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18.0 HUMAN HEALTH

18.1 Introduction

This section provides the methods and findings of the human health risk assessment (HHRA) portion of the Environmental Impact Assessment (EIA). The primary objective of the HHRA was to describe the nature and significance of potential health risks to humans from the emission or release of chemicals of potential concern (COPCs) from the Korea National Oil Corporation (KNOC) BlackGold Expansion Project (the project). In addition, the HHRA examined potential health risks attributable to the project, in combination with existing and approved regional developments as well as with future planned developments for the region.

18.1.1 Scope of Assessment

The overall scope of work for the HHRA was based on:

- the terms of reference (TOR) provided by Alberta Environment (AENV) (2009a); and
- health-related issues identified through the ongoing public consultation program for the project.

Further details associated with the scope of the HHRA are presented in the sections below.

18.1.1.1 Terms of Reference

The scope of the HHRA was designed to address provincial regulatory requirements established by AENV, as described in the TOR for the project (AENV 2009a). Specific health-related issues and concerns addressed by the HHRA are outlined in Part A, Section 6 (Public Health and Safety Assessment) of the TOR.

Part B Section 6 of TOR, which requires that “those aspects of the project that may have implications for public safety” be described, will be addressed as part of the emergency response plan (ERP) for the project. KNOC is currently developing a site-specific ERP for the BlackGold Initial Project that will be amended to include the project prior to commencement of operations.

18.1.1.2 Public Consultation

Public consultation conducted in support of the project is presented in [Volume 1, Section 4.0](#) of the application. Although health was not specifically raised as a key issue of concern, Aboriginal communities in the area have indicated that they are concerned with:

- an overall deterioration in environmental quality (i.e., air, water, fish, vegetation and wildlife);

- potential cumulative effects of existing and approved regional developments in combination with the project, as well as with future planned developments for the region; and
- the safety of traditional food consumption, including vegetation and wild game.

These concerns are consistent with the requirements of the TOR and are considered within the scope of the HHRA.

18.2 Study Area

18.2.1 Spatial Boundaries

The project is located approximately 10 km southeast of Conklin, Alberta within the Regional Municipality of Wood Buffalo (RWMB), which occupies 68 454 km², and has an estimated 103 334 residents in 12 communities and a number of oil sands work camps. Fort McMurray is the largest of these communities, with a population of 72 363 in 2008. Conklin is the closest community to the project, with a population of 372 (RMWB 2009).

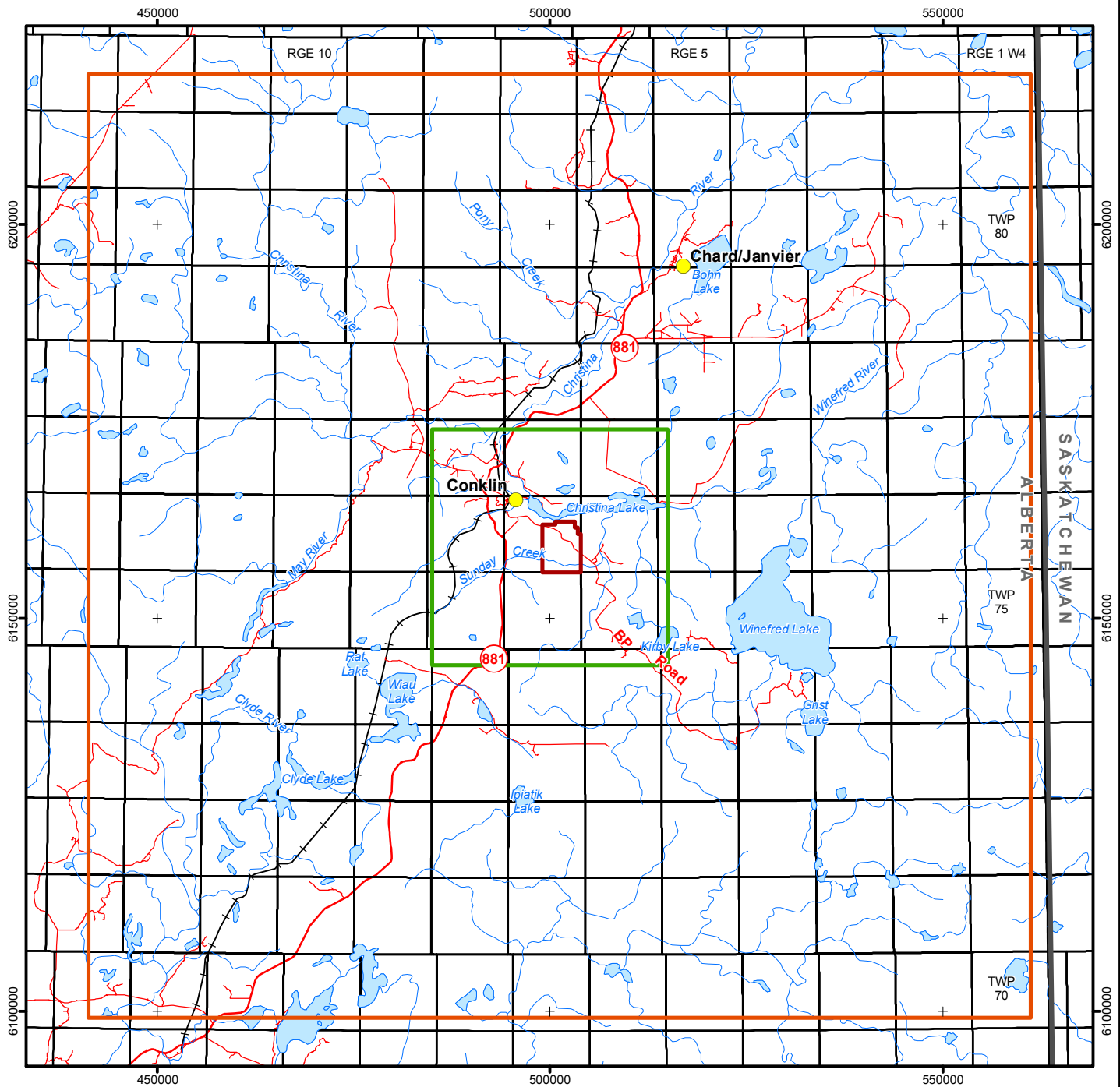
In determining the health study areas, consideration was given to the expected spatial extent of significant project air concentration contours, as well as the location of nearby communities potentially affected by air emissions from the project, such as Conklin. On this basis, the HHRA focused on potential health risks to people in the:

