = Metal Mining Liquid Effluent; NAAQO = national ambient air quality objectives; CNSC = Canadian Nuclear Safety Commission.

Table 2.5
Nuclear Fuel Dry Storage: Matrix of Health Impacts: Determinants of Health and Quality of Life Component

Determinant	Impact	Area of Influence	Population Concerned	Probability of Impact	Control Measures	Health Effects
Socioeconomic Aspects						
Revenues	positive	regional	regional communities and specialized trades	high	average income per capita	positive
Employment – construction and operations	positive	regional	regional communities	high	employment statistics	positive
Public Infrastructure	none	N/A	local communities	low	traffic monitoring	N/A
Health Services	occasional	site	workers	low	monitor usage	none
Education	none	N/A	N/A	very low	N/A	N/A
Social Fabric	positive	local	workers, their families, and local communities	low	crime statistics, recreational participation	none or positive
Lifestyles	positive	local	workers	low	recreational activities	none
Development of Healthy Children	none	local	families	very low	population health monitoring	none
Quality of Life						
Perception	none	local	workers and nearby residents	very low	opinion surveys	none
Landscape	positive or negative depending on viewpoint	site and immediate vicinity	workers and nearby residents	low	adherence to authorized plans	none
Recreational Use	N/A	site	workers	none	N/A	none
Cultural Activity	none	Aboriginal sites	Aboriginals	very low	consultation	none

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Notes:

3 TRANSPORTATION AND COMMUNICATION

Three types of projects have been selected to illustrate the diversity of the transportation and communication sectors and the wide range of impacts that can arise:

- roads and highways;
- long-distance transmission of electricity; and
- airport construction, expansion, and operation.

3.1 Road Construction

Canada is one of the industrialized nations with the most kilometres of road per capita. The size of the country and the very large distances between its major cities and capitals also account for the substantial amount of automotive traffic in Canada. This subject was therefore considered a priority in the Canadian context.

3.1.1 Canadian Context

Because of Canada's size and small population and the fact that many Canadian communities are located a fair distance from the country's more populated areas, automotive transportation is of vital importance in Canada. Moreover, the road network and the number of motor vehicles are growing steadily. In 1995, there were 901 900 km of road in Canada (4.4% more than in 1985), including 442 400 km of secondary gravel road. Saskatchewan has the most extensive road network; its nearly 202 000 km of road (22% of the Canadian total) represent 200 km per capita, compared with approximately 16 km per capita in the country's two most populated provinces (Ontario and Quebec). The Canadian average is 30.7 km of road per capita. Automobile use has increased from 117 billion traveller-kilometres in 1960 to 177 billion in 1970, 250 billion in 1980, and 383 billion in 1995. Automotive vehicle use has risen in tandem with the GDP since the 1950s, whereas other modes of transportation (air, bus, and train) have not matched this pace of growth.

In 1997, there were 17.5 million registered vehicles in Canada; with a population of approximately 30 million, Canada has one of the highest number of vehicles per capita in the world. Annual new vehicle sales in Canada since 1990 have ranged between 1.1 and 1.4 million. The total vehicle fleet (including commercial vehicles) used 34.8 million litres of fuel (including diesel) in 1998, or 8% more than in 1990 and 1982. Fuel consumption was stable during the 1980s. Consumption in 1998, however, was less than the figures recorded in the late 1970s, despite a 28% increase in the number of vehicles during this period. This is attributable to the greatly improved fuel efficiency of vehicles, from 17 L per 100 km in the 1970s to 10.5 L per 100 km between 1990 and 1995 (a fuel efficiency improvement of nearly 70%).

Because of all the gas and particulate emissions produced by combustion engines, the automobile remains a major source of pollution. It is estimated that automotive vehicles produce slightly more than 140 g of CO_2 (the principal greenhouse gas) per traveller-kilometre, compared with 75 g produced by buses, 90 g by trains, and nearly 180 g by aircraft. Although this figure is higher for aircraft, automotive vehicles produce more CO_2 overall because air travel is less prevalent than automotive travel. In 1998, automotive vehicles in Canada emitted nearly 60 million tonnes of CO_2 into the atmosphere, or about 13% of all Canadian emissions of this gas.

Fixed sources (combustion for energy production, industries, incinerators, etc.) constitute the largest source of Canadian CO_2 atmospheric emissions. However, the importance of motor vehicles' contribution to air pollution should not be minimized, even though considerable efforts have been made to reduce emissions, including the required use of three-way catalytic converters, which were first introduced in the mid-1980s. New vehicles manufactured since 1990 consequently produce only 5% of the overall pollutants produced by vehicles built in 1975. Since 1975, for example, total hydrocarbon emissions have declined from 1.2 to 0.25 g/km, CO emissions from 16 to 2.1 g/km, and NO_x emissions from 1.93 to 0.25 g/km. It should be pointed out, however, that the transportation sector is responsible for 70% of all Canadian emissions of benzene into the atmosphere; the carcinogenic nature of this compound makes this a source of concern.

3.1.2 Temporary Impacts of Road Construction or Repair

3.1.2.1 Environmental and Biophysical Health Impacts

The site preparation/excavation phase impacts are as discussed (generically) under Chapter 2 (Energy), with the additional consideration of such factors as the danger of public road traffic, if this construction overlaps with existing roadways. Injuries/fatalities due to vehicles striking construction workers have led to various precautionary measures in many jurisdictions, ranging from higher penalties for the public's violation of posted speed limits to a requirement that the construction crews be protected by appropriate physical barriers. Accordingly, such matters (even where not mandated by law) would need to be factored into the HIA. Where part of the site preparation involves the demolition/modification of existing concrete structures, there is also an (often-unrecognized) potential for silica exposure (NIOSH, 1996).

The laying down of the road surface is associated with exposure to additional materials such as asphalt and the various additives that it may incorporate. There has been sufficient concern about asphalt exposures to lead NIOSH to produce an information compendium (which may be found at http://www.cdc.gov/niosh/01-110pd.html) and to undertake a program leading to the development of engineering control guidelines for hot-mix asphalt pavers (NIOSH, 1997).

One of the main impacts of road development is truck and heavy equipment traffic. The increase in the volume and speed of commercial truck traffic as well as the resulting noise and dust are all sources of problems. Work schedules are an important aspect of construction sites, and such work is usually performed between 7:00 a.m. and 6:00-7:00 p.m. A highway (or any situation in which objects weighing several tonnes are moving at velocities in excess of 100 km/h and are subject to human control and the vagaries of weather and breakdowns) is an area of significant risk. From an occupational standpoint, NIOSH reported that in 1997 motor vehicle-related incidents were the leading cause of fatal workplace injury (this excluded incidents that occurred while driving to or from work) (NIOSH, 2000). [An information sheet intended for the truck driver is available at: http://www.thsao.on.ca/publications/trucking_operations.html]

Box 3.1
Exposure to Dust

Work involving machinery, such as road construction work, can generate substantial amounts of dust; such work generally produces gross particulate emissions. These dust particles range between 0.005 and 100 micrometres (µm) in size, but only those with a diameter of less than 10 µm (known as PM_{10}) are inhalable and penetrate into the tracheobronchial area of the respiratory tract. Respirable particulates of 2-3 µm or less ($PM_{2.5}$), however, can reach the alveoli of the distal portions of the lungs. PM_{10} and $PM_{2.5}$ can cause various acute or chronic problems, such as irritation, bronchial spasms, coughing, expectoration, infections, and cancer. Increases in hospitalization and mortality usually go hand in hand with higher atmospheric particulate concentrations. In Canada, in 1998, the NAAQOs recommended a maximum concentration (over a 24-hour period) of 25-40 µg/m^3 for PM_{10} and 15-25 µg/m^3 for $PM_{2.5}$. However, the maximum acceptable level (MAL) is 120 µg/m^3 (24-hour average) for total particulates of all sizes (CCME, 1999).

Given the relatively limited duration of road construction, it is reasonable to assume that people residing in the immediate vicinity will suffer only temporary problems. Road workers are often subject to greater exposure, since they are likely to work on such sites for many years.

In addition, road construction can entail safety problems for workers, residents, and drivers who are required to cross the construction site. Proper signage is a vital preventive tool for avoiding accidents. Risks resulting from blasting should also be mentioned.

3.1.2.2 Psychosocial Impacts

Road construction and repair can lead to certain psychosocial problems, related in particular to expropriation, destabilization of the agricultural or urban environment, and urban sprawl.

Expropriation often involves moving or even demolishing a place of residence. When there is no need for people to move out, however, the proximity of the road can generate safety concerns as well as noise and dust problems. The presence of a right-of-way literally “at one’s door” and the loss of landscape necessarily lower the value of a piece of property, even if there is little or no change to the municipal assessment. Stress, reduced quality of life, and, eventually, financial loss when a property is sold are the foreseeable consequences in these cases.

When farmland is lost, the agricultural environment is destabilized, as it becomes inaccessible or difficult to cultivate because of excessive urban infrastructure encroachment. Grid-patterned highway development leads to the fragmentation of farmland, limiting its accessibility or reducing its quality. The resulting potential land speculation also prevents the establishment of young farmers. In the urban environment, highways cut through neighbourhoods and isolate certain areas, adversely affecting the urban fabric, resulting in deteriorating socioeconomic conditions, and sometimes precipitating ghettoization and marginalization.

Urban sprawl may also be considered a consequence of road or highway construction, as access to rural areas is opened up. Suburbs, as a manifestation of urban sprawl, generate a greater need for new services, increase health care costs, and contribute to the deterioration of downtown cores; such deterioration tends to go hand in hand with increased crime statistics, higher poverty, and, in general, the development of a more or less unhealthy environment in which quality of life is adversely affected.

Noise

Road construction or repair can be the source of considerable noise pollution, generating sound levels of 65-80 dBA 30 m from the work site, as has been noted at a variety of road construction sites. This sound level is considered very disturbing and typically causes reactions such as stress, inability to concentrate, and even moodiness. Some types of work, such as hydrodemolition and sandblasting, generated sound levels of between 80 and 95 dBA at 30 m, which is unacceptable for periods measured in hours to those living within this radius.

As indicated in section 2.4.3, noise is the environmental nuisance most likely to be harmful to public health, as excessive levels can seriously affect the physical or psychological well-being of individuals. (See Box 2.2 in section 2.4.3 for details on noise definition, measurement, and WHO guidelines for acceptable levels of indoor and outdoor noise.)

3.1.3 Pollution Caused by Vehicle Traffic

3.1.3.1 Air Pollution

The principal pollutants generated by combustion engines are CO_2, CO, NO_x, and VOCs. Manganese has become a major pollutant in countries where it is used as a fuel additive in place of banned lead. The presence of dust of all origins, carried by vehicles or raised by the high-speed passage of vehicles, is also a problem. The air pollution caused by motor vehicles is now an accepted fact. (See Appendix A for a description of CO_2, CO, NO_x, and VOCs and their health effects.)

3.1.3.2 Water Pollution

Motor vehicles emit various substances, such as oils, greases, hydrocarbons, and car body metals, which are deposited on roads. In addition, 50 mg of hydrocarbons are released from a tire per kilometre of normal wear. These pollutants deposited on roadways or shoulders are leached into nearby streams by rain or snowmelt. This leaching water also contains several heavy metals, specifically cadmium, copper, lead, iron, and zinc, with the last two being present in larger concentrations. Public health problems may arise if drinking water wells are contaminated by any of these pollutants. Since the use of lead as a fuel additive has been banned completely in Canada since the 1990s, automotive traffic should no longer be a risk factor with respect to this metal.

Copper, iron, and zinc are not as toxic as cadmium and lead; in fact, they are essential to a number of physiological functions. However, maximum acceptable concentrations (MACs) in drinking water have been set, for aesthetic purposes, at 1.0 mg/L for copper, 0.3 mg/L for iron and 5.0 mg/L for zinc.

3.1.3.3 Snow Removal and Ice-melting Products

Each snowfall or buildup of ice on roadways necessitates the application of a variety of abrasives and ice-melting products. The most commonly used ice melter is sodium chloride (NaCl). Below -15ºC, however, calcium chloride ($CaCl_2$) must be used because it is more effective at very low temperatures. The abrasives used to prevent slipping and sliding on icy sidewalks and roads contain sand, gravel, or crushed stone.

Water resulting from the use of ice melters is usually characterized by an alkaline pH (pH 8.5), high conductivity and turbidity, and the presence of chlorides and sodium and calcium ions. The concentration of chlorides in runoff water can range from 3500 to 10 000 mg/L; this is very high, in that the maximum acceptable level in raw feed water, for organoleptic purposes (i.e., appearance, taste), should not exceed 250 mg/L. Chlorides in runoff water do not usually present a direct health risk for humans, unless the water table contaminates wells supplying drinking water.

3.1.3.4 Noise

Vehicle traffic is a major source of sound nuisance on roads. Such noise usually comes from three sources: friction between mechanical moving parts, air circulation around vehicles, and friction between tires and the road surface. In this last case, doubling of speed has been found to produce an increase of between 9 and 13 dB; the added presence of water on the road can also cause a noise increase of 10 dB. Urban expressways are a source of significant sound disturbance. Studies have shown that the average sound volume recorded within a radius equal to the distance of the first row of houses from urban and suburban expressways is 70-75 dBA, a level that is stressful.

There are various ways to reduce traffic noise. Limiting speeds is one way, but speed limits are rarely respected. Another fairly effective, aesthetic means of reducing noise is by establishing a buffer zone planted with vegetation such as trees or shrubs. In urban and urban-rural fringe areas where available space is limited, however, this is impossible. For these applications, noise abatement walls made of various materials, such as concrete, steel, plastic, and soil embankments, have been constructed.

3.1.3.5 Other Problems

In urban and urban-rural fringe areas, the construction of major thoroughfares or expressways often leads to higher accident rates, resulting in increased traffic-related mortality and morbidity. Pedestrians, cyclists, drivers, and vehicle passengers are all potential “traffic victims.” The higher the speed limit on a road, beyond the usual 50 km/h, the greater the risk of accidents. Faster traffic leads to increased mortality, even when an increase in speed is initially not considered excessive (e.g., an increase to 60 km/h from the usual 50 km/h). Traffic accidents have major social repercussions, in both human and financial terms, which cannot be overlooked.

Table 3.1a
Roads and Highways: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations[1]
Technological Disaster	toxic spills	depending on contaminant	local	management and control of movements of hazardous materials	provincial standards for the transportation of hazardous materials
Gas Emissions or Emissions to Air	suspended particles	pollution	local and regional	few measurements for vehicles	EQG, 24-hr (CCME) in μg/m^3: 25 (PM_{10}), 15 ($PM_{2.5}$)
	NO_x	effects on plant life	local and regional	catalytic reduction	NO_2: 200 μg/m^3 (24-h MAC, NAAQO Canada)
	VOCs	pollution	local and regional	catalytic reduction	benzene: 15 mg/m^3 (Health Canada, tumour-producing effects)
	photochemical smog	ground-level ozone, reduction in solar radiation	local, regional, continental	reduction of NO_x and VOCs	ground-level ozone, EQG: 100 μg/m^3 (1 h) and 30 μg/m^3 (annual)
	CO_2	climate warming	global	reduction of vehicle use	Rio (1992) and Kyoto (1997) commitments
	CO	pollution	local	catalytic reduction	15 mg/m^3 (8-h MAL, NAAQO Canada)
	PAHs	pollution, accumulation in wildlife tissues	local, regional, continental	catalytic reduction	0.001 μg/m^3 for 87 excess cancers/million over 70 years (WHO-Europe)
Liquid Emissions or Emissions to Water	heavy metals, particularly Cu, Fe, Pb, and Zn	toxicity to aquatic organisms	receiving watercourses	none	see Guidelines for Canadian Drinking Water Quality
	oil and grease	toxicity to aquatic organisms	receiving watercourses	none	visual for raw water supply (Environment Canada)
	chlorides	toxicity to aquatic organisms	receiving watercourses	reduction of de-icing salt use	none
Solid Emissions or Emissions to Soil	N/A	N/A	N/A	N/A	N/A
Nuisances	noise	health conditions	along the roadside	speed limits, noise screens	L_{eq} 45 dBA, (night) and 55 dBA (day) (WHO guidelines)
	dust		construction sites	dust control	

[1] EQG = environmental quality guidelines; CCME = Canadian Council of Ministers of the Environment; MAC = maximum acceptable concentration; NAAQO = national ambient air quality objectives; MAL = maximum acceptable level; L_{eq} = equivalent sound pressure level.

Table 3.1b
Roads and Highways: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	toxic spills	numerous, depending on contaminant	vicinity	rare to occasional	depending on the contaminant involved
Gas Emissions or Emissions to Air	suspended particles	respiratory irritation and problems, infections	primarily workers	rare to occasional	suspended particles in ambient air
	NO_x	irritation of respiratory tract	urban area residents	rare to occasional	ambient air NO_2 measure-ments
	VOCs	irritants; carcinogenic benzene; possible car-cinogenic formaldehyde	urban area residents, pump attendants (gaso-line pumps)	rare or unknown	ambient air VOC measure-ments (particularly benzene and formaldehyde)
	photochemical smog	ozone: pulmonary tissue inflammation	residents of urban and peri-urban areas	occasional in large cities	ground-level (tropospheric) ozone measurements
	CO_2	climate change	global	frequent	atmospheric CO_2 measurements
	CO	increase in % of carboxyhemoglobin	people working with vehicles in enclosed spaces	rare	atmospheric CO measurements
	PAHs	some compounds are carcinogenic	particularly people living near roads	unknown	measurements of certain PAHs, such as benzo[a]pyrene
Liquid Emissions or Emissions to Water	heavy metals, particularly Cu, Fe, Pb, and Zn	various toxic effects (no carcinogenic metals in this case)	consumers of polluted water	unknown	levels of heavy metals in drinking water
	oil and grease	if PAHs present: possible carcinogenic and muta-genic effects	consumers of polluted water	unknown	levels of PAHs in drinking water
	chlorides	no significant effects	consumers of polluted water	N/A	levels of chlorides in drinking water
Solid Emissions or Emissions to Soil	N/A	N/A	N/A	N/A	N/A
Nuisances[1]	noise	sleep quality, stress	vicinity	frequent to very frequent	dB measurements at various distances from the road network
	dust	stress, hearing problems	workers	occasional to frequent	

[1] BAPE reports; Lévesque and Gauvin (1996).

3.2 Power Transmission Lines

Given the importance of hydro-electricity in Canada, the conditions under which this type of energy is transported were selected for examination in this section. The province of Quebec is the world's third-largest producer of hydro-electricity, with a rated power capacity of 40 000 megawatts (MW), 75% of which is produced by the provincially owned corporation Hydro-Québec. Electricity is carried from production site (hydro-electric, thermal, nuclear, wind, solar) to users first via the transmission network and then through the distribution network. The transmission network transports electricity over long distances using high-voltage lines of 44-735 kilovolts (kV); the transmission cables are normally strung from metal towers. The Hydro-Québec transmission network, which extends some 37 000 km, is used as an example for this section. The distribution network covers more than 96 000 km. It is used to carry electricity to each point of use. The electrical cables in the distribution network are lower in voltage (less than 34.5 kV) and are normally strung from wooden poles.

3.2.1 Characteristics of the Transmission System

The manner in which electricity is produced in Quebec, in huge and often remotely located hydro-electric plants, has considerably influenced the design of the transmission system. In order to transport electricity from the La Grande complex in the James Bay area, from Churchill Falls in Labrador, and from the Manicouagan-Outardes-Bersimis complex in the Baie Comeau region, 735-kV transmission lines had to be installed over thousands of kilometres. These power cables are strung from braced lattice-type towers of up to 60 m in height. Near major urban centres, transformer stations reduce the voltage to 315 kV, and 315-kV lines carry current to other stations for further reduction, and then to the distribution network.

The transmission network therefore consists of lines carrying 120, 230, 315, and 735 kV of alternating current. These cables are carried on lattice-type metal towers varying in height according to the voltage involved; more visually attractive tubular towers have been used in urban areas for several years. The one exception is the Radisson-Nicolet-Des Cantons line near Sherbrooke. It is a 1120-km-long, 450-kV direct current line that crosses the St. Lawrence River in the Portneuf area at Grondines and was designed primarily to export electricity to the United States.

Tower height and width are determined by standards that set the horizontal clearance (distance between the cables), vertical clearance (the minimum distance between the ground and a cable at its lowest point between two towers), and phase clearance (distance between cables located on both sides of the tower). Since these distances increase with voltage, vertical clearance ranges from 13 to 18.6 m for a 735-kV line (depending on the obstacle involved – e.g., road, railway track, private road, etc.); and from 6 to 9.4 m for a 315-kV line.

3.2.2 Impacts of High-voltage Power Line Construction

Construction-related impacts, which disappear once a line is in service, usually result from the presence of various machinery and traffic. The main nuisances are noise, dust, exhaust fumes, interference with electrical appliances, and threats to the safety of nearby residents. These impacts are generally similar to those generated by any construction site (buildings, roads, etc.). Measures such as using dust control liquids, prohibiting machinery operation at night, and so on should be implemented to mitigate these impacts. When a line has to span a watercourse, the presence of heavy equipment, the building of temporary dams, and the dumping of plant waste into the water may significantly disturb aquatic life. Every effort must be made to avoid any major disturbances to the aquatic habitat of migratory and game species of fish. In the case of large watercourses, the construction of temporary dams can also lead to floods by causing ice jams during the spring thaw.

3.2.3 Permanent Impacts of High-voltage Power Lines

The many permanent impacts of the presence of high-voltage power lines are detailed briefly in the next few paragraphs. The issue of electromagnetic fields (EMFs) is described in section 3.2.4.

3.2.3.1 Incorporating Power Lines into the Natural and Traditional Landscape

People living near high-voltage power lines are becoming increasingly concerned with the visual impact of these lines. The presence of power cables in unique landscapes or near historical buildings is considered inappropriate. Power lines spanning watercourses are also a source of aesthetic problems.

3.2.3.2 Unwanted Noise Generated by Power Lines

High-voltage power lines generate discharges, producing what is known as a "corona effect," which in turn gives rise to crackling and frying noises that may even be audible in dry weather. According to Hydro-Québec, the maximum noise level during a light rain is estimated to be 42 dBA at the edge of a right-of-way and no more than 36 dBA at the closest homes. In dry weather, this same noise would be no more than 15-25 dBA in intensity, making it almost inaudible. Such noise is not considered a real nuisance, since the limits set for residential areas in existing standards or regulations are 40-50 dBA at night and 45-55 dBA during the day.

3.2.3.3 Collision Hazard for Moving Objects

The risk of small aircraft colliding with power lines is an ongoing source of concern. From 1975 to 1995, about 400 aircraft collided with power lines in Canada, and more than 100 people lost their lives in these accidents. At the rate of 20 accidents per year, this issue cannot be ignored and should be addressed whenever power lines are strung up near small airports.

When towers have to be raised in navigable waterways, the potential for boat collisions must be addressed. This is particularly true with regard to large ships, which may require several hundred metres to come to a full stop.

3.2.3.4 Economic Depreciation

Putting a new high-voltage power line into service in a highly urban setting is likely to hinder residential development. Developers of condominiums and seniors' residences, as well as owners of single-family homes, have expressed concern in this regard.

Recreation and tourism potential are also affected. Electricity towers and cables are not compatible with some infrastructures, such as nature parks, campgrounds, or even panoramic lookouts and observation points.

3.2.4 Electromagnetic Fields (EMFs)

Perhaps the greatest fear expressed by people living in very close proximity to high-voltage power lines is exposure to EMFs. Much scientific literature has been published on this subject, making it relatively well documented. To understand the effects of EMFs, however, it is important to first examine what they are and how they act on living organisms.

Box 3.2
Nature of Electromagnetic Fields

EMFs are made up of two types of fields: electrical fields and magnetic fields. An *electrical field* (EF) is generated the moment there is a voltage differential in a wire or line. An EF therefore is generated as soon as current is run through a line, even if no electrical equipment is operating (e.g., a lamp that is plugged in but not turned on). An EF is measured in volts per metre (V/m) or in kilovolts per metre (kV/m). The average EF in a home is 12 V/m, while the EF generated by a 735-kV power line can be as high as 10 000 V/m directly underneath the line. A *magnetic field* (MF) is generated by the passage of electrical current, and its intensity is expressed in micro-Tesla units (FT). Unlike an EF, an MF is generated only when current is used (e.g., when a lamp is turned on). The ambient domestic MF usually varies between 0.1 and 0.2 FT, while the maximum MF produced by a high-voltage power line ranges from 10 to 30 FT. Whereas an MF passes unchanged through most structures, such as buildings and the human body, an EF does not.

Both types of fields (electrical and magnetic) coexist in the environment, hence the term electromagnetic field (EMF). One of the characteristics used to describe an EMF is its frequency expressed in hertz (Hz). EMFs emitted by electrical power grids have a very low frequency of 1-300 Hz. Domestic electrical wiring generates an EMF frequency of 60 Hz.

3.2.4.1 Electromagnetic Field Sources and Exposure Levels

The levels of exposure to natural electric fields (EF) and magnetic fields (MF) are very low, at about 0.001 V/m and 10^{-12} FT, respectively. Average domestic exposure to an EF of 12 V/m and to an MF of 0.1-1 FT is caused by the presence of electrical wiring and equipment in homes. The daily use of various appliances generates a significant amount of EMFs:

- Appliances such as toasters, irons, refrigerators, and colour televisions generate an EF of 30-60 V/m and an MF ranging from 0.3 to 4 FT.
- A hair dryer produces an EF of 60 V/m and an MF ranging from 7 to 70 FT over a usage distance of between 30 and 15 cm.
- An electric blanket generates an MF of 10 FT at a distance of 1 cm, but an EF of about 10 kV/m, making it one of the highest EMF generators in the home.

The EFs generated by various household appliances and the average domestic EF are much lower than that generated by a high-voltage power line:

- A power line's maximum EF measured at ground level beneath the line is 10 kV/m, while it is 2 kV/m at the edge of the right-of-way.
- The maximum MF is 30 FT underneath a 735-kV line and 14 FT at the edge of the right-of-way.
- At a horizontal distance of 100 m from the power line, the MF would be only 0.1 FT – similar to the average domestic MF exposure level.

3.2.4.2 Fields and Induced Currents

Because they are good conductors of electricity, living organisms capture what are known as induced currents emitted by EMFs. These induced currents are measured in milliamperes (mA). EF- and MF-induced currents are usually perpendicular. An EF induces a current that flows from head to foot in the body of a person standing under a power line, while an MF induces a current that flows in a more circular pattern through the body's most conductive fluids, tissues, and organs.

In the case of a 10 kV/m EF, which is the maximum intensity measured at ground level beneath the cables of a 735-kV line, the maximum induced current in the organism is about 0.16 mA. This is well below the 0.66-1.0 mA sensory threshold. To put this in perspective, note that respiratory arrest can occur from muscle tetany (spasm) at between 18 and 30 mA; and a current ranging from 30 to 120 mA can cause cardiac arrest due to ventricular fibrillation.

3.2.4.3 Health Effects of Electromagnetic Fields

Biological Effects of EMFs under Experimental Conditions

Numerous studies have shown a series of biological effects on various animals exposed to EMFs. In terms of the neuroendocrinological system, disturbances in circadian rhythms and a marked decrease in melatonin secretion were observed in rats and mice at EFs of 2-130 kV/m. EFs of 3-30 kV/m were found to upset the nervous system, primarily by affecting dopamine and serotonin secretion. In humans, a slight decrease in cardiac rhythm was observed at an EF of 9 kV/m and an MF of 20 FT. Chicken and bird embryos showed significantly more deformities in the presence of an MF of between 100 and 1200 FT.

Possible Carcinogenic Effects of EMFs on Humans

Due to numerous contradictory studies, there is a great deal of controversy surrounding the carcinogenic properties of EMFs. It is clear, however, that there is no direct evidence of EMFs promoting cancer in adult humans. Even the most recent, strictly controlled studies have yielded inconsistent results, neither confirming nor disproving the assumption that a link exists between EMFs and cancer. No clear trend has been noted, but several results indicate relatively positive but nevertheless non-significant risks.

The Concept of Prudent Avoidance

Scientific research on the effects of EMFs on public health has not demonstrated clearly the existence of a significant risk, nor has it proven the complete absence of risk. In this context, prudent avoidance is recommended. This concept, developed at Carnegie Mellon University in Pittsburgh, Pennsylvania, recommends taking certain simple steps to reduce the public's exposure to EMFs. Because of the precedents it embodies, the application of this concept has given rise to considerable debate in the public and private sectors and in the scientific community.

Box 3.3
Electromagnetic Field Exposure Criteria or Standards

There is no specific regulation governing general EMF exposure. The International Radiation Protection Association recommends that the general public's exposure over 24 hours be limited to 5 kV/m for EFs and 100 FT for MFs. For the workplace, these recommendations are 10 kV/m and 500 FT, respectively. Currently, there are no recommendations or guidelines for EMF exposure related to transmission lines in Canada. The few U.S. states that have regulated exposure to the EF within a high-voltage power line right-of-way have established limits of between 8 and 10 kV/m.

3.2.5 Maintenance of High-voltage Power Line Rights-of-way

Approximately 20 000 of Hydro-Québec's 120 000 hectares (ha) of rights-of-way require annual maintenance to remove bush and tree growth beneath power lines so that towers and lines can be maintained. Removing this vegetation also helps limit potential damage from forest fires, the canopy flames of which burn at temperatures up to 800°C. Vegetation beneath power lines must therefore be kept low, and the right-of-way must be wide enough to prevent a forest fire's convection column from affecting the conductors.

There are two possible means of removing vegetation:

1) mechanical clearing; and
2) clearing with phytocides (herbicides).

3.2.5.1 Mechanical Clearing

A number of occupational health hazards are involved in the use of chain saws and strippers. Workers in forestry operations have more work-related accidents than do workers in any other trade in Canada. In addition, the use of vibrating tools for long periods of time leads to what is known as “white hand” syndrome. The average prevalence of this syndrome is 30.5% among chain saw operators, but it increases with the number of years of such work, and, after 20 years, 53% of workers are affected. Acoustic trauma is another health hazard for workers using chain saws. A mechanical saw operating at full speed produces a noise level of between 105 and 115 dBA; after 10 years at such noise levels, 55% of workers run the risk of occupational deafness.

Risk studies have also been conducted with regard to exposure to gaseous pollutants emitted by motorized tools. The main pollutants to which people who work with these tools are exposed are benzene, CO, formaldehyde, and PAHs. (For information on these pollutants, see sections 2.3, co-generation; 3.1, road construction; and 7.3, incineration.)

Box 3.4
Exposure to Benzene and Formaldehyde

Studies conducted since the 1980s indicate that exposure to benzene increases the risk of leukemia. Chain saw operators inhale air containing between 0.1 and 2.4 mg/m^3 of this gas. The U.S. Occupational Safety and Health Administration (OSHA) has set an exposure standard of 3 mg/m^3 in workplace air, while NIOSH recommends that the standard be lowered to 0.3 mg/m^3.

On average, workers are exposed to 34 mg/m^3 of CO, or 60% of the maximum allowable exposure of 57 mg/m^3 in the workplace. However, the American Conference of Governmental Industrial Hygienists (ACGIH) has suggested that exposure be limited to 29 mg/m^3. The average level of carboxyhemoglobin found in chain saw operators is 5%. (Carboxyhemoglobin is a compound formed in the blood when inhaled CO combines with hemoglobin. The increased amount of carboxyhemoglobin restricts the amount of oxygen that the blood can carry.)

The ambient air around chain saw operators also contains 0.08 mg/m^3 of formaldehyde. This is lower than the 2-3 mg/m^3 level known to cause symptomatic irritation of the respiratory mucosa and the eyes. Formaldehyde is considered potentially carcinogenic to humans.

3.2.5.2 Use of Phytocides

Phytocides are substances that are used to destroy vegetation (e.g., grass, shrubs, and trees). ("Phytocide" is the generally accepted term in forestry, while "herbicide" is the term used in agriculture and landscaping. The same basic product can be used in both instances.) There are dozens of phytocides that can be used, but only three examples will be presented here: 2,4-D, picloram, and dicamba. These homotypes of auxin hormones naturally present in plants act by disrupting plant metabolism and causing disorganized growth, malformations, and death. In general, herbicides are much less toxic to animals than are insecticides.

2,4-D

Because of its suspected but never clearly proven carcinogenic properties and teratogenic potential, 2,4-D is a controversial herbicide. Traces of dioxins (except tetrachlorodibenzo-*p*-dioxin, or TCDD) are also sometimes found in commercial 2,4-D preparations. The no-observed-adverse-effect level (NOAEL) for 2,4-D varies from 1 to 7 mg/kg body weight per day for a variety of animal species. It should be pointed out that the acceptable daily intake (ADI) for humans is estimated to be 0.003 mg/kg body weight. Since 2,4-D is adsorbed on organic matter in soil, leaching into the aquatic environment will be greater from soil that is poor in organic matter. The half-life of 2,4-D in water varies between 7 and 14 days.

Picloram

Picloram is a very powerful herbicide, and its use is currently restricted to very specific applications, such as clearing hydro-electric rights-of-way; however, no carcinogenic, teratogenic, or mutagenic properties have been detected for this product. Picloram is absorbed rapidly in the gastrointestinal tract and has a half-life of 20 minutes. Nearly 90% of absorbed picloram is excreted through the urinary system within 48 hours. Picloram's NOAEL has been set at 7 mg/kg body weight per day. The ADI has been set at 0.07 mg/kg body weight. It should be noted that commercial picloram preparations can be contaminated with hexachlorobenzene, which is considered a probable carcinogen. Like 2,4-D, picloram is retained in soil containing organic matter. Its half-life in water is about 10 days.

Dicamba

It is believed that dicamba, a herbicide in the benzoic acid group, may be teratogenic. More than 95% of the dicamba absorbed by an animal is excreted within 48 hours. In view of the possible effects on reproduction, the NOAEL has been set at 3 mg/kg body weight per day, while forestry workers' total exposure is on the order of 0.019 mg/kg body weight per day. The ADI has been set at 0.030 mg/kg body weight. Since dicamba is relatively mobile in soil, it leaches more readily into the aquatic environment, where its half-life is approximately seven days.

Table 3.2a
Electric Power Lines: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations[1]
Technological Disaster	presence of aerial cables	danger of collision with aircraft	site and perimeter	appropriate marker lights	provincial regulations where applicable
Gas Emissions or Emissions to Air	combustion gases (mechanical cutting of vegetation), including:	air pollution	site and perimeter	use of fuels containing less sulphur and limitation of exposure time	
	(1) benzene				15 mg/m^3 (Health Canada, tumour-producing effects)
	(2) CO				15 mg/m^3 (8-h MAL, EQG, CCME, Canada)
	(3) formaldehyde				0.1 mg/m^3 (30 min, WHO-Europe)
	(4) PAHs				0.001 µg/m^3 for 87 excess cancers/10^6 over 70 years (WHO-Europe)
	herbicides (2,4-D, picloram, dicamba)	air pollution, destruction of vegetation	site and perimeter	limitation of wind drift during spraying	0.2 mg/m^3 (Quebec work standards) or none
Liquid Emissions or Emissions to Water	2,4-D	all herbicides: water pollution and possible destruction of aquatic vegetation	all herbicides: site and perimeter	all herbicides: use minimum effective quantities	0.1 mg/L (MAC, Canada); 0.01 mg/kg body weight (ADI)
	picloram				0.19 mg/L (MAC, Canada); 0.02 µg/kg body weight (ADI)
	dicamba				0.12 mg/L (MAC, Canada); 12.5 µg/kg body weight (ADI)
Solid Emissions or Emissions to Soil	herbicides (see above)	same as above	same as above	same as above	same as above
Nuisances[2]	EMFs	disruption of radio communications	site and perimeter	buffer zone	apply concept of prudent avoidance by limiting exposure

[1] MAL = maximum acceptable level; EQG = environmental quality guideline; CCME = Canadian Council of Ministers of the Environment; MAC = maximum acceptable concentration; ADI = acceptable daily intake.

[2] EMFs are not a nuisance in the strict sense of the term; they have been placed in this section because they do not fall under the other types of stressor or exposure.

Table 3.2b
Electric Power Lines: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	presence of aerial cables	injury, trauma, death	aircraft passengers	very rare	public safety reports
Gas Emissions or Emissions to Air	combustion gases (mechanical cutting of vegetation), including:		for all gas pollutants, workers make up the population at risk in this specific case	frequent for signs of eye, nose, and throat irritation and headaches; rare or unknown for cancer development	ambient air concentration, carboxyhemoglobinemia in the case of CO and levels in the blood or various organs for the other pollutants, including herbicides
	(1) benzene	proven carcinogenic potential			
	(2) CO	increase in % of carboxyhemoglobin			
	(3) formaldehyde	possibly carcinogenic			
	(4) PAHs	some are carcinogenic			
	herbicides (2,4-D, picloram, dicamba)	see below	see below	see below	
Liquid Emissions or Emissions to Water	2,4-D	possibly carcinogenic and teratogenic	all pesticides: persons visiting treated rights-of-way or living nearby or eating contaminated fruit	all pesticides: rare or unknown	all pesticides: residual concentration in the environment and in the blood of exposed individuals, where applicable
	picloram	toxic (limited use)			
	dicamba	teratogenicity being assessed			
Solid Emissions or Emissions to Soil	herbicides (see above)	see above	see above	see above	see above
Nuisances	EMFs	carcinogenic nature suspected	vicinity, especially children	unknown or very rare	epidemiological studies on exposed populations

3.3 Airport Construction, Expansion, and Operation

[Note: The information used in the analysis presented in this section was drawn primarily from the impact study for the Toronto Lester B. Pearson International Airport expansion project in 1991. The project involved the construction of three new runways to accommodate high traffic volumes.]

The construction, expansion, and operation of an airport affect all components of the environment (air, water, land) and can also have consequences for human health, as well as psychosocial repercussions. The risk of a disaster, specifically of an aircraft crashing in an urban area, must also be taken into account.

3.3.1 Emergencies and Disasters

In addition to the risk of fire or explosion in one of the airport terminal buildings, an airport site inherently involves the risk of aircraft crashes. Apart from passengers and flight personnel, nearby residents are vulnerable to air crashes. The main risks are the physical destruction caused by an aircraft hitting the ground and the several fires that can result. Crashes that occur during or immediately after take-off have more disastrous effects because fuel tanks are full at these times. Aircraft also carry flammable equipment made from synthetic materials that can generate toxic gases and pollute the soil or the aquatic environment.

Airports must develop emergency response plans in collaboration with the appropriate services in local municipalities (i.e., police and fire departments, hospitals) to coordinate response activities. Whether a disaster occurs within or outside the airport site, coordination of emergency services between airport managers and municipal services is vital in order to evacuate injured people quickly.

3.3.2 Air Pollution

Machinery used in airport construction/expansion and in normal airport operations (e.g., aircraft, buses, and other motor vehicles circulating on the airport site) generates the kind of atmospheric emissions normally associated with the use of combustion engines. The principal pollutants are CO, CO_2, particulates, NO_x, and VOCs. (See Appendix A for a description of the health effects of these pollutants.)

The Pearson Airport expansion project impact study found that most of these pollutants present on the airport site originate from other, off-site locations. This airport is located in one of the most densely urbanized and industrialized areas of Canada. In a rural area, the main source of local air pollution would probably be the airport itself. The study also noted that the use of newer, high-performance aircraft is expected to help reduce pollution in the years to come.

3.3.3 Pollution and Disturbance of the Aquatic Environment

Essentially, two types of problems exist:

1) physical disturbances that arise during construction but remain permanent; and
2) pollution from the use of specific chemical substances.

Runway construction can have a considerable impact on the quality of the aquatic environment. The diversion of streams and the draining of land alter morphology and destroy aquatic habitats. Increasing the amount of paved area increases runoff to streams, thereby boosting the amount of suspended solids and sedimentation; the main consequence of this is the disturbance of fish habitats, particularly during the critical spawning periods.

Chemical water pollution specific to airport operations is caused by the use of certain products, such as aircraft de-icing fluids, products used to remove ice from runways, and products used to remove bits of rubber that stick to runways. To a lesser extent, liquids used during firefighter training exercises are also potential pollutants, but are normally contained within a specific perimeter.

3.3.3.1 Aircraft De-icing Fluids

Wing de-icing is necessary in winter, particularly during periods of freezing rain and as a preventive measure to stop ice from building up on wings as aircraft climb to higher altitudes. A hot solution of ethylene glycol ($C_2H_6O_2$) or propylene glycol ($C_3H_8O_2$) is sprayed on wings. The solution may also contain phosphorus-based corrosion inhibitors and wetting or thickening agents to promote adhesion.

Ethylene glycol is commonly used in car and truck antifreeze. It is a highly toxic water-miscible substance that is lethal to humans in a proportion of 1.4 mg/kg body weight; the ingestion of 100 mL of pure ethylene glycol can therefore kill an adult of average weight. The symptoms of intoxication are vomiting, dizziness, respiratory difficulty, and convulsions. Renal damage causing uremia and anuria is fatal. (Uremia is an abnormal condition resulting from the accumulation in the blood of waste products that should normally be eliminated in the urine. Anuria is characterized by the absence of urine or the inability to urinate.) Unlike ethylene glycol, propylene glycol is low in toxicity because it is oxidized to pyruvic and acetic acids. Even so, laboratory studies show an LD_{50} (lethal dose to 50% of test organisms) of 25 mg/kg body weight in rats.

More than half of sprayed-on de-icing fluids run off the wings onto the ground and into the local sewage system or open drainage ditches. Glycol solutions are the most significant water pollutants from airports. They harm aquatic fauna, since glycol is a major organic pollutant that stimulates bacterial growth, thereby reducing the amount of oxygen dissolved in water. The main consequences of this are the suffocation of fish and the creation of unpleasant odours caused by excessive proliferation of bacteria. The phosphorus that may be contained in some de-icing fluids stimulates the growth of aquatic vegetation, especially that of algae, thereby causing eutrophication in receiving waters. This results in conditions unfit for aquatic life and in the deterioration of recreational areas.

3.3.3.2 Runway De-icing

Runway de-icing is necessary to ensure safe take-offs and landings. Most airports use sand as an abrasive and urea as an ice melter. On average, Pearson Airport uses 7 tonnes of abrasive and melting agents per de-icing operation, done about a dozen times a year. This particular airport is in one of the mildest climate zones in Canada; use would therefore be higher at more northerly airports.

The abrasive helps prevent skidding, particularly at very low temperatures where ice melters are less effective. The main environmental impact of the use of abrasives is that they increase the level of suspended solids in water, thereby disturbing aquatic life, increasing turbidity, and silting watercourses.

A urea solution is used on airport runways instead of traditional ice melters such as sodium chloride (NaCl) and calcium chloride ($CaCl_2$), which are too corrosive and could cause aircraft operating problems. The problem with using urea, however, is that it changes into ammonia (NH_3) as well as nitrites and nitrates.

Ammonia dissolved in water is highly toxic; under generally existing pH conditions of less than 8, however, it occurs almost entirely as ammonium ion (NH_4^+), which is much less toxic. Nitrites (i.e., containing the NO_2^- ion) are highly toxic and can form methemoglobin, which prevents the transportation of oxygen in the blood. Nitrites can also bond with organic molecules to form carcinogenic nitrosamines. However, they are very unstable and change rapidly into nitrates, which are the principal nitrogenous form found in natural waters, since the nitrate ion (NO_3^-) is highly soluble and very stable. The main environmental impact is eutrophication resulting from the growth of algae and aquatic vegetation. Ingesting water containing more than 10 mg/L of nitrates can, in the long term, promote methemoglobin formation.

3.3.3.3 Runway Rubber Removal

During landings, pressure exerted by the weight and speed of aircraft is sufficient to leave rubber tire marks on runways. In order to maintain appropriate friction levels and to prevent skidding, such rubber must be removed from runways once or twice a year. Pearson Airport sprays a solution of sodium hydroxide (NaOH) and sodium metabisulphite ($Na_2O_5S_2$) on runways to soak and swell the rubber, which is then removed with powerful water jets. The solution and rubber particles are washed off the runways, and no special measures are used to collect them. Some of the solution evaporates into the atmosphere in any case. While a Transport Canada study did not consider the solution toxic, it should be noted that sodium hydroxide in solution is highly corrosive. On the other hand, sodium metabisulphite has a very low toxicity and is used in some pharmaceutical compounds.