- local study area (LSA), which encompasses an area of approximately 30 km by 30 km centred on the central processing facility (CPF). The LSA focuses the HHRA in the immediate vicinity of the project where the majority of the potential health risks associated with the project would be expected to occur. The health LSA directly corresponds to the air quality LSA (see [Volume 4, Section 4.2.1](#)); and
- regional study area (RSA), which extends north-south about 120 km to include such communities as Janvier to the north and extends east-west 120 km to capture the potential influence of the project on the recreational areas at Winefred Lake and Grist Lake.

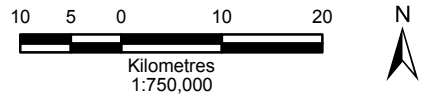
A map showing the health study areas in relation to all major air emission sources within the air quality RSA, including the project, is provided as [Figure 18.2-1](#).

18.2.2 Temporal Boundaries

Project construction is scheduled to begin in 2012, with initial production in 2015 (see [Volume 2, Section 2.1](#)). The project is expected to continue production for approximately 25 years.



- Legend**
- Health Regional Study Area
 - Health Local Study Area
 - Project Area
 - Open Water
 - Watercourse



Sources: GeoBase®, KNOC, Spatial Data Warehouse Ltd.

Korea National Oil Corporation BlackGold Expansion Project	
Health Local and Regional Study Areas	
DATE: March 2010	Figure 18.2-1
PROJECT: CE03745/600	Fig18.02-01 Study Area 10-03-31
ANALYST: TM KW EA DR	DRAWN BY: AMEC
PROJECTION/DATUM: UTM Zone 12 NAD83	PREPARED BY: Intrinsic

The HHRA assessed potential acute (short-term) and chronic (long-term) health risks to people associated with the chemicals emitted or released from the project. Acute exposure extends over a time period covering seconds to hours to a number of days, while chronic exposure occurs continuously or regularly over extended periods, lasting for periods of months through years, and possibly extending over an entire lifetime. For the purpose of the HHRA, chronic exposure was assumed to extend over a 75 year lifetime (as recommended in Health Canada 2004).

As such, the temporal scope of the HHRA extended from acute exposure durations in the order of 24 hours or less to chronic exposure durations equivalent to a lifetime. Although the operational life of the project is only expected to be 25 years, the HHRA assumed that the chemical emissions or releases attributable to the project would continue for a period of 75 years (i.e., equivalent to a person's lifespan).

18.3 Assessment Cases

Consistent with the air quality assessment (see [Volume 4, Section 4.4.1](#)) and the project TOR (AENV 2009a), potential health risks were evaluated for the following three assessment cases:

- *Baseline Case* – includes existing ambient air quality and existing and approved industrial projects or activities in the air quality RSA, which extends north-south about 409 km to include such communities as Fort Chipewyan to the north and Conklin to the south and encloses all of the major emissions sources in the Athabasca oil sands region, and extends east-west 212 km (for a total area of about 86 700 km²) to capture the potential emissions sources in the province of Saskatchewan (see [Volume 4, Section 4.2.1](#)). The approved developments include facilities that have regulatory approval by any federal, provincial or municipal regulatory authority but that are not yet in operation;
- *Application Case* – includes existing ambient air quality and existing and approved industrial projects or activities in the air quality RSA, as well as emissions from the project (i.e., Baseline Case plus the project); and
- *Planned Development Case* – includes all baseline emission sources plus the project (i.e., Application Case), and all other planned industrial projects or activities in the air quality RSA.

As part of the air quality assessment ([Volume 4, Section 4.2.1](#)), all existing, approved, and planned facilities were assumed to be operating at their maximum approved levels, including the project. As a result, the air quality predictions are likely to be conservative in nature. For a detailed description of the assessment cases and air quality assumptions, see [Volume 4, Section 4.4](#).

In addition to the three assessment cases, the incremental impacts associated with the project alone and future emission sources were evaluated. Incremental emissions associated with the project were provided by the air quality team, while future incremental impacts were evaluated by subtracting the Baseline Case from the Planned Development Case.

18.4 Assessment Methods

The HHRA examined potential acute and chronic health risks associated with the project using a conventional risk assessment paradigm. The paradigm is consistent with those developed by:

- Health Canada (Health Canada 1995, 2004);
- Canadian Council of Ministers of the Environment (CCME 2006);
- United States National Research Council (US NRC 1983, 1994); and
- United States Environmental Protection Agency (US EPA 1991; US EPA OSW 2005).

This methodology has been endorsed by regulatory authorities in Alberta, such as Alberta Health and Wellness (AHW), AENV and the Alberta Energy Resources Conservation Board (ERCB). The approach involves four steps as illustrated in the risk assessment paradigm (Figure 18.4-1).