3.3.3.4 Health Effects

The main water pollutants associated with airport terminal operations are not likely to cause immediate public health problems. Most of these pollutants normally run into drainage ditches or sewage systems. The substances most often used are not persistent toxic compounds that could bioaccumulate in the food chain. In terms of aesthetics and ecosystem conservation, however, their contributions to the proliferation of microorganisms and eutrophication should be taken into account.

3.3.4 Waste Production and Soil Pollution

This section looks at the presence of contaminated sites, the production of waste, soil pollution, and the loss of terrestrial wildlife habitat.

Airport sites cover vast areas, some of which are closed off to human activity. Despite the presence of aircraft, several animal species inhabit these areas. Ninety-six bird species and 11 mammal species have been counted on the site of Pearson Airport. In fact, restricted human access makes some urban airports virtual animal sanctuaries. While the construction or extension of runways destroys some land habitats, paved and non-natural surfaces generally make up only a small proportion (usually less than 15%) of the entire airport site. However, wildlife species do not have free run of the airport site; in most cases, habitats are manipulated, animals are trapped, and scaring techniques are used to keep birds away from take-off areas.

De-icing fluids and fuel can contaminate the ground on airport sites. Underground fuel tanks are also a risk and should be checked regularly for leaks. Contamination from spills of oil or more toxic substances such as polychlorinated biphenyls (PCBs) was found at a number of airports.

Daily airport operations generate domestic waste, primarily waste paper, plastics, and restaurant garbage. Waste production is substantially higher during construction of air terminal buildings or new runways, with sand, gravel, wood, and a variety of other debris being generated as well. Most of the domestic waste (about 60%) is recyclable. Restaurant waste can be composted, while paper and plastics can be recovered and recycled. Larger debris, such as tires, should also be sent to a recycling facility. In exceptional cases (particularly airports located in the far north), a landfill may be located on or near the airport site. Such landfills must be managed appropriately to prevent water and soil pollution (by percolation and leaching), air pollution (by wind-borne objects or particles), and the proliferation of vermin.

Waste generated inside aircraft in flight is considered international waste. Under Agriculture Canada, Health Canada, and Transport Canada regulations, it cannot be mixed with waste from the terminal or from ground operations and must be contained and sent to an incinerator as soon as it leaves the aircraft. Because air carriers are fully responsible for such waste management and its inherent costs, they may choose to return waste to its place of origin (where the materials consumed were prepared).

The existence of contaminated sites and the production of domestic waste do not present a specific risk to public health. The only real risk stems from the existence of unprotected landfills in far northern regions.

3.3.5 Noise

As discussed in section 2.4.3, noise is the environmental nuisance most likely to disturb public health. (See Box 2.2 in section 2.4.3 for details on noise definition, measurement, and WHO guidelines for acceptable levels of indoor and outdoor noise. The main problems that can be attributed to noise exposure are outlined in section 3.1.2.)

Close to Pearson Airport, outdoor average noise levels vary from 60 to 80 dBA during the day and from 50 to 70 dBA at night. During periods of intense flight activity, peaks of 100 dBA have been recorded. Outdoor activities are therefore likely to be affected when aircraft fly over residential areas. The Pearson Airport study found, however, that observed noise levels are unlikely to cause physical problems such as hearing loss and that nocturnal indoor levels are not sufficient to disturb sleep. There is no mention of follow-up studies of the local population to determine the existence of any long-term psychological or psychiatric problems. The new generation of aircraft fitted with turbojet engines is much quieter; consequently, noise pollution in airport vicinities is expected to decrease despite increased air traffic.

Nevertheless, airport construction or expansion projects almost inevitably elicit negative reactions from nearby residents.

Table 3.3a
Airport Construction/Operation: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations[1]
Technological Disaster	plane crash	destruction, pollution from toxic smoke and liquids	crash site and perimeter	covering, containment, collection	federal air transport safety standards
Gas Emissions or Emissions to Air	CO	negligible	local and regional	combustion control	15 mg/m^3 (8-h MAL, NAAQO Canada)
	CO_2	greenhouse effect	global	reduction of fossil fuels	Kyoto (1997) commitments
	NO_x	toxicity, smog formation	regional and continental	antipollution systems	NO_2: 200 μg/m^3 (24-h MAC, NAAQO Canada)
	VOCs	toxicity, smog formation	regional and continental	collection or increase in combustion performance	benzene, 15 mg/m^3 (Health Canada, tumour-producing effects)
	suspended particles	abrasion, stains, photosynthesis inhibition	local and regional	collection or filtration	120 μg/m^3 (24 h) MAC, NAAQO
Liquid Emissions or Emissions to Water	diversion and drainage of watercourses	destruction of wildlife habitats	watercourses on the site	mitigation measures, rehabilitation	provincial environmental legislation
	suspended solids	disturbance of aquatic fauna	watercourses on the site	mitigation measures, rehabilitation	500 mg/L (aesthetic objective, Environment Canada)
	ethylene or propylene glycol	organic pollution, oxygen deficiency	watercourses on the site	collection	none
	urea	pollution, eutrophication	watercourses on the site	collection	none
	sodium hydroxide	alkalinization, toxicity	watercourses on the site	collection, neutralization	none
Solid Emissions or Emissions to Soil	domestic waste	aesthetics, health conditions, vermin	site and perimeter	collection, recycling, sanitary landfill	municipal by-laws
	international waste	foreign parasites and microorganisms	N/A	incineration required	international agreements (Agriculture Canada, Health Canada, and Transport Canada)
	hazardous waste (oil, PCBs, etc.)	toxicity, unhealthy conditions	site and perimeter	containment, disposal using appropriate procedures	*Canadian Environmental Protection Act,* 1999
Nuisances	noise	N/A	local	establishment of buffer zones; use of new-generation aircraft; ban on night flights	L_{eq} 45 dBA (night) and 55 dBA (day) (WHO guidelines)

[1] MAL = maximum acceptable level; NAAQO = national ambient air quality objectives; MAC = maximum acceptable concentration; L_{eq} = equivalent sound pressure level.

Table 3.3b
Airport Construction/Operation: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	plane crash	trauma, injury, death	aircraft passengers and residents on the ground	rare	reports on mortality and morbidity; Transportation Safety Board[1]
Gas Emissions or Emissions to Air	CO	increase in % of carboxyhemoglobin	local residents	very rare	% blood carboxyhemoglobin
	CO_2	climate change	global	frequent	ambient air measurements
	NO_x	irritation of respiratory tract	urban area residents	occasional during summer	air measurements, epidemiological studies
	VOCs	irritation of respiratory tract, inflammation by smog	urban area residents	occasional during summer	air measurements, epidemiological studies
	suspended particles	various respiratory problems	urban area residents	rare to frequent, depending on location and environment	ambient air measurements
Liquid Emissions or Emissions to Water	diversion and drainage of watercourses	N/A	N/A	N/A	state of fish populations
	suspended solids	N/A	N/A	N/A	state of fish populations
	ethylene or propylene glycol	toxic if ingested (lethal dose: 1.4 mL/kg for ethylene glycol)	none	N/A	levels in watercourses or sewers
	urea	toxic if ingested or methemoglobin	none	N/A	levels in watercourses or sewers
	sodium hydroxide	toxic if ingested	none	N/A	pH measurements
Solid Emissions or Emissions to Soil	domestic waste	hygiene and health problems	primarily airport visitors and users	very rare	public complaints
	international waste	spread of exotic diseases	aircraft passengers	very rare or unknown	complaints, medical monitoring after incidents
	hazardous waste (oil, PCBs, etc.)	toxic and potentially carcinogenic effects	airport workers	rare	medical monitoring of workers
Nuisances	noise	quality of life, sleep disturbance, stress, aggressiveness, hypertension	residents around airport perimeter and under approach corridors	occasional to frequent	measurements of interior and exterior ambient noise, epidemiological monitoring studies

[1] Consult Transportation Safety Board (Ottawa).

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Notes:

4 FORESTRY

4.1 Canadian Context

Canada is a country covered by forests, and logging generates significant economic benefits, as shown by the following statistics:

The country has 418 million hectares of forest land, accounting for 42% of its total area, and of that figure, 244 million hectares constitute what is termed productive forest; the productivity of the remaining 173 million hectares is unknown, as it has never even been estimated.

Provincial governments own 77% of the productive forests (189 million hectares), while 24 million hectares (10%) are owned by 450 000 private woodlot owners; the rest is either federal Crown government land (3 million hectares) or Aboriginal land (19 million hectares).

Coniferous species account for 67% of all Canada's forests, while deciduous species account for 15%; the remaining 18% consists of mixed stands.

The annual allowable cut (AAC) is the volume of timber that may be cut during a specified period. The concept is used as a means of controlling harvesting to ensure a continuous supply of timber, taking account of the forest's rate of regeneration, whether natural or by means of replanting. From 1990 to 1997, the AAC declined slightly from 253 million cubic metres to 237 million cubic metres, of which 176 million cubic metres were coniferous species and 61 million cubic metres deciduous species. In 1997, 187.7 million cubic metres of roundwood (sections of tree stems, with or without bark) were produced. Of this total, 148.5 million cubic metres were used to manufacture construction materials (lumber, plywood, shingles, etc.), while 31.5 million cubic metres were used to manufacture paper pulp. Some 5 million cubic metres of wood, 75% of it from deciduous species, were used as fuel wood or fireplace logs.

In 1999, forest-related activities contributed $19.4 billion to Canada's GDP (i.e., approximately 1.9% of the total GDP). Exports of forest products earned $44.2 billion; in the absence of those exports, Canada's balance of trade would have been negative.

In that same year, 1999, the forestry sector provided 352 000 jobs, including 154 000 in the lumber industry, 118 000 in the pulp and paper sector, 58 000 in logging, and 22 000 in other forestry-related services. Total wages paid to the workers involved amounted to $11.8 billion.

4.2 Occupational Health Concerns

4.2.1 Physical Health Hazards and Effects

As might be imagined, tree felling is one of the most dangerous jobs in forest work, by virtue of the heavy physical workload, the equipment used (e.g., chain saws), the not always predictable behaviour of timber (especially with “hung-up” trees, also known as “widow-makers”), and the environmental conditions (e.g., undergrowth, rain, heat/cold) in which this work is conducted. The chain saw has been described as “clearly the single most dangerous tool in forestry” (Poschen, 1998) and is expected to remain a key problem. In addition to cuts (particularly to legs, feet, back, and hands), fractures and dislocations are other common injuries. Safe work requires training and good judgment/rules (e.g., with respect to the appropriate manner for bringing down “hung-up” trees); a common experience is that full-time forestry workers have 2-4 times fewer accidents than do seasonally employed workers. There has been increasing mechanization, which also reduces accidents (as well as the number of jobs); for the same amount of timber harvested, machine operators have perhaps one- fifth the accidents as compared with chain saw operators (Poschen, 1998).

There has been an increasing occupational disease problem in forestry. While conditions such as hearing loss and back injuries/pain persist, upper body complaints among machine operators are increasing in prevalence.

Hand-arm vibration (leading to conditions such as “vibration white finger”) has been limited by improved equipment design and personnel education.

In addition to manual cutting and herbicide use, another issue that might be considered is reforestation; this also incorporates the issue of the “young worker.” The 18-minute video “Survival of the Fittest,” at http://www.ofswa.on.ca/new_products/survival.html, and associated material, provides background:

> "Every year in Ontario, more than 5,000 workers are employed in what some seasoned veterans call the toughest job they will ever do: tree planting. This video examines some of the most severe risks for strain and sprain injuries and, through observations made by experienced tree planters, outlines key injury prevention strategies."

4.2.2 Psychosocial Impact

In addition to stand and terrain conditions, infrastructure, climate, technology, work methods, work organization, economic situation, contracting arrangements, worker accommodation, and education and training, worker psychosocial characteristics are an important determinant of health outcomes in forestry workers.

4.3 Use of Herbicides and Mechanical Clearing in Forest Regeneration

4.3.1 Background

The regeneration of young trees (e.g., conifers) after mature trees have been harvested is an important aspect of commercial forestry. The young trees grow relatively slowly and face competition from other less significantly valuable species. The species in question are not harmful, but rather are fast-growing opportunistic species such as fireweed, wild raspberry, various grasses, white birch, and alder. Vegetation of this kind becomes established quickly after a disturbance, such as logging, fire, wind, or insect pests. By blocking light, intercepting water and nutrients, and taking up a great deal of space, these plants may crowd out the young conifers. In view of the importance of coniferous species to the Canadian forest industry, the removal of competing vegetation is of crucial importance to logging firms.

4.3.2 Techniques for Removing Competing Vegetation

Various techniques are used to destroy competing vegetation and are grouped according to their mode of action, i.e.:

- biological (use of browsing animals, such as sheep or goats, in pastures);
- biomechanical (e.g., use of mulch to inhibit the growth of competing vegetation);

- mechanical; and
- chemical.

The latter two methods are the most common. *Mechanical clearing* involves the use of various tools, such as power-driven or manual mowers, machetes, circular saws, etc., to cut the competing vegetation, while *chemical clearing* involves the use of herbicides.

Competition removal is not carried out at all logging sites. The practice is reserved for areas where protection of regeneration is necessary (i.e., the growth of the young trees) and, moreover, is generally limited to plantations. Mechanical methods are by far the most common.

Herbicides are used in forestry, just as they are in agriculture. Herbicides are commonly used to promote the regeneration of young conifers after mature trees have been harvested. Herbicides may be applied by aerial spraying, via booms mounted on airplanes or helicopters. Alternatively, they may be applied from the ground by means of heavy machinery or motorized or manual devices (portable sprayers) carried by workers. When motorized ground spraying is carried out, the health impacts of workers' exposure to combustion gases must also be considered.

4.3.3 Effects of Portable Motorized Equipment on Human Health

As previously mentioned, portable motor-driven devices carried by workers in their hands or on their backs are frequently used for mechanical vegetation removal and sometimes for local spraying. These workers are exposed to toxic substances contained in the gases produced by the combustion of gasoline. Section 3.1 (road construction projects) lists the main pollutants resulting from the combustion of gasoline fuel.

In addition, the constant noise of an engine, even a small one, may cause such problems as hearing loss and stress. Noise may also affect heart rate and the immune system. A more detailed discussion of the effects of noise can be found at the end of section 3.3.

4.3.4 Herbicides: Glyphosate

The same herbicide product may be sold under two different names, depending on its use. Glyphosate, for example, is commonly sold as a forestry herbicide under the name Vision® and as an agricultural herbicide under the name Roundup®.

4.3.4.1 Nature and Action of Glyphosate

Glyphosate is one of the few herbicides used in forestry, where other herbicides, which are not banned outright, may be used only in exceptional situations. Glyphosate was originally developed in the 1960s. It is a non-selective herbicide that is effective against herbaceous plants, brush, and trees. It inhibits the synthesis of essential aromatic amino acids, thereby disrupting the plant's metabolism and causing death. It is a non-volatile product that remains temporarily in the air in the form of droplets when sprayed. All commercial preparations contain the same active ingredient (a.i.): a glyphosate isopropylamine salt. A surfactant (usually accounting for less than 15% of the formulation) and water are added to facilitate dispersal and penetration into the foliage. The predominant surfactant used in glyphosate-based products is a polyethoxylated tallowamine surfactant (Chemical Abstracts Service No. 61791-26-2), or POEA, which is derived from animal fatty acids.

Microorganisms in the natural environment quickly degrade glyphosate to aminomethyl phosphoric acid (AMPA), which subsequently breaks down into phosphates and CO_2. It has a half-life of less than 2 months and is undetectable after 12-15 months. It is ordinarily applied at a rate of 1.5 kg a.i./ha. Residues averaging 500 mg/g (wet weight) have been found on foliage, and contamination of the order of 35 µg/g (fresh weight) has been observed in such fruits as wild raspberries in the days immediately following spraying.

4.3.4.2 Environmental Impact

Information and data gathered by a variety of organizations have shown that glyphosate has little environmental impact (Box 4.1). The purpose of spraying is to promote growth of young conifers, and glyphosate has no effect on these, as it is generally applied after mid-August, when conifer buds become dormant for the winter, and consequently the glyphosate is not metabolized. However, because the metabolism of small deciduous species that compete with young conifers continues to be active beyond that period, those species are susceptible to the herbicide.

Box 4.1
Toxicity of Glyphosate

Animals and birds are usually not affected by glyphosate due to its low toxicity. In the laboratory, the acute oral LC_{50} (lethal concentration for 50% of test organisms) for rats is 5500 mg/kg body weight. In fish, the no-observed-adverse-effect concentration (NOAEC) for assessing acute toxicity ranges from 2 to over 1000 mg/L, depending on the species, whereas it varies from 2.4 to 52 mg/L for chronic exposure over a period of 21-255 days. On the basis of these studies, a toxicological reference value (TRV) of 0.74 mg a.i./L has been identified as a safe concentration of glyphosate in lakes and watercourses – i.e., one that will not expose fish to any measurable risk of adverse effects from chronic exposure.

Similar calculations have been carried out for birds and mammals. For birds, a TRV of 523 mg a.i./kg body weight per day has been identified as adequate for the avoidance of acute toxicity, while 93 mg a.i./kg body weight per day has been determined to be adequate for the avoidance of chronic toxicity. For mammals, the TRV that has been identified as being adequate for the avoidance of chronic toxicity is 410 mg a.i./kg body weight per day. As a rule, glyphosate is sprayed only once in any given area, and consequently chronic toxicity is a very low-level hazard for wildlife. However, defoliation is a problem for herbivorous species, forcing them to leave the area in search of food.

The toxicity of the surfactants must also be taken into account. POEA is more toxic than glyphosate itself, with a TRV for the avoidance of chronic toxicity in mammals of only 16.5 mg/kg body weight per day, which is 1/25 of the corresponding TRV for pure glyphosate. This situation is not unusual: there are a number of pesticides containing additives that are more toxic than the active ingredient.

4.3.4.3 Effects on Humans

Glyphosate is detectable in human urine, where its concentration is directly proportional to exposure. Contamination may occur by ingestion, inhalation, or absorption through the skin. Models indicate that a person living near a site that has been sprayed would receive a daily dose of approximately 0.0004 mg/kg body weight, while a person hunting or fishing in a recently sprayed area would receive a dose of 0.0006 mg/kg body weight. These concentrations are lower than the quantity ingested by the adult population from foods derived from crops treated with glyphosate (Roundup®), namely, 0.023 mg/kg body weight. According to the U.S. EPA, the acceptable daily dose of glyphosate is approximately 0.1 mg/kg body weight. We may note at this point that no teratogenic, mutagenic, or carcinogenic effects have ever been traced to chronic exposure to glyphosate. Moreover, skin tests on volunteers have shown no particular reactions or sensitivity.

Table 4.1a
Phytocide (Glyphosate[1]) Spraying or Mechanical Release to Promote Forest Regeneration: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations[2]
Technological Disaster	spill of phytocide (glyphosate)	contamination of soil and watercourses	spill site	preventive measures, training	
	crash of aircraft used for spraying	destruction, contamination	crash site and immediate perimeter	recovery of leaked substances	
Gas Emissions or Emissions to Air	glyphosate	deciduous defoliation	site and perimeter	limitation of drift by taking wind speed, wind direction, and humidity into account	none
	combustion gases	possibility of slight change in nesting bird populations	site and perimeter	none	combustion gases: CO: 15 mg/m^3 (MAL, NAAQO Canada); benzene: 3 mg/m^3 (occupational exposure); formaldehyde:0.3 mg/m^3 (occupational exposure)
		air pollution	site and perimeter		
Liquid Emissions or Emissions to Water	glyphosate	contamination of receiving aquatic environment, LC_{50}: 1-10 mg/L for most sensitive species	site and perimeter	buffer strip: 60 m for aerial spraying, 30 m for ground spraying	drinking water: 0.28 mg/L (MAC, Health Canada); 0.7 mg/L (U.S. EPA)
Solid Emissions or Emissions to Soil	glyphosate	soil contamination; microorganisms are the primary means of breakdown	site (glyphosate has little mobility in soil)	none	none
Nuisances	noise (engines)	health conditions	site, perimeter, and vicinity	engine mufflers	work standards as stipulated by each province
	vibrations	health conditions	site	filters	
	odours (gasoline and phytocide)				

[1] Glyphosate is the most widely used herbicide in forestry.

[2] MAL = maximum acceptable level; NAAGO = national ambient air quality objectives; MAC = maximum acceptable concentration.

Table 4.1b
Phytocide (Glyphosate[1]) Spraying or Mechanical Release to Promote Forest Regeneration: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	spill of phytocide (glyphosate)	nausea and vomiting; NOAEL: 175 mg/kg body weight per day	workers	site and immediate perimeter	medical monitoring
	crash of aircraft used for spraying	injury, death	pilot	site and immediate perimeter	public safety
Gas Emissions or Emissions to Air	glyphosate	no significant effects	N/A	N/A	N/A
	combustion gases	CO: increase in carboxyhemoglobinemia	workers, primarily those spraying on the ground with power machinery	occasional	blood CO concentration
		formaldehyde and NO_x: respiratory irritation		occasional	other pollutants: symptoms and medical monitoring
		benzene and PAHs: cancer		unknown	
Liquid Emissions or Emissions to Water	glyphosate	no significant effects at concentrations found in the environment	N/A	N/A	measurement of residue in drinking water; if necessary, determination of concentration in urine
Solid Emissions or Emissions to Soil	glyphosate	no effects	N/A	N/A	N/A
Nuisances	noise (engines)	loss of auditory acuity	primarily workers	frequent to long-term	audiometry
	vibrations	loss of sensibility, "dead-hand" syndrome	workers	frequent to long-term	medical monitoring
	odours (gasoline and phytocide)	nausea	workers/vicinity	indefinite	medical monitoring (workers)/complaints

[1] Glyphosate is the most widely used herbicide in forestry.

4.4 Use of the Insecticide *Bacillus thuringiensis* (Bt)

4.4.1 Background

The bacterial insecticide *Bacillus thuringiensis* (Bt) has been widely used in forestry since the 1980s against various insect pests, notably the spruce budworm (despite the insect's name, the coniferous species that is most vulnerable to it is the balsam fir). Since the early 1990s, it has also been used against various biting insects, such as mosquitoes and black flies, which are major nuisance pests or transmit disease.

4.4.1.1 Spruce Budworm

The spruce budworm, which belongs to the order Lepidoptera, causes serious damage to coniferous forests throughout Canada, from Yukon to Newfoundland and Labrador. Infestations are cyclical and occur on average every 30 years, sweeping the country from west to east. The spruce budworm attacks primarily balsam fir and white spruce, which may sustain mortality levels as high as 65% during the worst outbreaks.

The spruce budworm is the most harmful forest pest in eastern Canada. Introduced into the ecosystem 10 000 years ago, it has contributed to forest renewal by hastening the decline of overmature stands. The first documented spruce budworm infestation occurred in 1704. Half a dozen other infestations, some lasting as long as 10 years, occurred between that date and the end of the 19th century. A major outbreak occurred in eastern Canada in the 1920s. New Brunswick was particularly hard hit, and a number of forestry companies in that province were forced into bankruptcy.

For various reasons, including human intervention in forest ecosystems, the frequency and duration of spruce budworm infestations increased during the 20th century. The last major infestation in Canada began in the 1960s and 1970s and swept the country from west to east, ending in about 1987, although residual pockets of budworm activity were still observable in the eastern part of the country (in Quebec and New Brunswick) as late as the early 1990s. Since 1990, areas defoliated by spruce budworm in Canada have been much smaller; less than 900 000 ha were affected in 1998, compared with 10 million hectares in 1991.

4.4.1.2 Biting Insects

Biting insects, mainly mosquitoes and black flies, are a nuisance to both humans and domestic and wild animals. In Canada, one of their impacts is making life unpleasant to the point of restricting outdoor activities during the period when they are most active, from early June to the end of July. As a result, they can be an economic nuisance (i.e., cause economic losses) to the tourism industry. Mosquitoes are of concern because of West Nile virus and similar diseases that have recently emerged.

4.4.1.3 Insecticides Used in Canada before *Bacillus thuringiensis*

Intensive aerial spraying to control spruce budworm populations was first carried out in the 1950s in New Brunswick and eastern Quebec. Until 1962, DDT was the only pesticide used for that purpose. When it was banned early in the 1970s, it was replaced by fenitrothion (an organophosphorus insecticide) and aminocarb and mexacarbate (both carbamates). Mexacarbate was abandoned in 1977, and Bt was first used the following year. Since 1990, Bt has also been tried against three other forest insect pests: the hemlock looper, the jack pine budworm, and the Swaine jack pine sawfly.

4.4.2 Nature and Action of *Bacillus thuringiensis*

Bacillus thuringiensis is a rod-shaped aerobic bacterium that occurs throughout the world. It was discovered in Japan in the early 1900s, and its insecticidal properties were recognized in the 1920s. Close to 70 subspecies of Bt have been identified. The most widely used subspecies in Canada is *kurstaki* (Btk), which is used in aerial spray programs to control forest insect pests. Another subspecies, *B. t. israelensis* (Bti), is commonly used against biting insects. This form of the insecticide is generally sprayed directly into bodies of water, where it attacks mosquito and black fly larvae.

Bt formulations contain the endospore of the bacillus and a parasporal body known as a crystal. When the crystal dissolves in the alkaline digestive tracts of some insect larvae, it releases various proteins known as protoxins or d-endotoxins. In a larva's digestive tract, these endotoxins are transformed into active toxins (holotoxins), which deform the intestinal cells, causing perforation of the epithelium and osmotic imbalance. The larva stops feeding within a few minutes of ingesting the crystals and dies within a few hours. The toxins of the various subspecies or varieties (serotypes) are comparatively selective, the action spectrum of each being restricted to particular groups of insects.

4.4.3 Environmental Persistence and Mobility of *Bacillus thuringiensis*

The dispersal of Bt spores in the air, of course, depends on wind speed and direction, relative humidity, and the size of the insecticide particles comprising the spray. Bt concentrations in the air fall quickly: two hours after spraying, less than 2% of the total concentration can be detected. In municipalities located near areas that have been sprayed, a majority of air samples have been found to contain bacterial concentrations below 1 bacterium per cubic metre.

On trees and plants, Btk spores may persist for several weeks, although they will not necessarily remain viable for all that time. This persistence may be attributed to the fact that some spores end up in the crevices or creases of leaves or in cones or rough bark and are protected from the sun's ultraviolet rays, which are known for their bactericidal properties.

The environmental persistence of Bt in water is similar to its persistence in air. Observation reveals a rapid decline in viability during the first few hours and a medium-term persistence (for a few weeks or months) at very low concentrations (less than 1% of the maximum attained during the first few hours). After several weeks in the water, Bt is found primarily in the aquatic sediments, where it may undergo inactivation.

Bt persists the longest in soil, where it can remain for several years. One study found that spores and crystals had not broken down, or had broken down only slightly, after more than eight weeks in the soils of forested areas or farmland. Another study revealed that the concentration of Bt remained constant for up to a year after spraying. However, the vertical percolation rate for Bt in soil is very low: between 90% and 99% of the spores remain in the uppermost 5 cm, and, consequently, there is very little risk that the insecticide will find its way into the water table. Studies have also shown that the spores are unlikely to germinate in acidic soil, which is precisely the type of soil in which the boreal coniferous forest grows, and hence the type of soil onto which Bt is sprayed.

4.4.4 Effects of *Bacillus thuringiensis* on Humans

Experiments with humans and other mammals have revealed no adverse effects from exposure to Bt orally, by inhalation, subcutaneously, or through contact with the eyes. However, Bt has been found in the intestinal flora of exposed forestry workers three months after spraying operations. It also appears that it can be transmitted from person to person or through indirect exposure (via clothing).

It has sometimes been suggested that Bt may be opportunistic and may aggravate an illness or act as a co-pathogen or synergistic agent. However, little information is available in this area, and in the few documented cases, Bt appears to have played only a minor role.

Bt is also known to persist in the circulatory and digestive systems and also in various organs, including the eyes, nose, lungs, liver, spleen, kidneys, and brain, for periods that may range from a few hours to several months, depending on the organ involved and the initial concentration of the bacterium. In addition, Bt has been known to stimulate the formation of antibodies. These immunological reactions tend to occur in the presence of vegetative cells, rather than in the presence of spores or crystals. The antibodies in question persist for only a matter of months, and the workers and other persons in whom they have been observed have not been found to experience any health problems.

In the late 1980s, a far-reaching epidemiological study was conducted in Oregon, in a region with 120 000 residents where Btk had been sprayed to control an Asian gypsy moth infestation. Three cases were brought to light in which the role of Bt was not perfectly clear. The three persons concerned were all immunocompromised and had had health problems well before the spraying operation. It was not possible to attribute with certainty problems of an infectious nature to Btk or to rule out with certainty the etiological role of Bt.

In the mid-1990s, a number of strains of Bt were found to produce a diarrheal enterotoxin that may cause food poisoning. There have also been reports of Bt having been found in various foods of plant origin as a result of its use for pest control in agriculture. In an outbreak of food poisoning at a seniors' home in Canada, Bt was found in the systems of several of the patients; however, it was unclear whether Bt had played an etiological role. In tests on unbroken skin, no allergic sensitivity to Bt has been noted.

It is important to note that in all cases of suspected infection, detailed characterization was required to differentiate *B. thuringiensis* from *B. cereus*, which is a known human pathogen. The two are genetically similar, and, in view of the involvement of *B. cereus* in various infections, especially gastrointestinal disorders, it is obviously important to be able to distinguish them.

4.4.5 Effects of Additives in *Bacillus thuringiensis* Preparations

Commercial formulations of Bt contain essentially toxin crystals, spores, and cellular debris, along with various additives designed to increase the effectiveness of the insecticide. These additives are extenders (such as water, oil, or powdered clay), emulsifiers, thickeners, humectants, antifoaming agents, attractants (such as sugar) designed to induce insects to eat the crystals, and stabilizers (antioxidants, antibacterials, and evaporation suppressants). The nature and chemical composition of the various additives are trade secrets, and consequently it is impossible to determine the actual toxicity of commercial preparations of Bt.

The additives can, however, be mild irritants, as confirmed by the warnings that appear on the material safety data sheets of commercial preparations. The most sensitive organs appear to be the respiratory system and the eyes: eye irritation and conjunctival congestion have been observed in rabbits as a result of the abrasive nature of some additives. A corneal ulcer diagnosed in the case of a man who had got some insecticide in his eye appears to have been caused by additives as well. Lastly, one study found that workers exposed to Btk had a higher incidence of eye, nose, and throat irritation, chapped lips, and dry skin than members of a control group, but these symptoms may have been due to the presence of substances other than the bacteria. Similar symptoms have been observed in the case of people with a history of allergies (such as asthma, eczema, and hay fever).

Table 4.2a

Bacillus thuringiensis (Bt) Spraying to Control Certain Destructive Forest Insects and Biting Insects: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations
Technological Disaster	spill of concentrated insecticide solution	contamination of soil and watercourses	spill site	preventive measures, worker training	provincial regulations on handling pesticides
	crash of aircraft used for spraying	destruction, contamination	crash site and immediate perimeter	recovery of spilled substances	laws and regulations on piloting aircraft
Gas Emissions or Emissions to Air	Bt spores and crystals	deposit on vegetation; no known toxic effects	site, perimeter, and vicinity	limitation of spray drift	commercial Bt preparations are subject to the federal pesticide registration process
	various additives	unknown	unknown	limitation of spray drift	spraying: provincial regulations
Liquid Emissions or Emissions to Water	Bt spores and crystals	presence and persistence in surface water	site, perimeter, and vicinity	avoid passing over watercourses and water bodies	none
	various additives	unknown	unknown	avoid passing over watercourses and water bodies	
Solid Emissions or Emissions to Soil	Bt spores and crystals	presence and persistence in soil	site and perimeter	none possible	none
	various additives	unknown	unknown	none possible	none
Nuisances	N/A	N/A	N/A	N/A	N/A

Table 4.2b
***Bacillus thuringiensis* (Bt) Spraying to Control Certain Destructive Forest Insects and Biting Insects: Matrix of Health Impacts: Health Component**

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	spill of concentrated insecticide solution	irritation caused by additives	workers	rare	unknown (additives are protected trade secrets)
	crash of aircraft used for spraying	injury/death	fixed-wing aircraft/ helicopter pilot	very rare	Transportation Safety Board investigation (federal)
Gas Emissions or Emissions to Air	Bt spores and crystals	probably none, opportunistic infection in immunosuppressed individuals	immunosuppressed individuals (?)	unknown or very rare	spore and bacteria counts; epidemiological studies
	various additives	possible eye, skin, and respiratory tract irritation	exposed workers	rare	unknown (additives are protected trade secrets)
Liquid Emissions or Emissions to Water	Bt spores and crystals	probably none, opportunistic infection in immunosuppressed individuals	unknown	unknown or very rare	spore and bacteria counts in surface and drinking water
	various additives	unknown	unknown	unknown	unknown
Solid Emissions or Emissions to Soil	Bt spores and crystals	none	N/A	N/A	N/A
	various additives	unknown	unknown	unknown	unknown
Nuisances	N/A	N/A	N/A	N/A	N/A

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5 MINING

5.1 Socioeconomic Profile of Canada's Mining Industry

In 1997, there were 97 metal production operations in Canada and 587 operations producing industrial minerals. The majority (57) of metal mining operations produced gold, followed by nickel, copper, and zinc (21 in all). Most Canadian mining production (80%) is exported, with the industry ranked second after logging. In 1997, there were 25 000 mining jobs in the metals sector and 12 500 in industrial mineral mines, with salaries totalling $1.6 billion and $550 million, respectively. In 1997, the majority of mineral industry operations (metals and industrial minerals) were located in Quebec (214), followed by Ontario (204) and the Prairie provinces (141).

In 1998, Canada was still a major exporter of minerals, ranking second in the production of nickel (19% of world production), zinc (14%), and cadmium (10.5%). The country ranked third in the production of asbestos, titanium concentrate (ilmenite, rutile, and slag), aluminum, and platinum group metals.

5.2 Fundamentals of Mining

Mining operations involve several stages, including exploration and the removal and processing of the ore. An ore is a rock containing a sufficiently high concentration of useful minerals or metals to justify commercial exploitation. An ore also contains materials without commercial value called gangue. There are some 3000 types of ore on the planet.

From an economic point of view, the materials in ore can be divided into two groups:

1) metallic minerals, including ferrous and non-ferrous metals (e.g., copper, zinc, nickel, lead) and precious metals (silver, gold, and platinum); and
2) industrial minerals such as asbestos, gypsum, potash, salt, mica, talc, graphite, sulphur, silica, and peat.

Some statistics may also include a third group classified as construction or “quarry” materials, which include granite, limestone, marble, sandstone, slate, sand, gravel, lime, and cement.

An ore deposit is mined by removing the minerals and their gangue materials from the subsurface through open-pit (surface) mining or in underground operations. In open-pit mining, the pit is constantly deepened and widened as the ore is removed. In an underground operation, ore is removed through vertical shafts and horizontal drifts that follow the veins containing the materials being mined. Metals such as copper, zinc, and gold are generally removed by means of underground mining operations.

Many of the safety and health controls that must be applied in this industry (e.g., blasting controls, ground support, ventilation) are the purview of highly specialized professional fields, whose practitioners will be involved in the design of the project. The occupational health and safety considerations will differ on the basis of factors such as whether the mine is open-pit or underground, the nature of the rock and the extracted material, and the technology.

A broad-based and comprehensive web site for information on mining is: http://www.cdc.gov/niosh/mining/default.htm. It includes a mining health and safety “toolbox”: http://www.cdc.gov/niosh/mining/pubs/pubs.html

Box 5.1
Health and Safety Concerns of Coal Mines

Coal mines are particularly dangerous, because of the common presence of both coal dust and CH_4 (in so-called “gassy” mines). The Westray (Nova Scotia) disaster in 1991 resulted in the deaths of 26 miners. In the official inquiry (Richard, 1997) it was described as:

> “... a complex mosaic of actions, omissions, mistakes, incompetence, apathy, cynicism, stupidity, and neglect.... As outdated and archaic as the present [Coal Mines Regulations] Act is, it is painfully clear that this disaster would not have occurred if there had been compliance with the Act.... Management failed, the inspectorate failed, and the mine blew up.”

5.2.1 Mining Operations

Mining operations consist essentially of four steps:

1) exploration;

2) mining;

3) mineral processing and dressing; and

4) metallurgical processing.

Exploration (or prospecting) is an activity conducted to seek out deposits of economic interest. Since the 1990s, prospecting has made increasing use of satellite images, although traditional methods such as deep drilling and searching for surface outcrops are still widely used. The next step, *mining* (or extraction), involves removal of the desired minerals from the subsurface. The final *processing and dressing* stage consists of removing the minerals from the non-usable host rock (gangue) and concentrating them. Once a mineral has been partially treated, it then undergoes *metallurgical processing* to achieve a purity of over 98%. Metallurgical processing is generally regarded as an industrial rather than a mining process (see below).

5.2.1.1 Mineral Dressing

Mineral dressing refers to all the mechanical, physical, and chemical methods used to separate minerals from gangue and to partially treat them. This is usually the most polluting stage and the one that generates the greatest number of health risks. Historically, it includes three types of operations: 1) preparation, 2) concentration, and 3) conditioning. In the interest of protecting the environment, a waste treatment stage has been included since the 1980s.

Ore *preparation* involves crushing and grinding for size classification by screening. The purpose of *concentration* is to separate the mineral grains from the gangue. This can be achieved by gravitational techniques (based on the density or weight of the various materials), magnetic separation, or flotation. The latter technique is based on processes that involve bringing the mineral or metal particles to the surface of a liquid using various adjuvants such as surfactants or solvents. Various chemicals are used to alter the mineral properties in order to enhance their concentration; for example, cyanide is used with gold or silver. *Conditioning* involves compressing, drying, or agglomerating mineral particles in order to change their behaviour or strength. Its purpose is to make the ore ready for handling or further metallurgical processing; iron ore pelletizing is an example of conditioning. At the end of these three stages, the ore will be more concentrated, but the purity achieved can be fairly low (of the order of 20-40%). It is the subsequent metallurgical refining that significantly enhances purity. The final operation, referred to as waste treatment, is an environmental step and includes the processing of minewater (from drifts), flotation water (toxic), and solid mine waste.

5.2.1.2 Metallurgical Processing

Melting and refining operations are used to produce pure metals or to prepare alloys. Part of these processes can be carried out on site, but they generally take place elsewhere. Foundries, steel plants, and aluminum smelters are involved in metallurgical activities, but the environmental effects of these activities will not be dealt with in this chapter. However, in the case of gold, the product that leaves the mine is usually about 96% pure because the mineral dressing and metallurgical stages overlap; gold mining (section 5.3) will be used as a case example in this chapter.

5.3 Gold Mining

5.3.1 Background

Among the unique properties of gold are its malleability and ductility. For example, one ounce (31 g) of gold can be flattened into a thin, translucent sheet measuring 10×10 m in area or elongated into a wire stretching 80 km in length. The two main activities responsible for generating demand for gold are manufacturing and financial investment. Gold is used in the manufacture of such items as jewellery (70% of the total demand for gold), coins, and electronic components and in dentistry. A further 20% of the total demand is accounted for by gold that is held or invested (gold provides a hedge against stock market difficulties).

World demand for gold, which influences decisions about whether or not new mines will be opened, is generally driven by the monetary policies of central banks and financial institutions. Thus, the opening of a new mine may be delayed because the price of gold is too low. The number of Canadian gold operations rose from 57 in 1997 to 72 in 1999, an indication of the fact that economic interest persists despite stabilization of the price of gold per ounce.

In 2000, world production of pure gold was 2250 tonnes, most of which was produced by South Africa (19% of world production), the United States (15%), Australia (12.6%), and Canada (6.8%). The 153 tonnes of gold produced in Canada in 2000, represented a slight decrease from the 160 tonnes produced in 1996, despite the increase in the number of operations. The 153 tonnes of gold produced were valued at just over $2 billion.

5.3.2 Extraction Methods

Gold-bearing metals are usually found in a quartz or sulphide gangue. A quartz ore generates less pollution than a sulphide ore. Relatively pure gold is obtained primarily through the preparation and concentration processes. A gravity concentrate is first obtained by passing the crushed ore over a shaker table in a stream of water. This method is similar to that used by gold washers; it was particularly effective in the recovery of relatively pure gold nuggets.

In the next step, a gold concentrate is obtained by flotation, roasting, and cyanidation of the ore. Although this is the most common sequence, in certain cases flotation and roasting are omitted and the ore goes directly to the cyanidation stage. It should be noted that flotation and roasting are more commonly metallurgical processes used to concentrate gold that is found in association with sulphur minerals such as pyrite (FeS_2), chalcopyrite ($CuFeS_2$), and arsenopyrite (FeAsS). More specifically, the concentration process consists of the following steps:

1) After the ore has been crushed, an initial concentrate is prepared by flotation. The mineral grains are submerged in water containing certain chemicals. Because of a phenomenon involving electrical charges, the gold ore grains attach themselves to bubbles of air, which cause them to rise, and they are skimmed off the surface of the water.

2) The gold ore collected in the previous step is calcined at a temperature ranging from 400 to 750ºC. This step generates various atmospheric pollutants, including heavy metals, sulphates, and arsenic, if the ore contains arsenopyrite. Calcining produces a solid, porous residue called calcine.

3) Cyanidation of the gold is the final step in the concentration process. The calcine is transferred to a bath that usually contains sodium cyanide (NaCN). The cyanide ions penetrate the calcine and solubilize the gold. This is essentially an electrochemical process that separates the gold from the host rock in the presence of an oxidizing agent such as oxygen.

The gold is then concentrated and recovered from the dicyanoaurate ion $[Au(CN)_2^-]$ by absorption on activated carbon. Because of cyanide solution runoff, this process can be a source of water pollution; in addition, air pollution can result from the subsequent volatilization of cyanide ions.

Generally, the excavation hazards are similar to those in construction. Gold is found in hard rock, often at great depth, and in conjunction with arsenic. Accordingly, silica ("respirable quartz") is a prevalent concern, as a function of drilling, blasting, cutting rock in the extraction phase, and also crushing (in the milling phase). There may be a sharp geothermal gradient, with temperatures in deeper locations considerably higher than surface temperatures; the prevalent use of water (e.g., for dust suppression) may also compound heat stress. Other mines may operate in mountains, and the low atmospheric pressure may lead to altitude sickness. Noise and vibration exposures are prevalent.

Blasting results in the production of a variety of gases (largely NO_x, from the explosive) that are respiratory irritants, and miners are therefore not allowed into the area until an appropriate re-entry time has elapsed. Radon gas may permeate into the mineways from uranium-bearing host rock; it contributes to lung irradiation by "ionizing radiation" and increases lung cancer risk. Diesel particulate has gained much attention with respect to its potential to cause lung cancer and, as part of the more generic atmospheric $PM_{2.5}$ fraction, various other airway and cardiac diseases.

With respect to the use of cyanide, there is a comprehensive guideline, produced in South Africa, at: http://www.bullion.org.za/Departments/Enviroment/PDFs/Cyanide%20Guidelines%20new/SAGuidelineonCyanide.pdf

5.3.3 Air Pollution Produced by Mining Operations

The operations carried out in order to purify gold can produce atmospheric emissions of heavy metals, suspended particulates (including sulphates), and cyanides. (Details on the health effects of particulates and sulphates can be found in Appendix A; health effects of cyanides are described in section 5.3.4.3.)

5.3.4 Water Pollution

The mining industry in general consumes a considerable amount of water in order to process ore. In the case of gold mining, approximately 2.3 m^3 of water are used per tonne of crude ore processed. The pollutants that may be found in mining effluents include suspended solids and various heavy metals from the gangue. One type of pollution that is particularly harmful is acid mine drainage.

5.3.4.1 Acid Mine Drainage

Acid runoff generated by the mining of deposits containing sulphide minerals is the industry's most serious long-term environmental problem, and the gold sector is particularly affected. Exposure of sulphide minerals to air and humidity causes oxidation, which results in the formation of sulphuric acid, which can persist for hundreds of years. The process is accelerated by the presence of naturally occurring bacteria, which catalyse the reaction by oxidizing the iron sulphides and elemental sulphur. Microbial oxidation is 500 000 – 1 million times faster than open-air oxidation under similar environmental conditions. The bacteria involved belong to the genus *Thiobacillus*, which poses no risk to public health. Acid mine effluent is typically reddish-yellow in colour because of the high concentrations of ferric iron (Fe^{3+}).

Acid mine drainage is the result of a complex set of chemical and microbial reactions requiring the presence of oxygen. Microbial oxidation of elemental sulphur also produces sulphuric acid.

Highly acidic water solubilizes heavy metals (section 5.3.4.2). For example, although 30 tonnes of tailings may be dense enough to occupy only a small volume, they can release 20 tonnes of aluminum annually. Acidic water, with a pH ranging from 2.3 to 2.8, can attack infrastructures such as bridge piers and pipelines. Excessive acidity can disrupt aquatic life, eliminating many species of sensitive fish; salmonid populations are generally the first to be affected.

While acid mine drainage does not pose a direct risk to public health, solubilization of various heavy metals (aluminum, arsenic, cadmium, copper, lead, nickel, and zinc) enables them to find their way into streams and rivers. This, in turn, can cause problems in downstream areas, either because of the consumption of fish in which these metals have bioaccumulated or because drinking water is not treated in such a way as to eliminate these elements.

However, prevention of acid mine drainage is possible and relies on the following principles:

- Acidification is impossible in the absence of oxygen.
- Action must be taken quickly because, once the reaction begins, it is very difficult to stop.

The following preventive measures can be taken:

- Tailings can be covered with impermeable layers.
- Tailings can be covered with materials that consume oxygen (peat, wood chips, etc.).
- Tailings can be submerged under a deep layer of water to prevent oxygen diffusion.

5.3.4.2 Heavy Metals

As indicated above, effluents from gold mining operations may contain heavy metals. The *Metal Mining Liquid Effluent Regulations*, established under the federal *Fisheries Act*, set standards for the deposit of certain metals, including the following maximum authorized monthly mean concentrations (mg/L):

- arsenic, 0.5;
- copper, 0.3;
- nickel, 0.5;
- lead, 0.2; and
- zinc, 0.5.

It should be noted that these concentrations are for raw wastewater and far exceed allowable levels for drinking water. Box 5.2 contains more information on some of the metals that are of greatest concern from a public health point of view.

Box 5.2
Heavy Metals

Arsenic is a metalloid that bioaccumulates in algae, crustaceans, and fish. Chronic ingestion of arsenic leads initially to hyperkeratosis and the formation of "corns" (a type of keratosis) on the palms of the hands and the soles of the feet, with areas of hyperpigmentation (i.e., "black-foot" disease). Arsenic may also be carcinogenic. The proposed Canadian drinking water guideline (under consultation) for arsenic is 5 µg/L, the U.S. drinking water standard is to be 10 µg/L in 2006. WHO recommends a maximum concentration of 10 µg/L, based on the practical quantification limit and concerns regarding carcinogenicity. However, the main route of exposure for the Canadian population is through food consumption (80% of the total), with an average daily consumption of 0.2 µg/kg body weight. Ingestion rates may be greater in communities located close to emission sources.

Cadmium is a relatively toxic metal, with chronic poisoning affecting primarily the kidneys (at a concentration of 200 µg/g of tissue). Cadmium has also been associated with osteomalacia and hypertension. The carcinogenicity of cadmium is related to its inhalation, but not its ingestion. The Canadian drinking water guideline for cadmium is 5 µg/L.

Lead poses a greater risk to children than to adults; children are at higher risk of lead poisoning because their bodies absorb lead more easily than do adults. Lead poisoning is characterized by anemia as well as by problems related to the nervous and digestive systems. Chronic effects appear later: kidney failure, gout, and hypertension. Delayed growth and adverse neurobehavioural effects have been noted in children. The Canadian drinking water guideline for lead is 10 µg/L. However, a gold mine is unlikely to cause an increase in background levels of lead in water.

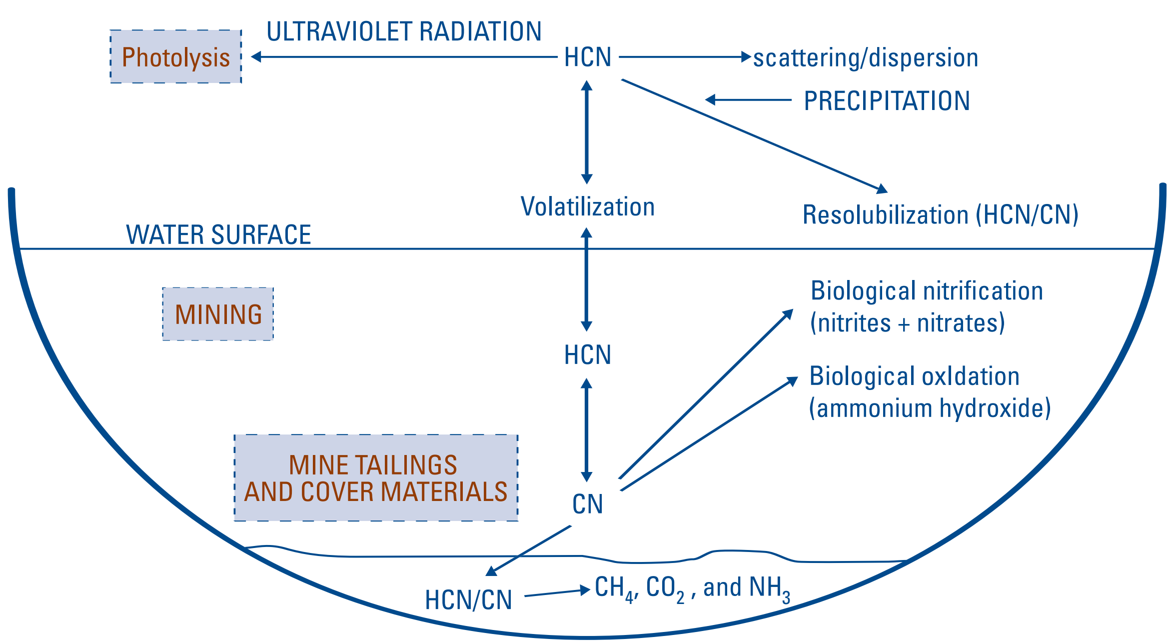
5.3.4.3 Cyanides

Cyanides include various types of inorganic and organic compounds that contain the CN radical, in which a carbon atom and a nitrogen atom are linked by a triple bond. Although most of the cyanide used in gold extraction is reused, wastewater may contain low residual amounts of this toxic substance. Depending on their physico-chemical properties, cyanides can be classified as free, simple, complex, or organic. In an aqueous environment, free cyanide refers to the total free anions (CN^-) in equilibrium with a molecular form – e.g., hydrocyanic acid or hydrogen cyanide (HCN) – with pH the determining factor in this equilibrium. Simple cyanides are compounds in which the CN^- radical is associated with a metal or non-metal; in water, these compounds readily break down to form the CN^- anion (free cyanide).

It is primarily the simple cyanide, NaCN, that is used in the extraction of gold, at a concentration of approximately 200 mg/L CN^- per gram of gold produced. However, the amounts of cyanide used can vary, depending upon the age of the mining operation and the type of ore being processed. Moreover, when mines are abandoned, considerable amounts of cyanide compounds are sometimes left behind. Quantities can be sufficient to potentially contaminate several dozen million litres of water; in some cases, cyanide concentrations of 26 mg/L have been identified in mining effluents.

The fate of cyanide in the environment is fairly complex, as demonstrated in Figure 5.1. The cyanide that is discharged into the water can be volatilized in the form of HCN, which can then be broken down by the ultraviolet rays of the sun in a process called photolysis. This degradation by sunlight is the basis of a treatment of choice that involves allowing the cyanide to break down in holding ponds with broad surface areas. In an aqueous environment, anaerobic bacteria can act on CN^- ions to produce methane, ammonia, nitrite, and nitrate. The cyanide ion can also be oxidized (aerobic reaction) or converted to HCN.

Figure 5.1
Fate of a Cyanide Ion



Cyanide toxicity is closely related to the form in which it occurs, with free cyanide being the most toxic. Of the simple compounds, the most toxic is hydrocyanic acid (HCN), which is the form that generally occurs at typical surface water pH levels. HCN penetrates an organism quickly and acts by attaching itself to ferric iron (Fe^{3+}), which plays an active role in several enzyme systems. Of the 40 human enzyme systems that can be deactivated by cyanide, the most important is the cytochrome oxidase complex, involved in the plasma transport of oxygen. With inhibition of this system, the generation of adenosine triphosphate (ATP) – essential to cellular energy metabolism – stops, and this produces the same pathological effect as a lack of oxygen in the blood. Cyanide acts quickly and can be fatal within a few minutes. Ingestion or inhalation initially causes headache, chest pain, and vomiting. Ingestion of a fatal dose is followed by respiratory difficulty, arrhythmia, and coma. It should be noted that cyanide poisoning is treatable with a kit containing various antidotes.

Box 5.3
Cyanide Toxicity

The presence of cyanide in mine wastewater is unlikely to be harmful to humans. However, given the high toxicity of this compound, its presence in water is always a matter of concern. For example, the LD_{50} (i.e., the dose that will result in the death of 50% of organisms tested) ranges from 0.03 to 0.15 mg/L for most freshwater fish, making cyanide a more powerful poison than mercury and all the heavy metals.

The tolerable daily intake (TDI) for humans is 0.012 mg/kg body weight (WHO, 1996) and the maximum acceptable concentration (MAC) in drinking water is 0.2 mg/L (Health Canada 1991). The airborne concentration normally tolerated in the workplace (i.e., the permissible exposure limit) is 5 mg/m^3 for free CN and 11 mg/m^3 for HCN (OSHA, 1997).

5.3.5 Mine Tailings

Mine waste consists of the following two types:

1) mine tailings, which consist of fine-grained mineral materials, sludges produced by ore treatment processes (i.e., concentration, flotation, and cyanidation), and slag generated by pyrometallurgical operations (calcination); and

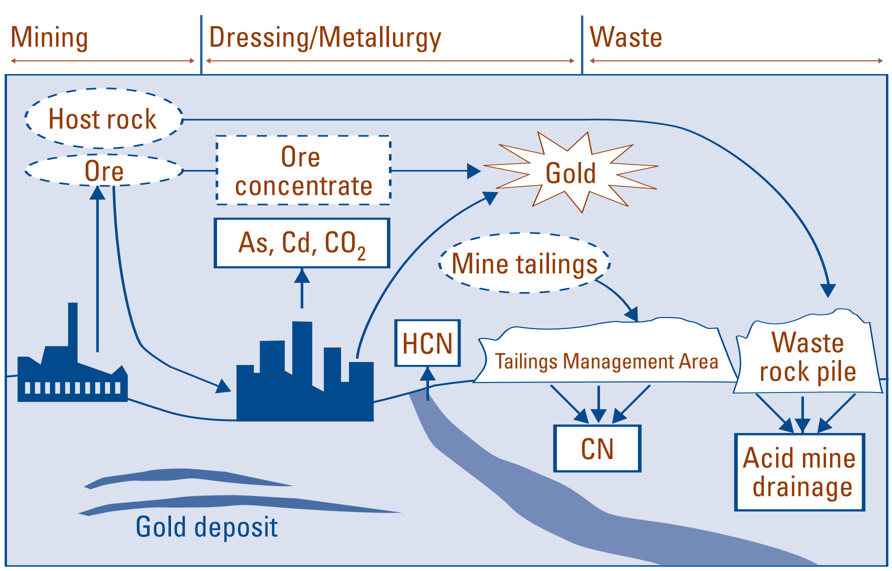
2) waste rock, which consists of the host rock (gangue) that is discarded in the preparation phase (i.e., crushing and grinding) and generally contains no commercially valuable ore.

In gold mining, 99% of the rock material removed from the ground consists of tailings and waste rock, normally stored in ponds that may cover several hectares or waste rock piles (hills) that can reach as much as 100 m in height.

Tailings facilities can be restored to an environmentally acceptable state by various methods. The fundamental approach is to contain and control drainage and to prevent contact with air. In the case of tailings facilities that have been abandoned for years, the strategy is to cover the waste with an impermeable layer of soil in which vegetation will be planted (replanting).

Figure 5.2 summarizes the activities involved in gold mining and the resulting atmospheric and water pollution.

Figure 5.2
Gold-mining Activities and Resulting Pollution



5.3.6 Nuisances and Psychosocial Impact

Public health issues associated with mining include the nuisance issues of dust in residential areas and aesthetic problems related to the presence of waste rock piles and tailings facilities. A potentially more serious health problem is that of noise caused by the operation of machinery or the movement of trucks. (See section 2.4.3 and Box 2.2 for details on noise definition, measurement, and WHO guidelines for acceptable levels of indoor and outdoor noise. The main problems that can be attributed to noise exposure are described in section 3.1.2.)

Among the mining impacts that can be referred to as “psychosocial,” some will be positive and others negative. Local job creation and the development of infrastructure (e.g., highways, schools, and health services) customarily translate into an increase in the quality of life of local residents. However, people residing in proximity to a mine site and to truck routes are likely to have their day-to-day lives disrupted and may see their property values decline.

The presence of a mine site and related infrastructure (particularly access routes and waste storage sites) detracts from the landscape and from the recreational and cultural use of the natural environment, which is normally a forest. In such a context, outfitters and Aboriginal communities may be negatively affected, as may trappers seeking small game.

Table 5.1a
Gold Mining: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations[1]
Technological Disaster	rupture of pond dams	water pollution by cyanides and heavy metals	mine and receiving watercourse	monitoring	CSA Z731-95, Emergency Planning for Industry
	collapse and flooding of tunnels			solidification of tunnels	
Gas Emissions or Emissions to Air	suspended particles	deposits on vegetation, aesthetics	site and perimeter	dust control on access roads to the site, vegetation cover on tailings	EQG, 24-h (CCME) in µg/m^3: 25 for PM_{10} and 15 for $PM_{2.5}$
	cyanides			change in processes	0.8 µg/kg U.S. body weight ADI (U.S. EPA)
	arsenic			change in processes	7.8 µg/m^3 (Health Canada, 1996)[2]
Liquid Emissions or Emissions to Water	cyanides	high toxicity to aquatic organisms (LD_{50}: 0.03-15 mg/L)	receiving water-courses and water bodies	retention pond (to promote degradation)	0.2 mg/L (MAC, Canada[3]); 20 µg/kg U.S. body weight ADI (EPA)
	heavy metals	variable toxicity to aquatic organisms	receiving water-courses and water bodies	treatment pond	MAC, Canada (mg/L): As, 0.025; Pb, 0.01[4]
	pH reduction (sulphuric acid)	toxicity to several aquatic organisms	receiving water-courses and water bodies	prevention of sulphide ore oxidation	objective in Canada: pH between 6.5 and 8.5 (drinking water)
Solid Emissions or Emissions to Soil	overburden	aesthetics (possibility of dust in the air)	site and perimeter	adequate storage	provincial standards if applicable
	waste rock and mine tailings	aesthetics (possibility of leaching cyanide and heavy metals)	site, perimeter, and vicinity	adequate storage; prevention of sul-phide ore oxidation	provincial standards if applicable
Nuisances	dust	health conditions, aes-thetics	site, perimeter, and vicinity	covering, dust control	provincial standards if applicable
	noise (mobile and fixed sources)	health conditions	site, perimeter, and vicinity	buffer zone, less noisy machinery	L_{eq} 55 dBA (day) and 45 dBA (night) in residential environment; 75 dBA in industrial environment (WHO)

[1] CSA = Canadian Standards Association; EQG = environmental quality quidelines; CCME = Canadian Council of Ministers of the Environment; L_{eq} = equilibrium sound pressure level.

[2] The concentration that results in a 5% increase in the incidence of tumours or in mortality caused by tumours.

[3] MAC = maximum acceptable concentration (taken from the Guidelines for Canadian Drinking Water Quality – see accompanying text for reference).

[4] Also see the accompanying text for the maximum values authorized under the *Metal Mining Liquid Effluent Regulations*.

Table 5.1b
Gold Mining: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	rupture of pond dams	see "cyanides" and "heavy metals"	riparian population (watercourses)	very rare	cyanide and heavy metal concentrations in the water
	collapse and flooding of tunnels	injury, death	workers	occasional	morbidity/mortality reports
Gas Emissions or Emissions to Air	suspended particles	various respiratory problems	workers, vicinity	rare to occasional	complaints, levels of atmospheric particulate matter
	cyanides	headaches, vomiting, arrhythmia, and coma	primarily workers	rare	monitoring of plasma concentration of cyanides
	arsenic	hyperkeratosis, possibly carcinogenic	primarily workers	rare	monitoring of plasma concentration of arsenic
Liquid Emissions or Emissions to Water	cyanides	weakness, headaches, tachycardia, coma, and possible death	consumers of contaminated water	very rare	monitoring of concentration of toxic elements in mine effluents and watercourses; levels of certain elements in risk groups (blood, urine)
	heavy metals	various toxic effects	consumers of contaminated water	very rare	pH monitoring of mine effluents
	pH reduction (sulphuric acid)	none	N/A	N/A	N/A
Solid Emissions or Emissions to Soil	overburden	none	N/A	N/A	N/A
	waste rock and mine tailings	see "cyanides" and "heavy metals" in water	vicinity and consumers of contaminated water	rare to occasional	levels of toxic elements
Nuisances	dust	hygiene, respiratory problems	vicinity and workers	rare to occasional	complaints
	noise (mobile and fixed sources)	sleep disturbance, stress, quality of life	vicinity and workers	occasional to frequent	complaints

5.4 Uranium Mining

5.4.1 Introduction

In Canada, the CANDU (**Can**adian **D**euterium **U**ranium) nuclear reactors use natural uranium that is bombarded with neutrons moderated by heavy water. The heat generated by the nuclear reactions is used to produce steam, which in turn drives turbines to generate electricity. As of 2001, there were 21 CANDU nuclear power reactors operating in Canada (see section 2.5). By comparison, worldwide in 1996, there were 442 nuclear power stations operating in 30 countries, with another

36 under construction. In 1999, the global electricity production from nuclear power generation in countries that are members of the OECD was 16%.

Assessing the environmental health impacts of nuclear electricity generation in Canada requires that impacts from each relevant part of the nuclear fuel cycle be considered. The stages in the nuclear fuel cycle include:

1) uranium exploration, mining, and milling;
2) nuclear power stations;
3) spent fuel storage; and
4) spent fuel disposal.

As discussed in section 2.5, the biophysical and socioeconomic health impacts of each of the various parts of the nuclear fuel cycle on both workers and the general public are caused to a greater or lesser degree by the same parameters and involve the same considerations. The biophysical components include the impact of radionuclides and heavy metals on the food chain by their release into the atmosphere, water, or ground; and consequential effects on fish, wildlife, vegetation, and country foods and, ultimately, on humans. In the case of external radiation exposure, the impact on humans is direct. Socioeconomic impacts include effects on public health and on the social fabric, Aboriginal/other cultures, and lifestyles; reduced business opportunities; boom-and-bust cycles and unemployment; and general stress factors associated with the dangers, perceived or real, from radioactivity.

The remainder of this section deals with the mining, milling, refining, and fuel fabrication stage of the nuclear fuel cycle and associated biophysical and socioeconomic impacts. (See also section 2.5, which addresses nuclear power generation and spent fuel storage and disposal.)

5.4.2 Mining, Milling, Refining, and Fuel Fabrication

In Canada, most ore deposits rich in uranium are currently found in northern Saskatchewan. The once rich northern Ontario veins in the Elliot Lake region are no longer prominent, their lodes having already been extensively mined and the facilities decommissioned. Whether or not mining is conducted in open pits or underground, there are environmental health hazards and impacts to workers and the general public that need to be considered. These include radiation hazards from radon gas, radium, thorium, and non-radioactive contamination from dust and heavy metals such as arsenic, lead, and nickel.

After uranium ore is mined, it is processed into yellowcake, a complex semirefined concentrate of uranium. This process takes place in specially equipped and designed mills that can be located at either the same mine site or a distant one. In some instances, milling facilities are shared by different companies operating different mines. External gamma radiation, tailings slurry, and wastewater are the main areas of health concern at this stage.

Refining of the yellowcake and nuclear fuel bundle fabrication are the final steps prior to irradiation of uranium in a CANDU nuclear reactor. Each fuel bundle is about the size of a fireplace log and consists of tubular zirconium alloy sheaths containing ceramic uranium oxide pellets. A typical bundle weighs about 24 kg, of which 19 kg is uranium. Each produces about 1 million kilowatt-hours of electricity, which is equivalent to about 400 tonnes of coal and is enough to heat 100 homes for a year.

The potential for health impacts from uranium mining does not differ much from those associated with other types of mining. Those that are common to both are not discussed in detail here, as they are described in other sections of this chapter. The aspect of uranium mining that separates it from other mining is the hazard to health caused by ionizing radiation from the uranium ore and radon gas and its progeny. Stage 1 health concerns revolve around the following biophysical (atmospheric, terrestrial, and aquatic) and socioeconomic impacts.

5.4.3 Biophysical Impacts

5.4.3.1 Atmospheric Impacts

The main atmospheric impacts from mining and milling are from the production of dust and radon. NO_x and SO_2 should also not be overlooked, although their impacts are expected to be minimal. Wastes from the chemically treated ore in the milling process are contained in tailings ponds near dikes and berms. Waste rock piles from mining are shielded by ground cover and, where necessary, by wetting, to control dust. Radon concentrations in the mines are reduced to acceptable levels by ventilation to the outside, where atmospheric dispersion quickly reduces concentrations to well below the maximum recommended levels for the general public. Regulations set by the CNSC are in place. These regulations specify the maximum allowable radiation levels for external gamma and radon daughter exposures for workers in the uranium mining and milling industries and for the general public.

5.4.3.2 Terrestrial Impacts

Open-pit mining, in which ore is mined from the surface layer by layer, has the most visual terrestrial impact. While there is little that can be done during the operational phase to rectify this, mitigation can be provided at decommissioning by in-filling with mine waste rock and subsequently covering the in-fill with either water or clean ground fill to restore the sites to an aesthetically pleasing state. The possibility of heavy metals and radioactive ore leaching into the surface and ground water is a concern along with the associated possibility of health impacts. These problems, along with the dangers posed by tailings, are addressed by ensuring that the mine site is sealed from the atmosphere by either ground fill or water. The chemically treated tailings and associated wastewater are retained in tailings ponds, to be released to adjacent rivers or lakes in controlled amounts. Appropriate dilution ensures that the pollution levels, from either radioactivity or heavy metals, are below allowable levels.

5.4.3.3 Aquatic Impacts

Surface water and ground water provide a primary pathway by which radioactivity and toxic heavy metal contaminants, such as lead, arsenic, nickel, and cadmium, can be leached under certain conditions, particularly from tailings. There is a serious possibility that the food chain can be contaminated unless appropriate mitigation is instituted. Fish, wildlife, vegetation, country foods, and drinking water are all at risk should spills or leakage occur. The need to manage the water from waste management areas is important, particularly if there are drinking water sources in the vicinity. It is necessary to ensure that relevant regulations and guidelines, such as the Guidelines for Canadian Drinking Water Quality of the Federal/Provincial/Territorial Committee on Environmental and Occupational Health and the *Metal Mining Liquid Effluent Regulations* of the Department of Fisheries and Oceans, are complied with. Wastewater treatment and tailings storage ponds are used to control any release of contaminated water into the local environment. Monitoring downstream on an ongoing basis is essential to confirm that levels of radioactivity and heavy metal concentrations are acceptable.

5.4.4 Human Health Concerns

Public concerns about non-radioactive metal contamination of the food chain and drinking water are common. However, the main concern is about radiation/radioactivity, because it is seen by many as an insidious contaminant that causes adverse health effects that do not manifest themselves until far into the future and that cannot be seen, smelled, heard, or touched. Significant excesses of lung cancers have been noted for uranium miners, and the risk of lung cancer mortality has been shown to be highly related to cumulative radon daughter exposures.

Box 5.4
Radiation Dose to Uranium Miners

Information in the National Dose Registry maintained by Health Canada showed that the average radiation dose to underground uranium miners in 1999 was 1.41 millisieverts (mSv), that to surface uranium miners, 0.15 mSv, and that to nuclear fuel processors, 2.40 mSv; these are compared with the regulatory occupational limit of 100 mSv over a 5-year period with a maximum of 50 mSv in any one year and the annual limit of 1 mSv for the general public.

5.4.5 Socioeconomic Impacts

In 1997, Canada accounted for about one third of the world production of uranium. At the present time, most of the mining and milling associated with uranium takes place in northern Saskatchewan. The potential impact on Aboriginal peoples and their distinct lifestyles is high, and exceptional arrangements are needed to allow, at least to some extent, for retention and continuation of the traditional Aboriginal ways of living. Serious attempts are made by the mining companies, not always with success, to employ Aboriginals in the mining and milling industries, with special allowances that attempt to meet their unique needs. An example is the introduction of a “seven-day in, seven-day out” cycle, which allows Aboriginal workers to return to their homes every other week. In this way, workers can frequently revert to traditional lifestyles, which in turn are protected from erosion. While all residents of local communities worry about environmental risks from waste rock and tailings and their long-term effects on human health, wildlife, vegetation, and water quality, this is of particular concern to the Aboriginal communities that have a special reliance on country foods, fish, and wildlife.

Concerns exist about the availability of financial resources to pay for decommissioning, radiation monitoring, and follow-up after the mining and milling projects have been completed, and it is felt that up-front financial guarantees are needed. The boom-and-bust mentality associated with mining contributes to continuing stress within the local communities, which worry about what will be left when the mining companies leave. Protection of communities and the people in them is as important as protection of biota. Members of the public, particularly northern residents, feel the need for local communities to be consulted on conceptual, operational, and final decommissioning plans. Since it is their descendants who will be faced with decommissioned sites, it is important that they be involved not only in developing plans, but also in implementing the decommissioning, reclamation, and post-decommissioning monitoring.

Table 5.2a
Uranium Mining: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations[1]
Technological Disaster	dike failure	water contamination by heavy metals and radioactivity	mine site, downstream and adjacent water bodies	physical inspection, water and tailings effluent monitoring	Health Canada drinking water guidelines (1996)
	water flooding	mine damage	mine	water pumping and drainage	*Metal Mining Liquid Effluent Regulations*
Gas Emissions or Emissions to Air	dust	vegetation and water contamination	wind dependent; several kilometres	wetting and ground cover	NAAQOs: 70 μg/m^3 - 1 year 120 μg/m^3 - 24 h
	radon gas			ventilation	
Liquid Emissions or Emissions to Water	heavy metals	toxic to vegetation, fish, wildlife, and water	mine site and downstream	monitoring, physical inspections of dikes and waste rock piles	Health Canada drinking water guidelines (1996)
	acid leachate			monitoring of pH levels in seepage water	*Metal Mining Liquid Effluent Regulations*
Solid Emissions or Emissions to Soil	heavy metals, radium, thorium	surface contamination	vicinity of dike failure	radioactivity monitoring; physical inspections	CCME guidelines
Nuisances	dust	discomfort	mine site and several kilometres	air monitoring	NAAQOs (see above)
	noise	quality of life, wildlife disturbance	transportation routes	monitoring and restricted to daylight hours	provincial guidelines
Indirect Impacts or Other Exposure	radiation	long-term health	mine site and vicinity	radiation protection monitoring	*Nuclear Safety Commission Act* Regulations

[1] NAAQO = national ambient air quality objectives.

Table 5.2b
Uranium Mining: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	dike failure	none or uncertain	workers and population downstream	infrequent	monitoring of water quality
	water flooding	severe injury or death	workers	rare	morbidity and mortality
Gas Emissions or Emissions to Air	dust radon gas	respiratory and lung cancer	workers and population in the vicinity	infrequent	air monitoring for dust and radioactivity
Liquid Emissions or Emissions to Water	heavy metals	toxic effects	people drinking water, eating fish	infrequent	monitoring downstream for heavy metals and pH levels
	acid leachate				
Solid Emissions or Emissions to Soil	heavy metals, radium, thorium	minimal	workers	infrequent	soil analyses
Nuisances	dust	respiratory	workers	chronic	dust sampling
	noise	minimal	people along transportation routes	periodic	public complaints
Indirect Impacts or Other Exposure	radiation	lung or other cancers	workers	low	radiation dosimetry for workers and the environment

Table 5.3
Uranium Mining: Matrix of Health Impacts: Determinants of Health and Quality of Life Component

Determinant	Impact	Area of Influence	Population Concerned	Probability of Occurrence	Control Measures	Health Effects
Socioeconomic Aspects						
Revenues	positive	regional	regional communities	high	average income per capita	positive
Employment – construction and operations	positive	regional	regional communities	high	unemployment numbers	positive
Public Infrastructure	marginal	local	local	low	traffic flow monitoring	none
Health Services	occasional	regional	regional communities	low	monitor usage	none
Education	neutral	local	regional communities	low	none	none
Social Fabric	positive and negative	regional	local and regional communities	high	crime statistics, charity contributions	negative
Lifestyles	positive and negative	local and regional	local and regional communities	high	monitor recreational activities	none or positive
Development of Healthy Children	uncertain	local	local communities	uncertain	population health monitoring	uncertain
Quality of Life						
Perception	positive and negative	regional and local	regional and local communities	high	periodic opinion surveys	marginal
Landscape	negative	regional and local	regional and local communities	high	in mine waste storage, land and water cover	negative
Recreational Use	positive	regional and local	regional and local communities	medium	activity and opinion surveys	positive
Cultural Activity	marginal	local	Aboriginal communities	medium	Aboriginal sites	negative

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Notes:

6 AGRICULTURE

Agriculture is one of the most important economic activities in Canada, but to a certain extent it is also harmful to the natural and human environment, particularly as a generator of non-point source pollution. However, in many ways, it is largely farmers and their families who are at risk through injury, allergies, and poisoning by various natural substances, such as pollen and dust, or synthetic substances, such as pesticides and veterinary drugs. This presents health officials with a unique occupational health challenge when dealing with this sector of the economy.

Overfertilization with synthetic fertilizers, local and regional overproduction of animal waste, and the recurring use of a wide variety of pesticides are among the riskiest activities for human health. The impacts of other phenomena, such as soil erosion or decreased soil organic matter, silting of waterways, and loss of biological diversity, are largely environmental in nature. However, although they undermine the recreational and aesthetic value of the environment, these phenomena can also have indirect health consequences. This chapter details two examples of activities that have been a cause of concern for Canadians for many years:

1) intensive livestock production (see section 6.2); and
2) heavy pesticide use (herbicides, insecticides, fungicides, and rodenticides) in fruit production (see section 6.3).

As indicated by NIOSH:

> "Agriculture ranks among the most hazardous industries. Farmers are at very high risk for fatal and nonfatal injuries. Farming is one of the few industries in which the families (who often share the work and live on the premises) are also at risk for fatal and nonfatal injuries."
>
> [Source: http://www.cdc.gov/niosh/injury/traumaagric.html]

[Note: A Canadian resource site for information on environmental and occupational health and safety related to agriculture is: http://www.fsai.on.ca/. Information topics include Strict Rules Apply to Pesticide Handling and Storage; Agricultural Mower Safety; Forklift Precautions; Harvesting Safety; Agricultural Machinery Hazards; For Safety's Sake, Take the Time to Train New Workers; Confined Space Entry in Agriculture; Combustion Fumes Harbour Silent Killer; Flowing Grain Entrapment; Rodents Carry Potentially Lethal Hanta Virus; Manure Gas Can Be a Killer; Dangers of Heat Stress; Prevent Tractor Overturns; Protect Yourself Against the Sun; Safe Lifting & Carrying Techniques; and Slips, Trips & Falls. (Many of these are available in several languages.)]

6.1 Canadian Socioeconomic Context

Despite its large size, only 11% of Canada's total area has agricultural potential, and less than 5% is truly suitable for agriculture. In 1996, when the last Canadian agricultural census was taken, farmland (cultivated and uncultivated) totalled slightly more than 65 million hectares. Most of this land is in Saskatchewan (approximately 26.5 million hectares) and Alberta (21 million hectares); these two provinces contain nearly 70% of the agricultural land in Canada.

Primary agriculture (which excludes the food bioprocessing and retail food sector) plays an important role in the Canadian economy, generating gross revenues of $28.7 billion in 1997. The agri-food sector as a whole (from gate to plate) employs 1.9 million people (13% of all Canadian jobs) and represents 9% of the GDP. Canada is a net exporter of agricultural products: in 1997, the value of primary agricultural exports was $10.6 billion and that of processed product exports (foods and beverages) was $10.9 billion. The main agricultural sectors are meat (cattle and swine) and grains and oilseeds (wheat, barley, flax, rapeseed, soybeans, and corn).

Over the past few decades, various factors have been transforming Canadian agriculture. The number of farm operations has decreased steadily, from slightly more than 700 000 in 1941 to 276 500 in 1996. At the same time, the size of farms has increased (average area of approximately 50 ha in 1941, as compared with 250 ha in 1991). Moreover, income distribution among farmers is very uneven. In 1996, the average net cash income was $20 100, but the median value was only $4200, proof of a wide gap between the most profitable farms and those with the lowest incomes. In fact, only 25% of farms surveyed in the census reported a net cash income of more than $28 500. In 1996, the sector with the highest median net cash income was the dairy products sector (median of $41 000), followed by swine production (median of $21 000) and wheat growing (median of $14 000). (It should be noted that farming has high capitalization requirements: land, buildings, machinery, animals, food, and various products such as pesticides, which reduce gross income considerably, often leading to a low net income, as indicated here.)

The drop in the number of farms, the increase in the amount of cultivated land, and, most importantly, the phenomenon of specialization have given rise to major changes that have led to the industrialization of agriculture. These changes have resulted in the appearance of many environmental problems since the late 1950s, due to mechanization and the use of fertilizers and pesticides. During the 1980s, agriculture joined industry and urban growth as one of the three economic activities that most adversely affect all elements of the environment (air, water, and soil).

6.2 Hog Production

Among all the animal production sectors, hog farming, given its constant growth since the 1970s and its expansion in many rural and even near-urban areas, is often publicly perceived as one of the most polluting agricultural activities. With the rise of this industry, environmental problems and perceived health risks have increased to the point where confrontations have occurred in several municipalities.

6.2.1 Economic Overview

With farm income of more than $2 billion (in Canada) in 1998, the hog industry represents nearly 30% of income from animal production and 10% of all income for Canadian agricultural producers and helps to maintain a positive balance in Canadian agricultural exports. With the second-highest median income after dairy farming, hog production is a lucrative activity that is increasingly valued and popular among farmers.

It was in Quebec, in the late 1970s, that hog farming experienced its first industrial boom. In 1961, there were slightly over 1 million hogs (1.114 million) in Quebec, and this number remained relatively stable for 17 years. Very strong growth occurred in the mid-1970s, when the number of hogs rose from 1.076 million in 1977 to 1.8 million in 1978, and then to 2.8 million in 1979. The number of animals totalled over 3 million in 1980 and peaked in 1983 at 3.1 million. This increase was sparked by sustained economic growth and the introduction of government financial incentives. [Note: The figures cited here represent the number of live animals on a given date, ordinarily July 1. This number is lower than the actual number of animals slaughtered in one year because the animals are slaughtered six months after birth. This means that without a net increase in production, the number of hogs being raised at any time is always the same throughout the year, because one pig-space is occupied by about two animals during one calendar year.]

Box 6.1
Recent Statistics on Hog Production

With the recession in the early 1980s and a drop in demand, the number of hogs remained stable until 1990 (i.e., 3 million hogs). New growth began in 1991, but it was much weaker than the growth during the 1977-1983 period. This second phase of expansion in Quebec was accompanied by a phase of Canada-wide expansion, particularly in Ontario, Alberta, and Manitoba. Hog farming in Canada grew by 23% between 1991 and 1998; in 2000, the number of hogs on Canadian farms was slightly over 12 million.

On July 1, 2000, Quebec had the largest number of hogs (3.74 million), followed by Ontario (3.25 million), Manitoba (1.86 million), and Alberta (1.76 million). Between 1991 and 1998, the areas where production increased the most were southern Alberta (along a line from Red Deer to the U.S. border, via Lethbridge); southern Manitoba (from north of Winnipeg to the U.S. border); southwestern Ontario (in a triangle formed by Sarnia, London, and Windsor); and three Quebec regions, including part of Montérégie (south and east of Montreal, in the St-Hyacinthe and Granby area), the Chaudière-Appalaches region (south of Quebec City, along the Chaudière river), and the Trois-Rivières region. Canada is now home to a record number of large-scale hog farms, with the average number of hogs per breeding unit having risen from 330 in 1988 to 680 in 1998. At the same time, the number of operations reporting hog farming was 18 500 at the end of 1998, down 45% from 33 400 in 1988.

[Note: The estimated number of hogs varies from one source to another. The figures used here are taken from the data published on the Internet by Statistics Canada, which are obtained from the 9500-9510 basic matrices from CANSIM (Statistics Canada on-line database) and Catalogue No. 23-603-XPF. These data do not necessarily agree with data from other sources.]

6.2.2 Types of Operations

In Canada, the majority of hogs are raised in a controlled environment, meaning that they are kept in specialized buildings (hog houses) at all times of the year for birthing, growth, and fattening. The most popular production unit is the farrow-to-finish operation, with between 200 and 240 sows and up to 2000 feeder pigs raised for slaughter. The feeder pigs come onto the market at the age of 180 days, when their weight is between 100 and 105 kg. The farrow-to-finish format significantly reduces productivity losses associated with stress caused by moving, adaptation to a new environment, dietary changes, and disease transmission. This type of unit can be operated like a family farm because it requires little labour. However, it cannot be described as a family farm in the traditional sense of the term. Large hog houses such as these are considered industrial operations; they could easily be located in industrial parks, were it not for the need to spread the slurry, which is seen as having very little economic value, on farmland near the production facilities in order to minimize the cost of transporting this liquid. [Note: Slurry includes all waste with a water content greater than 85-90% and is liquid in form. Otherwise, animal waste is called manure. Manure effluent, not to be confused with slurry, is the liquid flowing from stored manure.]

6.2.3 Pollution Caused by Pig Waste

Liquid management systems for pig waste involve the mixing of solid manure with urine, without the addition of bedding material such as sawdust, straw, or peat. The use of these systems creates slurry that is more harmful to the environment than manure because, as a liquid, it finds its way into the environment more easily. For example, 1 million hogs produce just over 2 million cubic metres of waste annually, and the liquid management system creates a total of 2.5 million cubic metres of manure to process.

Pig waste contains high concentrations of microorganisms, some of which can cause diseases in humans. This waste is also laden with mineral nutrients (nitrogen, phosphorus, potassium, etc.) and various organic materials. Nitrogen and phosphorus compounds are nutrients that foster the growth of algae and other aquatic plants, while the organic material present in the waste consumes a considerable quantity of the dissolved oxygen in water. Liquid management of animal waste is the method that is most harmful to the environment and most likely to produce foul odours.

Box 6.2
Nutrient Content of Pig Slurry

The total concentration of nitrogen in pig slurry can reach 3500 mg/L, and that of phosphorus can reach 2500 mg/L. This high nutrient content can be largely explained by the fact that up to 70% of the nitrogen in animal feed (mainly grains) can be lost through wastage or because of incomplete digestion. A feeder pig excretes about 24 g of nitrogen per day (in inorganic and organic form) and 7 g of phosphorus, as compared with 10 g and 2 g, respectively, in the case of humans. [This is a mathematical average, and the values can vary for each class of feeder pig (20-42 kg, 42-70 kg, etc.).] To obtain a clearer picture of such a pollution load, consider that 1 million people produce approximately 1000 kg of nitrogen daily, whereas 1 million pigs generate approximately 2400 kg of nitrogen daily.

6.2.4 Types of Pollution and Health Risks

6.2.4.1 Air Pollutants

It has been clearly shown that adverse health effects result from exposure to various air pollutants generated by hog houses. The specific pollutants of concern are ammonia, particulates, and bacterial endotoxins. The people most at risk are those who work inside the livestock buildings and are in direct contact with the animals. Air pollutants can be divided into three categories:

1) gases (including odours);

2) non-biological and abiotic aerosols; and

3) bioaerosols.

A number of viable microorganisms can also be transported by air; this phenomenon is discussed later in this section.

Box 6.3
Hog House Gases

The main gases of interest in terms of public health are ammonia (NH_3), hydrogen sulphide (H_2S), and, to a lesser degree, CO and CH_4. The concentration of NH_3 inside a hog house can range from 1.5 mg/m^3 to more than 30 mg/m^3; the exposure limit is set between 25 mg/m^3 (OSHA) and 50 mg/m^3 (NIOSH). Ammonia irritates the upper respiratory tract, eyes, skin, and mucous membranes. Concentrations of H_2S reported inside hog houses range from non-detectable to 1.4 ppm; workplace exposure limits are set between 5 and 20 ppm (depending on the exposure time and the regulatory body). In excessive concentrations, H_2S may irritate the eyes and respiratory tract. Poisoning may also be caused by manure gases, mainly during cleaning of manure gutters, normally located below the livestock building. Usually, H_2S is the gas responsible for these poisonings because it can reach high concentrations in closed environments. CH_4 and NH_3 can also reach lethal concentrations in manure gutters or other closed environments. Half of all cases of severe manure gas poisoning are fatal, and a few farm workers in Canada die from such poisoning each year.

Odours

The number of complaints about odours from animal production operations has increased sharply since the 1970s, mainly because of the transition from solid (manure) to liquid (slurry) waste management. As a result, in 1995, odours from buildings and slurry storage facilities were 5.2 times stronger than they were in 1961; and odours from spreading activities were 8.2 times stronger than in 1961.

Odours linked to hog production can be released by over 75 different compounds. Manure is clearly the main source of odour-causing compounds, which result from the activity of intestinal microbes and subsequent anaerobic fermentation of waste in the environment. The odour-causing substances are:

- organic acids (butyric acid, hexanoic acid, lauric acid, etc.);
- phenols (such as cresols);
- nitrogen compounds (ammonia, indole, and various substances with an NH_2 amino function); and
- sulphur compounds such as methyl mercaptan and dimethylsulphide.

Almost all of these odour-causing compounds are adsorbed on suspended particulates (dust) smaller than 10 microns (μm) in diameter (PM_{10}). Research in this field has clearly established that the critical factors in the spread of odours are the size and concentration of the particulates.

Stored slurry produces little odour, but as soon as it is disturbed, volatile compounds are released. Therefore, the strongest odours are produced when the slurry is taken from the tank, transported, and spread. Spreading is a major source of odour nuisance, mainly because a great deal of spreading equipment sprays the slurry from a few metres above the ground, which allows odours to spread via aerosols. Spreaders that do not disperse and spray the slurry are now recommended; with some systems, it is possible to spread the slurry very close to the ground, and even to mix it with the soil using coulters. As for odours emitted from the animal buildings, it is suggested that:

- the animals' diet be modified;
- the air undergo biological filtration before being released; and
- deodorizers be used, if necessary.

New production techniques, such as the use of biocontrolled bedding, are also suggested. This technique involves raising the animals on approximately 70 cm of bedding in which microorganisms are activated so that waste is composted in the bedding itself. This results in less odour production and destroys pathogenic microorganisms.

Abiotic Aerosols

This group includes particulate matter from food, hair, dried feces, and cells from animal skin. Health effects depend on the size of the particulates – whether they are inhalable or respirable and, if so, how far they can penetrate the respiratory tract. It has been shown that exposure to overly high concentrations of particulates can cause lung inflammation and that chronic exposure leads to bronchitis and asthma.

Bioaerosols

A bioaerosol is a suspension of non-viable microbial cells with which endotoxins can be associated. Endotoxins are cell wall components of Gram-negative bacteria, including an allergenic lipopolysaccharide fraction. Endotoxins are inherently toxic and can lead to various problems, but this occurs mainly when they are present in very high concentrations or when the microorganisms that produce them are viable. Like odours, endotoxins are carried mostly by airborne particles. Bioaerosols from hog houses mainly contain Gram-positive bacteria, and the genus *Enterococcus* accounts for between 70% and 90% of the group. However, the portion of fragments or viable Gram-negative bacteria adsorbed on the particles, and therefore likely to be a health risk, represents a significant 12-40% of bioaerosols.

Box 6.4
Health Risks from Exposure to Air Pollutants

Agricultural workers in animal buildings face the highest risk of developing various health problems caused by exposure to air pollutants. A variety of symptoms are associated with this type of exposure. The symptoms observed most often following short-term exposure are coughing, nasal congestion, headache, muscle ache, fatigue, nausea, and eye and throat irritation.