The four steps or phases of the risk assessment paradigm involve:

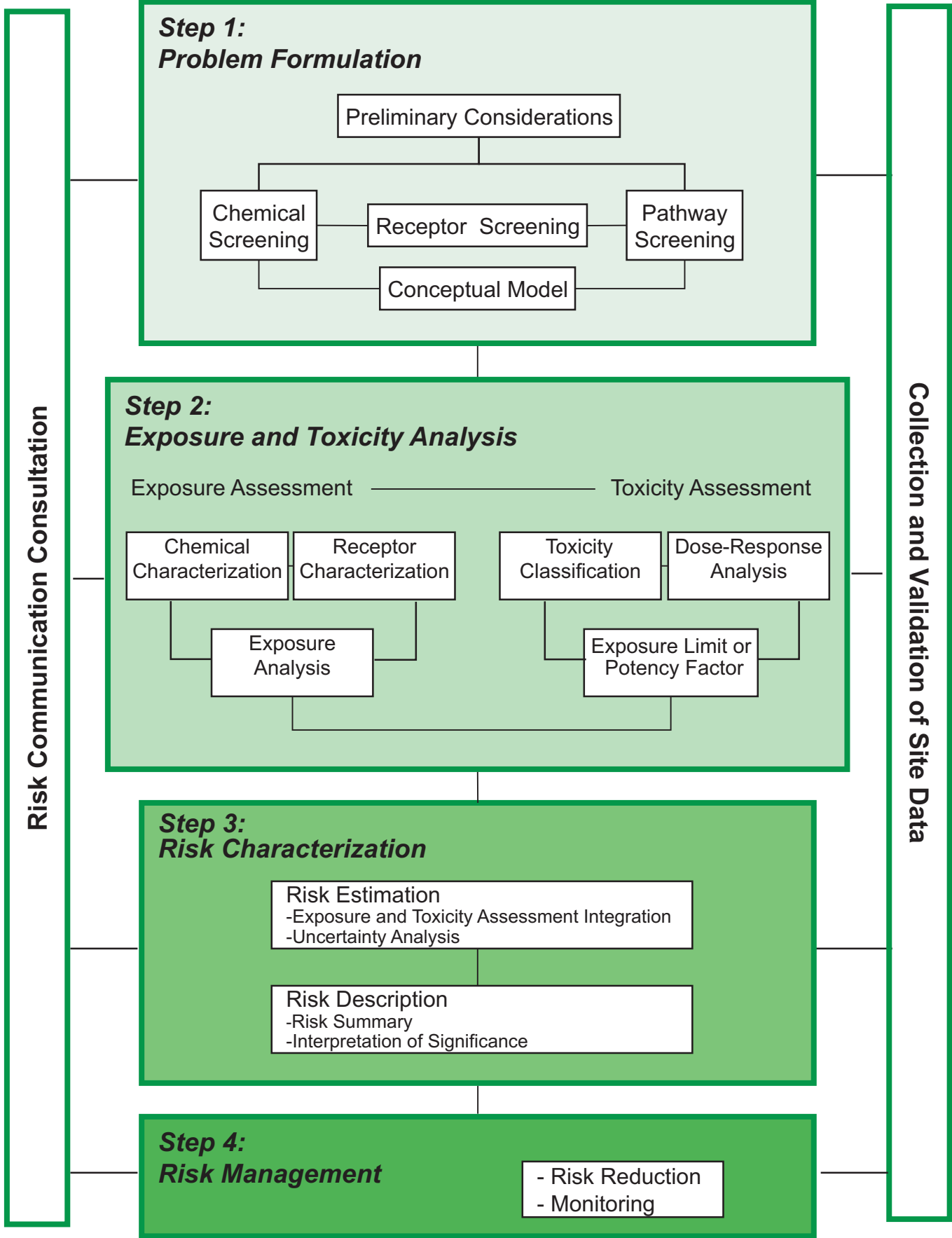
1. *Problem Formulation* – identification of the COPCs associated with project emissions or releases, characterization of people potentially ‘at risk’ and identification of relevant exposure pathways.
2. *Exposure Assessment* – quantification of the potential amount or dose of each COPC received by humans through all relevant exposure pathways.
3. *Toxicity Assessment* – identification of potential adverse health effects associated with exposure to each of the COPCs, the conditions under which these effects are observed and determination of the maximum safe dose of the chemical for sensitive human subjects following exposure for a prescribed period (i.e., identification of acute and chronic exposure limits for the COPCs).
4. *Risk Characterization* – comparison of estimated exposures (identified in the exposure assessment) with exposure limits (identified in the toxicity assessment) to identify potential human health risks for the different assessment cases, as well as discussion of uncertainties and how these were addressed.

Each of these steps is described in detail in the following sections.

18.4.1 Problem Formulation

The problem formulation is the initial step of the assessment, in which practical boundaries are placed on the overall scope of work and the key areas of concern are identified. The three major tasks of the problem formulation are described in detail below.

1. *Identification of the COPCs* – identification of the COPCs emitted or released from the project that might contribute to potential human health risks.



2. *Characterization of People Potentially at Risk* – characterization of people who might be exposed to project emissions or releases, with special consideration given to sensitive and more susceptible individuals (e.g., infants and young children, the elderly, individuals with compromised health).
3. *Identification of Exposure Pathways* – identification of all relevant exposure pathways for people who might be exposed to emissions or releases from the project.

18.4.1.1 Identification of the Chemicals of Potential Concern

The COPCs for the project were identified through:

- the development of an inventory of chemicals that the project could emit to ambient air or release to receiving waterbodies, soils or groundwater resources;
- the determination of whether or not sufficient toxicological information is available to assess potential health risks for a given substance (i.e., the availability of regulatory exposure limits); and
- selection of chemical surrogates to represent any of the compounds for which no suitable exposure limits were available.

Chemical Emissions Inventory for the Project

Identification of the COPCs began with the development of a comprehensive inventory of chemicals that could be emitted or released by the project and to which people might be exposed. Development of the chemical inventory considered possible project air emissions and water releases. Potential effects of soil contamination, i.e., spills, on surface water or groundwater were considered as part of the water quality assessment. Only project emissions or releases resulting in potential changes to environmental quality were identified in the initial inventory of chemicals for the project.

Air

The project will emit chemicals into the air from several sources, including natural gas and produced gas combustion sources (i.e., four steam generator boilers, two glycol heaters and flare pilots). As described in the air quality assessment (see [Volume 4, Section 4.6](#)), the project is predicted to increase the ambient air concentrations of certain compounds, thereby affecting regional air quality. The chemical air emission inventory for the project includes ([Table 18.4-1](#)):

- four federally regulated contaminants that are referred to as criteria air contaminants (CACs), including carbon monoxide (CO), nitrogen dioxide (NO₂), fine particulate matter (PM_{2.5}) and sulphur dioxide (SO₂);
- six volatile organic compounds (VOCs), including aliphatic and aromatic compounds; and
- nineteen polycyclic aromatic hydrocarbons (PAHs).

Table 18.4-1: Chemical Emissions Inventory for Air

Chemical Category	Chemical Constituents
CACs	CO, NO ₂ , PM _{2.5} ¹ , SO ₂
VOCs	Benzene, Dichlorobenzene, Formaldehyde, n-Hexane, n-Pentane, Toluene
PAHs	7,12-Dimethylbenz(a)anthracene, 3-Methylcholanthrene, 2-Methylnaphthalene, Acenaphthene, Acenaphthylene, Anthracene, Benz(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(g,h,i)perylene, Benzo(k)fluoranthene, Chrysene, Dibenz(a,h)anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-cd)pyrene, Naphthalene, Phenanthrene, Pyrene

Notes:

¹ PM_{2.5} includes both primary (emitted directly into the atmosphere) and secondary (formed in the atmosphere through chemical and physical transformations) particulates.

Surface Water

As part of the surface water quality assessment (see [Volume 4, Section 8.3](#)), the following pathways that potentially link project activities with surface water quality impacts were examined:

- withdrawal of groundwater for operational and utility water supply;
- changes in runoff characteristics, stream flow and erosion potential as a result of land disturbance during construction and operation of the project;
- wastewater releases into nearby waterbodies during operations;
- accidental spills of liquids that could reach surface waterbodies or groundwater infiltration; and
- changes in streams and lakes acidity in the region as a result of aerial deposition of air emissions.

After further evaluation, the surface water quality assessment concluded that project activities will have no or negligible impact on surface water quality, the exception being potential impacts to surface water quality in the aquatic LSA as a result of changes in annual runoff (see [Volume 4, Section 8.9](#)).

Low to moderate increases in annual runoff were predicted for Sunday Creek and areas of direct drainage, as well as East and West unnamed creeks (see [Volume 4, Section 8.6.2](#)). Changes in annual runoff can have an impact on stream conductivity. As such, total dissolved solid (TDS) and major ion concentrations were predicted for these creeks. Despite the expected increase in discharge to Sunday Creek, East Unnamed Creek and West Unnamed Creek, TDS and major ion levels were predicted to remain within or below the natural variation. On this basis, the overall impact rating for changes in annual runoff was determined to be low and localized in extent.

Although the project is predicted to have a low impact on surface water quality in the aquatic LSA, the predicted impact is not associated with an increase in chemical concentrations but instead with a decrease in stream conductivity. According to the fisheries and aquatic resources assessment, the project will not release industrial effluents, wastewater, or heavy metals to surface water (see [Volume 2, Section 9.6](#)). From this, no further chemicals were added to the initial chemical inventory.

Groundwater

Changes to groundwater quality from the operation of surface facilities, groundwater withdrawal, wastewater injection, and production and steaming were examined as part of the hydrogeology assessment (see [Volume 4, Section 6.3](#)). In general, the project is expected to have no to negligible impact on groundwater quality (see [Volume 4, Section 6.7](#)).

Bitumen thermal recovery increases the temperature of sediments and groundwater in the formations surrounding the steam and production wells. This increase in temperature has been associated with an increase in solubility of various minerals and metals, including arsenic. As a result, arsenic concentrations have been observed to increase in groundwater at several bitumen recovery facilities in Alberta. An assessment of heat propagation from project wells was conducted to determine the potential enhancement of mineral dissolution or precipitation reactions to occur. On this basis, the thermal plume was predicted to be approximately 550 to 800 m long, depending on the aquifer of concern (see [Volume 4, Section 6.6.4](#)). Water wells in closer proximity to the project (e.g., EnCana wells at 6-76-6 W4M and 7-76-6 W4M) are not used as a drinking water supply (see [Volume 4, Section 6.5](#)). As a result, the nearest drinking water well is located 10 km north of the project in the hamlet of Conklin. Because the predicted impacts to groundwater quality from the project are restricted to within 800 m of the steam and production wells, the likelihood of people being exposed to any potential chemical releases to groundwater associated with any project activities is low. On this basis, no further chemicals were added to the initial chemical inventory.

Toxicity Information

Health-based exposure limits developed or recommended by regulatory or reputable scientific agencies were identified for those chemicals emitted by the project. The scientific authorities consulted included:

- AENV;
- Agency for Toxic Substances and Disease Registry (ATSDR);
- American Conference of Governmental Industrial Hygienists (ACGIH);
- California's Office of Environmental Health Hazard Assessment (OEHHA);
- Canadian Council of Ministers of the Environment (CCME);
- Health Canada and Environment Canada;
- Netherlands National Institute of Public Health and the Environment (RIVM);
- Ontario Ministry of the Environment (OMOE);

- Texas Commission on Environmental Quality (TCEQ);
- United States Environmental Protection Agency (US EPA); and
- World Health Organization (WHO).