As previously mentioned, chronic bronchitis and asthma are the clinical results of long-term exposure.

People, other than agricultural workers, who live near hog farms suffer mainly the effects of odours. In this situation, it has been proven that certain odour-causing molecules can cause actual physical problems, such as eye, nose, and throat irritation. Studies have revealed the occurrence of respiratory effects (inflammation of the bronchi and bronchioles), nausea, dizziness, headache, and nasal discharge. These reactions may cause changes in respiratory volume and in inflammatory responses. The psychosocial impact of odours must also be considered, as various physical health problems may develop as a result of psychological distress (this issue is addressed in more detail later in this section).

6.2.4.2 Water Pollutants

Inadequate storage, leaking storage pits, and overfertilization with slurry can contaminate ground water and surface water with organic matter, nutrients, and infectious microorganisms.

Organic Matter

In rural and semirural regions, intensive livestock production is known to constitute an important source of water pollution via organic matter, which contaminates mainly surface water, since ground water is less vulnerable. Organic matter causes an oxygen deficiency in surface water (expressed in terms of dissolved oxygen or BOD). Such a deficiency is harmful to aquatic life and can result in the death of fish. The BOD of slurry is very high; at 40 000 mg/L, it is more than 250 times higher than that of typical urban wastewater.

The presence of excess organic matter in water is problematic for the production of drinking water. Organic carbon reacts with the chlorine used to treat water, and the more organic carbon in raw water, the more chlorine will be used for disinfection. Often, the result is less effective disinfection, which leads to microbial contamination problems. In addition, chlorine and organic matter react to form by-products, particularly trihalomethanes (THMs) such as chloroform, which have carcinogenic potential.

Nutrients

As indicated in section 6.2.3, animal waste is a major source of nutrients, with both surface water and ground water at risk of contamination. In the environment, nitrogen compounds can be poisonous to both fish and humans. The presence of excess nitrogen in the form of nitrates and nitrites in ground water can cause methemoglobinemia in newborn babies, particularly when synthetic fertilizers are used in addition to slurry and manure; however, this disease is extremely rare.

Phosphorus is the main cause of eutrophication of lakes and rivers. For a number of years, the phosphorus content of agricultural soils has been rising due to overfertilization resulting from the combined use of waste and synthetic fertilizers in concentrations that exceed crop needs. Because of its low solubility, the recirculation of accumulated phosphorus is a gradual and relatively slow process (around 25 years), posing a significant potential pollution problem in the medium term, even if agricultural inputs were to stop immediately. The most serious effect of the presence of phosphorus in an aquatic environment is excessive plant and algae growth; dissolved oxygen levels are lower following the decomposition of plants, which causes microbial proliferation and, in the most severe cases, leads to the death of fish. The risks to human health stem mainly from the proliferation of certain species of cyanobacteria (blue-green algae) that secrete toxins, particularly microcystins, which are believed to have a carcinogenic effect (specifically, they are thought to promote the growth and development of tumours, rather than to initiate them).

Box 6.5
Overall Health Risks from Water Pollution

Unlike air pollution, water pollution can be dangerous not only to the people who work with livestock, but to the entire local or regional population. The presence of THMs or cyanobacterial toxins in drinking water and the risk of methemoglobinemia pose the biggest threats to people whose water supply is in a contaminated agricultural zone. Pathogenic microorganisms are an additional danger (see section 6.2.4.3). In this context, water pollution caused by waste is first and foremost a public health concern.

6.2.4.3 Infectious Agents

Infectious microorganisms from livestock and livestock waste may be spread by air or water, and some (particularly zoonoses) require direct contact with livestock. Certain groups, or genera, are preferentially spread by one means or another, or by a combination of methods. The following information deals with certain groups of microorganisms that are present in hogs and are of significance to the health of agricultural workers and the general population.

Erysipelothrix rhusiopathiae can cause skin infections (most commonly), acute internal infections (septicemia), or chronic internal infections. Erysipeloid (skin form) is a benign disease that occurs fairly often in hog farm workers. This infection is characterized by a painful skin lesion with a raised edge. The bacterium is present in a number of animal organs and tissues, but is normally absent from muscles. The infections caused by this bacterium are recognized as occupational diseases affecting hog industry workers, particularly those who work in slaughterhouses. Although this bacterium can survive in the natural environment, it has not been shown to present a risk to the population.

A number of species of *Leptospira* can cause human infections, most of which are associated with a specific group of livestock. Contact with hogs, a significant reservoir of infection, can lead to Weil's syndrome (due to *Leptospira icterohaemorrhagiae*). As in the case of *E. rhusiopathiae*, the highest risk is faced by workers in the meat processing industry, including farm workers in contact with livestock. The public health risk is mainly associated with sports involving direct contact with water (swimming, rafting, water-skiing, etc.), but the magnitude of the risk is unknown.

Salmonellosis infections can come from many sources of pollution, including livestock farming. The strains in question here are only those that cause gastroenteritis, since typhoid fever cannot be spread by livestock. Hogs are known to be reservoirs of *Salmonella*, with the prevalence of the bacterium in their waste reaching up to 30%, with a survival time of over a month. Since hogs are often healthy carriers, it is impossible to know without conducting screening tests whether they are contaminated. Agricultural workers are at risk for contamination by hogs or their waste; the risk to the general population is not known, but it is likely to be limited.

Streptococcus suis can cause severe systemic illness in the form of meningitis, pneumonia, endocarditis, or arthritis. In a number of countries, adult meningitis caused by these bacteria is recognized as an occupational illness in workers in the hog industry, whether they are involved in the production stage or with handling carcasses. Cases have been reported in Asia, northern Europe, Canada, and New Zealand. Only 1 of the 30 known serotypes of *S. suis* is responsible for these cases of meningitis. This disease is not currently considered a risk to public health.

Yersinia enterocolitica includes swine and human strains that are difficult to distinguish from each other. Of all livestock, hogs are the most significant reservoir of *Y. enterocolitica*. Infection produces gastroenteritis and occasionally triggers pseudo-appendicitis, mainly in adolescents. This bacterium is present in a number of hog organs and tissues, as well as in waste. Although yersiniosis is mainly considered a food-borne infection, some specialists believe that it should also be seen as an occupational disease, despite the lack of cases demonstrating direct transmission from hogs to humans. However, epidemiological data (see Volume 3, Chapter 6, for an explanation on epidemiology) show much higher seroprevalence in hog industry workers. The risk of contamination of the unexposed population via the environment seems minimal.

The influenza virus is known as a microorganism that can cross the interspecies barrier, specifically between hogs and humans. In fact, hogs act as an intermediary between humans and wild ducks as well as domestic fowl, the two groups that constitute the most significant reservoir of all the strains of this virus. The genetic reassortment that enables the virus to jump the species barrier occurs in birds and hogs. Although hogs are often involved in the transmission of new virus strains to humans, this occurs mainly under relatively unhealthy conditions where there is a high degree of contact between livestock and humans.

Box 6.6
Summary of Human Health Risks from Infectious Agents

Constant exposure to the air inside a hog house can lead to several acute and chronic respiratory problems for people who work in this environment because the air in hog houses is 1200 times more laden with microorganisms than is ambient air. Hog house air contains greater numbers (10^5-$10^7/m^3$) of Gram-positive bacteria such as *Staphylococcus* sp., *Micrococcus* sp., and *Bacillus* sp. However, respiratory problems seem more closely connected with Gram-negative bacteria such as *Acinetobacter calcoaceticus*, *Flavobacterium* sp., *Pseudomonas* sp., and *Serratia marcescens*, mainly because of their endotoxins. The presence of mould in the air is also responsible for health problems such as organic dust toxic syndrome and, more rarely, extrinsic allergic alveolitis, or farmer's lung, the main causal agent of which is *Saccharopolyspora rectivirgula* (formerly *Micropolyspora faeni*).

With respect to public health, concentrations of bacteria in ambient air 300 m from a hog house were observed to be 4-10 times less than concentrations measured 5 m from the building. Beyond 300 m, the concentration would quickly become almost nil. Under such circumstances, the risk to public health of transmission of microorganisms by air is fairly limited, mainly affecting those whose homes or living environments are within 300 m of the hog house, i.e., usually the family that owns the farm and their visitors.

Contamination of water by pathogenic microorganisms could pose certain risks in the case of consumption of untreated ground water (e.g., water from a private well). The concentration of microorganisms in slurry is high, usually ranging between 10 million and 100 million per millilitre. The main risk to human health as a result of the presence of pathogens from hog slurry in water is bacterial enteritis caused by *Campylobacter* sp., *Salmonella* sp., and *Yersinia enterocolitica*. Slurry may also be the source of other bacteria, such as *Escherichia coli* (particularly those in the enterohemorrhagic subgroup), parasites such as *Cryptosporidium* sp., and viruses.

6.2.4.4 Psychosocial Impact

The development of large-scale hog operations and extensive spreading of pig slurry lead to social problems, mainly because of the offensive odours that affect the quality of life of residents in the surrounding areas. A study conducted in Quebec in 1992-93 as part of a broad investigation into psychological distress related to high-density hog farming revealed a significant increase in such distress, with the proportion of people affected rising from 20.8% during the fall/winter to 34.3% during the spring/summer period in municipalities with high-density hog production (20 000 hogs and more). However, the authors caution that they cannot establish a causal relationship between hog operations and psychological distress on the basis of these results. They do consider the hypothesis serious enough to warrant further analysis of the data or, preferably, a specific study on this issue (Pampalon and Légaré, 1997).

The difficulty in establishing a causal relationship stems from the fact that some studies, particularly in the United States, have not shown significant differences in symptoms such as anxiety and depression between groups of people living near hog farms and people in control groups. One fact that seems certain is the harmful effect that proximity to hog farms has on the quality of life, with several residents reporting that during times when foul odours are particularly strong, they limit their outdoor activities and do not open their windows. In addition to these observations, it should be pointed out that conflict can develop within a community between the proponent of a proposed hog operation (and its supporters) and the project's opponents. Lengthy debates in municipal councils, as well as verbal and physical violence, have been reported in such situations.

Table 6.1a
Hog Production: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations
Technological Disaster	fire, explosion	deposits, smoke, destruction	site and perimeter	covering, collection	
	failure of slurry pit	soil and water pollution	site, perimeter, and vicinity	sealing off, repair	installation of inspection windows
	inhalation of heavy sulphurous gases in the holding tank	N/A	site	avoid going down into the holding tank without breathing equipment	
Gas Emissions or Emissions to Air	CH_4, NH_3, H_2S	greenhouse effect	global	collection	CH_4: none NH_3: 25-50 ppm (OSHA, NIOSH) H_2S: 10-20 ppm
	viruses, bacteria, and endotoxins	pollution	site	hog farming methods and ventilation	none
	mould and actinomycetes	contamination of air inside buildings	site		none
Liquid Emissions or Emissions to Water	nutrients (nitrogen, phosphorus)	eutrophication, algal growth (see below)	vicinity and community	leak-proof slurry pit, buffer zone during spreading	NO_3: 45 mg/L; NO_2: 3.2 mg/L (Health Canada); phosphorus: no standard
	organic compounds	increased BOD, oxygen deficiency of aquatic environment, formation of THMs	receiving water	same as above plus raising hogs on biocontrolled litter	THMs: 0.1 mg/L (Health Canada)
	suspended solids	pollution, health conditions	receiving water	same as above	*Fisheries Act* (Canada); applicable provincial/territorial statutes
	microorganisms: *Salmonella* spp., *Campylobacter* spp., *Yersinia enterocolitica*, *Escherichia coli*, *Cryptosporidium* spp.	pollution, health conditions	receiving water	same as above plus raising hogs on biocontrolled litter	fecal coli: 0; total coliforms: 10/100 mL
	microalgae: *Microcystis*	pollution, health conditions	water receiving nutrients (nitrogen and phosphorus)	activated charcoal and ozonation for drinking water	microcystin-LR: 1.5 µg/L (Health Canada)
Solid Emissions or Emissions to Soil	see "emissions to water" section	pollution	local and regional	avoid overfertilization with liquid manure	none, except agricultural regulations on spreading solid and liquid manure
Nuisances	odours	health conditions	vicinity and community	buffer zone; biofiltration of building air; aeration of slurry; hog farming methods	municipal by-laws; departmental directives concerning odours in agricultural environments

Table 6.1b
Hog Production: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	fire, explosion	respiratory irritation, burns, death	workers	rare	reports on fires, morbidity, mortality
	failure of slurry pit	unhealthy conditions	vicinity	rare to occasional	reports by environmental monitoring organizations
	inhalation of heavy sulphurous gases in the holding tank	poisoning, death	workers	rare	detection of heavy gases in holding tank, coroner's inquest or police inquiry
Gas Emissions or Emissions to Air	CH_4, NH_3, H_2S	climate change	global	frequent	air emissions of CH_4, NH_3 and H_2S
	viruses, bacteria, and endotoxins	various respiratory problems	primarily workers	frequent	presence of Gram-negative bacteria in hog house air
	mould and actinomycetes	allergic alveolitis	primarily workers	rare to occasional	presence of mould spores and actinomycetes
Liquid Emissions or Emissions to Water	nutrients (nitrogen, phosphorus)	methemoglobinemia if nitrogen concentration too high	consumers (especially infants) of polluted ground water	very rare	overt symptoms: respiratory problems, cyanosis, etc.
	organic compounds	unhealthy conditions plus possible formation of carcinogenic THMs: bladder, colon	consumers and users of polluted water	frequent	BOD of surface water, THM levels in drinking water
	suspended solids	unhealthy conditions	users of polluted water	unknown	suspended solid levels in water
	microorganisms: *Salmonella* spp., *Campylobacter* spp., *Yersinia enterocolitica*, *Escherichia coli*, *Cryptosporidium* spp.	gastroenteritis, mucosal and skin/erysipeloid infections, meningitis (*Streptococcus suis*)	consumers and users of polluted water	frequent	list of indicator/pathogenic microorganisms
				rare to occasional	gastroenteritis monitoring
	microalgae: *Microcystis*	hepatic toxicity, potential tumour-causing effect	farm workers	occasional	microalgae detection and microcystin levels in water
			consumers of polluted water	unknown	
Solid Emissions or Emissions to Soil	see "emissions to water" section	see section above	farm workers and nearby population	unknown	nitrogen and phosphorus concentrations in soil (long-term indicator)
Nuisances	odours	stress, psychological problems, insomnia, and nausea in extreme cases	vicinity and community	occasional to very frequent	volatile fatty acids, sulphur compounds; complaints, perception studies

6.3 Pesticide Use in Apple Production

In addition to animal production, the use of pesticides is an agricultural activity that is highly harmful to the environment; it is also a source of much concern for residents. Although pesticides are used on a wide variety of crops, apple growing has been chosen for discussion here because it leads all other crop productions in terms of the unit areas involved, the number of sprayings per season, and the variety of pesticides used. This section uses data gathered in Quebec as an example, mainly because the amounts of pesticides used for all sectors, including apple growing, are known, and a major study on the effect of pesticide drift on human health was conducted in that province in the late 1990s. Despite the regional nature of the example chosen, we believe it is possible, to a certain extent, to extrapolate to orchards in other provinces and to other Canadian fruit crops, such as plums and peaches.

6.3.1 General Information on Pesticides

Agricultural industrialization has led to a greater use of synthetic pesticides of all kinds. With farms engaging in monoculture over extensive areas, it became necessary to use pesticides to protect crops against insects and fungi and also to control competing vegetation whose growth rate is usually greater than that of planted crops. The reason for such an extensive use of pesticides is that, on a global scale, agricultural products are threatened by some 8000 fungal species, 10 000 insect species, and 2000 weed species.

Hundreds of active ingredients can be used as herbicides, insecticides, fungicides, and rodenticides. The active ingredient (e.g., malathion, atrazine, captan, etc.) is the chemical substance in a pure state used in the formulation of a pesticide. The concentration of the active ingredient can be as low as 1%, while the rest of the formulation is composed of inert materials or substances to assist in dispersion or environmental release of the active ingredient or to improve its ability to penetrate insects or plants. In the case of liquid pesticides, mineral oils are often used as adjuvants to stimulate the action of the active ingredient. Statistical data on pesticides usually refer to the amount of active ingredients used or sold, without taking into account the adjuvants, which can also be toxic.

In the 19th and early 20th centuries, mostly inorganic substances were used, including copper sulphate, arsenic salts, and mineral oils, whose toxicity could have a devastating effect both on the targeted organisms and on humans. DDT made its appearance following the Second World War. It is an organochlorine insecticide that was to become famous for its efficiency, as well as its toxicity and persistence in the environment. The use of pesticides in industrialized nations increased steadily from 1945 until the early 1990s. Over the past several years, there has been a levelling off of and perhaps even a slight decrease in the agricultural use of these substances in a number of developed countries.

The only data compiled on pesticide use were made public by the Canadian Parliament's Standing Committee on Environment and Sustainable Development in 2000. According to these data, 7000 pesticides (commercial products, several of which contain the same active ingredients) are registered in Canada. In 1997, pesticide sales totalled slightly over $1.25 billion; herbicides accounted for 85% of this amount and insecticides only 4%. Sales are concentrated in the provinces of Saskatchewan (36%), Alberta and British Columbia (24% combined), Manitoba (18%), and Ontario (16%). The majority of pesticides sold (91% of sales) are used in agriculture. However, because no national databank exists, no data are available on the total volume used in Canada.

In Quebec, over 3.4 million kilograms of active pesticide ingredients were sold in 1997, representing a drop of 10% since 1992. Herbicides are the most widely sold pesticides, accounting for 59% of the market, followed by insecticides (16%) and fungicides (10%). In terms of chemical groups, carbamates (insecticides and fungicides) are the most widely sold (14% of the market), followed closely by herbicides from the following groups: amides, acetamides, and anilines (14%); triazines and triazoles (11.8%); and aryloxy acids (10.9%; this is the group that includes 2,4-D).

In Quebec, farm operators purchase slightly over 78% of all pesticides sold, followed by the household sector (11%). Industrial, forestry, and landscaping applications each represent less than 5% of the market.

6.3.2 Apple Production in Canada

According to Statistics Canada data from 1996, Canadian apple production occupies 34 593 ha, includes just over 12 million productive trees, and is carried out in 7100 operations reported as farms. The industry is most extensive in British Columbia (7464 ha and more than 4.6 million productive trees) and Ontario (12 353 ha and 4.3 million productive apple trees). Quebec follows with 7865 ha (8868 ha in 1997, according to figures from the Government of Quebec) and 2.1 million productive trees. These three provinces produce nearly 90% of the apples grown in Canada.

6.3.3 Pesticides and Apple Production (Case Study – Quebec)

6.3.3.1 Background

Apple growing is subject to numerous uncertainties related to climate, insects, and disease. With respect to climate, a prolonged thaw in winter followed by a sudden, severe freeze or a major ice storm can cause irreparable losses; some orchards were almost completely wiped out during the huge ice storm in Quebec in January 1998. Apple trees are susceptible to attack by some 15 insect species, the most important of which is the apple fly, which burrows into the fruit. The plum curculio, which feeds on buds, fresh leaves, and young apples; the European red mite; and the tarnished plant bug are other major insect pests in apple production. Among microorganisms, apple scab, caused by a fungus (*Venturia inaequalis*), is considered a serious threat; the microorganism spends the winter on dead leaves, and the spores are carried to the leaves on growing apple trees during spring rains. Apple scab causes spots on leaves and fruit, making retail marketing of the affected apples impossible. Other important microbial diseases in apple growing are calyx-end rot, alternaria, and bacterial blight. In addition, competing vegetation can interfere with tree growth, particularly in the case of dwarf varieties. Finally, apple trees can be threatened by rodents, such as meadow voles, which attack the bark.

As previously mentioned, pesticides are used most extensively in apple orchards. Typical applications are estimated at 30 kg a.i./ha for apples, compared with an average of approximately 3 kg a.i./ha for corn. As a general rule, a wide variety of pesticides is used, and applications are frequent: between 11 and 15 times a year, on average. In apple production, approximately 6 herbicides, 15 insecticides, 8 fungicides, and 2 rodenticides are recommended, along with plant growth regulators. Apple scab is such a serious threat that it is targeted by 10% of all fungicides used in Quebec; captan, myclobutanil, and mancozeb are the active ingredients most often used. In Quebec, 25% of all insecticides used fight insect pests that attack apple trees. The most popular substances are azinphos-methyl, dimethoate, and mineral oil insecticide. The main herbicides used are glyphosate, paraquat, and simazine.

Between 1994 and 1996, a number of studies were conducted in Quebec, mainly in the southwest part of the province near Montreal, in order to measure residual concentrations of pesticides in the air, water, soil, and humans as a result of pesticide spray drift. Of all the pesticides used in apple orchards, organophosphorus insecticides are considered the most dangerous to human health. Therefore, the studies focused on the drift and the measurement of these substances, although certain fungicides were also studied. These substances are much less environmentally persistent than organochlorines: they have half-lives of a few days to a few weeks, as opposed to years, as in the case of chlorinated substances. Despite this, their acute toxicity is much higher, making them effective in controlling insects. Organophosphorus insecticides are primarily contact insecticides, inhibiting cholinesterase, a neurotransmitter that regulates the amount of acetylcholine involved in the transmission of nerve impulses. The acute toxicity of fungicides to mammals is generally lower than that of organophosphorus insecticides; however, captan is highly toxic and is considered mutagenic and teratogenic.

6.3.3.2 Residues after Spraying

The Quebec studies revealed the presence of pesticide residues in air, water, and soil outside the spray areas. The atmospheric concentrations of organophosphorus insecticides and fungicides are higher during spraying, but these products can still be detected in fairly high concentrations 6-12 hours after spraying. In the hours following spraying, atmospheric concentrations of azinphos-methyl (an insecticide) ranged from 0.25 to 2.7 µg/m^3, and concentrations of phosmet (an insecticide) ranged from 0.131 to 2.6 µg/m^3. Captan (a fungicide) was also detected in concentrations ranging from 0.043 to 0.5 µg/m^3. These concentrations were measured at a maximum distance of 30 m from the orchards. Soil residue concentrations were measured at distances up to 30 m from the spray area in concentrations ranging between 0.001 and 1.7 µg/m^3. Phosmet and azinphos-methyl were the two active ingredients found in the highest concentrations. The authors of the study have concluded that residents in the immediate vicinity of an orchard on the day of spraying are exposed to drift from the pesticides applied.

Monitoring of pesticide residues in water revealed the presence of a number of substances in surface water in concentrations exceeding the criteria established for protection of aquatic life, particularly fish. These substances included the insecticides azinphos-methyl, phosmet, cypermethrin, carbaryl, diazinon, and chlorpyrifos; and the fungicide captan. (Note: The use of chlorpyrifos is being re-evaluated in Canada and the United States; for more information, contact the Canadian Pest Management Regulatory Agency.) Concentrations were higher during periods of rain as a result of leaching through the soil surface. Samples were also taken from 42 private wells (both shallow and deep), generally located less than 50 m from a spray zone. The results revealed moderate contamination of 40% of all the wells (17 wells); those belonging to orchard owners were affected in more cases (43%) than those located in the area around the orchards (29%). The product most frequently detected was the herbicide simazine; organophosphorus insecticides (azinphos-methyl, carbaryl, dimethoate, phosmet, phosalone, and malathion) and fungicides (captan and myclobutanil) were also found, although more rarely.

However, the concentrations of all these products (ranging from 0.02 to 0.6 µg/L) did not exceed the Canadian guidelines for drinking water quality.

The results of the Quebec studies are consistent with those published elsewhere. In a study in the San Joaquin Valley region of California, atmospheric concentrations of 1.0 µg/m^3 of parathion, chlorpyrifos, and diazinon and 30 µg/m^3 of methidathion were detected within a 30-m radius of a spray area. The authors of this study indicate that air contamination can have a serious impact on humans, other animals, and vegetation. On the basis of an average respiratory capacity of 10 L/min and the average concentration of pesticide residues found in the air, exposure by inhalation could reach 1.5 µg/day or, for a 70-kg person, 0.02 µg/kg body weight per day. This figure is probably insignificant for each substance taken individually, since the ADI is between 2 and 10 µg, but the authors consider that it could become significant in the case of simultaneous exposure to a number of products. They state that for people living near orchards, where air concentrations can reach 1 µg/m^3 for each pesticide, exposure by inhalation is significant and must be considered in the calculation of total exposure and in risk assessment.

In the northwestern United States (Oregon and Washington), where apple production is a major industry, residues of the insecticide carbaryl and the fungicide captan have been reported in soil up to 50 m away at the time of application and in the air 150-500 m away. Atmospheric and soil residues have been detected up to 150 m from dwarf orchards and up to 240 m from semi-dwarf orchards. In the Okanagan Valley in British Columbia, soil residue concentrations of 0.142 µg/m^3 of the insecticide phosmet have been reported on the day it was applied, along with residues of 0.125 µg/m^3 in a recreational area between 5 and 25 m from the orchard two days after the insecticide was applied.

6.3.3.3 Health Effects

As mentioned above, Quebec pesticide drift studies were accompanied by an evaluation of the health effects of organophosphorus insecticides. One study dealt with a sample of 16 farm labourers working in orchards, 30 children living near orchards, including 7 whose parents were orchard owners, and a control group of 23 people living more than 500 m from any spray area. The levels of alkyl phosphates (a derivative used to measure the presence of organophosphorus compounds in the human body) identified in urine from people exposed to these substances indicate that the workers absorb a significant amount of organophosphorus insecticides, even when using protective clothing and equipment. An increase in concentrations of alkyl phosphates in children who live near orchards the day after spraying suggests an absorption of insecticides attributable to the application of pesticides. The study also revealed that the children of apple growers absorb six times more pesticides than others who live near orchards. However, analysis of the potential impact of the amounts absorbed indicates that no group had accumulated a body burden large enough to have an immediate harmful effect on health. At the same time, the data collected relate only to certain organophosphorus insecticides, and little is known about the potential long-term effects of exposure to various pesticides.

Table 6.2a
Pesticide Spraying in Orchards: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations[3]
Technological Disaster	fire in pesticide storage facility	destruction, contamination	site and perimeter	covering, collection, and containment, emergency plan	none
	accidental spill of concentrated pesticides	contamination, destruction	usually on the site	collection, cleanup, decontamination; prevention	follow mixture preparation directions
Gas Emissions or Emissions to Air	organophosphorus insecticides[1]	air pollution caused by pesticide drift, particularly in the wind direction	site and perimeter (about 30 m from sprayed area)	avoid spraying during nesting and pollination periods	azinphos-methyl: 0.2 mg/m^3 (skin contact, NIOSH); 0.02 mg/L MAC (drinking water, Health Canada)
	fungicides[2]	air pollution caused by pesticide drift	site and perimeter	avoid spraying during windy and rainy periods	captan: no standard
Liquid Emissions or Emissions to Water	organophosphorus insecticides[1]	disturbance of aquatic life; toxicity can be very high (e.g., 3 µg/L for rainbow trout)	surface water on site and at perimeter	avoid spraying during rainy periods; buffer zone	0.07 µg/L for azinphos-methyl (MEF criterion for raw water intake)
	fungicides[2]	high toxicity: 56 µg/L for trout and salmon	surface and ground water on site and at perimeter	avoid spraying during rainy periods; buffer zone	captan 0.1 mg/kg body weight per day (safe level for occupational exposure, EXTOXNET) 13 µg/L for captan (MEF and Environment Canada criteria for raw water), 0.13 mg/kg body weight per day (US EPA)
Solid Emissions or Emissions to Soil	organophosphorus insecticides[1]	soil and water table pollution	site and perimeter (up to 30 m from sprayed area)	none	none
	fungicides[2]	soil and water table pollution	site and perimeter	none	none
Nuisances	odours	quality of life, stress	vicinity	buffer zone	none
	noise (spraying)	quality of life, stress	vicinity	less noisy sprayers	none

[1] Azinphos-methyl is the typical substance considered for reference purposes; however, it is to be phased out in 2005.
[2] Captan is the typical substance considered.
[3] MAC = maximum acceptable concentration; MEF = Ministère de l'Environnement et de la Faune du Québec.

Table 6.2b
Pesticide Spraying in Orchards: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	fire in pesticide storage facility	injury, poisoning, burns, death	workers, firefighters, vicinity	rare	morbidity and mortality reports
	accidental spill of concentrated pesticides	acute: blurred vision, stomach pains, nausea, loss of consciousness; chronic: neuropathy, various central nervous system disorders	handlers of concentrated solutions	rare	medical, public safety reports
Gas Emissions or Emissions to Air	organophosphorus insecticides[1]	cholinergic effects of varying intensity depending on extent of exposure	workers and producers' children most at risk; nearby population less at risk	occasional to frequent among groups at risk	measurements of alkylphosphates in urine: 5.3 mg/g creatinine equals the NOAEL for workers; 2.2 mg/g creatinine equals the NOAEL for children
	fungicides[2]	captan: dermatitis, allergies, potentially teratogenic and mutagenic	same as above	same as above	no data for captan
Liquid Emissions or Emissions to Water	organophosphorus insecticides[1]	same as above; acute lethal dose in humans: 5-50 mg/kg body weight	consumers of contaminated water	unknown	same as above
	fungicides[2]	same as above; NOAEL: 12.5 mg/kg body weight per day (rat) for captan	consumers of contaminated water	unknown	no data for captan
Solid Emissions or Emissions to Soil	organophosphorus insecticides[1]	same as above	consumers of ground water	unknown	N/A
	fungicides[2]	same as above	consumers of ground water	unknown	N/A
Nuisances	odours	stress, anxiety concerning health	vicinity	rare to frequent	complaints, perception studies
	noise (spraying)	quality of life, disturbance	vicinity	rare	complaints

[1] Azinphos-methyl is the typical substance considered for reference purposes; however, it is to be phased out in 2005.
[2] Captan is the typical substance considered.

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7 WASTE MANAGEMENT

The management of household waste has become a major environmental and political problem in both industrialized and developing countries. In industrialized countries, the shorter life cycle of consumer products and unregulated use of natural resources have led to increased use of those resources to produce more and more consumer goods. The processing of waste is rendered problematic by the fact that unknown materials may be encountered. Generally, waste reduction, reuse, recycling, and recovery (4Rs) are being promoted to reduce natural resource use, while at the same time efforts are directed at reducing waste landfilling and incineration, two highly polluting waste management practices that are currently used in industrialized countries.

7.1 Canadian Context

In 1996 (the latest year for which data are available), some 20.6 million tonnes of waste were collected in Canada. An undetermined volume of waste continues to be disposed of at illegal dump sites, particularly in rural communities. On a per capita basis, Canada is one of the largest generators of waste, generating 690 kg of waste per capita annually (including commercial, institutional, and construction wastes). Per capita waste generation was lower than the national average in the Atlantic provinces, Ontario, and British Columbia, but was slightly higher in Quebec (at 750 kg per capita). The provinces of Manitoba, Saskatchewan, and Alberta generated between 840 and 880 kg of waste per capita. From 1980 to 1996, the total volume of waste generated increased by 17%, whereas per capita generation declined by 4%.

In 1996, industrial, commercial, and institutional waste comprised the largest proportion of the waste stream, at 35%, followed by residential waste (30%), construction and demolition wastes (23%), and hazardous wastes (7%), with the remaining 5% composed of miscellaneous wastes. The composition of a typical bag of household garbage in Canada can be broken down as follows: putrescible organic matter or green waste, 34%; paper and cardboard, 28%; plastics, 11%; metal, 8%; glass, 7%; and textiles and miscellaneous, 13%.

In 1996, close to 80% of the waste stream was landfilled, 3-5% was incinerated, and the remaining 15-17% was recycled or composted, a dramatic improvement over the 6% that was recycled or composted in 1988. In 1996, Canada had 42 incinerators and some 700 regulated landfills. Annual waste disposal costs, including collection, transport, and disposal, are estimated at over $3 billion (1995 data), not counting the environmental and social costs (negative externalities) associated with the loss of resources. This sector generated close to 20 000 jobs in 1995.

The improvement in waste recycling is due in part to the introduction of measures proposed by the Canadian Council of Ministers of the Environment (CCME) aimed at reducing the waste stream by 50% by the end of the 20th century. However, this objective has not been met. In addition to promoting recovery at the municipal level, the measures promoted by the CCME also covered packaging, which had already been reduced by 21% between 1988 and 1993.

7.2 Landfilling

The concept of landfilling is simple. It involves the disposal of waste in one of three ways:

1) above ground (in “mounds”);

2) in trenches; or

3) in quarries (filling natural or excavated depressions with wastes).

In principle, landfilling should be done on an impermeable soil. Otherwise, a watertight membrane liner (geomembrane) is required. The waste is generally spread in an even layer no more than a few metres thick and compacted by repeated passes by heavy machinery. It is covered at regular intervals with a layer of inert granular material (gravel, sand, earth) in order to prevent the formation of a continuous mass of waste.

A sanitary landfill should be subdivided into separate cells that prevent the flow of contaminated waters between them. The cells should also be surrounded by a drainage system to divert runoff waters. A gas collection system should be installed in each cell to collect gases generated by the fermentation of the waste stream; the gases should then be burned. The water that percolates through the waste should also be collected by a network of perforated drains and shipped to a wastewater treatment centre.

An American study (Hoskin *et al.*, 1994), actually focusing on traumatic fatality at hazardous waste site remediation projects (incorporating three alternative methods: excavation/landfill, capping, capping/slurry-wall), found that the riskiest jobs were those of truck driver followed by labourer, oiler, and bulldozer operator. In comparing the three remediation alternatives, the risk of experiencing at least one fatality was found to be more than 10 times greater for the excavation/landfill approach, relative to the other two methods.

7.2.1 Air Pollutants

7.2.1.1 Biogas

The various gases produced at landfill sites are collectively known as biogas. It is formed by the microbial decomposition of the organic matter in the waste. The process can last several decades and occurs in several stages: hydrolysis of organic matter into basic molecules (amino acids, sugars, fatty acids, etc.) and simple molecules or atoms (NH_3, hydrogen, CO_2, etc.); acetogenesis of the simple molecules or atoms (conversion to acetic acid); and methanogenesis (conversion of acetic acid to CH_4 and CO_2).

Box 7.1
Composition of Mature Biogas

The composition of a mature biogas is almost always constant and consists essentially of equal parts of CH_4 and CO_2 (47% each). It also contains gaseous nitrogen (close to 4%) as well as several dozen compounds in concentrations of less than 1%. The principal classes are:

- aromatic hydrocarbons, including VOCs (e.g., benzene, toluene, xylene);
- halogenated hydrocarbons (e.g., vinyl chloride, dichloromethane, chloroform);
- sulphide compounds (e.g., H_2S, mercaptans);
- various alcohols (e.g., methanol, isopropanol); and
- other substances, such as acetone, ethane, and propane.

According to a California study of 224 landfill sites, the compounds found most frequently and at the highest concentrations are dichloromethane (4589 µg/m^3), tetrachloroethylene (1853 µg/m^3), trichloroethylene (710 µg/m^3), benzene (140 µg/m^3), and carbon tetrachloride (96 µg/m^3).

The problems caused by biogas can be largely reduced if the biogas is burned to destroy the CH_4 and trace compounds. Given the heat value of CH_4, biogas can be used as an energy source. However, biogas must be burned at temperatures of over 800°C in order to avoid the synthesis of other toxic substances, such as dioxins and furans. In addition, biogas collection under landfill cells must be adequate to prevent underground lateral migration to inhabited areas.

7.2.1.2 Health Effects of Biogas

A number of polluting gases can have a variety of impacts on health. CO_2 and CH_4 are greenhouse gases partially responsible for global warming.

Methane and Biogas

The accumulation of CH_4 in confined spaces or enclosed structures can result in asphyxia, explosions, and fires, which may cause injury or loss of life. The risk of CH_4 gas explosions is highest at ambient concentrations of between 5% and 15%. Underground migration of biogas (lateral migration) can result in its infiltration into buildings and can cause explosions or asphyxia in confined spaces.

Organic Compounds at Low Concentrations

A number of organic compounds are toxic, including several VOCs, which can cause health problems following chronic exposure. These include, for example, aplastic anemia; teratogenic and fetotoxic effects; damage to the liver, lungs, and kidneys; nervous system damage; and various cancers, such as leukemia and myelomas. It is important to note, however, that these effects are associated with high concentrations, which are not necessarily found in proximity to landfills. Those at greatest risk are landfill workers, particularly operators of heavy equipment used to compact the waste.

Under section 77 of the *Canadian Environmental Protection Act, 1999* (CEPA 1999), certain toxic compounds or groups of substances can be added to the Priority Substances List (Schedule 1 to the Act) due to the health risks they pose. Three of the substances identified in substantial concentrations in biogas appear on the list: benzene, dichloromethane, and trichloroethylene. A brief description of each of these substances follows.

Benzene is a clastogenic agent (causing chromosome breaks and aberrations) and a known human carcinogen. Associations have been observed between leukemia and exposure to benzene in the workplace. In humans, the tumorigenic concentration of benzene (i.e., the concentration that causes a 5% increase in tumour incidence, or TC_{05}) is estimated at 15 mg/m^3, which is far higher than the concentration found in polluted Canadian cities or near properly managed landfills.

Dichloromethane is considered to be a likely human carcinogen. Cohort studies conducted in exposed workers have shown excess mortality due to certain cancers. In laboratory animals, concentrations of over 10 000 mg/m^3 are clearly carcinogenic; in humans, the TC_{05} is 2000 mg/m^3. In Canada, the average concentration in polluted Canadian cities is 0.0026 mg/m^3. While concentrations may be higher in the immediate vicinity of landfills, they are well below the TC_{05}.

Trichloroethylene has been classified as a likely human carcinogen. However, in several studies, a consistent association has not always been shown between exposure and a particular cancer. A concentration of over 2000 mg/m^3 has a carcinogenic effect in laboratory animals; in humans, the TC_{05} is 82 mg/m^3, whereas the average concentration in polluted Canadian cities is less than 0.020 mg/m^3. Again, it is unlikely that the concentration would reach the TC_{05}, even near a landfill.

7.2.2 Water Pollution

7.2.2.1 Leachate

The water percolating through landfills is called *leachate*. It is a complex, highly variable mixture, consisting of various organic and inorganic compounds and microorganisms. Leachate is generated by precipitation or by other moisture that enters the landfill from the breakdown of organic matter or from ground water (water table). It is generally characterized by a strong odour and dark brown colour and contains high levels of pollutants, creating a BOD of 5000 mg/L, compared to 100-200 mg/L for typical municipal wastewater. The average absorptive capacity of household waste in landfill is 8.5 cm of liquid per metre of thickness.

Inorganic Pollutants

Inorganic pollutants consist essentially of heavy metals, generally present at low concentrations, with the exception of iron and manganese, which are usually present in the form of more or less insoluble metal salts. Some particularly toxic metals can pose a risk if they infiltrate ground water aquifers used for drinking water.

Organic Pollutants

Organic compounds come from many domestic products: disinfectants, deodorants, cleaning agents, pesticides, furniture cleaners and waxes, cosmetics, soaps and shampoos, dyes, paints and varnishes, medications, etc. Landfills contain thousands of organic compounds. However, the following compounds are universally found or are found in larger concentrations in leachate:

- benzene (solvents, dyes, pesticides, detergents);
- vinyl chloride (manufacturing of various products);
- dichloromethane (solvents, liquid refrigerant, use by the pharmaceutical industry);
- tetrachloroethylene (dry-cleaning solvent, inks, rubber solutions, paint solvents);
- carbon tetrachloride (aerosols, dry cleaning);
- toluene (solvents, dyes, pharmaceutical manufacturing);
- 1,1,1-trichloroethane (cosmetics, aerosols); and
- xylene (dyes, pharmaceutical products, insecticides, solvents, resins, varnish, and polyester products).

Pathogens

The main sources of pathogens are facial tissues, pet feces, diapers, paper towels, and food waste. Wastewater treatment sludge, contaminated industrial waste, and biomedical wastes can also be transported to certain sanitary landfills, thus increasing the number of microorganisms. The presence of vermin (rats, wild animals, birds, and insects) also contributes to increasing the pathogen load.

Leachate contains bacteria (including coliforms, fecal coliform bacteria, and *Pseudomonas aeruginosa* and *Aeromonas hydrophila*); viruses (particularly the hepatitis A and Norwalk group viruses); and protozoan parasites (such as *Giardia lamblia* and *Cryptosporidium parvum*).

7.2.2.2 Reduction of Water Pollution

To prevent off-site migration of leachate, the landfill site must be naturally impermeable (clay soil) or a watertight geomembrane barrier must be installed. The leachate must be collected by means of a network of perforated piping and transported to a treatment plant similar to that used to treat urban wastewater. Both physicochemical treatment (oil removal system, filters, coagulation, precipitation, etc.) and biological treatment (biofilters, activated sludge, etc.) are generally required, given the very high levels of contaminants in landfill leachate. The local hydrogeology and the containment technologies and impermeabilization systems employed are therefore key factors in terms of environmental and health risks. An uncontrolled above-grade landfill located near a stream poses considerable risks to water quality.

7.2.2.3 Potential Health Effects of Leachate

The effects of leachate result from potential contamination of the water table or of surface waters through lateral migration. There are three classes of contaminants that pose a risk:

1) inorganic contaminants, which consist essentially of toxic metals that have no physiological role: arsenic, cadmium, mercury, and lead;
2) organic compounds, of which there are many, although some are more common or are found at higher concentrations; and
3) various pathogenic microorganisms.

Little is known about the health risks associated with water contamination by landfill leachate. Leachate has never been implicated in any deaths or disease outbreaks, although it is known that private wells and community sources of drinking water have been contaminated by leachate. The difficulty in establishing a cause-and-effect relationship is exacerbated by the facts that:

1) exposed populations are small;
2) there is a long latency period before the appearance of certain adverse health effects;
3) the acute effects are non-specific (e.g., headaches, fatigue); and
4) leachates contain a large number of poorly identified contaminants.

The toxic metals *arsenic*, *cadmium*, *lead*, and *mercury* commonly found in leachate pose the greatest risk. The adverse health effects associated with the first three of these inorganic contaminants, as well as drinking water guidelines for each of the three, are outlined in Chapter 5 (see Box 5.2 in section 5.3.4.2 on metal mining liquid effluent). The fourth metal, inorganic mercury, can be transformed into a highly toxic organic form, methylmercury, which first accumulates in erythrocytes and then spreads to the liver, kidneys, and brain. The many health effects include kidney failure, neuropathies, paresthesia, vision and hearing loss, emotional instability, and irritability. The Canadian drinking water guideline for mercury is 1 µg/L, while the provisional tolerable weekly intake (PTWI) is 5 µg/kg body weight.

Microorganisms

The principal bacteria that pose health risks are coliform bacteria. They consist essentially of organisms of the family Enterobacteriaceae (*Enterobacter* sp., *Escherichia* sp., *Klebsiella* sp., *Proteus* sp., *Salmonella* sp., *Shigella* sp., *Yersinia* sp., and about 20 other genera). These microorganisms of the Enterobacteriaceae family cause various infections that primarily affect the gastrointestinal system. Several of these species of bacteria do not survive in the environment or are opportunistic pathogens, triggering an infection in high-risk persons only (those with a weakened immune system, for example). The Canadian drinking water guideline for coliform bacteria calls for a maximum of 10 coliforms/100 mL and no *Escherichia coli*.

Organic Pollutants

Table 7.1 presents the main organic compounds found in landfill leachate, a brief overview of their toxic effects, and their maximum acceptable concentrations in drinking water.

Table 7.1
Organic Compounds in Landfill Leachate, Their Toxic Effects, and Maximum Acceptable Concentrations in Drinking Water

Compound	Toxic Effects[1]	Maximum Acceptable Concentration in Drinking Water[2]
■ benzene	■ anemia, fetotoxic, carcinogenic	■ 5 µg/L
■ vinyl chloride	■ decreased fertility	■ 2 µg/L
■ dichloromethane	■ neurotoxic	■ 50 µg/L
■ tetrachloroethylene	■ pulmonary edema, depression of the central nervous system, liver disorders	■ 50 µg/L
■ carbon tetrachloride	■ depression of the central nervous system, hepatotoxic, nephrotoxic, carcinogenic	■ 5 µg/L
■ toluene	■ nephrotoxic, neurotoxic, hepatotoxic, arrhythmia, decreased respiratory function, fetotoxic	■ 24 µg/L (aesthetic criteria)
■ trichloroethane	■ depression of the central nervous system, hepatotoxic, nephrotoxic	■ none
■ xylenes	■ neurotoxic, mucocutaneous irritation, teratogenic in animals	■ 300 µg/L (aesthetic criteria)

[1] These effects appear at much higher concentrations than those found in water from a landfill.

[2] Based on Health Canada's guidelines for drinking water quality.

7.2.3 Nuisances and Psychosocial Impact

The following nuisances may be associated with the operation of a landfill:

- malodours due to sulphur compounds and organic acids;
- dust, particulates, and waste carried by the wind;
- vermin (rats and small wild mammals) and some birds, such as gulls, that are attracted by organic waste; and
- increased heavy vehicle traffic (noise, dust, risk of accidents).

The most common social impacts include:

- decline in the property value of nearby homes;
- presence of malodours; and
- heavy vehicle traffic.

The social impacts concern a number of health determinants and can lead to psychological problems (e.g., stress, anxiety, and aggressiveness). Without mitigation measures, long-term degradation of the human environment and social fabric can occur. It is important to bear in mind that sanitary landfills generally have only a minor economic impact (few jobs created) and that this type of project is always very negatively received by the community affected.

Table 7.2a
Sanitary Landfilling: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations
Technological Disaster	fire	smoke/dust deposits	plume dispersion	covering	application of provincial laws and regulations concerning landfill site management
	explosion	destruction	site and perimeter	biogas management, leak-proof site	
Gas Emissions or Emissions to Air	biogas	greenhouse effect	global	collection and burning	none
	CH_4, CO_2	greenhouse effect	global	none	international commitments to counter the greenhouse effect
	VOCs	air pollution	local and regional	collection and destruction	benzene: 15 mg/m^3 (Health Canada tumour producing effects)
					dichloromethane: 2200 mg/m^3
					trichloroethylene: 82 mg/m^3 (Health Canada, tumour producing effects)
Liquid Emissions or Emissions to Water	leachate BOD, COD[1]; heavy metals, organic compounds, and microorganisms	all pollutants: disturbance of aquatic life, pollution of surface and ground water	local and in receiving environment (downstream) or in water table	all pollutants: collection and processing in the water treatment plant	BOD: none
					for metals, organic compounds, and microorganisms: Health Canada, drinking water guidelines
Solid Emissions or Emissions to Soil	N/A	N/A	N/A	N/A	N/A
Nuisances	noise	unhealthy conditions	vicinity and community	all these nuisances: buffer zone; litter fence; daily covering; reduction in waste handling operations	L_{eq}[2] 55 dBA (day) and 45 dBA (night) (WHO guidelines)
	odours	unhealthy conditions	vicinity and community		none
	airborne waste	aesthetics and unhealthy conditions	air/ground perimeter		none
	vermin	unhealthy conditions	local		none

[1] COD = chemical oxygen demand.

[2] L_{eq} = Equivalent sound pressure level.

Table 7.2b
Sanitary Landfilling: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	fire	irritation, asphyxia, burns	vicinity and workers	unknown	fire and injury reports
	explosion	trauma, death	vicinity and workers	31 cases in the USA between 1967 and 1987	morbidity/mortality, explosibility
Gas Emissions or Emissions to Air	biogas	asphyxia, injury	workers, nearby residents	rare	explosibility (CH_4) (<1.25% by volume)
	CH_4, CO_2	climate change (CH_4 and CO_2)	global	frequent (greenhouse effect)	atmospheric CH_4 and CO_2
	VOCs	various types of poisoning, tumour-producing potential	landfill workers and nearby residents	unknown	benzene and VOC levels
Liquid Emissions or Emissions to Water	leachate BOD, COD[1]; heavy metals, organic compounds, and microorganisms	for leachate: unhealthy conditions, acute or chronic poisoning; possible carcinogenic, teratogenic, or mutagenic effects	primarily consumers of contaminated water; children most vulnerable	acute poisoning: very rare chronic poisoning: unknown	monitoring of the various pollutants in the leachate and in the natural receiving water bodies
Solid Emissions or Emissions to Soil	N/A	N/A	N/A	N/A	N/A
Nuisances	noise	quality of life and of sleep	vicinity and community	occasional	L_{eq}[2] 45 dBA, (night) and 55 dbA (day) WHO guidelines
	odours	quality of life	vicinity and community	occasional to frequent	complaints/perception
	airborne waste	quality of life, hygiene	vicinity and community	occasional to frequent	site inspection
	vermin	spread of disease	primarily children	rare	complaints from residents

[1] COD = chemical oxygen demand.

[2] L_{eq} = Equivalent sound pressure level.

7.3 Incineration

7.3.1 Atmospheric Emissions

The potential atmospheric emissions from waste incineration are generally a source of local concern. Combustion fumes contain gases (CO, CO_2, and SO_2), dusts, and fly ash, small particles that are easily airborne. Particulate matter and fly ash may consist of inert particles, often silica, but they may also contain various volatilized metals. Metals such as cadmium and chromium pose a low risk, as do mercury and lead. Metals are released by incinerators that are not equipped with proper scrubbers. Such cases, which were still common in Canada in the 1990s, are now the exception. Several underperforming incinerators have been closed, while others have undergone major modifications.

Substances that are not completely burned in the combustion process, such as VOCs, PCBs, PAHs, and dioxins and furans, can condense on particles emitted by combustion. Canadian incinerators account for only 3.7% of total atmospheric emissions of dioxins and furans. According to the literature, the carcinogenic risk is not significantly higher for incinerators that are in compliance with the standards. In fact, it is estimated that, in the worst-case scenario, the excess absorption of dioxins and furans would account for only 5% of "background" levels, essentially of food origin.

Incinerator smoke also contains many other gases, including hydrogen chloride (HCl), a very acidic gas with similar properties, to hydrochloric acid. These substances generally do not cause adverse environmental or health effects at the quantities and concentrations emitted by incinerators that are in good working order. However, they add to other pollutants that cause climate change, destroy the ozone layer, and contribute to acid precipitation or urban smog.

7.3.2 Solid Wastes

The majority of solid wastes resulting from incineration (95%) consist of bottom ash, which is generally not toxic and is usually shipped to sanitary landfills for disposal. However, bottom ash concentrates various metals and, like hazardous wastes, requires stringent management. In some European countries, bottom ash is used in road construction or as fill material.

7.3.3 Health Effects

If incinerators are equipped with proper pollution control systems (activated charcoal beds, spray dry scrubbing, etc.), the health risks of incineration are very low. The main atmospheric pollutants associated with incinerators are CO; CO_2; particulate matter; SO_2; the heavy metals cadmium, chromium, mercury, and lead; and dioxins and furans. (The potential health effects associated with CO, particulate matter, and SO_2 are outlined in Appendix A, while those associated with heavy metals are described in Box 5.2 and section 7.2.2.3.) Because bottom ash is generally sent to sanitary landfills for disposal, the risks associated with it are similar to those described in the section on landfilling (section 7.2).

Table 7.3a
Waste Incineration: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations[1]
Technological Disaster	fires and explosions	air pollution from smoke; destruction	air, water, and soil, locally and regionally	technical controls, emergency measures, containment	CSA standard on emergency measures, if applicable
Gas Emissions or Emissions to Air	CO_2	climate change	global	none	Rio (1992) and Kyoto (1997) commitments
	CO	negligible	local	combustion control	15 mg/m^3 (8-h MAL, NAAQO Canada)
	SO_2	acid rain, smog	local to continental	gas scrubbing	30-60 µg/m^3 (EQG, CCME Canada)
	HCl	acidification of the environment	local to regional	gas scrubbing	none
	dioxins and furans	bioaccumulation in living organisms	local to global	increased temperature of combustion and scrubbers	5 pg/m^3 (TEQ1) 24 h average dioxins and furans (Ontario)
	heavy metals (Cd, Cr, Hg, and Pb)	contamination of the environment and organisms	local to regional	flue gas scrubbing	in µg/m^3: Cd - 0.005, Cr - 0.04, Hg - 1.0, Pb - 0.5 (WHO-Europe)
	particles	abrasion, staining, corrosion	local to regional	scrubbers	EQG (CCME) in µg/m^3: 25 (PM_{10}), 15 ($PM_{2.5}$)
Liquid Emissions or Emissions to Water	N/A	N/A	N/A	N/A	N/A
Solid Emissions or Emissions to Soil	N/A	N/A	N/A	N/A	N/A
Nuisances	noise	negligible impacts on the natural environment	local	all nuisances: buffer zones, mufflers, filtration	L_{eq} 45 dBA (night) and 55 dbA (day) (WHO guidelines)
	aesthetics		local		none
	odours		local		municipal by-laws

[1] CSA = Canadian Standards Association; MAL = maximum acceptable concentration; NAAQO = national ambient air quality objectives; EQG = environmental quality guidelines; CCME = Canadian Council of Ministers of the Environment; TEQ = toxicity equivalent; L_{eq} = equivalent sound pressure level.

Table 7.3b
Waste Incineration: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	fires and explosions	trauma, injury, death	workers, vicinity, and community	rare	morbidity and mortality reports, fire department reports
Gas Emissions or Emissions to Air	CO_2	morbidity, mortality	global	frequent	geoclimatic data and climatological events
	CO	increase in carboxy-hemoglobin	workers	very rare	blood carboxyhemoglobin levels
	SO_2	respiratory problems (asthma, bronchitis, etc.)	vicinity	rare	atmospheric SO_2 levels
	HCl	respiratory irritation	primarily vicinity	rare	epidemiology of respiratory illnesses
	dioxins and furans	potential carcinogenic, mutagenic, and teratogenic effects	vicinity	very rare	epidemiology of respiratory illnesses
	heavy metals (Cd, Cr, Hg, and Pb)	certain types of cancer (lung, leukemia) and neurotoxicity	workers, residents under the dispersion plume	0.3-21 cases per 10^6 persons exposed	few sufficiently sensitive indicators
	particles	respiratory pathologies	workers and vicinity (children) under the plume	rare or insignificant	air analysis, epidemiological studies under the dispersion plume
			vicinity	rare to frequent	measurements of suspended particulate matter in the air
Liquid Emissions or Emissions to Water	N/A	N/A	N/A	N/A	N/A
Solid Emissions or Emissions to Soil	N/A	N/A	N/A	N/A	N/A
Nuisances	noise	sleep disturbance, stress	vicinity	rare to occasional	noise measurements
	aesthetics	quality of life	vicinity	occasional	perception studies
	odours	environmental allergies	vicinity	rare to occasional	perception studies, assessment of odours

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8 WASTEWATER AND SLUDGE MANAGEMENT

8.1 Wastewater Treatment Plant Construction and Operation

Although the construction of wastewater treatment plants must be viewed as a positive step towards improving the quality of the environment, such facilities generate pollution and raise social concerns. It is therefore important to understand the nature of wastewater treatment plants in order to be able to assess their public health risks.

A major environmental factor category of concern is the "biological" – i.e., (formerly) living organisms and/or their products. The possible consequences of exposure would include infection by various pathogens (i.e., disease-causing organisms – bacteria, viruses, protozoa, and helminths (parasitic worms)). Possible routes of contamination include direct splashes by water/sludge, aerosols (considered abundant at this site), and hand contamination (if employees do not wash their hands prior to eating or do not change their clothing).

8.1.1 General Description of Wastewater and the Situation in Canada

The percentage of Canada's urban population served by wastewater treatment increased from 72% in 1983 to 93% in 1994 (the year for which the most recent data are available). Of that figure, 40% are served by tertiary treatment (see definitions below in section 8.1.2), one third by secondary treatment only, and just over 20% by primary treatment only. In Ontario, British Columbia, and the Prairie provinces, close to 100% of the urban population is served by wastewater treatment plants. Of all the provinces, Ontario has the highest proportion of residents (88% of the population) who are served by tertiary treatment, the most complete treatment; this is in contrast to the Prairie provinces, where only 28% of the population is served by tertiary treatment. In British Columbia, less than 10% of the population is served by tertiary treatment, and 66% is served by primary treatment only. In Atlantic Canada, less than 50% of the population is served by municipal wastewater treatment, the lowest in Canada, and tertiary treatment is non-existent. Finally, 85% of urban dwellers in Quebec are served by wastewater treatment plants, but tertiary treatment remains marginal (serving less than 10% of the population).

A typical North American city generates, on average, 225-380 L of wastewater per person per day. The larger the city, the larger the figure; this is because average volume includes wastewater released by industry and businesses, which are more numerous in larger cities.

Box 8.1
Pollutants in Municipal Sewage

Solids and chemical substances make up only 0.1% of the pollutants in municipal sewage. Organic matter accounts for close to 70% of these pollutants, and inorganic matter 30%. The concentration of suspended solids, both organic and inorganic, generally varies from 100 to 400 mg/L, while the BOD, which is essentially a measure of organic matter, also varies from 100 to 400 mg/L. The concentration of phosphorus can reach 15 mg/L. In addition to these pollutants, municipal sewage contains varying amounts of synthetic chemicals (solvents, PCBs, acids, etc.) from industrial and commercial sources, as well as many groups of microorganisms, particularly coliforms, viruses, and certain parasites, including protozoans and helminths. A large part of these pollutants are ultimately found in wastewater treatment sludge.

8.1.2 Urban Wastewater Treatment Processes

Each wastewater treatment plant is specifically designed to meet the needs of a given region and can consist of multiple combinations of treatment processes. In small municipalities, very simple processes, such as aerated lagoons, are used; in larger municipalities (over 40 000 residents), treatment facilities consisting of a more complete series of treatments are required. This section describes the operations involved in a relatively complete wastewater treatment plant.

In most cases, urban wastewater is treated using conventional processes (pretreatment and primary and secondary treatment). Occasionally, advanced or tertiary, also called special complementary, treatment techniques are used.

Pretreatment consists of (1) screening, which removes coarse solids over 15-25 mm in diameter; and (2) grit removal, which removes particles between 0.2 and 25 mm in diameter. Pretreatment can also include de-oiling and degreasing processes, which remove insoluble liquids from the water (e.g., oil, hydrocarbons, greases).

Primary treatment consists of the removal of settleable solids by the action of sedimentation. It removes 70% of fine inorganic solids (0.05-1.0 mm), called suspended solids, and reduces BOD – a measure of the level of organic pollution as determined by a specific laboratory measurement – by 40%.

Secondary treatment is a biological process that relies on microorganisms that are naturally present in wastewater, particularly bacteria, which convert organic matter into microbial biomass and, ultimately, non-metallic elements (e.g., nitrogen, phosphorus) and CO_2. Secondary treatment removes non-settleable organic matter, which is not removed by primary treatment, and generally destroys pathogenic microorganisms (bacteria, viruses, fungi, and protozoa) that are unable to survive in conditions typical of wastewater. The most commonly used secondary processes are activated sludge and trickling filters. Increasingly, biological treatment is considered to be essential because it is the only process that can significantly reduce organic and microbial pollution.

As mentioned above, advanced or *tertiary treatment* of wastewater is much less common. It is designed to produce an almost pure, but not potable, water. It consists of both *physical processes*, such as sand filtration (retention of particles and microorganisms), activated charcoal (adsorption of refractory organic matter), and disinfection by ozonation or ultraviolet light; and *chemical processes*, such as the use of flocculants and coagulants, which promote the precipitation of organic matter and phosphorus, which has very high eutrophication potential. Chlorinated compounds are also used in the disinfection of wastewater. *Biological processes* rely on bacteria, microscopic algae, or aquatic plants, particularly for the elimination of nitrogen or phosphorus (e.g., phosphate removal).

8.1.3 Atmospheric Emissions and Potential Health Effects

The machinery used in the construction of a wastewater treatment plant emits various pollutants, primarily CO_2, CO, NO_x, and VOCs, which can also be emitted during the operation of the treatment facility. (See Appendix A for health effects information on these pollutants.)

8.1.4 Releases into the Aquatic Environment and Potential Health Effects

While treatment facilities certainly improve the quality of sewage discharged into receiving waters by reducing its pollutant concentration, it is important to bear in mind that the water discharged is not pure and can have potential effects, particularly in the plume – i.e., the area in and downstream from the discharge zone.

The health risks can be assessed on the basis of the type of water use: 1) primary-contact recreational activities (swimming, water-skiing, etc.); and 2) consumption of water and aquatic organisms living in the vicinity of the treatment plant outfall. The risk assessment must also take account of the type of treatment used. Secondary treatment is more effective than primary treatment for the removal of pathogenic microorganisms. The effectiveness of disinfection (by ultraviolet light, ozone, and chlorination) is highly variable, since the presence of various contaminants (total suspended solids, organic matter, and microorganisms) can make it almost totally ineffective.

8.1.4.1 Recreational Water Use

The health risks associated with recreational water use are due primarily to the presence of pathogenic microorganisms, which cause clinical symptoms of gastroenteritis. These microorganisms include bacteria, viruses, and protozoa.

Bacteria

The family Enterobacteriaceae (Gram-negative enteric bacilli) poses the greatest risk with respect to bacteria in wastewater. The most commonly implicated genera are *Escherichia*, *Enterobacter*, *Proteus*, *Salmonella*, *Shigella*, and *Yersinia*. Other common bacteria include *Campylobacter jejuni*, which is now considered the most common cause of bacterial enteritis in North America; and *Enterococcus faecalis*, which is resistant to virtually all antibiotics and therefore requires close surveillance. Many of these bacteria naturally colonize healthy persons and pose a risk only to persons with weakened immune systems. Infections are often opportunistic, and the risk of infection to exposed swimmers is only 0.02-0.3%. Some bacteria, such as *E. faecalis*, survive in the aquatic environment for long periods of time. The risk of infection to swimmers by *E. faecalis* is 1-2%, or 10-100 times higher than for enterobacteria. The detection of this bacterium is increasingly considered a good indicator of swimming water quality, although total coliforms are still the standard indicator organisms.

Viruses

In the context of wastewater, the scientific literature describes the risks associated with two specific groups of viruses of the family Picornaviridae and belonging to the genus *Enterovirus*: coxsackievirus and echovirus. The clinical manifestations of infection by these viruses include aseptic meningitis, conjunctivitis, pericarditis, myocarditis (coxsackieviruses are reported to be responsible for a high percentage of cases of acute myocarditis), diarrhea, and encephalitis, which can lead to Reye syndrome or Guillain-Barré syndrome. The likelihood of transmission of the polio virus (Picornaviridae) through wastewater is reported to be very low. The Norwalk virus, a member of the family Caliciviridae, causes violent gastroenteritis that lasts 24-48 hours and is usually found in persons who have drunk non-potable water or who were engaged in primary-contact water activities. Urban wastewater may also be the source of infections by viruses of the family Hepadnaviridae (hepatitis A).

Protozoa

Giardia lamblia and *Cryptosporidium parvum* are the two parasites most commonly found in wastewater. The cysts and oocysts of these organisms are extremely resistant to wastewater treatment processes, including disinfection by chlorination. Moreover, given their high infectivity, the risk of infection is high. The incidence of waterborne giardiasis and cryptosporidiosis rose steadily in North America in the 1980s and 1990s, and giardiasis is now the most common protozoan infection of the human intestine.

Due to the risk associated with water activities, primary-contact recreational activities, such as swimming, windsurfing, and water-skiing, are generally prohibited in urban wastewater discharge zones, even if the wastewater is treated. Secondary-contact recreational activities (canoeing) should be allowed only after a proper assessment of the presence of pathogenic microorganisms, including groups other than coliforms.

8.1.4.2 Consumption of Drinking Water and Aquatic Organisms

Organisms that filter large quantities of water during feeding, such as molluscs, are particularly susceptible to contamination by bacteria and viruses. The main pathogenic bacteria found in molluscs are *Campylobacter jejuni*, *Salmonella enteritidis* (non-typhoid species), and *Shigella* sp., which generally cause gastroenteritis infections. Contamination by the viruses mentioned above for recreational activities is also possible. As a general rule, it is recommended that molluscs not be consumed from urban areas, polluted areas, or areas located in wastewater treatment plant plumes.

The risk associated with the consumption of potable water and non-filtering aquatic organisms (e.g., fish, crustaceans) is based primarily on the bioaccumulation of various toxic inorganics – such as heavy metals (particularly copper, cadmium, and mercury) – and organics, including PAHs and PCBs.

Toxic Inorganic Substances

Copper is a metal that is essential to many physiological functions. However, exposure to high levels of copper can cause hepatic necrosis in very rare instances. Ingestion of the methylated form of mercury, *methylmercury*, can result in mercury poisoning. Methylmercury attacks the nervous system, causing irreversible effects. It affects visual and auditory functions and coordination. With respect to *cadmium*, it persists in humans for very long periods, i.e., roughly 20 years. Chronic exposure causes renal necrosis. It should be noted that although cadmium absorbed by inhalation is considered a potential carcinogen, the same is not true of cadmium absorbed by ingestion.

Toxic Organic Substances

PCBs are organochlorines, and their ability to bioaccumulate in the food chain is widely recognized. They are heat resistant and are destroyed only at temperatures of close to 1000°C, which makes them very environmentally stable. Although they were banned in Canada in 1980, they are still present in the environment and contaminate virtually all human and natural environments. Chronic exposure to PCBs can cause hepatic damage and congenital anomalies. PCBs have also been shown to be carcinogenic in laboratory animals.

PAHs are generated primarily by the pyrolysis and carbonization of organic matter. Their presence in wastewater is due to the washing and cleaning processes of certain industries (particularly heavy industry, such as steelmaking). Public health risks are associated primarily with the presence of certain mutagenic, teratogenic, and carcinogenic compounds, such as benzo[a]pyrene.

In addition to this list of potential toxic substances, there are also domestic pesticides, oils, and greases (from various machinery and illegal motor oil dumps) and endocrine disruptors, the potential effects of which are only now being evaluated. Endocrine disruptors include a number of pesticides, particularly insecticides and fungicides; organochlorines, including PCBs; and nonylphenol ethoxylates, which are part of the chemical family of the alkylphenols. Nonylphenols are present in many consumer products, including some detergents and stain removers for clothing. These substances are believed to affect the reproductive system and can, in some cases, lead to the development of cancers.

Box 8.2
Exposure to Treated Wastewater Substances

According to impact studies, it can be concluded that conventional treatment of wastewater, despite the presence of heavy metals and organic compounds, is not the source of contamination in humans. The concentrations of these substances in treated wastewater do, however, represent an additional risk of exposure.

8.1.5 Psychosocial Impacts

Wastewater treatment plants usually have beneficial social impacts because they result in a reduction in water pollution. Water quality and aesthetics are also improved, the public is able to enjoy recreational uses of the water, and there are fewer problems associated with producing potable water downstream. A major wastewater treatment facility could have psychosocial impacts on nearby residents if it generates offensive odours. For that reason, it is important to ensure that the odours generated by the treatment process and by the storage of sludge do not reach the nearest homes. Consequently, either treatment plants are generally constructed in relatively uninhabited areas or grass or treed buffer zones are established around the plants. If the sludge is incinerated on site, efforts must be taken to ensure that the fumes are not too dense or malodorous (see section 8.2.2).

Table 8.1a
Wastewater Treatment Plant Construction and Operation: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations[1]
Technological Disaster	fires and explosions	pollution from smoke, particulates	air and water: site and perimeter	containment, collection, emergency measures	emergency measures planning (CSA, etc.)
Gas Emissions or Emissions to Air	CO	negligible	site and perimeter	combustion control	15 mg/m^3 (8-h MAL, NAAQO Canada)
	NO_x	smog and tropospheric ozone	local to regional	catalytic reduction	NO_2, 200 $\mu g/m^3$ (24-h MAC, NAAQO Canada)
	dioxins, furans	bioaccumulation in animals	continental and global	improved combustion	5 pg/m^3 (TEQ1) 24 h average dioxins and furans (Ontario)
	heavy metals (Hg, Cr, Cd)	contamination of animals	regional and continental	scrubbing of incineration flue gases	in $\mu g/m^3$: Cd - 0.005; Cr - 0.04; Hg - 1.0; Pb - 0.5 (WHO-Europe)
	VOCs	smog and tropospheric ozone	local to regional	collection or increase in combustion performance	benzene, 15 mg/m^3 (Health Canada, tumour-producing effects)
	PAHs	air pollution	local to continental	collection	0.001 $\mu g/m^3$ for 87 excess cancers/ million over 70 years (WHO-Europe)
Liquid Emissions or Emissions to Water	heavy metals (Cd, Cr, Hg, Pb)	toxicity to certain aquatic organisms	all pollutants: receiving watercourses; contamination distance variable, depending on concentration, solubility, temperature, pH, etc.	all pollutants: use of adequate, high-performance treatment techniques; as a minimum, secondary treatment to remove pathogenic microorganisms; persistent organic substances (PCBs, PAHs) may require tertiary treatment	in µg/L: Hg - 1; Cr - 50; Cd - 0.5; Pb - 10 (MAC, Canada)
	PCBs	bioaccumulation in food chain			0.02-0.07 µg/kg body weight per day (U.S. EPA)
	endocrine disruptors	reproduction disturbance, fetal malformations			none
	suspended solids	unhealthy conditions, reduced visibility			500 mg/L (aesthetic objective, Canada)
	enterobacteria and *Enterococcus* spp.	unhealthy conditions			for bacteria (per 100 mL): 0 fecal coli, 0 *E. coli*, 10 total coliforms
	Picornaviridae and hepatitis A	unhealthy conditions			no standards for viruses
	Cryptosporidium and *Giardia*	unhealthy conditions			no standards for protozans
Solid Emissions or Emissions to Soil	decantation/sedimentation sludge	unhealthy conditions, toxicity	storage site and perimeter	containment, burial, or fertilization	municipal by-laws or provincial regulations
	bottom ash	unhealthy conditions	storage site and perimeter	containment or burial	municipal by-laws or provincial regulations
Nuisances	odours	unhealthy conditions	site and perimeter	buffer zone	municipal by-laws

[1] CSA = Canadian Standards Association; MAL = maximum acceptable level; NAAQO = national ambiet air quality objectives; TEQ = toxicity equivalent; MAC = maximum acceptable concentration.

Table 8.1b
Wastewater Treatment Plant Construction and Operation: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	fires and explosions	trauma, injury, death	workers, persons on site	very rare	morbidity and mortality; fire department reports
Gas Emissions or Emissions to Air	CO	increase in % carboxyhemoglobin, death	primarily workers	rare	% blood carboxyhemoglobin
	NO_x	irritation of respiratory tract	urban and periurban areas	rare to moderate	ambient air measurements
	dioxins, furans	some carcinogenic compounds	unknown	rare or unknown	ambient air measurements if possible; epidemiological studies
	heavy metals (Hg, Cr, Cd)	some types of cancer, renal or hepatic toxicity	workers and those near emission sources	rare or unknown	ambient air measurements, epidemiological studies
	VOCs	irritation of respiratory tract, tissue inflammation caused by smog	urban and periurban areas, exposed workers	rare to moderate, in major urban centres	ambient air VOC and ozone measurements at ground level, epidemiological studies
	PAHs	some carcinogenic compounds	workers and local population	unknown	ambient air benzo[a]pyrene and other PAH concentrations
Liquid Emissions or Emissions to Water	heavy metals (Cd, Cr, Hg, Pb)	some types of cancer, renal or hepatic toxicity	consumers of fish or crustaceans	unknown or rare	levels in fish and crustacean flesh; epidemiological studies
	PCBs	possible carcinogenic effects	primarily eaters of fatty fish	unknown or rare	levels and epidemiological studies
	endocrine disruptors	reproduction effects, reduced sperm count?	unknown	unknown	epidemiological studies
	suspended solids	unhealthy conditions, no direct effects	recreational use	occasional to frequent	suspended solids measurements in recreational waters
	enterobacteria and *Enterococcus* spp.	gastroenteritis, other infections	recreational use, drinking water	rare to moderate, depending on location	coliform, enterobacteria, and *Enterococcus* levels, medical reports
	Picornaviridae and hepatitis A	encephalitis, meningitis, pericarditis, and hepatitis	recreational use, drinking water	rare to moderate, depending on location	epidemiological monitoring, public health reports
	Cryptosporidium and *Giardia*	gastroenteritis	recreational and drinking water	rare to moderate, depending on location	epidemiological monitoring, public health reports
Solid Emissions or Emissions to Soil	decantation/sedimentation sludge	possible carcinogenic effects, pathogenic micro-organisms	workers, sludge handlers	rare or unknown	medical monitoring
	bottom ash	possible toxicity	workers, ash handlers	rare or unknown	medical monitoring
Nuisances	odours	quality of life	vicinity	rare to moderate	complaints, perception

8.2 Management of Municipal Wastewater Treatment Sludge

Sewage sludge is generated mainly by primary and secondary wastewater treatment and accounts for the largest volume of solid waste generated by municipal wastewater treatment plants. On average, approximately 150 kg of dry matter are produced per 1000 m^3 of treated wastewater.

Some biosolids (a term more politically correct than "sludge") may contain the same types of pathogens as the source sewage, at reduced concentrations. NIOSH has pointed out that U.S. EPA "Class A biosolids have undergone treatment to the point where the concentration of pathogens is reduced to levels low enough that no additional restrictions or special handling precautions are required by federal regulations [40 CFR Part 503]" (NIOSH, 2002). Nonetheless, NIOSH (2002) has prepared guidelines to protect workers, under the following headings:

- Provide basic hygiene recommendations for workers.
- Provide appropriate protective equipment, hygiene stations, and training.
- Extend good environmental practices to prevent and minimize occupational exposures. [Details on each of these are included in the NIOSH (2002) document.]

8.2.1 Preliminary Treatment of Sludge: Dewatering and Thickening

Sludge is over 95% water and must generally undergo various treatment processes aimed at reducing its water content, as well as a biological stabilization process. The water content is generally reduced by thickening and dewatering. Sludge thickening is achieved through the use of drum thickeners and gravity belt thickeners, while dewatering is done by means of centrifugation, filtration, or thermal drying. While it is possible to obtain a sludge with a water content of 10%, most treatment plants generate sludge with a water content of over 50% due to the costs required to obtain additional reductions.

The final step, stabilization, is designed to reduce the fermentation potential of the organic matter present in the sludge and to reduce the concentration of pathogenic microorganisms. Stabilization can be achieved through microbial, anaerobic, or aerobic digestion. Fresh organic matter (composed of proteins, lipids, and polysaccharides) is broken down into simple organic compounds (amino acids, fatty acids, and simple sugars), which are in turn broken down into mineral compounds or gases (nitrogen, phosphorus, CO_2, CH_4, etc.). Sludge can be stabilized by composting, which reduces the concentration of fermentable organic matter and eliminates most pathogens through the action of the heat generated by microbial activity (between 55 and 60°C). Sludge can also be chemically stabilized. Chemical stabilization does not work by eliminating organic matter, but rather by bactericidal action resulting from the action of chemical reagents, such as lime. Sludge stabilization also mitigates odours, as fresh sludge, especially primary treatment sludge, is highly malodorous. Dewatered, stabilized sludge is generally in the form of a "cake" that still contains some water. Sludge cakes can be landfilled (see section 7.2 on sanitary landfills), incinerated (section 8.2.2), or used as a soil amendment (section 8.2.3).

8.2.2 Incineration of Sludges

The combustion of sludges produces fly ash (small airborne particles that can penetrate deep into the respiratory tract), volatile particulate matter, and non-volatile bottom ash. Particulates and fly ash contain a number of inert materials, such as silica, as well as various volatilized metals. Organic matter that is not completely burned and that is found in the fumes in the form of gases can also condense on the particles; this gaseous organic matter includes VOCs, PCBs, PAHs, and dioxins and furans. Sludge incineration can also result in emissions of CO, CO_2, NO_x, SO_2, and HCl.

The health risks associated with each of these groups of pollutants are the same as those described in section 9.2.3 (air emissions from aluminum smelters) and in section 9.3.3 (air emissions from pulp and paper mills), specifically in respect of PAHs.

Bottom ash is very dense and consists of uncombusted materials, steel, and vitrified, carbonized, or crystallized organic matter. It contains predominantly heavy metals, often in the form of insoluble oxides and silicates, as well as PAHs, chlorobenzenes, and chlorophenols. The risks to health depend on the presence and concentration of these compounds, but, as a general rule, bottom ash is not considered toxic. Nevertheless, it must be landfilled at special sites located at a sufficient distance from populated areas to prevent inhalation of dusts carried by the wind. The contamination of the water table must also be avoided by selecting landfill sites with an impermeable soil; otherwise, the use of impermeable geomembranes and the installation of a leachate collection system must be considered (for more information, see section 7.2.2 on water pollution caused by landfill leachate).

8.2.3 Agricultural and Silvicultural Use of Sludge

Sewage sludge contains major plant nutrients, such as nitrogen and phosphorus, and can therefore be used in agriculture. Sludge can also be used as an organic amendment and a lime amendment. Sewage sludge can also be used in silviculture, particularly nurseries, and applied to farmland. This use is limited, however, by the possible presence of toxic substances, particularly heavy metals and persistent organic compounds such as organochlorine pesticides, PCBs, phenols, and hydrocarbons. Sewage sludge may also contain certain pathogenic microorganisms. Composting and land application as a fertilizer kill the microorganisms but have no effect on toxic substances, apart from the fact that some are volatilized.

8.2.3.1 Typical Composition of Sludges Recovered for Reuse

The polluting nature of sludge as well as its potential toxicity and pathogenicity are a function of the presence of various groups of pollutants, which are briefly described below. These pollutants must be characterized and quantified to assess the potential of using the sludge in agriculture or silviculture.

Inorganic Compounds

The most common inorganic compounds found in sludge are nitrogen, phosphorus, potassium, calcium, magnesium, and heavy metals. The concentration of nitrogen ranges from 1 to 5% of dry matter. Before stabilization, the largest proportion of nitrogen is in organic form (proteins and amino acids); after stabilization, the largest proportion of residual nitrogen (a significant proportion can volatilize during the process) is inorganic, in the form of ammonia nitrogen (anaerobic stabilization) or nitrates/nitrites (aerobic stabilization). The total phosphorus concentration of a sludge is between 1 and 4% (dry weight basis). It is present predominantly in inorganic form (50-75%) in both raw and stabilized sludge.

Heavy metals are present in varying concentrations, with manganese and copper being the most abundant. The presence of heavy metals is due primarily to industrial discharges and stormwater runoff, which flow over streets and commercial and industrial land. The elements of most concern due to their toxicity are cadmium, mercury, and lead, but copper, chromium, nickel, and zinc also pose health risks. Heavy metal concentrations are generally below the levels considered dangerous and, moreover, are relatively immobile in the soil. Concentrations of heavy metals following application of sludge to agricultural or forest land are generally non-detectable. However, a risk of forest wildlife contamination by cadmium and zinc has been reported.

Organic Compounds

Most organic compounds found in sewage sludge are non-toxic and include plant and animal matter, such as proteins, amino acids, sugars, and oils and greases.

Oils and greases from non-food companies may also be included in this category. These substances cause an increase in BOD, which significantly reduces the quantity of oxygen available to aquatic organisms. In stabilized sludge, the quantity of non-toxic biodegradable organic matter is reduced by the action of microorganisms.

There are hundreds of different types of toxic organic compounds. The groups most commonly found in sludge are PAHs, pesticides, PCBs, chlorobenzenes, VOCs, phenols, and dioxins and furans. Substances found in stabilized sludge in concentrations over 10 mg/kg include phthalates, surfactants (particularly nonylphenol and alkyl benzenes), chlorobenzenes, and a few PAHs. Phthalates are found in very high concentrations because they are largely used in the manufacturing of adhesives, glues, and lubricants. The high concentration of surfactants can be explained by the fact that they are found in detergents, stain removers, and cleaning products.

8.2.3.2 Health Risks

Water Pollution

If present in concentrations exceeding 10 mg/L, nitrates and nitrites pose a health risk to consumers of well water. Long-term ingestion of nitrates or nitrites contained in water may result in the formation of methemoglobin in the blood and of nitrosamine derivatives, which are recognized to have carcinogenic potential. With respect to phosphorus, there is a possibility of surface water contamination, but the public health risk is minimal, except in cases of overfertilization, which can cause excessive growth of cyanobacteria (blue-green algae), some of which produce toxic substances.

The majority of organic compounds in sewage sludge (e.g., PCBs, PAHs, organochlorines) do not migrate to water because they are hydrophobic and firmly adsorbed on soil particles. Certain pesticides and soluble substances, such as surfactants (nonylphenol) and chlorobenzenes, can leach into water, but the risk of water contamination is considered low or undetermined for the entire population. Some studies have shown that nonylphenols may disrupt hormone cycles responsible for reproduction in mammals, even at very low concentrations.

Soil Pollution

Most of the pollutants found in sewage sludge may be released to the soil through land application. The pollutants bind, more or less reversibly, with various components of the soil – i.e., sand, silt, and humus. Most synthetic organic compounds, even the most toxic, such as dioxins, are generally broken down by soil microorganisms in a relatively short period of time. With respect to surfactants, it appears that annual application could result in long-term accumulation.

Metals are generally not metabolized by soil microorganisms and, if immobile, will persist in the soil. An important aspect of the presence of metals is their absorption by plants. It appears, however, that heavy metal absorption by plants is low, and the risk to consumers is generally considered minimal.

Pathogenic Microorganisms

Many of the microorganisms found in sewage sludge are potentially pathogenic. These microorganisms include parasites, viruses, bacteria, and fungi.

Parasites

Parasites of interest from a public health perspective are protozoa, such as amoebae, *Toxoplasma gondii*, *Giardia lamblia*, and *Cryptosporidium* sp.; and helminths, such as *Ascaris* sp., *Trichuris* sp., and *Taenia* sp. These parasites can be found in sludge in the form of cysts or eggs, ranging in number from several hundred to several thousand per kilogram. This number is high, considering that the infectivity (the dose needed to cause infection) of several parasites is very low. Moreover, the eggs and cysts are very persistent in sludge and can be destroyed only by thermal treatment at temperatures of at least 70ºC. If present in the soil as a result of land application of sludge, eggs or cysts can survive several years. Health risks are primarily to workers at sites where sludge has been applied.

Viruses

Raw sludge can contain up to 1000 viruses per gram. That number can be reduced by the stabilization process. Several types of viruses are present, the most numerous being those that attack the digestive system, i.e., enteric viruses (including the hepatitis A virus). In the soil, some viruses can survive for several months in the first 5-15 cm of soil. However, these organisms are relatively immobile, which limits the risk of water contamination.

Bacteria

Like viruses, the bacteria most commonly found in sewage sludge are of enteric origin (i.e., enterobacteria). Members of the genera *Streptococcus*, *Clostridium*, *Mycobacterium*, and *Listeria* are also found. The presence and concentration of a given pathogenic microorganism depend, however, on the presence of healthy or sick carriers in a population. From 10^8 to 10^9 total coliforms per gram of dry matter can be counted, whereas fecal coliforms usually number 10^6-10^7/g dry weight, and salmonellae range from 10^2 to 10^3 /g dry weight. As a general rule, bacteria can survive in the soil for a few months; some are rendered partially or completely inactive by temperatures below the freezing point or by summer dry spells. It is recommended to wait a full year, or at least one summer, before using farmland to which sludge has been applied.

Fungi

Few studies have been conducted on the fungi (yeasts and moulds) present in sewage sludge. However, several pathogenic organisms, such as *Aspergillus fumigatus*, *Candida albicans*, and *Cryptococcus neoformans*, have been detected in sewage sludge. Since human infection is through direct contact or inhalation, workers who handle sludge are at the greatest risk.

Table 8.2a
Incineration or Land Application of Municipal Sewage Sludge: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations
Technological Disaster	N/A	N/A	N/A	N/A	N/A
Gas Emissions or Emissions to Air	a number of pollutants resulting from the incineration of sludge: see grid on waste incineration	see grid on waste incineration	see grid on waste incineration	see grid on waste incineration	see grid on waste incineration
Liquid Emissions or Emissions to Water	heavy metals (Cd, Cr, Hg, Pb)	toxic to aquatic organisms	receiving watercourses; distance variable, depending on many parameters, including concentration and solubility of pollutants, temperature, spreading method, etc.	observance of protective riparian strips and land slope, no spreading in winter, stabilization of sludge before spreading, etc.	in µg/L: Hg - 1; Cr - 50; Cd - 0.5; Pb - 10 (MAC, Canada)
	organic compounds: surfactants, PCBs, etc.	disruption of reproduction, toxicity, carcinogenesis			surfactants and disruptors: none; PCBs: 0.02-0.07 µg/kg body weight per day (U.S. EPA)
	eggs and cysts of protozoans: *Giardia, Toxoplasma, Cryptosporidium, Taenia*	microbial contamination		for microorganisms, prior heat treatment of sludge may be effective	none
	enteric bacteria: *Salmonella, Shigella, Vibrio*	contamination			0 fecal coli, 0 *E.coli,* 10 total coliforms/100 mL (drinking water)
	enteric viruses	contamination			none
Solid Emissions or Emissions to Soil	heavy metals	soil pollution, health conditions; extent of pollution depends on pollutant content of sludge and quantity applied	usually on the site, as most of these pollutants have little mobility	do not apply sludge too often on any given site	none
	organic compounds (PCBs, PAHs, dioxins, etc.)				none
	eggs and cysts of parasites (see above)				none
	bacteria and viruses				none
Nuisances	odours, insects, vermin	health conditions	site and perimeter	buffer zone, stabilization of sludge	municipal by-laws

Table 8.2b
Incineration or Land Application of Municipal Sewage Sludge: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Affected Area	Biological/Environmental Monitoring Indicators
Technological Disaster	N/A	N/A	N/A	N/A	N/A
Gas Emissions or Emissions to Air	a number of pollutants resulting from the incineration of sludge: see grid on waste incineration	see grid on waste incineration	see grid on waste incineration	see grid on waste incineration	see grid on waste incineration
Liquid Emissions or Emissions to Water	heavy metals (Cd, Cr, Hg, Pb)	various toxic effects and neurotoxicity	consumers of polluted water	rare or unknown	all pollutants in this section: determination of concentration of contaminants in runoff from application sites; water analysis of individual wells
	organic compounds: surfactants, PCBs, etc.	disturbance of the reproductive system, possibility of cancer	consumers of polluted water	rare or unknown	
	eggs and cysts of protozoans: *Giardia, Toxoplasma, Cryptosporidium, Taenia*	various parasitoses	consumers of polluted water	rare or unknown	epidemiological monitoring of local populations near sites on which applications are frequently made (primarily cases of gastroenteritis)
	enteric bacteria: *Salmonella, Shigella, Vibrio*	primarily gastroenteritis	consumers of polluted water	rare or unknown	
	enteric viruses	gastroenteritis	consumers of polluted water	rare or unknown	
Solid Emissions or Emissions to Soil	heavy metals	variable toxicity	primarily workers	unknown	all soil pollutants: determination of concentration, monitoring of workers if necessary
	organic compounds (PCBs, PAHs, dioxins, etc.)	possible carcinogenic effects	primarily workers	unknown	
	eggs and cysts of parasites (see above)	various parasitoses	primarily workers	unknown	
	bacteria and viruses	gastroenteritis	primarily workers	unknown	
Nuisances	odours, insects, vermin	quality of life	vicinity and community	rare or unknown	complaints, perception studies

8.3 Septic Tank Sludge (On-site Treatment)

8.3.1 Background

On-site treatment is used when domestic sewage is not routed to a sewage system. The simplest method of containment of fecal matter, and one that is still used by hundreds of millions of people throughout the world, is the use of dry latrines –

i.e., a simple hole in the ground that is covered once full. A more evolved form of on-site treatment is the use of a septic tank, which is the method generally used in industrialized countries to treat domestic sewage from isolated residences. Typical domestic wastewater from a North American home contains some 450 mg/L of suspended solids and an organic load equivalent to 400 mg/L of BOD. (It is important to bear in mind that this load should not exceed 3 mg/L for aquatic life and 7 mg/L for raw water to be treated and used as drinking water.)

Wastewater treatment in septic tank systems occurs in two stages. First, effluent from the home enters an underground tank that holds between 1500 and 5000 L; the average retention time in the tank is 2-3 days. The partially treated effluent flows from the tank and seeps into the ground through a system of perforated pipes. The soil is a natural filter and has the capacity to complete the treatment that began in the tank.