Each exposure limit was reviewed to ensure that the information, upon which it was based, was relevant (i.e., protective of health) and sufficient (i.e., based on adequate supporting documentation). Further details regarding the selection of the exposure limits are provided in the toxicity assessment (see [Section 18.4.3](#)) and in [Appendix J1](#). Health-based exposure limits were identified for all of the chemicals listed in the initial chemical emissions inventory. Thus, these chemicals were selected as COPCs for the HHRA.

Surrogates

Surrogate chemicals were used to represent those chemicals for which exposure limits could not be identified. This step relied on the toxicological principle that states that the molecular structure of a chemical has a distinct bearing on its reactivity, biological activity and toxicity. The principle allows for the toxicity of a chemical, for which little or no toxicological information exists to be predicted on the basis of information available on another chemical of similar molecular structure. The second chemical is termed a “surrogate”. For example, an acute health-based exposure limit for the aromatic C₉-C₁₆ group, which includes 2-methylnaphthalene, acenaphthene, acenaphthylene, anthracene, fluoranthene, fluorene, naphthalene, phenanthrene and pyrene, is currently not available, but a health-based exposure limit is available for a suitable surrogate: naphthalene. Therefore, the aromatic C₉-C₁₆ group was assessed on an acute basis using the exposure limit for naphthalene. This was the only case in which a surrogate was applied.

Chemicals of Potential Concern

The COPCs identified for inclusion in the HHRA are listed in [Table 18.4-2](#). Because the project is not expected to change chemical concentrations in surface water or groundwater as a result of possible releases, atmospheric emissions were the only project emissions assessed in terms of potential human health risks. Twenty-nine chemicals formed the initial emissions inventory for the identification of the COPCs associated with the project. Based on the above chemical selection process, all 29 of these chemicals were carried forward as COPCs for the purposes of the HHRA.

Table 18.4-2: Chemicals of Potential Concern for the Project

Chemical of Potential Concern	Chemical Constituent(s)
Aliphatic C ₅ -C ₈ group	n-Hexane, n-Pentane
Aromatic C ₉ -C ₁₆ group ¹	2-Methylnaphthalene, Acenaphthene, Acenaphthylene, Anthracene, Fluoranthene, Fluorene, Naphthalene, Phenanthrene, Pyrene
Aromatic C ₁₇ -C ₃₄ group ¹	7,12-Dimethylbenz(a)anthracene, 3-Methylcholanthrene, Benz(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(g,h,i)perylene, Benzo(k)fluoranthene, Chrysene, Dibenz(a,h)anthracene, Indeno(1,2,3-cd)pyrene
Benzene	Benzene
Benzo(a)pyrene and equivalents ²	7,12-Dimethylbenz(a)anthracene, Benz(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(g,h,i)perylene, Benzo(k)fluoranthene, Chrysene, Dibenz(a,h)anthracene, Fluoranthene, Indeno(1,2,3-cd)pyrene, Phenanthrene
CO	CO
Dichlorobenzene	Dichlorobenzene
Formaldehyde	Formaldehyde
n-Hexane	n-Hexane
Naphthalene	Naphthalene
NO ₂	NO ₂
PM _{2.5}	PM _{2.5}
Pyrene	Pyrene
SO ₂	SO ₂
Toluene	Toluene

Notes:

¹ The carcinogenic PAHs (i.e., 7,12-Dimethylbenz(a)anthracene, benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene, indeno(1,2,3 cd)pyrene, and phenanthrene), for which potency equivalence factor (PEF) values have been assigned by Health Canada (2006), were not included in the aromatic C₉-C₁₆ group and aromatic C₁₇-C₃₄ group on a chronic basis as per CCME (2008) recommendations. Further details are provided in [Appendix J1](#).

² PAHs for which a PEF has been developed by Health Canada (2006) were included.

Most of the chemicals identified in the initial inventory were assessed either as individual chemicals (e.g., benzene) or as chemical constituents within an aliphatic or aromatic group. Additionally, several of the COPCs were assessed both as an individual chemical (e.g., n-hexane) and as part of an aliphatic or aromatic group (e.g., in this case, the aliphatic C₅-C₈ group). In these instances, the exposure limit identified for the individual chemical was lower (i.e., more conservative) than the exposure limit for the aliphatic or aromatic group as a whole.

Although the project will not emit ozone (O₃) directly to the atmosphere, it will emit its precursor chemicals, such as nitrogen oxides (NO_x) and VOCs. Precursor chemicals react to form O₃ downwind from emissions sources under specific meteorological conditions (i.e., high solar radiation, high temperature and low wind speed; found typically on a hot summer day). It is important to note that although some meteorological conditions lead to the reactions that produce O₃, others favour O₃ destruction. Also, reactions that create O₃ can occur simultaneously with those that destroy O₃.

In the air quality assessment (see [Volume 4, Section 4.7.10.3](#)), it was concluded that project emissions of O₃ precursor chemicals could potentially increase regional emissions by 0.2%. The Ozone Modeling Working Group sanctioned by and accountable to the Wood Buffalo Environmental Association (WBEA) predicted that a near doubling of anthropogenic (man-made) NO_x and VOC emissions would increase peak-hourly O₃ concentrations by as much as 30 ppb on hot, stagnant days (Syncrude 1998). On this basis, the project's estimated increase in O₃ precursor emissions would likely result in an increase in peak-hourly O₃ concentrations of less than 1 ppb. According to the air quality assessment (see [Volume 4, Section 4.7.10.3](#)), the final impact rating for changes in O₃ concentrations as a result of project precursor emissions is expected to be low.