Septic tanks are underground and are generally constructed of concrete, plastic, or fibreglass. They generally have two chambers separated by a wall that allows the wastewater to flow easily from the first chamber into the second. Solids that are denser than water sink to the bottom, whereas oil, grease, and low-density solids float on the surface, forming the scum layer or crust. The wastewater flows continually, whereas the sediments must be regularly pumped (every few years) to prevent overload of the system.

8.3.1.1 Microbial Dynamics of Septic Tanks

As with municipal wastewater treatment, the fresh organic matter that enters the septic tank is metabolized by various microorganisms. A first group of facultative anaerobic and aerobic bacteria converts the complex organic compounds into simple substances such as monosaccharides, amino acids, and volatile fatty acids. A second group of strict anaerobic bacteria then converts the initial metabolites into molecules such as CO_2, hydrogen (H_2), CH_4, and H_2S. The formation of CH_4 is uncommon in Canada because methanogenic bacteria grow very slowly below 20°C. The main gases that are produced break away from the sediments in the form of bubbles and, as they rise to the surface, entrain particles of sludge to form part of the scum layer.

Mineralization of organic matter generally occurs after a retention time of one year in the septic tank. The production of CH_4, if possible, does not begin until the second year of operation without pumping. Pumping the septic tank every two years therefore will prevent methanization. The regular pumping of the septic tank is required to prevent the sludge from overflowing into the second chamber, then into the tile field; an excess of total suspended solids in septic tank effluent could plug the pipes that carry the effluent to the tile field.

The substances formed by anaerobic decomposition are responsible for the unpleasant and penetrating odour of the sludge. The odours are caused in part by gases, such as H_2S, but also by volatile fatty acids and compounds such as indole and skatole, which are responsible for fecal odour.

8.3.1.2 Quantity of Sludge Produced

In general, the rate of annual sludge accumulation gradually declines over time. After the first year of septic tank operation, sludge and scum production ranges from 80 to 180 L per person, falling to 40-100 L after three years of operation. The tank's contents should be completely pumped out to promote a higher rate of sludge accumulation the following year. The decline in the rate of sludge accumulation over time is normal with anaerobic digestion, a process that reduces microbial biomass.

A low annual temperature promotes the accumulation of sludge owing to the slow-down in microbial activity responsible for the degradation of the organic matter. Below 10°C, bacterial metabolism is virtually inhibited, which results in a considerable increase in sediments during the cold season. Discharges of large quantities of organic matter promote an increase in sludge and reduced water flow, which will tend to result in poor operation of the septic tank.

8.3.2 Pollutant Load of Septic Tank Sludge

Septic tank sludge consists of scum (composed of greases and floating solids), sediments, and the water removed from the septic tank during pumping. Apart from various non-decomposable solid materials (sand, pieces of plastic or metal), the sludge is essentially composed of a dark brown to black mass.

Septic tank sludge contains very high levels of contaminants, as can be seen from the following figures:

- BOD, 5000-10 000 mg/L;
- total suspended solids, 20 000-40 000 mg/L;
- total nitrogen, 100-1000 mg/L; and
- total phosphorus, 30-300 mg/L.

According to the available data, septic tank sludge contains no hazardous organic compounds, such as chlorinated substances (e.g., PCBs) or PAHs. However, surfactants from detergents, such as nonylphenol or alkyl benzene, may be present, as well as phthalates, which are used in the production of adhesives, glues, and lubricants.

During normal operation, the concentrations of pollutants in treated wastewater leaving the septic tank are reduced: BOD, 30-250 mg/L; total suspended solids, 30-200 mg/L; total nitrogen, 10-300 mg/L; and total phosphorus, 1-20 mg/L. This effluent is carried to a tile field, where the concentration of the pollutants is further reduced by microorganisms in the soil.

The sludge recovered during septic tank pumping has a high pollutant load, and its management is problematic because it contains several groups of potentially toxic or pathogenic substances.

8.3.2.1 Heavy Metals

Septic tank sludge contains low concentrations of heavy metals. The main sources of metals are domestic sanitary products and metal pipes. The primary metals found in septic tank sludge are as follows:

- iron, roughly 200 mg/L;
- aluminum, 50-250 mg/L;
- zinc, roughly 35 mg/L; and
- copper, roughly 10 mg/L.

These concentrations are usually below the values recommended for the use of sewage sludge in agriculture (iron, 1000 mg/L; zinc, 500 mg/L; copper, 100 mg/L), with the exception of aluminum, the maximum concentration of which should not exceed 100 mg/L.

8.3.2.2 Microorganisms

The microbial flora of septic tank sludge is similar to that of primary sludge from a municipal wastewater treatment plant. The type and number of the key organisms identified are as follows (per 100 mL):

- total coliforms, 10^7-10^9;
- fecal coliforms, 10^6-10^8;
- fecal streptococci, 10^6-10^7;
- sporulating anaerobic bacteria (primarily *Clostridium* and Bacteroides), approximately 10^5; and
- salmonellae, 1-100.

Septic tank sludge also contains various parasites, such as *Ascaris* and *Trichuris*, as well as many viruses, such as rotaviruses, the Norwalk virus, and enteric adenoviruses.

Special caution must therefore be exercised in the handling and management of septic tank sludge because, like municipal sewage sludge, it can cause various gastrointestinal infections.

8.3.3 Sludge Management

The reclamation of septic tank sludge is desirable. However, if there are no other options, the disposal of septic tank sludge at sanitary landfills is acceptable. There are four main management methods:

1) impoundment;
2) dewatering;
3) agricultural reclamation; and
4) discharge into municipal sewage systems.

In addition, composting is a promising technique that is currently being developed.

8.3.3.1 Impoundment

Impoundment is a form of anaerobic stabilization that allows inert settleable solids to separate from the liquid and sink to the bottom. The sludge is poured into lagoons, which are usually installed at sanitary landfill sites. The liquid part of the sludge seeps into the soil and is treated by natural microflora. This practice is inexpensive, but there is a risk of contamination of the water table by the lagoons. This type of management is coming under increasing criticism and is not a long-term solution, particularly in terms of public health risks.

8.3.3.2 Dewatering

Dewatering by fixed or mobile equipment produces a relatively solid "pelletable" sludge, which can be sent to a sanitary landfill for disposal. The filtrate (liquid fraction removed from the sludge) must, however, be sent to an on-site treatment system or to a municipal wastewater treatment system.

8.3.3.3 Agricultural Reclamation

The use of septic sludge in agriculture is possible, but there are two factors that pose obstacles to this practice: the cost of transporting small volumes from each septic tank; and the need to stabilize the sludge in order to destroy the pathogens and to mineralize the organic matter. Moreover, the sludge cannot be land-applied at just any time, which means that temporary storage structures must be available.

The application of raw sludge to agricultural or forest land is not recommended because the organic matter is not sufficiently broken down to meet the fertilization needs. Moreover, the presence of pathogenic microorganisms in fresh sludge must also be considered. Studies have shown that the composting of septic tank sludge is technically feasible. In addition, the resulting compost meets agronomic standards associated with available nutrients (particularly nitrogen and phosphorus), organic amendment, and the number of pathogenic microorganisms.

8.3.3.4 Discharge into Municipal Sewage Systems

Septic sludge can be discharged directly into municipal sewage systems if volumes are low relative to the capacity of the treatment plant. Treatment plants are generally not designed to treat water with high concentrations of total suspended solids and a very high BOD. This type of management is not recommended.

It is very difficult to quantify the health risks associated with the management of septic sludge because no epidemiological follow-up is carried out on persons handling septic tank sludge on a daily basis.

Table 8.3a
Handling or Land Application of Septic Tank Sludge: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations
Technological Disaster	N/A	N/A	N/A	N/A	N/A
Gas Emissions or Emissions to Air	viable microorganisms, spores, and endotoxins	pollution, unhealthy conditions	local	proper handling, application into the soil rather than onto the surface	none
Liquid Emissions or Emissions to Water	some heavy metals (mainly Fe, Al, Zn, and Cu)	toxicity to certain aquatic organisms	receiving watercourses and water table	observance of protective strips, avoidance of areas at risk	none; for Al, target value of 0.1-0.2 mg/L (MAC, drinking water)
	biodegradable organic compounds (proteins, sugars, lipids)	decrease in dissolved oxygen in water	same as above	same as above	none
	enteric bacteria and viruses	unhealthy conditions	same as above	same as above	0 fecal coli, 0 *E. coli*, 10 total coliforms/100 mL (for drinking water)
	eggs and cysts of parasites (*Cryptosporidium, Giardia*, and a few others)	unhealthy conditions	same as above	same as above	none
Solid Emissions or Emissions to Soil	some heavy metals	soil pollution	usually on the site (low mobility)	do not apply sludge too often on any given site	none
	eggs and cysts of parasites; bacteria and viruses	unhealthy conditions	usually on the site (low mobility)		none
Nuisances	odours	unhealthy conditions	site and perimeter	buffer zone, injection of sludge into soil	municipal by-laws

Table 8.3b
Handling or Land Application of Septic Tank Sludge: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	N/A	N/A	N/A	N/A	N/A
Gas Emissions or Emissions to Air	viable microorganisms, spores, and endotoxins	allergies, respiratory irritation, possible infection	vicinity	unknown	determination of microorganisms/m^3 of air in relation to exposed populations
Liquid Emissions or Emissions to Water	some heavy metals (mainly Fe, Al, Zn, and Cu)	little probability of toxic effects	consumers of polluted water	unknown	all pollutants: determination of concentration in runoff from application sites and in wells supplying drinking water
	biodegradable organic compounds (proteins, sugars, lipids)	no effects	consumers of polluted water	unknown	
	enteric bacteria and viruses	mainly gastroenteritis	consumers of polluted water	unknown	epidemiological monitoring of local populations near sites on which applications are frequently made
	eggs and cysts of parasites (*Cryptosporidium*, *Giardia*, and a few others)	parasitosis and gastroenteritis	consumers of polluted water	unknown	
Solid Emissions or Emissions to Soil	some heavy metals	see above	sludge handlers	unknown	determination of the presence of pollutants; monitoring of workers if necessary
	eggs and cysts of parasites; bacteria and viruses	see above	sludge handlers	unknown	
Nuisances	odours	quality of life	vicinity and community	unknown	complaints, perception studies

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Notes:

9 MANUFACTURING INDUSTRIES

9.1 Canadian Socioeconomic Profile

Manufacturing is a key component of Canada's economy, with some 39 000 manufacturing establishments generating 18% of the country's GDP. In 2000, the total value of shipments of manufactured goods was $787 billion. The manufacturing sector's contribution to the Canadian economy, however, has been declining steadily since 1961, when it accounted for approximately 25% of the GDP; a similar trend has also been noted in the primary sector (metals, pulp and paper, mining activities). The manufacturing sector provides employment for about 1.8 million people, or 13% of the labour force. In 1998, the average employee salary in the manufacturing sector was $35 400. In 1996, the two largest components of the manufacturing sector were transportation equipment manufacturing (22.7% of all manufacturing activity) and food processing (11.5%). Most of Canada's manufacturing (70%) is concentrated in the Windsor-Quebec City corridor.

9.2 Aluminum Production

Canada is a vital player in global aluminum production. Although the construction of aluminum smelters is not a frequent occurrence, the establishment of such companies can have a significant local and regional impact, and some pollutants can be transported over considerable distances. Aluminum production has been selected as a typical example of a large-scale metal production industry.

The main chemical exposures of concern in this industry have been fluorides (as hydrogen fluoride gas and as particulate), PAHs, and the gases CO and SO_2. Various studies of existing facilities have demonstrated worker exposures in excess of the appropriate occupational exposure limits. As well, various physical factors (heat stress, EMFs, vibration) may be problematic.

As part of the preparation for a proposed facility, it would be necessary to review each process with respect to potential emissions of exposures to the chemicals and to consider the lessons learned from previous studies/designs.

9.2.1 Socioeconomic Profile of Aluminum Production

Aluminum production is part of the primary metal industries sector (copper, iron, steel, etc.) that consists essentially of various smelting plants. Canada produces about 2.8 million tonnes of aluminum each year, or slightly more than 11% of the world's primary production (excluding recycled metal). It ranks third in aluminum production behind the United States and the republics of the former USSR. In 1995, Canadian aluminum shipments were valued at $2.5 billion, or 9.4% of the value of Canadian shipments in the primary metal industries, and aluminum production provided slightly more than 15 000 direct jobs.

9.2.2 Aluminum Production Process

Aluminum is one of the most abundant elements on Earth (8%), after oxygen and silicon. Since it does not occur in its pure form in nature, but rather as various oxides, it must be extracted from ore and produced in specialized foundries known as smelters. Aluminum is currently one of the metals most widely used in the manufacture of various objects. Aluminum production is a very energy-intensive process that requires some 13 million watt-hours (13 340 kilowatt-hours) per tonne of metal produced. It also generates a great deal of residue; 2 tonnes of alumina obtained from 2.6 tonnes of bauxite are required to make 1 tonne of aluminum. It is 99% recyclable, which allows for substantial savings in terms of energy and raw materials.

Steps in Aluminum Production

The three basic steps in the production of aluminum are:

1) extraction of alumina from bauxite;
2) electrolytic processing of alumina into aluminum; and
3) casting of ingots and making of alloys.

Step 1: Extraction of Aluminum from Bauxite: The Bayer process is used to extract alumina from bauxite. Bauxite contains hydrated alumina ($Al_2O_3 \cdot H_2O$) and various metal oxides (e.g., iron, titanium). The world's principal deposits of bauxite are in Australia, Africa, Jamaica, and Brazil. Bauxite is mixed with caustic soda (NaOH) in an autoclave to form sodium aluminate ($Na_2O \cdot Al_2O_3$). This compound is heated at 1000ºC to obtain calcined aluminum oxide (Al_2O_3), in powder form, which will undergo electrolysis. Only one Canadian aluminum smelter extracts alumina from bauxite: the Alcan smelter in Jonquière, Quebec. Other companies purchase extracted alumina from Alcan or from other producers outside Canada.

Step 2: Electrolysis: Alumina is introduced into an electrolytic (reduction) cell or "pot" filled with two molten electrolytes: cryolite (Na_3AlF_6) and aluminum fluoride (AlF_3). The cell consists of a basin (the cathode) made up of heat-refractory material and a cathode lining, in which anodes made of carbon material are suspended. A current of 60 000-300 000 amperes is passed from the anode to the cathode at a temperature of 950°C. At this temperature, the alumina is transformed into pure liquid aluminum by a reduction process (oxygen removal), according to the reaction: $2\ Al_2O_3 + 3\ C \rightarrow 4\ Al + 3\ CO_2$. Carbon (the 3 Cs) from the anodes is used in the reaction; as a result, the anodes become smaller and have to be replaced periodically. The additives (cryolite and aluminum fluoride) must also be replaced regularly because they evaporate and react with water vapour.

Step 3: Casting of Metal Alloys and the Production of Anodes: Molten aluminum settles to the bottom of the electrolytic cells, from which it is siphoned off and cast into ingots of various shapes. To increase its malleability, weldability, and mechanical strength, aluminum may be combined with metals and other elements (manganese, magnesium, copper, zinc, and silicon) to create alloys.

Anode Production

Another important part of the overall process is the production of anodes, the positive electrodes through which electrical current is run in the electrolysis pot. Because anodes are consumed in the reaction, they must be replaced periodically. Anodes are made primarily of a mixture of coke (solid residue from petroleum distillation) and pitch (residue from the distillation of coal tar). It should be pointed out that several Canadian aluminum smelters purchase prefabricated or precooked anodes from other companies.

9.2.3 Atmospheric Pollutants and Their Possible Health Effects

The extraction of alumina from bauxite, the electrolysis process, the casting of metal, and the production of anodes generally produce several types of atmospheric pollutants: particulates, SO_2, CO_2, fluorinated compounds, and PAHs.

9.2.3.1 Particulates

Eighty percent of particulates are generated by the electrolysis process and consist mainly of fluorinated particulates. Although today's aluminum smelters are equipped with air cleaning systems, some pollutants escape through roof vents. The environmental and health impacts of particulates are described in section 9.3.3.

9.2.3.2 Sulphur Dioxide

SO_2 emissions are generated mainly (98%) by electrolysis and are usually not collected or scrubbed. SO_2 can have adverse effects on plants, mostly because it is converted to sulphuric acid by contact with moisture. Conifers, lichens, and mosses are among the plants most sensitive to SO_2, which is one of the principal pollutants contributing to acid rain. The possible health effects of SO_2 are described in Appendix A.

9.2.3.3 Carbon Dioxide

Most CO_2 emissions are produced in the electrolysis process and in the production of anodes. The amount of CO_2 emissions is quite large: a company producing 370 000 tonnes/year of aluminum can release as much as 600 000 tonnes/year of this greenhouse gas into the environment, where it can have various health impacts within the context of global warming (see Appendix A).

9.2.3.4 Fluorinated Compounds

Fluorinated compounds are usually released as hydrogen fluoride (HF) associated with particulates. Ninety-nine percent of these emissions are produced by electrolytic cells. Dust control systems, however, do prevent some of these emissions from entering the environment. Fluorine is a highly reactive, very toxic halogen that is absorbed by plants that are very sensitive to it (particularly conifers). Animals, including livestock, that feed on contaminated plants can develop osteoporosis or even osteosclerosis. The permissible limit for fluorine in forage is usually of the order of 40 ppm.

Exposure to HF can lead to eye and skin irritations (> 900 $\mu g/m^3$), irritations of the respiratory tract (> 2100 $\mu g/m^3$), dental fluorosis, and osteoporosis (>1780 $\mu g/m^3$ – 8 h/day of continuous exposure). In North America, ambient air concentrations are scarcely higher than 1.9 $\mu g/m^3$. Aluminum plant workers are the most exposed, since ambient concentrations in potlines can sometimes reach 1500 $\mu g/m^3$. In Canada, the EQG for HF is 1.1 $\mu g/m^3$ in a 24-hour period.

9.2.3.5 Polycyclic Aromatic Hydrocarbons

PAHs are mostly generated in the production of anodes. These compounds belong to a family of chemicals produced by the combustion of various carbon-based materials. Although there was a substantial decrease in PAH production by the aluminum industry (-75%) between 1980 and 1995, effects on public health are possible under certain circumstances. Several PAHs are considered carcinogens or potential carcinogens. Workers are most at risk, and bladder cancer has been associated with PAH exposure. Public health risks must be assessed in terms of anticipated or measured ambient concentrations. Benzo[a]pyrene is a typical PAH, and its ambient air concentration should not exceed 0.9 ng/m^3. Concentrations usually found in the environment outside a new aluminum plant vary from 0.05 to 0.1 ng/m^3; they can be much higher, however, near old aluminum smelters (2-35 ng/m^3). The tumorigenic concentration of benzo[a]pyrene in air leading to a 5% increase in the incidence of tumours (TC_{05}) has been estimated by Health Canada to be 1.6 mg/m^3.

9.2.4 Liquid Effluents and Their Possible Health Effects

There are three main sources of liquid effluents in aluminum production:

1) process water, used mainly for cooling during metal casting and in the production of anodes. Process water contains small quantities of organic matter, aluminum, fluorides, suspended solids, oils, industrial greases, and PAHs;
2) wastewater from restroom, cafeteria, and laboratory facilities, containing suspended solids and organic matter; and
3) drainage water, which consists primarily of rainfall (or snowmelt) runoff from buildings and the land around them.

In modern aluminum smelters, these waters are normally collected and sent to a water treatment centre where most pollutants are eliminated. Suspended solids and organic matter discharges are also reduced. In a modern, environmentally sound aluminum smelter, therefore, liquid effluents have a limited impact on health and the environment. Suspended solids, organic matter, and industrial greases and oils, however, quite apart from their aesthetic impact, have a negative impact on aquatic life.

9.2.4.1 Fluorides

Fluorides can accumulate in aquatic organisms and can work their way into the water table. Too much fluorine in water can lead to dental fluorosis during the critical tooth development period in children less than six years of age and, on a longer-term basis, to osteoporosis. Daily intakes of fluoride by means of food, toothpaste, and mouthwash (17-78 µg/kg of adult body weight), however, are generally higher than all other forms of absorption. To prevent dental fluorosis, the Canadian government has set the MAC for fluorine at 1.5 mg/L in drinking water, which also corresponds to the WHO guideline.

9.2.4.2 Aluminum

Aluminum is toxic to fish and aquatic insects in concentrations exceeding 1 mg/L. This metal may also constitute a slight risk to public health. It has a low acute toxicity (1 µg/kg body weight) and is neither mutagenic nor carcinogenic. When ingested in excessive amounts, aluminum (or its salts) causes nausea, vomiting, diarrhea, and oral ulceration. Aluminum has been shown to have neurotoxic effects in some animals, but no causal link has been established between aluminum intake and Alzheimer's disease. No recommendations exist with respect to drinking water, and alum (a major source of aluminum) is almost universally used in water treatment processes (for the flocculation of suspended solids); a maximum concentration of 0.2 mg/L of aluminum would be desirable in water.

9.2.4.3 Polycyclic Aromatic Hydrocarbons

PAHs can be released directly into water (wet scrubbing of electrolytic gases, cell waste, spent anodes, maintenance waste, etc.) or be atmospheric in origin. Aluminum smelters constitute a significant potential source of PAH water pollution, the health impact of which must be given due consideration. In Canadian surface waters, the average concentration of benzo[a]pyrene is of the order of 3 ng/L. The benzo[a]pyrene concentration associated with a one-person-per-million (10^{-6}) increase in the incidence of cancer is 20 ng/L, which corresponds to a daily dosage of 0.4 ng/kg body weight. The MAC of benzo[a]pyrene in drinking water is set at 0.01 µg/L.

9.2.5 Solid Waste Residues and Their Possible Health Effects

The principal forms of solid waste residues generated by aluminum production are:

1) red mud, produced when alumina is extracted from bauxite;

2) spent potlining generated when electrolytic cells are refurbished; and

3) dross from aluminum casting.

Added to these residues are various wastes (spent anodes, aluminum pellets, domestic waste, etc.) that present a limited risk to public health.

9.2.5.1 Red Mud

Red mud is the unused portion of bauxite. Iron oxide makes up about 38% of its content, accounting for its colour. Every tonne of aluminum produced generates 1.6 tonnes of red mud. Major aluminum smelters can generate up to 500 000 tonnes of red mud annually. Red mud can be thickened prior to final disposal in specific landfills. Aside from its unpleasant appearance, it has no impact on public health.

9.2.5.2 Spent Potlining

The refractory material in the electrolytic cells, referred to as potlining, must be replaced every 5-8 years. The principal solid waste from the electrolysis process is spent potlining. A major smelting plant can generate as much as 10 000 tonnes of spent potlining annually. Because of its cyanide and fluoride content, spent potlining is considered hazardous waste and must be stored safely. If it is properly stored or recycled, it poses little risk to public health; however, its toxicity must be taken into account in the event of an industrial accident or a natural disaster (e.g., fires and floods). When exposed to water, acids, or alkaline substances, potlining can emit toxic, flammable, and potentially explosive gases (fluorides, ammonia, hydrogen cyanide, sulphur oxides, hydrogen, and acetylene). Symptoms of toxicity may arise following contact with the skin or eyes or following inhalation. Acute effects include burns to the skin and severe irritation of the respiratory tract. Spent potlining should not be transported in a warm or damp state, and care should be taken to avoid all skin contact. The risk to public health is minimized if spent potlining remains on the aluminum plant site. Plant workers receive the greatest amount of exposure.

9.2.5.3 Dross

The residue produced during ingot casting is called dross. It contains 50% aluminum, and it can react vigorously with water or moisture to produce highly toxic fluorinated gases. In today's modern aluminum plants, dross is usually recycled; however, it must be stored in argon containers to reduce its reactivity during transportation. As is the case with spent potlining, dross can release toxic, flammable, and potentially explosive gases (fluorides, ammonia, hydrogen, and acetylene) when exposed to water, acids, or alkaline substances. Exposure to vapours can lead to acute reactions, such as eye, skin, and respiratory tract irritations and bronchial spasms and dyspnea. Dross and its vapours must not come into contact with the skin or eyes.

Dross should be stored dry and protected from bad weather. The main risk to public health would stem from accidental spillage in transportation; under normal circumstances, plant workers are the group most highly exposed to dross.

9.2.6 Nuisances and Technological Risk

9.2.6.1 Noise

As with many industrial activities, noise is one of the possible nuisances that can have an impact on public health. Noise can be produced by fixed sources (e.g., ventilators, compressors, generators, and electrical transmission lines) or mobile sources (e.g., trucks and trains). Without mitigation measures, an aluminum smelter can produce an average noise level (L_{eq} 1 hour) of 55 dB at a distance of 2 km and 45 dB (L_{eq} 1 hour) at more than 3 km. With noise mitigation measures, however, intensity is reduced to 35 dB at 2 km and 25 dB at 4 km. The WHO recommends desirable maximum noise levels outdoors of 55 dBA in the daytime and 45 dBA at night.

Aluminum plants are extremely large and aesthetically unappealing facilities. Their related infrastructure (high-voltage power lines, railway lines, and roads) can also disrupt the agricultural, forest, and urban environments. A fairly broad buffer zone must be planned around a plant site, in anticipation of fluorine and PAH fallout. Aluminum plants and their infrastructure can affect local quality of life and lower residential property values. Notwithstanding the economic benefits of aluminum plants (jobs, commercial businesses, etc.), their negative social impacts should not be overlooked.

9.2.6.2 Technological risk

The potential for industrial accidents is generally confined to the plant itself and poses little risk to public health. Possible events that must be considered public health risks are:

- a break in a gas or oil pipeline resulting in an explosion, which can cause injuries up to a distance of 100 m; and
- an ammonia cloud caused by dross or potlining coming into contact with water (effects may extend as far as about 200 m from the point of incident).

In Canada, industries must develop emergency response plans that comply with the CAN/CSA Z731-M91-M95 standard published by the Standards Council of Canada.

Table 9.1a
Aluminum Production[1]: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations[2]
Technological Disaster	fires, explosions, spills, floods	toxic gases and liquids; destruction	site, perimeter, and vicinity	covering, containment, collection	CSA Z731-95, Emergency Planning for Industry
Gas Emissions or Emissions to Air	fluorides	vegetation dieback and decalcification in mammals	site, perimeter, and vicinity	scrubbers, new technologies, buffer zones	HF: 1.1 µg/m³ (24-h EQG, CCME Canada)
	SO_2	acute chronic lesions on vegetation	regional (up to 100 km)	scrubbers, non-sulphur fuel	see NAAQOs (340 ppm 1- hr, 110 ppm 24- hr, 20 ppm annual
	CO_2	greenhouse effect	global	none, other than to modify the manufacturing process	none (compliance with international commitments)
	PAHs (anodes in particular)	air pollution	local, regional, and continental	collection, or modification of the manufacturing process	0.001 µg/m³ for 87 excess cancers/million over 70 years (WHO-Europe)
Liquid Emissions or Emissions to Water	aluminum	toxicity to fish and aquatic insects	all pollutants: receiving watercourses	all pollutants in water: collection and treatment	none, operational targets between 100 and 200 µg/L
	fluorides	bioaccumulation in aquatic organisms			1.5 mg/L (MAC in Canada); 4.0 mg/L (U.S. EPA)
	dissolved organic matter and suspended solids	unhealthy conditions, reduced visibility			500 mg/L (Canada, aesthetic objective)
	oil and grease	unhealthy conditions			none
	PAHs	neoplastic and genotoxic effects			0.01 µg/L (MAC, Canada, for benzo[a]pyrene)
Solid Emissions or Emissions to Soil	used potlinings	high toxicity	site	safe containment	solid pollutants: provincial regulations on waste or hazardous waste
	dross, grit, etc.	unhealthy conditions	site	recovery, recycling	
Nuisances	noise (fixed and mobile sources)		site and perimeter	noise abatement berm; buffer zone	L_{eq} 45 dBA (night) and 55 dbA (day) WHO guidelines

[1] Impacts evaluated in the current context, excluding old polluting technologies (e.g., anodes of the Soderberg type with horizontal studs). The analysis includes anode production (carbon plant), although this is a sector not found in all smelters, but excludes the production of alumina from bauxite, a process that normally takes place outside Quebec.

[2] CSA = Canadian Standards Association; MAC = maximum acceptable concentration; EQG = environmental quality guideline; CCME = Canadian Council of Ministers of the Environment; NAAQO = national ambient air quality objectives; L_{eq} = equivalent sound pressure level.

Table 9.1b
Aluminum Production[1]: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	fires, explosions, spills, floods	respiratory irritation, asphyxia, trauma, death	workers and immediate vicinity	very rare	morbidity/mortality reports
Gas Emissions or Emissions to Air	fluorides	eye and skin irritation, dental fluorosis, osteoarthritis	workers	rare to very rare	fluorides in ambient air
	SO_2	irritation of respiratory mucosae	probably none at the concentrations emitted	rare to very rare	SO_2 in ambient air
	CO_2	climate change	global	frequent	concentration of atmospheric CO_2
	PAHs (anodes in particular)	types of cancer (mainly lung, bladder)	workers and local population	unknown	concentration of benzo[a]pyrene and other PAHs in ambient air
Liquid Emissions or Emissions to Water	aluminum	neurological problems	consumers of water from the receiving watercourse	unknown	aluminum concentration in the water
	fluorides	probably none at concentrations found	same as above	unknown	fluoride concentration in the water
	dissolved organic matter and suspended solids	formation of THMs with chlorine in drinking water	same as above	very rare to frequent	visual inspection or suspended solids levels in the water
	oil and grease	unhealthy conditions	unknown	very rare	visual inspection or oil/grease levels in the water
	PAHs	types of cancer	consumers of water or aquatic organisms	unknown or very rare	concentration of various PAHs in the water and in wildlife
Solid Emissions or Emissions to Soil	used potlinings	high toxicity, irritation of skin and respiratory tract	primarily workers	very rare	accident reports on plant incidents
	dross, grit, etc.	irritation of upper respiratory tract	primarily workers	unknown	accident reports on plant incidents
Nuisances	noise (fixed and mobile sources)	sleep quality, stress	vicinity	occasional	complaints/perception

[1] Impacts evaluated in the current context, excluding old polluting technologies (e.g., anodes of the Soderberg type with horizontal studs). The analysis includes anode production (carbon plant), although this is a sector not found in all smelters, but excludes the production of alumina from bauxite, a process that normally takes place outside Quebec.

9.3 Pulp and Paper Production

The pulp and paper industry is linked closely to Canada's forest resources. It is a strong contributor to the GDP and a major source of employment. The production of pulp and paper has a history of serious pollution problems, however, which were not effectively addressed until the start of the 1990s, when production processes were changed and waste treatment systems installed. It should be noted that pulp production generates more pollution than does the production of paper (from pulp).

Box 9.1
Exposures of Pulp and Paper Workers

An international group (Kaupinnen *et al.*, 2002) has published a paper in which 31 000 pulp and paper worker exposures to 246 chemicals, determined in 13 countries (including Canada), were compiled and analysed by means of a database devised for this purpose. The "major exposures" were to acid mist, asbestos, chlorine compounds (inorganic and volatile organic), combustion products, formaldehyde, fungal spores, oils, pulp/paper dust, solvents, reduced organic sulphur compounds, SO_2, talc, terpenes, titanium dioxide, welding fumes, and wood dust. Overall, the group found that "exposure to chemical agents turned out to be widespread and complex with frequent multiple exposures." However, in keeping with the trend towards increased mechanization and remote operation, worker exposures should decrease.

9.3.1 Socioeconomic Profile

The significance and socioeconomic impact of the Canadian pulp and paper industry may be summarized as follows:

- There are about 150 pulp and paper mills in nine of Canada's provinces.
- Canada is the world's fourth largest producer of pulp and paper, with 29 million tonnes in 1998, and the leading producer of newsprint (9 million tonnes).
- Wood pulp and paper production provided 118 000 jobs in 1999.
- In 1998, pulp and paper industry shipments were valued at $24 billion, or 5.4% of the total for the entire manufacturing sector.
- In 1998, the average salary was $62 000, which is well above the manufacturing sector average ($35 400).

9.3.2 Pulp and Paper Production Technologies

Nowadays, paper is made almost exclusively from wood fibre (cellulose) that is first broken down and suspended in water in the form of pulp. This is then poured onto a fine screen and dried to produce a sheet of paper.

Papermaking involves several basic steps:

1) debarking (removal of bark from logs);
2) washing (of debarked logs);
3) pulping (conversion of wood into pulp by a mechanical or chemical process);
4) bleaching (of pulp); and
5) sheeting and drying.

Box 9.2
Cellulose

Cellulose is a very long, linear polymer. Each link in the cellulose chain is made up of a cellobiose molecule, which is in turn composed of two glucose molecules. Cellulose chains combine to form the basic structure of wood. Since cellulose is hydrophilic, it can be easily solubilized to produce paper. Cellulose must first be separated from lignin, a substance that interferes with papermaking. Chemical and mechanical processes are used to separate these components.

9.3.2.1 Mechanical Pulping

Mechanical pulp is obtained by pressing debarked logs on rotating grindstones (pulpstones) or by grinding wood chips between two grooved steel plates (refiner). This type of pulp is generally referred to as stone groundwood pulp or refiner mechanical pulp. If wood chips are steamed before, during, and after defibrization, the resulting thermomechanical pulp is of higher quality. The addition of various chemicals makes it possible to produce a chemi-thermomechanical pulp of superior quality.

Mechanical pulps are not very resistant, and so they are used mostly for manufacturing newsprint and toilet paper. The ratio of wood fibre yield to quantity of paper is high, however, and these pulps generate less pollution because there are fewer added chemicals.

9.3.2.2 Chemical Pulping

This type of fibrization is achieved through the use of chemicals rather than grindstones or steel plates. Wood chips are cooked at about 180ºC in pressure vessels (digesters) containing acid (sulphite process) or alkaline (Kraft or sulphate process) substances. The sulphite process is less recent and uses a highly acidic solution of sulphurous acid (H_2SO_3) and bisulphite ions (HSO_3^-). The Kraft (sulphate) process uses a highly caustic solution of sodium hydroxide (NaOH) and sodium sulphide (Na_2S).

Chemical pulps are used for making highly resistant products, such as fine papers, office paper, and paperboard. Yields can be lower than in mechanical pulping, however, and these pulps, particularly those from the Kraft process, cause substantial pollution.

9.3.2.3 Pulp Bleaching

Bleaching is required for manufacturing certain types of white, more resistant paper. Mechanical pulps are bleached with hydrogen peroxide (H_2O_2), a low-polluting bleaching agent, and sodium hydrosulphite ($Na_2 S_2 O_4$). Chemical pulps are particularly dark and require a multistep bleaching process; otherwise, the end product is a brown paper used for manufacturing bags and wrapping paper (Kraft paper). The main agents used in this process are pure oxygen (O_2), hydrogen peroxide (H_2O_2), sodium hypochlorite (NaOCl), and chlorine dioxide (ClO_2). Because of its environmental impact, elemental chlorine is virtually never used in Canada anymore.

9.3.2.4 Sheeting and Drying

After any bleaching that may be necessary, pulp is applied under pressure onto a large moving canvas beneath which there is a water suction system (the traditional paper machine). The sheet of paper that gradually forms is then dried as it comes into contact with steam-heated cylinders.

9.3.3 Atmospheric Pollutants and Their Possible Health Effects

Pulp and paper mills release numerous pollutants into the air, water, and soil. Some of these substances do not pose any particular risk because of the type and location of emissions; the risks associated with others, however, are either unknown or poorly characterized. This should be taken into account in interpreting the information presented below, and technical documents or specific studies should be referred to for a better interpretation of the available information.

The following atmospheric contaminants originate primarily from chemical pulp production processes and from the adjacent thermal power plants supplying energy to the mills:

- particulates;
- CO;
- CO_2;
- sulphur compounds;
- NO_x;
- PAHs; and
- VOCs.

[For details on the health effects of these pollutants, see Appendix A.]

Unlike pollution discharges into the aquatic environment (which are discussed in the next section), no overall assessment exists of the extent to which the Canadian pulp and paper industry has reduced its various atmospheric pollutant emissions, even though it is an accepted fact that such emissions have been reduced considerably in this and other industrial sectors.

9.3.4 Liquid Effluents and Their Possible Health Effects

Most of the pollution from pulp and paper mills is in liquid form, and the principal types of pollutants contained in these effluents are:

- suspended solids;
- dissolved organic matter;
- non-chlorinated organic compounds; and
- chlorinated organic compounds.

9.3.4.1 Suspended Solids

Suspended solids consist of wood fibres, chips, fine bark, ash, and various pulp additives (clay, calcium carbonate, etc.). They settle to the bottom of watercourses and can affect aquatic life by interfering with fish breeding or by preventing access to food sources. They can also release phenols (see below), H_2S, and nutrients (nitrogen and phosphorus) that promote eutrophication. It is important to note, however, that mean suspended solid releases from Canadian paper mills have decreased considerably, from 18.7 kg/tonne of pulp produced in 1980 to 3.7 kg/tonne in 1997. No specific impact on human health is ascribed to suspended solids.

9.3.4.2 Dissolved Organic Matter

Dissolved organic matter is decomposed by bacteria that consume oxygen contained in water, creating a BOD. The resulting reduced level of dissolved oxygen in water can lead to fish mortality or affect fish respiration, growth, and reproduction. Since 1980, the average BOD generated by the production of 1 tonne of pulp has decreased considerably, from 42.8 kg to 2.2 kg in 1997. Dissolved organic matter has no direct impact on human health. Like suspended solids, however, it makes water unsafe and unsuitable for human consumption or for recreational and other uses.

9.3.4.3 Organic Compounds

The principal groups of organic compounds in liquid effluent from pulp and paper mills are listed below, and the first two of these can have an impact on human health:

- phenolic compounds;
- resin and fatty acids;
- machine lubricants; and
- a number of organic compounds used in pulp bleaching.

Phenolic Compounds

Wood, particularly softwood, contains several phenolic compounds, such as cresols and catechol. Although these substances are toxic, the chlorophenols contained in wood, which are part of the organochlorine family (see below), are of greater concern in terms of public health. Phenolic compounds are highly soluble in water; concentrations of less than 1 mg/L are sufficient to poison rainbow trout eggs and fry and to lower the metabolism of certain bacteria. At 5 µg/L, they give water an unacceptable taste and odour. Humans are rarely poisoned by phenols, which can be readily detected from their odour and taste. In Canada, a MAC of 2 µg/L for phenols in drinking water was set in 1979, but it was removed from the most recent version of the Guidelines for Canadian Drinking Water Quality (1996).

Resin Acids

Resin acids come essentially from softwoods. They include, among others, abietic and pimaric acids. Resin acids are found in all raw effluents, in concentrations of as much as 10 mg/L. Although these acids are not soluble in water, their salts are. River water acid levels, after dilution, should not exceed 0.25 mg/L in order to limit toxic effects on aquatic life. While the effects of these acids on humans are not well known, some are relatively toxic. No human health protection standards exist regarding these acids.

Chlorinated Organic Compounds

These compounds are created by the addition of at least one chlorine atom to an organic molecule (e.g., resin acids, phenols, fatty acids, alcohols, hydrocarbons). Mills using chlorine-based bleaching processes generate organochlorines. The use of chlorine dioxide also generates organochlorines, but in lesser quantities. The reduced use of chlorine and the establishment of water treatment systems have considerably decreased the presence of these compounds in paper mill effluents.

The serious human and animal health impacts of organochlorines have been known since the 1960s, from the numerous studies on organochlorine pesticides. These substances accumulate in fatty tissue and increase in concentration as they rise up the food chain, through a process called bioaccumulation. Moreover, they can remain in the environment for decades before they are completely broken down. Organochlorines (such as chlorophenols and chlorinated resin acids) have chronic effects on fish, such as reduced fertility, hepatic problems, and skeletal deformation. Twenty-seven mutagenic and some carcinogenic organochlorines, including chloroform and 2,4,6-trichlorophenol, have been found in mill effluents. As for chlorophenols, the MAC in Canadian drinking water varies from 5 to 900 µg/L, depending on the nature of the compound. The WHO has set the threshold at which the risk of cancer is raised by one case per 100 000 people (10^{-5}) over a lifetime (70 years) at 0.2 mg/L for 2,4,6-trichlorophenol.

9.3.5 Solid Waste Discharges and Their Possible Health Effects

Pulp and paper mills produce several types of residue or waste, including:

- sludge from effluent treatment facilities;
- sludge from the de-inking of old paper;
- ash from combustion facilities;
- bark and wood residue (wood chips, twigs, etc.); and
- sludge from the Kraft process (lime mud, green liquor residue, etc.).

Primary and secondary sludge from effluent treatment facilities and from the Kraft process is particularly toxic. Primary sludge results from effluent decantation and contains mostly macroscopic particles that are visible to the naked eye. Secondary sludge usually contains numerous contaminants from the pulpmaking process, such as heavy metals (zinc, cadmium, copper, chromium, lead, etc.), phenols, resin acids, chlorinated organic compounds, and various microorganisms.

Solid waste does not generally pose a threat to public health if it is buried or stored properly in sites that are closed to public access. However, sludge from wastewater treatment and from the de-inking process can harbour pathogens (microorganisms) and contain heavy metals and various undesirable substances. The risk it poses to public health is indirect and can stem from the agricultural use of sludge, which usually requires specific approval.

9.3.6 Nuisances and Technological Risks and Their Possible Health Effects

Pulp and paper mills can release foul-smelling compounds that adversely affect the quality of life and contribute to various reactions (e.g., stress, anxiety, declining property values). The following specific nuisances should also be noted: noise and visual and aesthetic impacts.

9.3.6.1 Noise

As mentioned above in section 9.2.6, noise can be produced by fixed sources (ventilators, compressors, generators, and electrical transmission lines) or mobile sources (e.g., trucks and trains). Without mitigation measures, some equipment can generate a noise level (L_{eq} 1 hour) of 55 dB at a distance of 1-2 km. With noise mitigation measures, however, intensity can be reduced to acceptable levels. The WHO's maximum noise levels outdoors are set at 55 dBA for the daytime and 45 dBA at night.

9.3.6.2 Visual and Aesthetic Impact

The visual and aesthetic impacts of pulp and paper mills are proportionate to their large size and appearance. Related infrastructure (high-voltage power lines, railway lines, roads, etc.) can also disrupt the agricultural, forest, and urban environments. The presence of a mill and its related infrastructure can affect the local quality of life and lower residential property values. The economic benefits of pulp and paper mills (jobs, commercial businesses, etc.) notwithstanding, their negative social impacts should not be overlooked.

9.3.6.3 Technological Risks

Technological risks may result from industrial accidents that are generally confined to mill sites and pose little threat to public health. Since hazardous materials are used in the production of pulp (particularly fuels as well as strong acids and bases), the risk to public health would stem from the possibility of a spill along a road or rail line or as a result of an explosion. As noted in section 9.2, in Canada, industries must develop emergency response plans that comply with the CAN/CSA Z731-M91-M95 standard published by the Standards Council of Canada.