Because of the uncertainty associated with the sources of O₃ in northeastern Alberta, the chemical reactions associated with O₃ formation and destruction, and the possible transport of O₃ over long distances, ground-level O₃ concentrations were not predicted in the air quality assessment (see [Volume 4, Section 4.7.10](#)) and O₃ was not included as a COPC in the HHRA.

The most effective approach to assessing possible links between O₃ concentrations in the oil sands region and human health is through the continuous monitoring of O₃ concentrations that people are exposed to in the region. Environment Canada and WBEA are carrying out ambient monitoring and photochemical modelling of O₃ in the oil sands region. This program was initiated in an effort to determine the roles that precursor emissions and photochemistry play in contributing to O₃ levels in the region. Currently, WBEA's focus is on the area to the north of Fort McMurray; however, there is increasing interest to extend the focus further south to include the *in-situ* developments in the Conklin area. Recognizing the value of this multi-stakeholder group, KNOC plans to cooperate with WBEA by supplying project-specific air monitoring data should the regional monitoring network expand southward in the future.

18.4.1.2 Characterization of People Potentially at Risk

People potentially at risk include individuals who receive the highest exposures to the project emissions, as well as individuals who are more sensitive or susceptible to project emissions. In this regard, consideration was given to:

- the people who are known or anticipated to spend time near the project;
- the physical characteristics of the individuals in the region;
- the lifestyles of the individuals in the region (e.g., consumption patterns, portion of diet obtained locally); and
- the sensitivity or susceptibility of individuals in the region (e.g., infants and young children, the elderly, individuals with compromised health).

Additional details regarding the characteristics of people potentially at risk from project emissions are provided below and in [Appendix J2](#).

Locations at Which People Reside or Visit

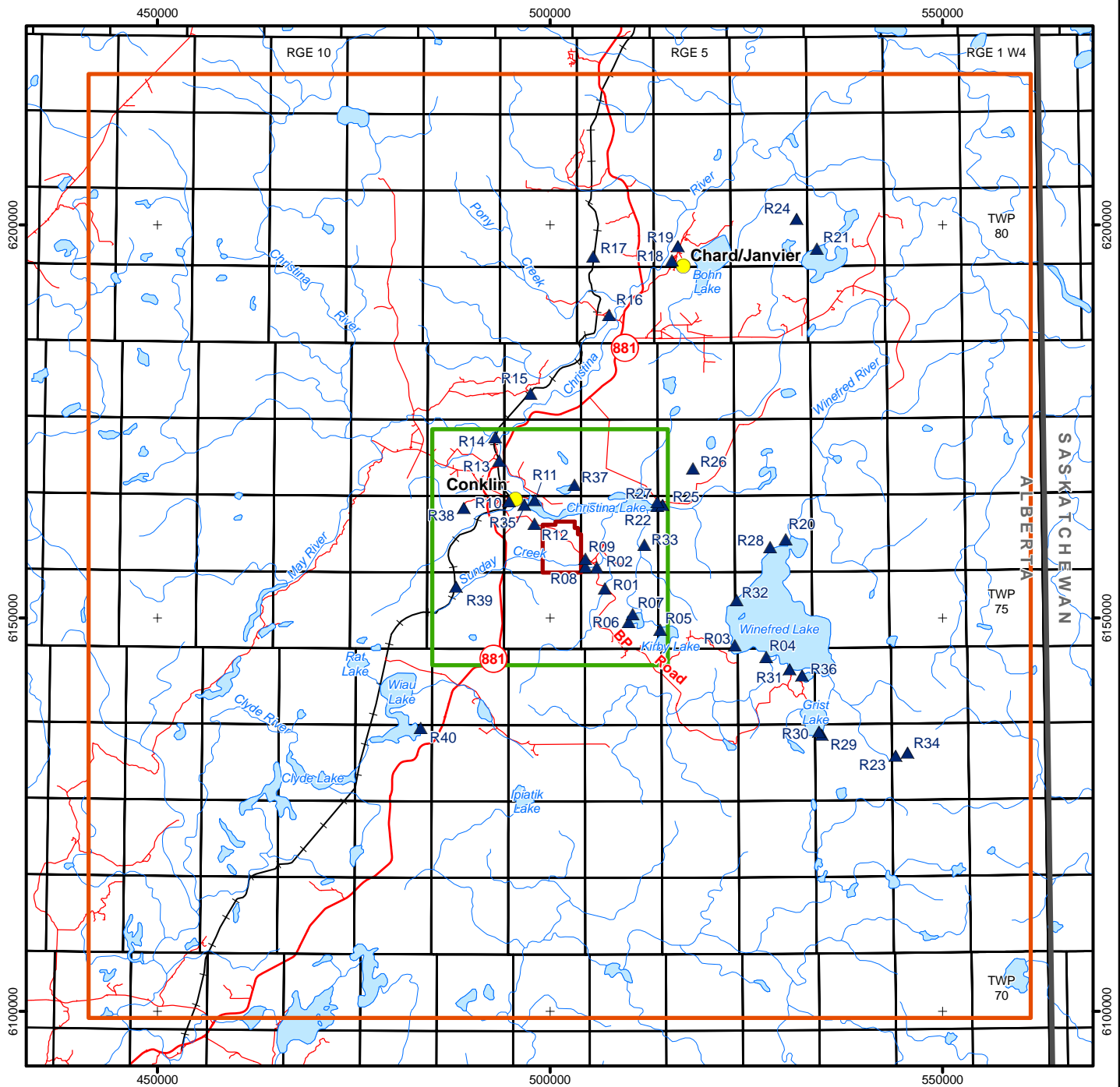
Recognizing that people use the area in the vicinity of the project for recreational and traditional activities, the HHRA included an assessment of potential health risks to people active anywhere within the health LSA (i.e., within approximately 15 km of the project), including the location at which the highest ground-level air concentrations of the COPCs were predicted to occur. For the HHRA, this location is referred to as the local maximum point of impingement (MPOI) (i.e., within the health LSA).

Forty (40) locations where people are known or anticipated to spend time were identified within the health RSA and assessed in the HHRA. These locations are listed below and shown in relation to the project in [Figure 18.4-2](#).

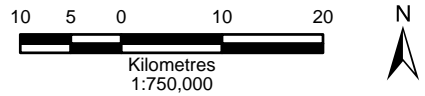
- R01 – Cabin A
- R02 – Camp A
- R03 – Winefred Lake Fish Plant
- R04 – Winefred Lake Cabin
- R05 – Kirby Lake Cabin
- R06 – West Hay Lake Cabin(s)
- R07 – North Hay Lake Cabin(s)
- R08 – Cabin B
- R09 – Metis Trailer Camp
- R10 – Conklin
- R11 – Christina Lake Cabins
- R12 – Plant Harvesting Area
- R13 – Cabin C
- R14 – Cabin D
- R15 – Leismer
- R16 – East Chard
- R17 – Pingle
- R18 – Chard School
- R19 – Janvier IR 194
- R20 – Winefred Lake IR 194B
- R21 – Cowper Lake IR 194A
- R22 – Christina Lake Fishing Camp
- R23 – Fire Lookout Tower A
- R24 – Fire Lookout Tower B
- R25 – AltaGas House
- R26 – MEG Energy House
- R27 – Christina Lake Grave Site
- R28 – Winefred Lake Grave Site
- R29 – Grist Lake Lodge
- R30 – Grist Lake
- R31 – Winefred Lake Lodge
- R32 – Winefred Lake
- R33 – EnCana House
- R34 – Winefred Lake Lookout
- R35 – Christina Lake Campground
- R36 – Wild Rice Operation A
- R37 – Wild Rice Operation B
- R38 – Fire Lookout Tower C
- R39 – Devenish
- R40 – Wiau Lake Cabins and Settlement

Of the 40 locations assessed in the HHRA, half are located within the health LSA where maximum project-related changes in air quality are predicted to occur. These include:

- the communities of Conklin (R10) and Devenish (R39);
- a number of neighbouring camps and cabins (R01, R02, R05-R09, R13, R14, R22);
- a wild rice operation (R37);
- a fire lookout tower (R38);



- Legend**
- Health Regional Study Area
 - Health Local Study Area
 - Project Area
 - Open Water
 - Watercourse
 - ▲ Recreational Area and Community Receptor



Sources: GeoBase®, KNOC, Spatial Data Warehouse Ltd.

Korea National Oil Corporation
BlackGold Expansion Project

Health Receptors Locations

DATE: March 2010	Figure 18.4-2
PROJECT: CE03745/600	Fig18.04-02 Health Receptors 10-03-25
ANALYST: TM KW EA DR	DRAWN BY: AMEC
PROJECTION/DATUM: UTM Zone 12 NAD83	PREPARED BY: Intrinsic

- two housing complexes for AltaGas and EnCana workers (R25, R33); and
- a number of recreational areas, such as campsites and areas potentially used for plant and berry gathering (R12, R27, R35).

Although further removed from the project (located outside the health LSA), residents of six neighbouring communities were considered in the HHRA: Leismer, Chard, Cowper Lake, Pingle, Janvier and Winefred Lake. A number of recreational areas (including local lodges, cabins and fishing areas) and commercial locations (including fire lookout towers, two wild rice operations and a housing complex for MEG Energy workers) also were identified and assessed.

General Physical Characteristics

Individuals residing at or visiting the locations in the HHRA study areas include members of the general population, with the exception of the housing complexes for AltaGas, EnCana and MEG Energy that will be occupied by adult workers only. Thus, for the people at the remaining locations, it was necessary that all age classes or life stages be considered. The five receptor life stages that were included in the HHRA are consistent with Health Canada guidance (Health Canada 2004):

- Infant (0 to 6 months – 0.5 years);
- Toddler (7 months to 4 years – 4.5 years);
- Child (5 to 11 years – 7 years);
- Adolescent (12 to 19 years – 8 years); and
- Adult (20 to 75 years – 56 years).

General physical characteristics were obtained from documents published by Health Canada (2004) and CCME (2006). For the physical characteristics assumed in the HHRA, see [Table 18.4-3](#).

Table 18.4-3: General Physical Characteristics

Physical Characteristics	Life Stages				
	Infant	Toddler	Child	Adolescent	Adult
Body weight (kg)	8.2	16.5	32.9	59.7	70.7
Inhalation rate (m ³ /day)	2.1	9.3	14.5	15.8	15.8
Soil ingestion rate (g/day)	0.02	0.08	0.02	0.02	0.02
Water ingestion rate (L/day)	0.3	0.6	0.8	1.0	1.5
Body surface area – arms and legs (cm ²)	1 460	2 580	4 550	7 200	8 220
Body surface area – hands (cm ²)	320	430	590	800	890
Soil adherence factor (g/m ² /day)	0.1	0.1	0.1	0.1	0.1
Soil adherence factor – hands (g/m ² /day)	1	1	1	1	1

Common Lifestyles

Based on the general land-use category of the location at which people were assumed to spend time, individuals were assigned to one of the following lifestyle categories:

- *Residents* – includes all individuals who use the camps and cabins located within the health study areas as temporary residences while engaged in recreational or traditional activities, as well as all permanent residents of neighbouring communities;
- *Workers* – includes all workers who reside at the housing complexes for AltaGas, EnCana and MEG Energy during their employment; and
- *Recreational Persons* – includes all occasional or seasonal visitors to the health study areas for recreational or traditional activities such as hunting, trapping, or plant and berry gathering.