Table 9.2a
Pulp Production: Matrix of Health Impacts: Biophysical Environment

STRESSOR/ EXPOSURE	Nature of Stressor	Impact on Environment	Affected Area	Control Measures	Standards or Recommendations
Technological Disaster	fire, explosion, chemical spill	smoke deposits, destruction, contamination	site and perimeter	collection, containment, covering	CSA Z731-95, Emergency Planning for Industry
Gas Emissions or Emissions to Air	vapour plume	reduced visibility	site	remoteness from traffic routes	none
	CO_2	greenhouse effect	global	reduction in use of fuel and biomass	compliance with international commitments (Kyoto)
	NO_x	contribution to formation of ground-level ozone and photochemical smog	local and regional	collection and treatment, increase in energy efficiency	NO_2: Canadian national objectives
	particulates	unhealthy conditions	site and vicinity	dust collector	Canadian national objectives
	sulphurous gases	contribution to formation of acid rain	local, regional, and continental	use of non-sulphur fuels	SO_2: Canadian national objectives
Liquid Emissions or Emissions to Water	suspended and dissolved matter	unhealthy conditions, reduced visibility	all pollutants: receiving watercourses	decantation, primary treatment	500 mg/L (aesthetic objective, Health Canada)
	phenols	toxicity to fish		secondary treatment	provincial regulations on drinking water or none
	resin acids	high toxicity to fish		secondary treatment	0.6 mg/kg body weight per day (U.S. EPA)
	organic matter	decrease in dissolved oxygen in water		secondary treatment	provincial regulations on drinking water or none
	organochlorine compounds	sublethal toxicity and bioaccumulation		do not use chlorine to bleach paper	variable, depending on compound (see drinking water guidelines, Health Canada)
Solid Emissions or Emissions to Soil	bark, wood, or pulp waste	unhealthy conditions (floating debris, foam)	site and perimeter	recovery, energy conversion	all solid waste: provincial or federal regulations on pulp and paper mills
	organic and inorganic matter from sedimentation sludge	unhealthy conditions, soil pollution	site or off-site landfill	burial in closed locations	
Nuisances	odours	unhealthy conditions	site, perimeter, and vicinity	buffer zone, collection and treatment	none or municipal by-laws

Table 9.2b
Pulp Production: Matrix of Health Impacts: Health Component

STRESSOR/ EXPOSURE	Nature of Stressor	Effects on Health	Population at Risk	Probability of Occurrence	Biological/Environmental Monitoring Indicators
Technological Disaster	fire, explosion, chemical spill	respiratory irritation, trauma, death	workers and vicinity	very rare	morbidity/mortality reports
Gas Emissions or Emissions to Air	vapour plume	none	local	occasional to frequent	N/A
	CO_2	climate change	global	frequent	atmospheric CO_2 concentration
	NO_x	impaired respiratory function	residents of urban and periurban environments	rare to occasional (especially in summer)	atmospheric NO_x concentration, epidemiological surveys of pulmonary disorders
	particulates	irritation of respiratory tract	vicinity (asthmatics)	rare	epidemiological monitoring, levels
	sulphurous gases	respiratory irritation	local (especially asthmatics)	rare	ambient air levels, monitoring of asthma cases received by emergency departments
Liquid Emissions or Emissions to Water	suspended and dissolved matter	unhealthy conditions	water users (swimming, boating, fishing)	occasional to frequent	visual appearance of water-course and suspended solids measurements
	phenols	bad-tasting water or aquatic organisms	consumers of water from polluted watercourse	unknown	phenol levels in drinking water
	resin acids	unknown	unknown	unknown	levels of resin acids
	organic matter	unhealthy conditions plus possible formation of THMs with chlorinated water	consumers of chlorine-treated water from polluted environment	rare to occasional	BOD plus level of THMs in drinking water
	organochlorine compounds	possibility of carcino-genic effects	consumers of contaminated water	unknown or very rare	levels of organochlorine compounds
Solid Emissions or Emissions to Soil	bark, wood, or pulp waste	unhealthy conditions (detritus on the ground), risk of injury	workers and vicinity	rare to occasional	complaints, visual appearance
	organic and inorganic matter from sedimentation sludge	unhealthy conditions (presence of vermin, insects, birds)	workers and neighbours of landfill sites	unknown	complaints, visual appearance, inspection of landfill sites
Nuisances	odours	quality of life	vicinity and community downwind	rare to frequent	complaints, perception studies

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Carcinogens

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Environment Canada. National Pollutant Release Inventory: http://www.ec.gc.ca/pdb/npri/npri_home_e.cfm

U.S. Environmental Protection Agency. Integrated Risk Information System (IRIS): http://www.epa.gov/iris/subst/index.html

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Pulp and Paper

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http://strategis.ic.gc.ca/sc_ecnmy/sio/homepage.html

Centre de Recherche en Pâtes et Papiers de l'Université du Québec à Trois-Rivières:
http://www.uqtr.ca/crpp/

Forest Products Association of Canada (FPAC): http://www.cppa.org (links to major Canadian pulp and paper mills that are members of FPAC can be found at: http://www.cppa.org/en/aboutFPAC/member_companies.html)

Pulp and Paper Research Institute of Canada: http://www.paprican.ca

Pulp and Paper Technical Association of Canada:
http://www.paptac.ca/english/layout/index.htm

Quebec Forest Industries Association: http://www.aifq.qc.ca

Technical Association of the Pulp and Paper Industry: http://www.tappi.org

Industrial Safety

Industrial Accident Prevention Association (Ontario): http://www.iapa.on.ca/

Pulp and Paper Health and Safety Association: http://www.pphsa.on.ca/

Notes:

A

Appendix A: Air Quality and Related Health Effects

[Note: The information presented in this appendix originates from the Health Canada web site: http://www.hc-sc.gc.ca/hecs-sesc/air_quality/]

Canadians are becoming increasingly aware of and concerned about the future health of the environment, and in particular the quality of the air. Although some hazardous contaminants in the air, such as lead, have declined in recent years, others remain and continue to become more problematic. Canada is a large industrialized country, responsible for the release of a variety of pollutants into the air. In addition to this, certain areas of Canada are located downwind of industrialized areas of the U.S., with resultant higher levels of pollution. Despite this, Canadians enjoy good air quality when compared to many other countries.

However, evidence gathered over the last 10 years has increased concerns about the health effects of air pollutants. As a result, governments and the public have increasingly focused on this area.

A.1 Ambient Air Quality

Air is a mixture of gases that surrounds the Earth and makes up our atmosphere. Pure air consists of 21% oxygen and 78% nitrogen by volume, plus traces of other substances and gases, both natural and anthropogenic (man-made). The air that we breathe may actually contain thousands of chemical and biological substances. Many of these are pollutants, such as: ground-level ozone (O_3), total suspended particulate (TSP), fine particulate matter less than 2.5 microns in diameter ($PM_{2.5}$) or particles less than 10 microns in diameter (PM_{10}), sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NO_x), volatile organic compounds (VOCs), sulphates (SO_4), and nitrates (NO_3).

The most commonly measured outdoor air pollutants in Canada include ground-level ozone, particulate matter, carbon monoxide, sulphur dioxide, and nitrogen oxides. These substances are the principal ingredients or precursors of *smog*, and some also contribute to acid rain.

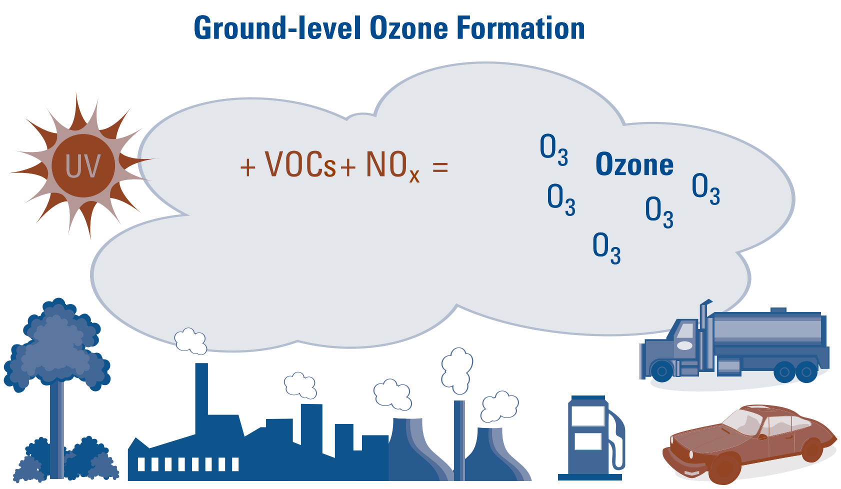
Additional air pollutants of concern include toxic metals (lead, mercury, cadmium, manganese, etc.) and compounds such as benzene, formaldehyde, polychlorinated biphenyls (PCBs), dioxins, and other persistent organic compounds.

A.2 Major Air Pollutants

Outdoor air contaminants come from both natural and human sources. Natural sources include smoke from forest fires, wind-blown dust from soil and volcanoes, bacteria, fungi, and chemicals released by plants and animals. However, air pollution is primarily associated with everyday human activities. Pollutants are released by motor vehicles, industrial processes (pulp and paper mills, ore smelters, petroleum refineries, power generating stations, and incinerators), and the burning of fossil fuels such as gas, oil, coal, and wood.

Air pollutants can be carried thousands of miles across borders and oceans or from one urban area to another. This phenomenon is common around the world and is referred to as “long-range atmospheric transport” or “trans-boundary pollution.”

A.2.1 Ground-level Ozone (O_3)



Ozone is a naturally occurring gas in the lower atmosphere that increases in concentration when volatile organic compounds (VOCs) and nitrogen oxides (NO_x) react in the presence of sunlight and stagnant air. High levels of ground-level ozone often occur during hot summer days in or downwind of heavily populated areas, where sources emit the necessary VOCs and NO_x to produce ozone.

Ground-level ozone, a primary component of smog, differs markedly from the protective blanket of ozone high above the Earth (also known as the "ozone layer" or "stratospheric" ozone), which acts to shield the Earth's surface from intense ultraviolet (UV) radiation produced by the sun.

Ground-level ozone has been linked with a broad spectrum of human health effects. Because of its reactivity, ozone can injure biological tissues and cells. Exposure to ground-level ozone for even short periods at relatively low concentrations has been found to significantly reduce lung function in healthy people during periods of exercise. This decrease in lung function is generally accompanied by other symptoms, including tightness of the chest, pain and difficulty breathing, coughing, and wheezing. The data on health effects of ozone have been examined in human epidemiological studies, and exposure to ozone has been associated with mortality, hospital admissions, emergency department visits, and other adverse health effects.

A.2.2 Nitrogen Oxides (NO_x)

Nitrogen oxides include a number of gases that are composed of oxygen and nitrogen. In the presence of sunlight these substances can transform into acidic air pollutants such as nitrate particles. The combustion of fuel for transportation, home, and industrial use accounts for approximately 94% of the emissions of nitrogen oxides produced by human activities in Canada. The nitrogen oxides family of gases can be transported long distances in our atmosphere. Nitrogen oxides play a key role in the formation of smog (ground-level ozone). At elevated levels, NO_x can impair lung function, irritate the respiratory system, and, at very high levels, make breathing difficult, especially for people who already suffer from asthma or bronchitis.

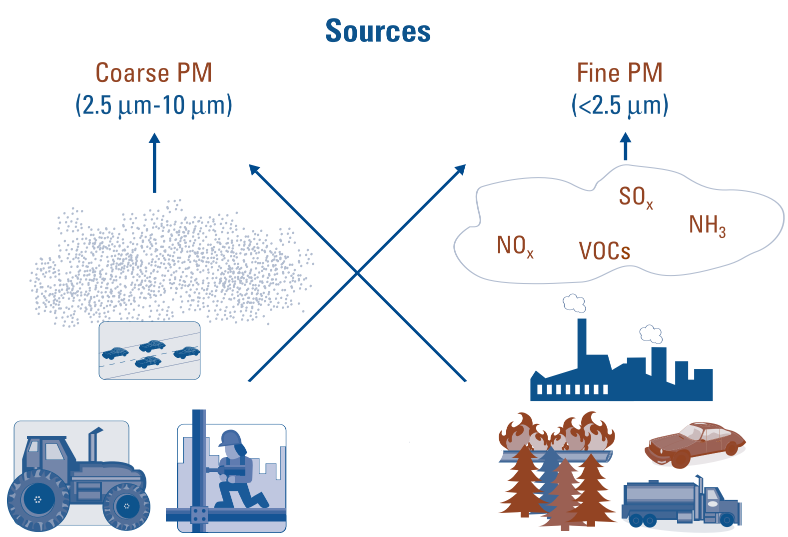
A.2.3 Sulphur Dioxide (SO_2)

SO_2 is a naturally occurring substance that becomes problematic at higher concentrations. Like nitrogen oxides, sulphur dioxide is produced primarily by industrial processes and fuel combustion. SO_2 can be chemically transformed in the atmosphere in the presence of other chemicals and sunlight to form acidic pollutants such as sulphuric acid and sulphates. SO_2 is a common air pollutant found in outdoor environments. SO_2 can cause breathing problems in people with asthma, but at relatively high levels of exposure. There is some evidence that exposure to elevated SO_2 levels may increase hospital admissions and premature deaths.

A.2.4 Volatile Organic Compounds (VOCs)

Volatile organic compounds are a group of carbon-containing compounds that tend to evaporate quickly at ordinary temperatures. VOCs are present in our atmosphere at very low levels. Generally, VOCs are found in higher concentrations indoors than outdoors. VOCs can react with nitrogen oxides to form ground-level ozone. Thousands of natural and synthetic chemicals are VOCs, including benzene, which is a natural component of crude oil and petroleum products. Some VOCs are carcinogenic, such as formaldehyde and benzene, and some are irritants as a group of precursors to ozone.

A.2.5 Airborne Particles



Airborne particles are known as “particulate matter (PM)” or simply “particles.” These particles are very small solids and/or liquids that are produced by a variety of natural and man-made sources. Airborne particles vary widely in their chemical composition and size.

The size of particles may range from 0.005 µm to 100 µm in diameter. The suspended portion (total suspended particulates or TSP, i.e. found floating in air) is generally less than 40 µm. PM_{10} are particles that are 10 µm or less in diameter. PM_{10} are split into two portions: coarse particles ($PM_{2.5\text{-}10}$) and fine particles ($PM_{2.5}$). $PM_{2.5}$ are particles of 2.5 µm or less in diameter. The finer particles pose the greatest threat to human health because they can travel deepest into the lungs. Particles are also an important component of smog. Short-term exposure to airborne particles at the levels typically found in urban areas in North America is associated with a variety of adverse effects. Particulates can irritate the eyes, nose, and throat and cause coughing, breathing difficulties, reduced lung function, and an increased use of asthma medication. Exposure to particulates is also associated with an increase in the number of emergency department visits, an increase in hospitalizations of people with cardiac and respiratory disease, and an increase in premature mortality.

A.2.6 Carbon Monoxide (CO)

The principal human source of CO is from fuel combustion, primarily vehicles. CO concentrations are much higher in urban areas due to the number of human sources, although this gas is also released by natural sources such as volcanoes and forest fires. It is an odourless gas that, when inhaled, reduces our body’s ability to use oxygen. Health effects associated with relatively low-level, short-term exposure to CO include decreased athletic performance and aggravated cardiac symptoms. At the levels typically found in large cities, CO may increase hospital admissions for cardiac diseases, and there is also evidence of an association with premature deaths.

For more information regarding atmospheric issues, see the Meteorological Service of Canada (Environment Canada) web site at the following address: http://www.msc-smc.ec.gc.ca/saib/smog/smog_e.html

A.2.7 Other Air Contaminants

A variety of other contaminants can be found in our air, such as hydrogen sulphide (H_2S), total reduced sulphur (TRS) compounds, toxic metals (cadmium, chromium, nickel, manganese), formaldehyde, polychlorinated biphenyls (PCBs), dioxins, and other persistent organic pollutants (POPs). Each is released by human sources and associated with direct effects on human health.

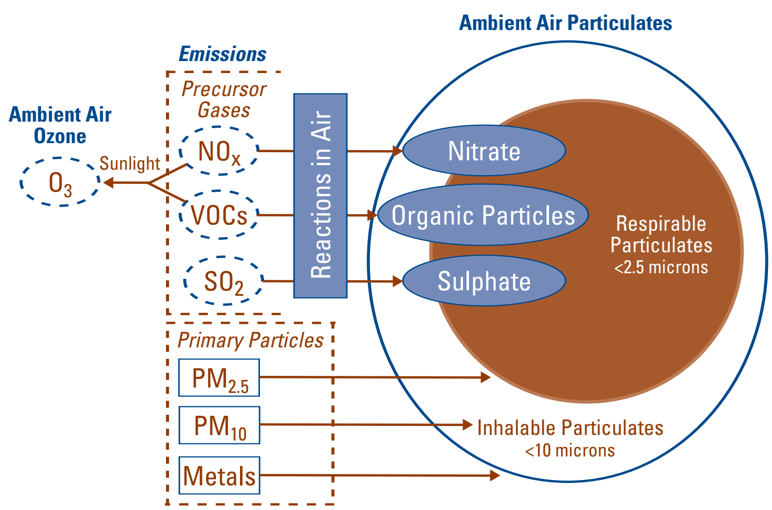
A.3 Smog

The term smog was first used to describe the combination of smoke and fog in the atmosphere. In recent years it has become the term given to the chemical soup that is often visible as a yellow-brown haze that hangs over many cities on calm summer days. Smog is a mixture of airborne chemicals that originate from or are produced by motor vehicle and industrial pollution.

A major component of smog is ground-level ozone (O_3), which is formed when two main pollutants, nitrogen oxides (NO_x) and volatile organic compounds (VOCs), react in sunlight and stagnant air. Airborne particles such as fine particles or sulphates are also an important component of smog. Because smog formation depends on heat and sunlight, smog generally peaks in late afternoon and early evening. Smog is most obvious in large cities, although suburban and rural communities are not spared. The Windsor-Quebec City corridor, the Atlantic provinces, and the Lower Fraser Valley in British Columbia have the most smog episodes in Canada.

Breathing in smog has adverse and varied consequences for human health, with the cardiorespiratory system being the main target of concern. Wherever its location and whether visible or not, smog is hazardous to human health.

Origins of Particulate Matter and Ozone



For more information on smog issues, see:

Environment Canada's Clean Air web site:
http://www.ec.gc.ca/air/introduction_e.html

Health Canada: http://www.hc-sc.gc.ca/english/iyh/environment/smog.htm/

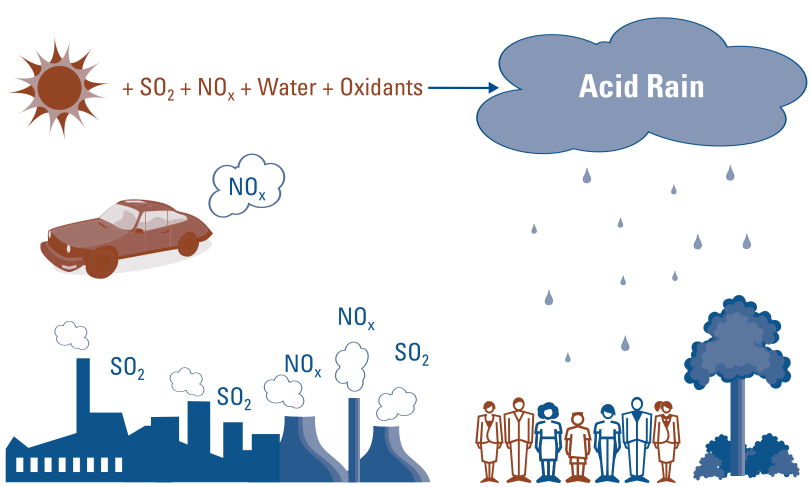
OMA-Smog: http://www.oma.org/phealth/smogmain.htm

City of Toronto: http://www.city.toronto.on.ca/health/hphe/air_quality/smog.htm

A.4 Acid Rain

Air pollution from the burning of fossil fuels is the major cause of acid rain. Acid rain is the popular name for precipitation acidified by atmospheric pollutants. Acid rain is caused by pollutants such as nitrogen oxides (NO_x) and sulphur dioxide (SO_2), which in the atmosphere are converted chemically to nitric acid and sulphuric acid. Diluted forms of these two acids fall to earth as rain or snow.

Formation of Acid Rain



More than 90% of the NO_x and SO_2 emissions occurring in North America are due to human activities. Acidic pollutants may be transported over great distances by winds and weather systems. It is estimated that more than 50% of the acid rain falling in Southern Ontario and the Atlantic region comes from U.S. sources.

Acid rain can affect lakes, forests, materials such as buildings and cars, and human health. The health concerns related to acid rain are derived primarily from the precursors SO_2 and NO_x. In the air, SO_2 can react with water and other chemicals to form very fine particles. NO_x is a precursor of ozone and particles.

For more information on this topic, see also:

Environment Canada: http://www.ec.gc.ca/acidrain/

EPA-Acid Rain Program: http://www.epa.gov/airmarkets/arp/

A.5 Climate Change

Human activities are affecting the Earth's atmosphere in ways we have never experienced before. The emissions of greenhouse gases into the atmosphere have increased at a rapid rate during the past few decades, and the large-scale combustion of fossil fuels is currently one of the biggest contributing factors affecting this kind of change. The principal greenhouse gases are:

- carbon dioxide (CO_2);
- methane (CH_4);
- chlorofluorocarbons (CFCs);
- nitrous oxide (N_2O); and
- ozone (O_3).

These gases have the ability to absorb infrared radiation from the sun and to trap this energy. The trapping of this heat is known as the greenhouse effect, which results in a global warming of the atmosphere with various impacts on Earth. Each of these greenhouse gases has unique sources and characteristics. Carbon dioxide is the most common greenhouse gas and is responsible for about half of the atmospheric heat retained by greenhouse gases. The effects of global climate change include more frequent heat waves, unstable weather systems, violent and more frequent weather events (storms, hurricanes, floods), threats to food and water supplies, and change in vector-borne disease distributions, among other things. The implications for human health are enormous.

Health Canada is involved in climate change activities. For additional information regarding the Climate Change and Health Office of Health Canada, see the following address: http://www.hc-sc.gc.ca/hecs-sesc/ccho/index.htm

For more information on this topic, see also:

Environment Canada: http://www.ec.gc.ca/climate

Government of Canada: http://www.climatechange.gc.ca/english/

Natural Resources Canada: http://www2.nrcan.gc.ca/es/es/change_e.cfm

A.6 Health Effects of Air Pollution

The human health effects of poor air quality are far-reaching, but principally involve the body's respiratory system and the cardiovascular system. Individual reactions to air pollutants depend on the type of pollutant a person is exposed to, the degree of exposure, the individual's health status, and genetics. People who exercise outdoors, for example, on hot, smoggy days increase their exposure to pollutants in the air.

The health effects caused by air pollutants may range from subtle biological and physiological changes to difficulty breathing, wheezing, coughing, and aggravation of existing respiratory and cardiac conditions. These effects can result in increased medication use, increased doctor or emergency room visits, more hospital admissions, and even premature death.

A.6.1 Heart and Lung Diseases

Heart and lung illnesses and diseases are common in Canada, and there are many factors that can increase the chances of contracting them, such as smoking and genetic predisposition. The role of air pollution as the underlying cause remains unclear but is the subject of considerable research. However, it is clear that air pollution, infections, and allergies can exacerbate these conditions. An early diagnosis can lead to appropriate treatment and ensure a normal or close to normal quality of life. In many cases, however, there is no cure, and those affected may die prematurely. The most prevalent diseases are:

- minor lung illnesses;
- lung infections;
- asthma;
- chronic obstructive pulmonary disease (COPD);
- lung cancer;
- coronary heart disease;
- heart failure; and
- heart-rhythm problems.

Minor Lung Illnesses: The common cold is the most familiar of these, with symptoms including sore throat, stuffy or runny nose, coughing, and sometimes irritation of the eyes.

Lung Infections: Croup, bronchitis, and pneumonia are caused by viruses or bacteria and are very common. Symptoms may include cough, fever, chills, and shortness of breath.

Asthma: An increasingly common chronic disease among children and adults, asthma causes shortness of breath, coughing, or wheezing or whistling in the chest. Asthma attacks can be triggered by a variety of factors, including exercise, infection, pollen, allergies, and stress. It can also be triggered by a sensitivity to non-allergic types of pollutants present in the air, such as smog.

Chronic Obstructive Pulmonary Disease (COPD): COPD is also known as chronic obstructive lung disease and encompasses two major disorders: emphysema and chronic bronchitis. Emphysema is a chronic disorder in which the walls and elasticity of the alveoli are damaged. Chronic bronchitis is characterized by inflammation of the cells lining the inside of bronchi, which increases the risk of infection and obstructs airflow in and out of the lung. Smoking is responsible for approximately 80% of COPD cases, while other forms of air pollution may also influence the development of these diseases. Symptoms include cough, production of mucus, and shortness of breath. It is important to note that no cure exists for people suffering from COPD, although healthy lifestyle and appropriate medication can help.

Lung Cancer is the most common cause of death due to cancer in women and men. Cigarette smoke contains various carcinogens and is responsible for most cases of this often fatal disease. The symptoms of lung cancer begin silently and then progress to chronic cough, wheezing, and chest pain. Air pollution has been linked somewhat weakly to lung cancer.

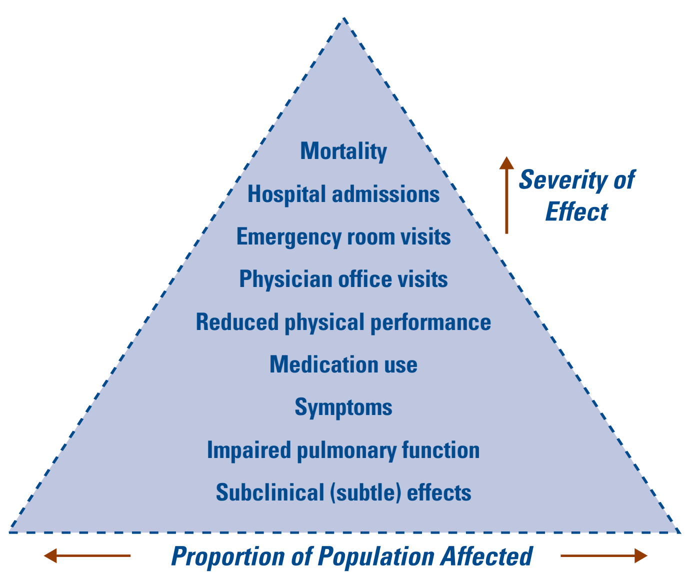
Coronary Artery Disease refers to the narrowing or blocking of the arteries or blood vessels that supply blood to the heart. This disease includes angina and heart attack, which share similar symptoms of pain or pressure in the chest. Unlike angina, the symptoms caused by heart attack do not subside with rest and may cause permanent damage to the heart. Smoking, lack of exercise, excess weight, high cholesterol levels in the blood, family history, and high blood pressure are some of the factors that may contribute to this disease.

Heart Failure is a condition in which the heart is unable to cope with its work load of pumping blood to the lungs and the rest of the body. The most common cause is severe coronary artery disease. The main symptoms are shortness of breath and swelling of the ankles and feet.

Heart-Rhythm Problems are irregular or abnormal rhythms of the heart beat. In some cases heart-rhythm problems are caused by coronary artery disease. Symptoms of heart-rhythm problems include fluttering in the chest (palpitation) and feeling light-headed. Some heart-rhythm problems are life-threatening and need emergency treatment.

A.6.2 Pyramid of Health Effects

Air pollution can affect both the respiratory and cardiac systems. The health effects of air pollution can be seen as a pyramid, with the mildest but not uncommon effects at the bottom of the pyramid, and the least common but most severe at the top of the pyramid. The pyramid demonstrates that as severity decreases, the number of people affected increases.



The health endpoints associated with increased levels of air pollutants include the following:

- mortality: all non-accidental mortality causes;
- hospital admissions: cardiovascular and respiratory hospital admissions;
- emergency room visits: visit to an emergency department;
- asthma symptom days: exacerbation of asthma symptoms in individuals with diagnosed asthma;
- restricted activity days: days spent in bed, days missed from work, and days when activities are partially restricted due to illness; and
- acute respiratory symptoms: respiratory-related symptoms such as chest discomfort, coughing, and wheezing.

A.6.3 Populations at Risk

Although everyone is at risk from the health effects of air pollution, certain sub-populations are more susceptible. Individual reactions to air contaminants depend on several factors, such as the type of pollutant, the degree of exposure, and how much of the pollutant is present. Age and health are also important factors.

The elderly and people suffering from cardiorespiratory problems such as asthma appear to be the most susceptible groups.

Children and newborns are also sensitive to the health effects of air pollution, since they take in more air than adults for their body weight and, consequently, a higher level of pollutants. People who exercise outdoors on hot and smoggy days are also at greater risk due to their increased exposure to pollutants in the air.

B

Appendix B: Occupational Health and Safety Considerations

B.1 General Considerations

According to 2002 International Labour Organization (ILO) figures, 270 million workers experience occupational accidents annually (approximately 360 000 fatally), while another 160 million workers incur occupational diseases, with about a million dying each year (ILO, 2002). There are many more whose well-being is adversely affected (without necessarily progressing to a disease in the classic biophysical sense).

Even within a health impact assessment (HIA), hazards and risks faced by workers – usually greater than in the case of the general population, by virtue of the nature of the exposure – are typically not specifically reviewed. Or, there may be a casual consideration; it might be simply assumed that the benefits of employment will outweigh any detrimental health effects of on-the-job factors and/or that the workers themselves can make the appropriate judgments.

For each project, potential worker impacts should be delineated and separately considered for each phase:

1) construction (preparation of site and facilities);

2) operation; and

3) decommissioning (“retirement”).

Potential worker impacts may be direct and/or indirect and may arise in various ways – for example, by virtue of workers bringing materials home from the worksite, either inadvertently or deliberately, but in either case inappropriately. (For more information on “take-home exposures,” see (e.g.) “Protecting Workers’ Families,” NIOSH, 2002a.)

These *hazards* (potential to cause harm) and *risks* (likelihood and severity of such occurrences) are commonly considered under an “occupational health and safety” rubric.

Safety encompasses such occurrences as traumatic (mechanical) injury (e.g., slips/trips/falls, falls from heights, cuts/amputations), fires and explosions, and electrocution.

The *factors related to health* are often categorized into:

- biological;
- chemical;
- physical;
- ergonomic; and
- psychosocial.

Such matters as “back injury” or “repetitive strain injury” would fit into the “ergonomic category”, whereas cultural demands would be considered under “psychosocial.”

In any project, workers should be protected, as a *minimum*, to the extent mandated by specific laws. In Canada, we have 14 different jurisdictions for occupational health and safety. Often there are significant differences between jurisdictions with respect to their specific requirements (the examples provided here are largely drawn from Ontario or international sites, reflecting the diversity of issues). However, in all cases there is a need to enumerate the biological, chemical, and physical factors to be encountered and to consider likely exposure level and duration scenarios. Lethal acute (short-term) exposures may occur in “confined spaces.” (This term has specific definitions in the various jurisdictions; an attempt to harmonize these nationally was unsuccessful.) Diseases may occur after longer-term (chronic) exposure, but excessive short-term exposures also need to be limited even for substances that would not be expected to have immediate effects. Post-project analysis (e.g., assessment of workers operating the facility) should be an integral part of any environmental assessment (EA) where exposures of significance are likely.

In addition to specific regulatory requirements, there is a “general duty” that everything “reasonable under the circumstances” be done to protect the health and safety of the workers. (Another phrase commonly encountered in this context is “due diligence,” often invoked as a defence that duty has been duly exercised.) It is often the case that there are no legally prescribed norms for specific factors, or those in existence may not be considered adequate for appropriate protection. Also, in view of the fact that legislation typically lags behind scientific and technical developments, other standards/guidelines would be invoked to determine what would constitute a "reasonable" action. For example, the Canadian Standards Association in 2002 issued a standard for safety boots to be worn by forestry chain saw operators; current regulatory language (Ontario) stipulates only "appropriate" footwear.

There are many resources available to assist in these efforts. For example, the Canadian Centre for Occupational Health and Safety promotes a safe and healthy working environment by providing information and advice about occupational health and safety. (See http://www.ccohs.ca/ for a compendium of relevant Canadian information and resources. The two main U.S.-based organizations in this field are at http://www.aiha.org/ and http://www.acgih.org/.)

Globally, the "especially hazardous" work sectors identified by the ILO are:

- forestry;
- agriculture;
- mining;
- construction;
- fishing;
- ship-breaking; and
- "informal" sector.

In this increasingly global society, multicultural elements may need to be addressed even within the confines of an assessment focusing on workplace issues within one province. The Industrial Accident Prevention Association (Ontario – web site: http://www.iapa.on.ca/) has developed a comprehensive set of safety rules that have been translated into 17 languages in addition to English and French (i.e., Chinese, Farsi, German, Greek, Hindi, Italian, Oji-Cree, Polish, Portuguese, Punjabi, Russian, Serbo-Croatian, Sinhalese, Spanish, Tagalog, Tamil, and Vietnamese).

With projects in less accessed locations, there is often a significant gap between the safety culture in the area and Canadian societal expectations; developing the appropriate level of control is often a challenge.

In Ontario, there has recently been added a specific legal requirement (Reg. 528/00, incumbent upon owners/employers) for "pre-start health and safety reviews" in factories. These are required if designated occupational risks may be introduced as a result of new or modified processes that are to be introduced. Before the process(es) can be started, a written report (that details compliance measures required) must be prepared and implemented. Such initiatives should serve to make project designers more likely to anticipate and consider hazards generally and to mitigate unacceptable risks in the design phase. Accordingly, the task of conducting the workplace aspect of an HIA should become progressively more developed.

B.2 Sector-specific Occupational Health and Safety Considerations

In the sections that follow, occupational health and safety considerations are presented by economic sector (e.g., energy, transportation and communication, forestry, mining, agriculture, manufacturing). [Note: These economic sectors coincide with the chapter headings of Volume 4 of this *Canadian Handbook on Health Impact Assessment*; the sector-specific occupational health and safety comments below are presented by Volume 4 chapter and section, but only those sections and their respective section numbers for which occupational health and safety considerations apply are listed (i.e., some sections do not have any such considerations).]

2. Energy

2.2 Hydro-electric Dams

2.2.1 Construction Phase

The construction activities of most large projects can be divided into two categories/sequences from an occupational health and safety standpoint:

1) site preparation/excavation; and
2) fabrication/erection of superstructure. [Note: There is also "deconstruction," i.e., as part of the (eventual/ultimate) decommissioning phase, which has the additional and often dominant risk factors associated with the materials processed/produced during the life of the facility (e.g., toxic and/or explosive chemicals, radionuclides), as well as the potentially decreased structural integrity due to renovations and/or wear and tear. However, this is very much a hazard-specific consideration (epitomized by the nuclear, biological warfare, and pharmaceutical industries) and will not be specifically considered here.]

The risks inherent in site preparation/excavation to a large extent may depend on the local geology and are in turn shared with projects such as mining.

Generally, injuries/fatalities may arise due to activities such as blasting and the use of heavy equipment. These risks are compounded in areas of confinement (e.g., tunnels, trenches), due to physical constraints, reduced visibility, the potential for rockfalls/trenchslides, etc.

In areas composed of "hard rock" (e.g., granite), there is a need to involve more blasting, leading to a potential for exposure; and the dust generated is more toxic by virtue of its silica content (as compared with areas where the excavation may be in, for example, limestone). Even in the 1990s, there were U.S. worker deaths (e.g., in sandblasting occupations) due to "progressive massive fibrosis." The U.S. National Institute for Occupational Safety and Health (NIOSH) and two United Nations agencies, the ILO and the World Health Organization (WHO), have a major initiative targeting the global elimination of silicosis. NIOSH (1996) cautions that exposure to respirable crystalline silica dust during construction activities can cause serious or fatal respiratory disease.

Noise and vibration overexposures are prevalent in the construction trades, as are various repetitive motions that may lead to repetitive strain injuries. It is not uncommon for task noise exposures (e.g., breaking concrete pavement with a pneumatic drill) to be well in excess of 100 dBA – i.e., levels that should preclude work durations (with unprotected ears) of more than a few minutes (or less) per day.

There may also be a variety of chemical exposures – e.g., fuel combustion products, cement and other caustics, and isocyanates (lung sensitizers).

Of course, exposure to climatic factors (solar ultraviolet radiation, heat, biting insects, and "ambient" air contaminants such as ground-level ozone/smog) is greater for all outdoor workers in an exposed (particularly summertime, urban) situation (similar factors would also apply in tree planting in, for example, clear-cut zones). With respect to biting insects, they are of interest particularly since the concern about West Nile virus, and similar diseases with insect vectors, has emerged even in the Canadian climate (see section 4.4.1.2 for details on biting insects). Outdoor levels of ozone may episodically (multiple days over the summer) exceed the limits set to protect worker health, particularly for "heavy work."

The following web sites (ranging from provincial to global in intended application) are recommended for further information:

- Construction Safety Association of Ontario: http://www.csao.org/; Content: Erecting and dismantling frame shoring towers; masonry scaffold erection procedures; health risks for heavy equipment operators; musculoskeletal injuries in the masonry trade; cement hazards and controls; carbon monoxide poisoning alert; heat stress, etc.

- U.S. National Institute for Occupational Safety and Health (NIOSH): http://www.cdc.gov/niosh/elcosh.html; Electronic Library of Construction Safety and Health
- International Labour Organization (ILO): http://www.ilo.org/public/english/protection/safework; SafeWork

From the ILO web site is drawn the following listing of the health and safety concerns that may be associated with the operation of a heavy truck; this is to serve as an example of one worker category that would be found in construction and operation of many projects.

Accident Hazards:

- Slips, trips, and falls from a tall cabin, cabin ladder, or trailer
- Overturning of heavily loaded truck due to mechanical failure, difficult road conditions and/or excessive speed, head-on collisions, etc., with resulting life-threatening trapping of driver inside cabin or under the truck
- Injuries due to accidental bumping into unguarded rigid parts of truck or cargo
- Injuries while performing various functions of a heavy truck driver (e.g., field repair-work, tire change, unfastening tight bands and ropes, etc.)
- Danger of being crushed between tractor and trailer, or between trailers, while trying to disengage one from another
- Accidents caused by uncoupling the locking device securing the tractor to the trailer
- Traumas, such as hernia rupture, due to physical overexertion (changing tires, moving heavy pieces of cargo, fastening ropes, etc.)
- Explosions, chemical burns, acute intoxication by dangerous chemicals, etc., caused by hazardous cargo, such as explosives and flammables, strong chemicals, toxic substances, and dust-forming bulk solids
- Acute poisoning by exhaust gases, including carbon monoxide
- Increased risk of road accidents due to lengthy driving periods (especially for long-haul truck drivers), including at night, in bad weather and with poor road conditions, and through traffic jams (risk is increased by fatigue due to long driving hours, short rest periods, drowsiness, hunger and thirst, use of alcohol, and driving at high speeds due to the bonus wages system)

- Fire hazards from spills and leaks of inflammables (usually in tank-trucks) that may ignite on contact with open flame, hot surfaces, electric sparks, atmospheric or electrostatic discharges, or as a result of mechanical shock following collision, etc.
- Explosion of over-inflated tires, car battery

Physical Hazards:

- Exposure to prolonged engine noise of high amplitude (>80 dBA) and/or low frequency, resulting in early (severe headache) or delayed (e.g., hearing loss) detrimental effects
- Exposure to ionizing radiation while transporting radioisotopes (frequently kept, for security reasons, inside the driver's cabin)
- Exposure to direct and reflected ultraviolet (solar) radiation
- Exposure to potentially health-detrimental climatic factors, such as extreme cold or heat, or combinations of temperature, humidity and wind, resulting in frostbite or heat stroke
- Exposure to sudden ambient temperature changes when leaving and entering the climatic-conditioned cabin, resulting in colds and/or rheumatic effects
- Whole-body vibrations that may impair functions of the chest, abdominal organs, and musculoskeletal system, contribute to driver's fatigue and decrease his/her [concentration]

Chemical Hazards:

- Exposure to various toxic substances (in solid, liquid, or gaseous state) while transporting hazardous cargo
- Skin diseases/conditions (dermatitis, skin sensitization, eczema, etc.) caused by chemicals (cleaning compounds, antifreeze, brake fluids, gasoline, diesel oil, oils, etc.)
- Chronic effects caused by inhalation of gasoline, diesel-fuel fumes and other exhaust fumes containing carbon monoxide, nitrogen oxides (NO_x), hydrocarbons, etc.
- Exposure to dust (especially on desert roads, etc.)
- Exposure to various automobile fluids (e.g., battery fluid, brake fluid)

Biological Hazards:

- Contamination and infection caused by exposure to biologically hazardous cargo

Ergonomic, Psychosocial, and Organizational Factors:

- Pains in the low back and in the joints (of legs and hands/arms) caused by prolonged driving, sometimes over bumpy roads; and/or inadequate seat
- Overexertion while moving or otherwise handling bulky and heavy loads, equipment, etc.
- Digestive tract disorders caused by irregular eating, bad diet habits, and stress
- Hypnotic hallucinations during periods of drowsiness, and psychotic disorders caused by mental and emotional stress factors
- Smoking inside cabin, contributing to health deterioration
- Visual discomfort and eye problems caused by inadequate illumination and eyestrain (especially when driving at dark times on interurban roads)
- Exposure to peer violence (e.g., in roadside cafeterias, etc.) and to petty and gang (including organized) crime attracted by valuable cargo
- Development of lumbago due to poor vehicle suspension, uncomfortable seat, etc.
- Psychological discomfort, as a result of possible control by cellular phone or radio communication equipment

2.2.2 Operational Phase

Some of the specific health ("physical") and safety factors to be considered in hydro-electric generating station operations include (respectively):

- high magnetic fields, noise, and heat; and
- confined spaces, drowning, electrocution, etc.

There is ongoing concern regarding the numbers of workers injured/killed by contact with electricity in all industrial sectors. Further information is provided at: http://www.eusa.on.ca/

3. Transportation and Communication

3.1 Road Construction

3.1.2 Temporary Impacts of Road Construction or Repair

The site preparation/excavation phase impacts are as discussed (generically) under Chapter 2 (Energy), with the additional consideration of such factors as the danger of public road traffic, if this construction overlaps with existing roadways. Injuries/fatalities due to vehicles striking construction workers have led to various precautionary measures in many jurisdictions, ranging from higher penalties for the public's violation of posted speed limits to a requirement that the construction crews be protected by appropriate physical barriers. Accordingly, such matters (even where not mandated by law) would need to be factored into the HIA. And, where part of the site preparation involves the demolition/modification of existing concrete structures, there is an (often-unrecognized) potential for silica exposure (NIOSH, 1996).

The laying-down of the road surface is associated with exposure to additional materials such as asphalt and the various additives that it may incorporate. There has been sufficient concern about asphalt exposures to lead NIOSH to produce an information compendium (which may be found at http://www.cdc.gov/niosh/01-110pd.html) and to undertake a program leading to "Engineering Control Guidelines for Hot-Mix Asphalt Pavers, Part I, New Highway-Class Pavers" (NIOSH, 1997).

Operation

A highway (or any situation in which objects weighing several tonnes are moving at velocities in excess of 100 km/h, subject to human control and the vagaries of weather and breakdowns) is an area of significant risk. From an occupational standpoint, NIOSH reported that in 1997 motor vehicle-related incidents were the leading cause of fatal workplace injury (this excluded incidents that occurred while driving to or from work) (NIOSH, 2000). An information sheet, intended for the truck driver, is available at: http://www.thsao.on.ca/publications/trucking_operations.html.

4. Forestry

As might be imagined, tree felling is one of the more dangerous jobs in forest work, by virtue of the heavy physical workload, the equipment used (e.g., chain saws), the not always predictable behaviour of timber (especially with "hung-up" trees, also known as "widow-makers"), and the environmental conditions (e.g., undergrowth, rain, heat/cold) in which this work is conducted. The chain saw has been described as "clearly the single most dangerous tool in forestry" (Poschen, 1998) and is expected to remain a key problem. In addition to cuts (particularly to legs, feet, back, and hands), fractures and dislocations are other common injuries. Safe work requires training and good judgment/rules (e.g., with respect to the appropriate manner for bringing down "hung-up" trees); a common experience is that full-time forestry workers have 2-4 times fewer accidents than do seasonally employed workers. There has been increasing mechanization, which also reduces accidents (as well as the number of jobs); for the same amount of timber harvested, machine operators have perhaps one fifth the accidents as compared with chain saw operators (Poschen, 1998).

There has been an increasing occupational disease problem in forestry. While conditions such as hearing loss and back injuries/pain persist, upper body complaints among machine operators are increasing in prevalence.

Hand-arm vibration (leading to conditions such as "vibration white finger") has been limited by improved equipment design and personnel education.

In addition to manual cutting and herbicide use, another issue that might be considered is reforestation; this also incorporates the issue of the "young worker." The 18-minute video "Survival of the Fittest," at http://www.ofswa.on.ca/new_products/survival.html, and associated material, provides background:

> "Every year in Ontario, more than 5,000 workers are employed in what some seasoned veterans call the toughest job they will ever do: tree planting. This video examines some of the most severe risks for strain and sprain injuries and, through observations made by experienced tree planters, outlines key injury prevention strategies."
>
> [Source: http://www.ofswa.on.ca/new_products/survival.html]

In addition to "stand and terrain conditions; infrastructure; climate; technology; work methods; work organization; economic situation; contracting arrangements; worker accommodation; and education and training," worker psychosocial characteristics are an important determinant of outcomes in forestry workers.

5. Mining

Many of the safety and health controls that must be applied in this industry (e.g., blasting controls, ground support, ventilation) are the purview of highly specialized professional fields, whose practitioners will be involved in the design of the project. The occupational health and safety considerations will differ on the basis of factors such as whether the mine is "open pit" or "underground," the nature of the rock and the extracted material, and the technology.