It was assumed that the people within each lifestyle category would share common behavioural characteristics, such as time spent at the specific location, dietary consumption patterns and portion of diet obtained locally, that would result in a similar level of exposure. The individuals with the highest predicted exposure of each lifestyle category were conservatively assumed to represent the potential health risks for all of the people assessed as part of the particular lifestyle category.

For locations included in each lifestyle category, see [Table 18.4-4](#). Specific characteristics of the individuals within each lifestyle category are described in the following sections.

Table 18.4-4: Lifestyle Category and Corresponding Locations

Lifestyle Category	Location(s)	
	Count	Designation
Recreational persons	1	local MPOI ¹
Residents	37	R01-R24, R27-R32, R34-R40
Workers	3	R25, R26, R33

Notes:

¹ Although the air quality assessment (see [Volume 4, Section 4.10](#)) predicts ground-level air concentrations of the COPCs at the regional MPOI (i.e., within the air quality RSA), the project contributes less than 1% to these predicted values. On this basis, the HHRA focused on the potential health risks associated with the local MPOI (i.e., within the health and air quality LSA).

Recreational Persons

It was assumed that recreational persons could be situated at the local MPOI for periods of 24 hours or less. Due to the short-term nature of their potential exposure to the COPCs at these locations, recreational persons were assessed on an acute basis only.

Recreational persons were assumed to reside at one of the nearby camp, cabin or community locations. Thus, potential chronic health risks to recreational persons associated with the long-term exposures associated with the inhalation of the COPCs and ingestion of local wild game, fish, vegetation and surface water potentially impacted by the project emissions were captured as part of the resident lifestyle category, as described below.

Residents

Although people would likely only occupy camps and cabins during recreational or traditional activities, the actual time spent at these locations could not be definitively determined. As such, it was assumed that people would maintain permanent residency at the camps and cabins within the health study areas, as they would at residences within the nearby communities. It was assumed that individuals residing at the camps, cabins and community residences would be at the particular location 24 hours per day, 365 days per year over a 75 year lifespan. On this basis, residents were assessed on both an acute and chronic basis.

All residents were determined to potentially be exposed to project emissions via direct inhalation, inhalation of dust, inadvertent ingestion of soil, and dermal contact with soil. In addition, it was assumed that residents would obtain 100% of their food from local food sources (e.g., wild game, fish, wild plants and berries, and garden produce), swim in local waterbodies, and drink water from local sources. Consumption rates of local foods are listed in [Table 18.4-5](#) for all life stages.

Table 18.4-5: Consumption Rates for Residents

Local Foods	Consumption Rate [g/d]					Reference
	Infant	Toddler	Child	Adolescent	Adult	
Moose	0	65	95	133	205	Health Canada 2004; Wein <i>et al.</i> 1991
Ruffed grouse	0	14	20	28	43	Health Canada 2004; Wein <i>et al.</i> 1991
Snowshoe hare	0	7	10	14	22	Health Canada 2004; Wein <i>et al.</i> 1991
Fish	0	20	33	40	40	Health Canada 2007
Labrador tea leaves	0	1	1	3	3	Wein 1989; Wein <i>et al.</i> 1991
Cattail roots	0	1	1	3	3	Wein 1989; Wein <i>et al.</i> 1991
Garden root vegetables	0	105	161	227	188	Health Canada 2004
Garden leafy vegetables	0	67	98	120	137	Health Canada 2004
Fruits, including wild berries	0	39	66	59	45	Health Canada 1994
Breast milk	664	0	0	0	0	O'Connor and Richardson 1997

Consumption rates for wild game were based on Health Canada's food ingestion rates for Canadian First Nations populations in combination with the frequency of consumption reported for Native Canadians near Wood Buffalo National Park (WBNP) by Wein *et al.* (1991). Food consumption patterns were obtained by repeated 24-hour food recall surveys: two surveys were completed between late August and mid-November 1986; and, two surveys were completed between late April and mid-July 1987 (Wein *et al.* 1991). One hundred and seventy-eight individuals over 12 years of age were interviewed. According to Wein *et al.* (1991), large mammals constituted 76% of the wild game consumed by the 120 Native households interviewed, small mammals constituted 16%, and upland birds constituted 8%. Using Health Canada's (2004) adult ingestion rate of 270 grams per day of wild game, it was assumed that adults living at the nearby camps, cabins and communities would consume 205 grams of moose per day ($270 \text{ g/d} \times 76\%$), 43 grams of snowshoe hare per day ($270 \text{ g/d} \times 16\%$), and 22 grams of ruffed grouse per day ($270 \text{ g/d} \times 8\%$).

Recent Health Canada (2007) guidance has recommended an adult subsistence consumption rate of 40 grams of fish per day. This value was obtained from a Market Facts of Canada (1991) study on national seafood consumption and a Bureau of Chemical Safety (BCS) evaluation of current intake rates by Canadian consumers (BCS 2004). The BCS (2004) study considered the information provided in multiple studies and recommended subsistence consumption rates that included consideration of sport, subsistence and Aboriginal fish eaters. Similar fish consumption rates have been reported in the 1997 diet and activity survey conducted in Swan Hills by Alberta Health and Wellness (AHW) where the 'medium consumer' was reported to ingest 47 grams of fish per day (AHW 1997), and in a 1999 survey conducted by Health Canada of an Aboriginal population in the Lesser Slave Lake region of Alberta where a moderate consumer was reported to consume, on average about 46 grams of fish per day (Health Canada 1999).

Plant consumption rates were segregated into traditional above-ground plants (e.g., wild mint and Labrador tea leaves) and below-ground plants (e.g., cattail root), as well as garden above-ground vegetables (e.g., broccoli) and below-ground vegetables (e