Coal mines are particularly dangerous, because of the common presence of both coal dust and methane (in so-called "gassy" mines). The Westray (Nova Scotia) disaster in 1991 resulted in the deaths of 26 miners. In the official inquiry (Richard, 1997), it was described as:

> "... a complex mosaic of actions, omissions, mistakes, incompetence, apathy, cynicism, stupidity, and neglect.... As outdated and archaic as the present [Coal Mines Regulations] Act is, it is painfully clear that this disaster would not have occurred if there had been compliance with the Act.... Management failed, the inspectorate failed, and the mine blew up."

A broad-based and comprehensive web site is:
http://www.cdc.gov/niosh/mining/default.htm.

It includes a mining health and safety "toolbox":
http://www.cdc.gov/niosh/mining/pubs/pubs.html

5.3 Gold Mining

The excavation hazards are similar to those in construction, generally. Gold is found in hard rock, often at great depth, and in conjunction with arsenic. Accordingly, silica ("respirable quartz") is a prevalent concern, as a function of drilling, blasting, cutting rock in the extraction phase, and also crushing (in the milling phase). There may be a sharp geothermal gradient, with temperatures in deeper locations considerably higher than surface temperatures; the prevalent use of water (e.g., for dust suppression) may also compound heat stress. Other mines may operate in mountains, and the low atmospheric pressure may lead to altitude sickness. Noise and vibration exposures are prevalent.

Blasting results in the production of a variety of gases (largely oxides of nitrogen, from the explosive) that are respiratory irritants, and miners are therefore not allowed into the area until an appropriate re-entry time has elapsed. Radon gas may permeate into the mineways from uranium-bearing host rock; it contributes to lung irradiation by "ionizing radiation" and increases lung cancer risk. Diesel particulate has gained much attention with respect to its potential to cause lung cancer and, as part of the more generic atmospheric $PM_{2.5}$ fraction, various other airway and cardiac diseases.

With respect to the use of cyanide, there is a comprehensive guideline, produced in South Africa, at http://www.bullion.org.za/Departments/Enviroment/PDFs/Cyanide%20Guidelines%20new/SAGuidelineonCyanide.pdf

6. Agriculture

As indicated by NIOSH:

> "Agriculture ranks among the most hazardous industries. Farmers are at very high risk for fatal and nonfatal injuries. Farming is one of the few industries in which the families (who often share the work and live on the premises) are also at risk for fatal and nonfatal injuries."
>
> [Source: http://www.cdc.gov/niosh/injury/traumaagric.html]

6.3 Pesticide Use in Apple Production

[It is important to emphasize that the insecticides (organophosphates, etc.), as compared to herbicides, are highly acutely toxic to humans.]

A Canadian resource site is http://www.fsai.on.ca/. Information topics include: Strict Rules Apply to Pesticide Handling and Storage; Agricultural Mower Safety; Forklift Precautions; Harvesting Safety; Agricultural Machinery Hazards; For Safety's Sake, Take the Time to Train New Workers; Confined Space Entry in Agriculture; Combustion Fumes Harbour Silent Killer; Flowing Grain Entrapment; Rodents Carry Potentially Lethal Hanta Virus; Manure Gas Can Be a Killer; Dangers of Heat Stress; Prevent Tractor Overturns; Protect Yourself Against the Sun; Safe Lifting & Carrying Techniques; and Slips, Trips & Falls. (Many of these are available in several languages.)

7. Waste Management

The processing of waste is rendered problematic by the fact that unknown materials may be encountered. [There are (for example) instances of domestic refuse collectors experiencing life-threatening exposures.]

7.2 Landfilling

An American study (Hoskin *et al*., 1994), actually focusing on traumatic fatality at hazardous waste site remediation projects (incorporating three alternative methods: excavation/landfill, capping, capping/slurry-wall), found that the riskiest jobs were those of truck driver followed by labourer, oiler, and bulldozer operator. In comparing the three remediation alternatives, the risk of experiencing at least one fatality was found to be more than 10 times greater for the excavation/landfill approach, relative to the other two methods.

Construction (and facility maintenance) activities are often more dangerous than routine operations. For example, at a garbage dump in Montreal, a worker climbed down into a 3-m-deep trench (being dug to install drainage piping) to retrieve his safety helmet (which he had accidentally dropped); he died as a result of inhaling the gases that had accumulated.

7.3 Incineration

In one Ontario study (Mozzon *et al*., 1987), air samples were collected during the transfer, incineration, and landfilling of refuse. Although "representative annual exposure profiles" were not developed, this work demonstrated that, during the warmer and dryer part of the year, dust and respirable quartz (with significant exposures – up to twice the threshold limit value – found at all sites) were issues of concern.

8. Wastewater and Sludge Management

8.1 Wastewater Treatment Plant Construction and Operation

A major environmental factor category of concern is the "biological" – i.e., (formerly) living organisms and/or their products. The possible consequences of exposure would include infection by various pathogens (i.e., disease-causing organisms – bacteria, viruses, protozoa, and helminths (parasitic worms)).

Three cases of hepatitis A were reported among workers in a wastewater treatment facility built in 1991 (De Serres and Laliberte, 1997). Possible routes of contamination included direct splashes by water/sludge, aerosols (considered abundant at this site), and hand contamination (they did wash their hands prior to eating, but did not change their clothing).

There is also an acute risk associated with the gases produced by microorganisms in bulk/containment. In one instance in Kentucky, an operator and a shift foreman died as a result of entering a sludge distribution chamber, which was subsequently found to have an airborne concentration of hydrogen sulphide greater than 500 ppm; the concentration considered "immediately dangerous to life or health" (NIOSH) is 100 ppm.

8.2 Management of Municipal Wastewater Treatment Sludge

Some biosolids (a more politically correct term than "sludge") may contain the same types of pathogens as the source sewage, at reduced concentrations. NIOSH has pointed out that U.S. Environmental Protection Agency "Class A biosolids have undergone treatment to the point where the concentration of pathogens is reduced to levels low enough that no additional restrictions or special handling precautions are required by federal regulations [40 CFR Part 503]" (NIOSH, 2002b). Nonetheless, NIOSH (2002b) has prepared guidelines to protect workers, under the following headings:

- Provide basic hygiene recommendations for workers.
- Provide appropriate protective equipment, hygiene stations, and training.
- Extend good environmental practices to prevent and minimize occupational exposures. [Details on each of these are included in the NIOSH (2002b) document.]

9. Manufacturing Industries

9.2 Aluminum Production

The main chemical exposures of concern in this industry have been fluorides (as hydrogen fluoride gas and as particulate), polycyclic aromatic hydrocarbons (PAHs), and the gases carbon monoxide and sulphur dioxide. Various studies of existing facilities have demonstrated worker exposures in excess of the appropriate occupational exposure limits. As well, various physical factors (heat stress, electromagnetic fields, vibration) may be problematic.

As part of the preparation for a proposed facility, it would be necessary to review each process with respect to potential emissions/exposures of the chemicals and to consider the lessons learned from previous studies/designs.

9.3 Pulp and Paper Production

The Ontario industry health and safety association web site is at http://www.pphsa.on.ca/. Worker exposures to airborne contaminants are primarily to sulphur (hydrogen sulphide, methyl mercaptan, sulphur dioxide, sulphuric acid, etc.) and chlorine compounds.

An international group (Kaupinnen *et al*., 2002) has published a paper in which 31 000 pulp and paper worker exposures to 246 chemicals, determined in 13 countries (including Canada), were compiled and analysed by means of a database devised for this purpose. The “major exposures” were to acid mist, asbestos, chlorine compounds (inorganic and volatile organic), combustion products, formaldehyde, fungal spores, oils, pulp/paper dust, solvents, reduced organic sulphur compounds, sulphur dioxide, talc, terpenes, titanium dioxide, welding fumes, and wood dust. Overall, the group found that “exposure to chemical agents turned out to be widespread and complex with frequent multiple exposures.” However, in keeping with the trend towards increased mechanization and remote operation, worker exposures should decrease.

The Industrial Accident Prevention Association (Ontario) web site is at: http://www.iapa.on.ca/.

For an example of a specific Canadian workplace task study (from an ergonomics/materials-handling standpoint), please refer to the case study “Bottle Recycling Department of a Brewery” at: http://www.ccohs.ca/oshanswers/occup_workplace/brewery.html.

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Notes:

C

Appendix C: Glossary (Volumes 1-4)

Abiotic: 1) Having no life; lifeless; 2) independent of the vital processes of a living organism.

Actinomycetes: Any one of a group of bacteria found in soil that are structurally similar to certain fungi. Antibiotics such as streptomycin and chloramphenicol are derived from some actinomycetes.

Acute (toxicity): Toxicity manifested within a relatively short time interval after toxicant exposure (i.e., as short as a few minutes to as long as several days). Such toxicity is usually caused by a single exposure to the toxicant.

Adenocarcinoma: A cancer that originates in the epithelium (a thin layer or layers of cells forming a tissue that covers surfaces of the body and lines hollow organs) of a gland or duct.

Adenosine triphosphate (ATP): A compound found in the cells of organisms and consisting of adenosine and three phosphate groups. The removal of phosphate releases large amounts of energy for use in biological reactions or processes such as muscle contraction and the metabolism of sugars.

***Alternaria*:** Any one of a genus of fungi that cause fruit and vegetable blight, mould, or rot.

Alveolitis: Inflammation of the alveoli (the small air sacs of the lungs, where exchange of gases (oxygen, carbon dioxide) occurs.

Anadromous species: Species that travel up rivers from the sea to spawn (e.g., of salmon and shad).

Anaerobic bacteria: 1) Bacteria that can live without free oxygen or bacteria that cannot live in the presence of oxygen; 2) bacteria living, growing, or residing where there is no free oxygen. Some anaerobic bacteria get their oxygen from the matter released during fermentation, which takes place in the absence of free oxygen.

Anuria: The absence of urine; the inability to urinate.

Aplastic anemia: A severe anemia caused by failure of the bone marrow to produce various blood elements, such as red blood cells, as a result of exposure to, for example, certain antibiotic drugs, poisons, or ionizing radiation (e.g., large doses of X-rays), or for unknown reasons.

Audiometry: The testing of the sense of hearing.

Auxin hormone: Any hormone of a group synthesized in the protoplasm of the young, active parts of plants, which regulates plant growth and development.

Baseline status: Refers to the conditions prior to the construction and/or preparation of the development/remediation project.

Benefit transfer technique: An economic tool that uses estimates from existing research to valuate the potential health benefits and detriments of development project scenarios under consideration. The main advantage of benefit transfer is that the process is less expensive and time consuming than primary valuation techniques. The benefit transfer technique consists of five steps: 1) describe the project case; 2) identify relevant studies; 3) review relevant studies for quality and applicability; 4) transfer the benefit estimates; and 5) address uncertainty.

Bioaccumulation: Occurs when a substance is assimilated into an organism through eating another organism (plant or animal). Depending on the substance, it may be passed through the body fairly quickly or it may accumulate (concentrate) in certain tissues or organs. Small animals bioaccumulate toxic substances, for example, by feeding on smaller organisms, and as they in turn are eaten by larger animals, they pass the absorbed contaminants along to the next higher level in the food web.

Bioaerosol: A suspension of airborne particles, large molecules, or volatile compounds that are living or were released from a living organism; also defined as a suspension of non-viable microbial cells with which endotoxins can be associated. Individual aerosol particles range from submicroscopic (<0.1 μm) to greater than 100 μm in diameter.

Biological monitoring: A tool used to assess environmental or occupational exposures and involving the analysis of appropriate bodily fluids (e.g., blood, urine, exhaled breath) or tissues and comparing the results with guideline values such as maximum acceptable concentrations (MACs) or biological exposure indices (BEIs).

Biomagnification: The increase in the concentration of toxic chemicals with each new link in the food chain. For example, a pesticide sprayed on vegetation can concentrate in the fat of animals and fish that eat vegetation and then is further concentrated in the fat of meat and fish eaters, resulting in an overall biomagnification of the chemical.

Boundaries: Spatial boundaries are set on the basis of the geographical limits of project impacts. Temporal boundaries deal with the timing and the life span of the impacts arising from the project. Jurisdictional boundaries refer to the legal requirements to which the project must adhere.

Calcination: The act or operation of calcining – i.e., burning or incinerating (something) to ashes or powder.

Canadian Environmental Assessment Agency: Federal government organization that administers the *Canadian Environmental Assessment Act* and reports directly to the Minister of the Environment.

Carboxyhemoglobin: The compound formed in the blood when inhaled carbon monoxide combines with hemoglobin, thereby restricting the amount of oxygen that the blood can carry; the resulting condition is known as carboxyhemoglobinemia.

Case-control study: (Syn: case-referent study, case comparison study) A type of observational analytical study. Enrolment in the study is based on the presence ("case") or absence ("control") of a disease of interest. Histories of previous exposures to some suspected risk factor(s) are then compared between cases and controls, controlling for potential "confounders." Causal factors should occur more frequently among cases than among controls.

Central agency: Component of government playing a key role in the successful formulation and implementation of government policies and programs by overseeing interdepartmental mechanisms of information-sharing, consultation, and coordination. In the case of the Canadian federal government, the Privy Council Office, Treasury Board, and the Department of Finance are its central agencies.

Chronic (toxicity): The adverse effects manifested after a long period of uptake of small quantities of a toxicant. The most serious manifestation of chronic toxicity is carcinogenesis, but other types of chronic toxicity are also known (e.g., reproductive and neural effects).

Clastogenic: Causing chromosome breaks and aberrations.

Cohort: A well-defined group of people who have had a common experience or exposure and who are then followed up after entry in the cohort (e.g., date of hire, date of birth, date of moving into a neighbourhood) for the incidence of new diseases or events, as in a cohort or prospective study. A group of people born during a particular period or year is called a birth cohort.

Cohort study: (Syn: follow-up, longitudinal, or incidence study) A type of observational analytical study. Enrolment in the study is based on membership in a "cohort" and on exposure characteristics. Disease, death, or other outcome rates are ascertained over the follow-up period and are compared between different exposure subsets of the cohort.

Confounding: The undesired mixing of effects of extraneous risk factors with the main effect of the targeted risk factor(s). The influence of cofactors (e.g., smoking) biases (distorts) the observed main effect of interest (e.g., dusts and lung cancer). Confounding is usually controlled for by multivariate analysis and other statistical adjustment techniques.

Conjunctival congestion: Congestion of the conjunctiva, the mucous membrane that covers the front of the eyeball and the inner surface of the eyelids.

Cost-benefit analysis (benefit-cost analysis): The principal analytical framework used to evaluate public expenditure decisions. It attempts to evaluate a project before it is undertaken to help stakeholders (in the case of environmental assessment) and decision-makers determine in what form and at what scale it should be undertaken, and indeed whether it should be undertaken at all. Cost-benefit analysis involves the following steps: 1) identification of the project or projects to be analysed; 2) enumeration of all project impacts, both favourable and unfavourable, present and future, on all members of the public (e.g., a community) if a particular project is adopted; 3) valuation of these impacts in monetary terms (favourable impacts are registered as benefits, and unfavourable impacts as costs); and 4) calculation of the project's net benefits (total benefits minus total costs).

Country foods: Foods that are harvested by hunting, trapping, or fishing; and produce such as that grown in vegetable gardens and orchards or collected from naturally occurring sources (e.g., wild berries).

Creatinine: A constituent of urine produced by the breakdown of creatine (a compound found chiefly in the muscles of vertebrate animals, which is involved with supplying energy for voluntary muscle contraction); also found in blood, muscle, plants, soil, etc.

Cross-sectional study: (Syn: prevalence study) An observational study in which the presence of exposure and the presence of disease (or other health-related variables) are ascertained simultaneously at the time of the study. Participants are sampled irrespective of their disease or exposure status. While being less expensive than others, such studies have little statistical power, i.e., few cases and few people exposed. They are best used to describe prevalence of diseases or exposures in a population.

Cryptosporidiosis: A gastrointestinal infection caused by the enteric protozoan *Cryptosporidium*, usually through waterborne transmission and resulting in symptoms of gastroenteritis. The most common sources of this protozoan include domestic animals (e.g., cattle, sheep), contaminated recreational waters, drinking water treatment systems, and well and spring water.

Decibel (dB): A unit for measuring the relative intensity of sounds, equal to 1/10 of a bel. The decibel scale used for this measurement is logarithmic, with every 3-dB increase indicating a doubling of noise intensity. The term dBA is the dB sound pressure level filtered through an A filtering network to approximate human hearing response at low frequencies. The decibel is also used to describe levels of sound power and is the logarithm of sound power level. A two-fold increase in the power output of a source will result in a 3-dB increase in power level and correspondingly a 3-dB increase in sound power level at any distance from the source. Sound power level will be reduced 6 dB for every doubling of distance from a source.

Decision-makers: Persons (e.g., cabinet ministers, senior officials, regulatory authorities, etc.) who help determine if a project should be permitted to proceed.

Determinants of health: Interacting factors that influence the health status of individuals and populations and that determine health differentials and inequalities. These factors are many and varied and include biology and genetic endowment, income and social status, social support networks, education, employment and working conditions, physical environment, personal health practices and coping skills, healthy child development, and health services. These determinants of health are interlinked, and differentials in their distribution lead to health disparities in a given population.

Distributional analysis: An economic analytical technique that evaluates the distribution of project impacts across segments of the economy. For example, an economic impact analysis might examine the impacts of a project on the revenues and profits of particular industries or on employment in those industries. Economic impact analysis can help to identify the segments of the economy within the local region that stand to gain or lose from a project's development and can also help to predict the likely distribution of impacts between geographic regions.

Dose: In the context of this volume, dose refers to the contaminant intake from the consumption of a food and is measured in units of µg/kg body weight per day. It is the product of the mean of the levels of the contaminant of potential concern found in the food (C_f in µg/g) and the rate of consumption of the food (IR_f, in g/day), divided by body weight (BW, in kg); i.e., Dose = $C_f \times IR_f$ / BW.

Dyspnea: Difficult or laboured breathing.

Ecological bias and fallacy: The relationship observed between variables at an aggregate level in an ecological study does not necessarily represent the relationship that exists at an individual level. This phenomenon is said to result from an ecological bias. Inferring that the relationships at the individual level are the same as those observed at an aggregate level is called the "ecological fallacy" (an error of inference due to failure to distinguish between different levels of organization). One must be extremely careful in making inferences or generalizations about individuals based on ecological studies.

Ecological risk: The toxicological risk to an ecosystem.

Ecological study: (Syn: aggregate study, correlational study) A type of observational study in which the units of observation are populations or groups of people rather than individuals. The question asked is: Do geographical populations with a higher occurrence of a specific exposure tend also to be those with a higher occurrence of health outcomes or mortality? In ecological studies, data on aggregate measures (averages or rates) of exposure and of health outcomes are obtained for each "ecological unit of analysis" (i.e., geographically and chronologically defined populations), and the relationship between the summary exposure and outcome measures is analysed across ecological units. Ecological studies are often a preliminary step in investigating a suspected exposure-outcome relationship, particularly in the investigation of environmental health impacts, and the results from these studies should be confirmed by cohort, case-control, or cross-sectional studies.

Ecosystem: A biological community of interacting organisms and their physical environment.

Endocarditis: Inflammation of the endocardium (i.e., the smooth membrane that lines the cavities of the heart).

Endospore: 1) The inner coat or wall of a spore of certain plants; endosporium; 2) a spore formed within a cell of certain bacteria.

Endotoxin: A toxic substance that remains inside the organism (e.g., bacteria) that produces it. Endotoxins are cell wall components of Gram-negative bacteria and are inherently toxic and can lead to various problems, but this occurs mainly when they are present in very high concentrations or when the microorganisms that produce them are viable.

Enterobacteria: Intestinal bacteria, especially those belonging to a large family of rod-shaped coliform bacteria that includes the genera *Escherichia* (e.g., *E. coli*) and *Klebsiella*.

Enterotoxin: An intestinal toxin produced by certain bacteria that causes symptoms of food poisoning.

Environment: Refers to the components of the Earth and includes: 1) land, water, and air, including all layers of the atmosphere; 2) all organic and inorganic matter and living organisms; 3) the social, economic, recreational, cultural, spiritual, and aesthetic conditions and factors that influence the life of humans and communities; and 4) a part or combination of those things referred to in 1) and 3) and the interrelationships between two or more of them.

Environmental assessment: A comprehensive and systematic process designed to identify, analyse, and evaluate the environmental effects of a project in a public and participatory manner. Environmental assessment involves the use of technical experts, research and analysis, issue identification, specification of information requirements, data gathering and interpretation, impact prediction, development of mitigation proposals, external consultations, and report preparation and review. In this Handbook, the term “environmental assessment” is used synonymously with “environmental impact assessment,” “impact assessment,” etc.

The International Association for Impact Assessment defines environmental impact assessment as the process of identifying, predicting, evaluating, and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made.

Environmental assessment practitioner: Someone who is involved in the environmental assessment process (i.e., government employee, knowledgeable person in the environmental assessment field, etc.).

Environmental audit: An internal evaluation by a company or government agency, to verify its compliance with legal requirements as well as its own internal policies and standards. It is carried out by either outside consultants or employees of the company or facility from outside the work unit being audited. Audits can identify compliance problems, weaknesses in management systems, or areas of risk. The findings are documented in a written report.

Environmental effect: Any change that the project may cause in the environment, including any change it may cause to a listed wildlife species, its critical habitat or the residences of individuals of that species, as those terms are defined in subsection 2(1) of the *Species at Risk Act*; and including any effect of any such changes on health and socioeconomic conditions, on physical and cultural heritage, on the current use of lands and resources for traditional purposes by Aboriginal persons, or on any structure, site, or thing that is of historical, archaeological, paleontological, or architectural significance.

Environmental epidemiology: The application of epidemiology to suspected environmental health problems. It seeks to determine whether a link exists between diseases or health outcomes and environmental factors. Environmental epidemiological studies are used to assess the health status of populations exposed to suspected environmental sources of pollution and to identify potential health problems; to identify more vulnerable subgroups within environmentally exposed populations; to assess the health risks or effects of environmental exposures; and to assess the contribution of environmental factors to suspected environmental diseases, deaths, or other health conditions.

Epidemiology: The study of the distribution and determinants of health-related states or events in specified populations, and the application of this study to the control of health problems.

Equity assessment: An economic technique that examines the distribution of project impacts on different segments of society – i.e., across a range of demographic variables, such as income group, race or ethnicity, age, gender, and others. Equity assessments are often designed to provide information on how a project is likely to affect groups that are significantly disadvantaged (e.g., low-income households) or particularly vulnerable to adverse impacts (e.g., children or the elderly).

Erysipeloid: 1) An infectious disease, resembling erysipelas (an acute infectious disease that causes fever and chills and a rapid spreading, deep-red inflammation of the skin, caused by streptococcus), but not attended with fever, contracted by people who handle animals infected with erysipelas; 2) an acute or chronic bacterial disease of hogs, and less commonly of turkeys and sheep, characterized by enteritis, red patches on the skin, and arthritis.

Eutrophication: The accumulation of nutrients in lakes and other bodies of water, causing rapid growth of algae, which deplete the water of oxygen.

Experimental study: A study in which the investigator specifies (ideally by random allocation) the exposure category for each individual (clinical trial) or community (community trial), then follows the individuals or community to detect the effects of the exposure. Only therapeutic and preventive experimental studies can ethically be conducted on human individuals or communities. Hence, epidemiological studies conducted under health impact assessments rely on "observational" and not on experimental epidemiological studies.

Exposure ratio (ER): Also termed the Hazard Index, it is the ratio of the dose (i.e., contaminant intake from food consumption, in µg/kg body weight per day) and the toxicological reference value (TRV, also in µg/kg body weight per day) for a specific contaminant; i.e., ER = Dose/TRV.

Fetotoxic: Toxic to the fetus or embryo.

Fluorosis (dental): A disease condition characterized by a mottled tooth enamel and caused by the ingestion of excessive amounts of fluorine in drinking water. Fluorosis negatively affects tooth development, particularly in children less than six years of age, and, on a longer-term basis, leads to osteoporosis.

Genotoxic: Toxic to the genetic material (i.e., genes, made up of DNA) in an organism's cells.

Genotoxic carcinogens: Cancer-causing agents that are toxic to the genetic material (i.e., genes made up of DNA) in an organism's cells.

Giardiasis: An infection caused by the protozoan parasite *Giardia lamblia* and characterized by a form of gastroenteritis known as beaver fever. This enteric pathogen is the most commonly implicated agent in waterborne disease outbreaks in North America and other parts of the world. A waterborne outbreak often occurs as a result of human or animal fecal contamination of a water supply. Natural hosts include beaver, muskrat, and deer.

Government departments/ministries or agencies: The federal, provincial, and/or territorial government institutions partaking or providing guidance in the environmental assessment.

Health: Defined by the World Health Organization as a complete state of physical, mental, and social well-being and not merely the absence of disease or infirmity. Consistent with this definition, health has been defined in this Handbook in terms of its physical and sociocultural dimensions. "Health and well-being" is synonymous with this definition of "health" and has been used to emphasize the inclusion of physical health and sociocultural well-being. The Aboriginal definition of health is "obtaining and maintaining a balance of all aspects of the self – mental, emotional, spiritual, and physical – with and through the help and involvement of the family and the community."

Health impact assessment: A combination of procedures, methods, and tools by which a policy, program, or project may be judged as to its potential effects on the health of a population and the distribution of those effects within the population (see: http://www.who.int/hia).

Health professional: A person who has formal education and/or experience in how the environment and other factors can affect human health and well-being. This includes professionals in the medical field (i.e., doctors, nurses, epidemiologists, toxicologists, etc.), professors and experts in the social science field, and the occupational health and safety experts in government and industry.

Health promotion: The process of enabling people to increase control over and improve their health; and the combination of educational and environmental supports for actions and conditions of living conducive for health. "Environmental," in this context, usually refers to the social, political, economic, organizational, policy, and regulatory circumstances bearing on health and not the physical environment or the provision of medical services.

Helminthes: Parasitic worms.

Hepatitis: 1) Inflammation of the liver; 2) a contagious viral disease characterized by inflammation of the liver, fever, and usually jaundice. Infectious hepatitis is known as hepatitis A, and serum hepatitis as hepatitis B.

Hepatotoxic: Toxic to the liver.

Histological diagnosis: Medical diagnosis based on the analysis of the microscopic structure of the tissues and cells of animals and plants.

Immunosuppression: Suppression of the immune system. Immunosuppression may result from certain diseases such as AIDS or lymphoma or from certain drugs such as some of those used to treat cancer. Immunosuppression may also be deliberately induced with drugs, as in preparation for bone marrow or other organ transplantation to prevent the rejection of the transplant.

Incidence rate ratio: A measure of effect, the incidence rate ratio is the incidence rate of the health outcome in the exposed group relative to the incidence rate in the unexposed group. The incidence rate ratio is usually the preferred measure of effect because it accounts for duration of exposure and follow-up time for each member of the cohort(s).

Indigenous health impact assessment: The health impact assessment methods and approaches identified by indigenous communities in Canada. Indigenous health impact assessment is based on three concepts: 1) indigenous communities rely heavily on naturalized knowledge systems; 2) health impact assessment is very closely linked to environmental impact assessment; and 3) health impact assessment as a process depends on measurement and evaluation of health indicators, and indigenous communities themselves must develop their own specific community health indicators.

Leachate: Any substance that has undergone leaching – i.e., the dissolving out of soluble parts from, for example, ashes, ores, or other matter – by running water or other liquid through slowly; a substance subjected to the action of percolated water. The contaminated water or leachate in landfill sites is a complex, highly variable mixture, consisting of various organic and inorganic compounds and microorganisms. It is generated by precipitation or by other moisture that enters the landfill from the breakdown of organic matter or from ground water. It is generally characterized by a strong odour and dark brown colour and contains high levels of pollutants.

Life Indicators Wheel: An important part of the indigenous environmental assessment process, the Life Indicators Wheel holds that community health depends on some balance of the corporal and spiritual “opposites” and of the intellectual/visceral. Community life indicators (i.e., values, morale, responsibility, spirituality, economics, environment, politics, and religion) are represented on the perimeter of the wheel. The health of the community is the balance point in the centre of the wheel, and community health indicators are developed from one-on-one links across the centre (i.e., environment-morale, economics-values, politics-responsibility, and religion-spirituality). The Life Indicators Wheel and community health indicators reflect and support the values of cultural sustainability of traditional First Nations societies.

Lipopolysaccharide: A compound formed by a lipid (a type of fatty substance; includes fatty acids, oils, waxes, and steroids) and a polysaccharide (a complex sugar); e.g., bacterial lipopolysaccharides.

Meta-analysis or Bayesian approaches: Statistical methods used in the benefit transfer process to derive values from the study case and apply them to the project case, and which combine estimates from several studies of similar effects; the resulting estimates may be more accurate and reliable than point estimates or valuation functions. Meta-analysis can be used to integrate the results when many relevant studies are available; the Bayesian approach includes data on the project case as well as data from existing studies.

Methemoglobin: A compound that can be formed from nitrates and nitrites and that restricts or prevents transportation of oxygen by the blood, resulting in a condition known as methemoglobinemia. Ingesting water containing more than 10 mg/L of nitrates can, in the long term, promote methemoglobin formation.

Mitigation: The elimination, reduction, or control of a project’s adverse environmental effects, including restitution for any damage to the environment caused by such effects through replacement, restoration, compensation, or any other means.

Mucocutaneous irritation: Irritation of the mucous membranes of the skin (e.g., the lining of the nose, throat, and other cavities of the body that are open to the air; tissue containing glands that secrete mucus; mucosa).

Multifactorial: Having many contributing causes, as in, for example, the context of disease risks.

Multiple myeloma: A very painful cancer usually affecting a number of bones, originating in bone marrow, and causing lesions of the bone and of certain soft tissues such as the kidneys.

Myeloma: A malignant tumour of the bone marrow.

Myocarditis: Inflammation of the myocardium, the muscular part of the wall of the heart.

Naturalized knowledge systems: This term is used in various contexts and generally refers to traditional indigenous or Aboriginal knowledge. A key element of indigenous health impact assessment, naturalized knowledge systems are bodies of ideas, values, and concepts that social systems use to function within their environment. This process is dynamic and cumulative – i.e., it adapts itself to new technological and socioeconomic conditions as they emerge. Naturalized knowledge systems are based on the principles of respect, equity, and empowerment. They focus on the understanding of the importance of the environmental knowledge of First Nations communities and the complexity of traditional approaches to environmental systems. Naturalized knowledge systems link the observation and appreciation of the physical world with the philosophy and attitudes created and supported by the close interaction among the environment, health, and lifestyle.

Neoplastic: Having to do with a neoplasm – i.e., a new, abnormal growth of tissue, such as a tumour.

Nephrotoxic: Toxic to the kidneys.

Net efficiency criterion: Decision-making within the context of benefit-cost analysis depends on the net efficiency criterion – i.e., in any choice situation, one selects the alternative that produces the greatest net benefit. In some cases, of course, the net benefits of all alternatives evaluated may be negative – i.e., their costs outweigh their benefits; in such cases, the best alternative is to do nothing, which produces a net benefit of $0.

Neuroendocrinological system: The physiological system having to do with the nervous system and the endocrine glands (i.e., the glands that secrete hormones directly into the blood).

Neurotoxic: Being or caused by a neurotoxin; toxic to the nervous system.

Observational study: A class of epidemiological studies that are "observational" in nature, and where nature is allowed to take its course. Changes or differences in one characteristic are studied in relation to changes or differences in others, without the intervention of the investigator. There are four types of observational studies: 1) cohort; 2) case-control; 3) cross-sectional; and 4) ecological. Each study design has its own economic and scientific advantages and disadvantages.

Occupational hygiene: Generally defined as the art and science dedicated to the anticipation, recognition, evaluation, communication, and control of environmental hazards or stressors in, or arising from, the workplace that may result in injury, illness, or impaired well-being of workers and/or members of the community. These hazards or stressors can be biological, chemical, physical, ergonomic, or psychosocial. Occupational hygiene also deals with the assessment of the extent of risk posed by the hazards and the development of effective strategies to eliminate or control the risks (risk management).

Occupational hygienist: An occupational health professional with expertise in the anticipation, recognition, evaluation, communication, and control of environmental hazards in, or arising from, the workplace that may cause injury, illness, or impaired well-being of workers and/or members of the community. These hazards can be biological, chemical, physical, ergonomic, or psychosocial. The International Commission on Occupational Health uses the term "occupational health professional" to encompass occupational health physicians and nurses, occupational hygienists, ergonomists, and safety specialists (see: http://www.crboh.ca).

Odds ratio: The standard measure of effect used in case-control studies. The odds ratio is a measure of association that quantifies the relationship between an exposure and health outcome in a comparative study; also known as the cross-product ratio. In incidence case-control studies, the odds ratio approximates the incidence rate ratio.

Oocyst: A thick-walled structure in which sporozoan zygotes develop.

Opportunity cost: Represents the value of goods and services that society loses by forgoing allocation of a resource to its best alternative use. While market prices generally reflect opportunity costs, adjustments may be necessary in certain instances – e.g., when the size of a project is so substantial that it may actually influence the market price of a resource.

Organoleptic: Using various sense organs to determine flavour, texture, or other quality.

Osteoporosis: A disease in which the bone spaces or Haversian canals become enlarged and the bones become weak and brittle. It occurs especially in elderly people, causing bones to break easily and heal slowly.

Osteosclerosis: An abnormal hardening and increased density of bone, especially at the ends or outer surface, often caused by an infection or a tumour.

Paresthesia: An abnormal sensation of prickling, tingling, or itching of the skin.

PCB congeners: Each polychlorinated biphenyl (PCB) molecule consists of two six-carbon rings with one chemical bond joining a carbon from each ring. Chlorine can attach to any of the other 10 carbons. There are 209 possible arrangements called "congeners"; congeners with the same number of chlorines are called isomers. PCB molecules with the two rings in the same plane (i.e., the two rings are not twisted) are termed "coplanar." Coplanar molecules have dioxin-like properties. There are currently 13 PCB congeners listed by the World Health Organization with interim toxic equivalent factors for human intake of dioxin-like PCBs. The potential toxicity of various PCB mixtures present in the environment varies, depending on the composition of the PCB mixture.

Pericarditis: Inflammation of the pericardium, the membranous sac enclosing the heart.

Perinatal: Of or having to do with the period of a child's life including the five months preceding birth and the first month after birth.

Prevalence ratio: The prevalence of a specific health outcome in an exposed group relative to its prevalence in an unexposed group; i.e., a comparison of two groups in terms of prevalence of the specific health outcome.

Product life cycle analysis: Analysis taking a "cradle to grave" approach to thinking about products, processes, and services. It recognizes that all product life cycle stages (extracting and processing raw materials, manufacturing, transportation and distribution, use/reuse, recycling, and waste management) have environmental and economic impacts.

Project: Any proposed physical undertaking or activity required to undergo an environmental assessment. Most environmental assessment legislation defines the types of development projects subject to environmental requirements.

Proponent: An individual, organization, or company that proposes a development project.

Psychosocial (risk): Of or involving the influence of social factors or human interactive behaviour.

Public: Local residents, environmental groups, Aboriginal people, local businesses, and other citizens. Does not include proponents or government departments (see definition of stakeholder).

Putrescible: Likely to putrefy or rot.

Pyrolysis: Chemical decomposition produced by exposure to high temperatures.

Randomized controlled trial: The ideal experimental epidemiological study design, in which individuals are randomly assigned to different preventive or therapeutic interventions and are then followed prospectively to assess any differences in outcomes between the intervention ("test") groups and the control group(s). Such randomization tends to make study groups comparable in every respect that can affect the outcome. Most often, randomized controlled trial studies are conducted "blind" – i.e., participants do not know which treatment/exposure they are receiving. Ideally, randomized controlled trials are "double blind": neither the participants nor the observers (including caregivers) know which treatment/exposure is given to whom until the end of the trial.

Receptor: Refers to the human population residing in the development/remediation project area that may be exposed to potential contaminants from the consumption of country foods. In those cases where no communities exist near the project site, receptors can be humans who frequent the area to gather country foods.

Recommended maximum weekly intake (RMWI): In the context of food consumption, it is the product of the toxicological reference value (TRV, in µg/kg body weight per day) for a specific contaminant and body weight (BW, in kg), divided by the mean of the levels of the contaminant of potential concern found in the food (C_f, in µg/g); multiplied by 7 (i.e., days in a week); that is: RMWI (in g/week) = $(TRV \times BW/C_f) \times 7$.

Regional public health authorities: Provincial/territorial or regional government bodies with responsibility to address public health concerns (e.g., Medical Officers of Health).

Relative risk: (Syn: risk ratio) A ratio of the risk of some health-related event such as disease or death among the exposed group to the risk among the unexposed group. This measure is usually used in cohort studies, and sometimes in cross-sectional studies. It is sometimes used as a synonym for "odds ratio" or "incidence rate ratio" if the disease is "rare" (i.e., incidence rate <10%).

Revealed preference methods: Economic valuation methods that are based on observed behaviours that can "reveal" the values of non-market goods based on prices and preferences for related market goods or services. Revealed preference methods include wage-risk studies, cost-of-illness studies, and averting-behaviour studies.

Risk assessment: The qualitative or quantitative estimation of the likelihood of adverse effects that may result from exposure to specified health hazards or from the absence of beneficial influences. Risk assessment attempts to calculate or estimate the risk to a given target system following exposure to a particular substance, taking into account the inherent characteristics of the substance of concern as well as the characteristics of the specific target system. The process includes four steps: 1) hazard identification, 2) dose-response assessment, 3) exposure assessment, and 4) risk characterization (see: http://www.who.int/health_topics/risk_assessment).

Risk management: A decision-making process involving considerations of political, social, economic, and technical factors with relevant risk assessment information relating to a hazard so as to develop, analyse, and compare regulatory and non-regulatory options and to select and implement the optimal decisions and actions for safety from that hazard. Essentially, risk management is the combination of three steps: 1) risk evaluation; 2) emission and exposure control; and 3) risk monitoring.

Septicemia: Blood poisoning, especially in which microorganisms and their toxins enter the bloodstream.

Silviculture: The cultivation of woods or forests; the growing and tending of trees as a branch of forestry.

Social impact assessment: The process of analysing, monitoring, and managing the intended and unintended social consequences, both positive and negative, of planned interventions (policies, programs, plans, projects) and any social change processes invoked by those interventions. Its primary purpose is to bring about a more sustainable and equitable biophysical and human environment. Social impact assessment is a project planning and decision-making tool that describes the social context within which development projects are undertaken; assesses, in advance, the social impacts of a policy, program, or project on affected communities; and proposes mitigation measures to avoid, reduce, or compensate for the impacts. Social impact assessment also identifies those groups at risk or at benefit and, when possible, the extent of the impacts (see: http://www.iaia.org).

Social learning theory: Supports the ideas that people self-regulate their environments and actions and, though people are acted upon by their environments, that they also help create their surroundings.

Sociosanitary: Of or having to do with social health and well-being; favourable to social or public health. Issues such as public water supplies, sewage systems, air pollution, and radiation controls – as in the construction of dams, pipelines, incinerators, and the like – are examples of sociosanitary issues.

Spatial (scale): Of or concerning space; a geographical analytical scale for the assessment of health impacts. The zone of influence in a spatial scale varies depending on the nature of the exposure to a risk factor. For example, the zone affected by the effluent produced by a smokestack is different from the area affected by noise. When studies are based on official maps and related attributes, sometimes massive but poorly detailed scales (e.g., 1:500 000) are used, which provide a means of "overlooking" certain fragile areas or historical sites and also serve to reduce impact study costs. The Inter-American Development Bank now stipulates minimum scales (e.g., 1:50 000) for these studies in order to avoid such problems.

Sporulation: The formation of or conversion into spores or sporules (small spores), e.g., as in certain protozoa.

Stakeholder: Any individual, organization, or company that has an interest, financial or otherwise, in a project. Types of stakeholders commonly associated with environmental assessments include the proponent, government departments, local residents, environmental groups, Aboriginal people, local businesses, and others (see definition of public).

Stated preference methods: Economic methods used in valuating health effects and that typically employ survey techniques and ask respondents to state what they would pay for the anticipated reduction in adverse health effects (or what they would pay to avoid unfavourable health effects). These methods can be used to directly valuate the development project of concern and to assess the values for specific effects. Stated preference methods include contingent valuation, conjoint analysis, and risk-risk trade-offs.

Strategic environmental assessment: The systematic and comprehensive process of assessing the environmental effects or implications of a proposed strategic decision or action, policy, plan, program, and its alternatives. At the same time, strategic environmental assessment is the process of integrating the concept of sustainability into strategic decision-making. A good-quality strategic environmental assessment process informs planners, decision-makers, and affected public on the sustainability of strategic decisions, facilitates the search for the best alternative, and ensures a democratic decision-making process. This enhances the credibility of decisions and leads to more cost- and time-effective environmental assessment at the project level. For this purpose, a good-quality strategic environmental assessment process is integrated, sustainability-led, focused, accountable, participative, and iterative (see: http://www.iaia.org).

Stressor: Any stimulus that produces stress or strain.

Surveillance system: A systematic, ongoing process whose components are data collection, expert analysis and interpretation, and response (communication of information for action).

Sustainable development: Development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.

Temporal (scale): Of or concerning time. In the context of health impact assessment, "temporal" refers to an analytical scale relating to the time scale for the assessment of health impacts. For example, on a temporal scale, toxicity can be variously described as acute, chronic, or even transgenerational. Therefore, it is important to specify desirable spatial and temporal scales for every significant risk. Scale determination is crucial and can exert a considerable influence on the perceived importance of a pollution problem.

Teratogen: A substance (e.g., a drug or other agent) that causes birth defects or malformations of the embryo or fetus.

Teratogenicity: The quality of being teratogenic, i.e., the tendency to cause malformations of the embryo or fetus or birth defects.

Tetany: A condition characterized by muscle spasm or prolonged contraction of a muscle.

Threshold limit values: The most universally accepted occupational exposure limits, established by the American Conference of Governmental Industrial Hygienists.

Occupational exposure limits are not “ideal” or “target” workplace levels, but rather the current maximum acceptable (airborne) levels of contaminants. In the case of occupational exposure limits adopted by regulation, they are legal maxima. Even in situations where exposures are below the occupational exposure limits, the former should be reduced to the lowest practical levels on a matter of principle.

Time-weighted average: A time-weighted average is the “average” exposure over the working day. The time-weighted average numerical limits that are listed assume that there is an 8-hour exposure. If worker exposure occurs over a longer period and/or there is not a 16-hour period between exposures, then adjustments may have to be made to these values from a legal standpoint and/or to conform to fundamental toxicological principles.

Toxicity: The ability of a substance to produce deleterious or adverse effects in the exposed organism.

Toxicological reference values: Reference values indicating the toxicity of specific contaminants and used for risk assessment purposes. Toxicological reference values are established by appropriate agencies and are used to determine the human health risks associated with exposure to contaminants in the development/remediation project area. For example, toxicological reference values specific to food-borne contaminants and approved by Health Canada are preferable for the assessment of human health risks posed by contaminants in country foods.

Toxicological risk analysis: The determination of the probabilities and magnitude of potential toxic effects due to exposure to xenobiotics or to ionizing radiation.

Transboundary environmental impacts: Typically refers to a local source of pollution that causes environmental impacts across political perimeters.

Transgenerational (toxicity): Toxicological effects occurring in the offspring of the exposed organism.

Trihalomethanes: A class of chemical organic compounds that are chlorination by-products formed when organic matter naturally present in surface water reacts with the chlorine added during the disinfection process (chlorine treatment of drinking water).

Uremia: An abnormal condition resulting from the accumulation in the blood of waste products that should normally be eliminated in the urine. Nephritis (inflammation of the kidneys) is a frequent cause of uremia.

Valuation of health effects: An assessment of the monetary value of the health effects of a development project. If a project is expected to have a favourable effect on human health, the benefit should be valuated by gauging individuals' willingness to pay for the anticipated reduction in adverse effects. Similarly, if a project is expected to have unfavourable health effects, then individuals' willingness to pay to avoid these effects should be added to the project's cost. By valuating health effects in this manner, economic analysis can integrate such impacts into a benefit-cost framework.

Zoonosis: Any of various infectious diseases that can be transmitted under normal conditions from animals to humans (e.g., tuberculosis, rabies).

Notes: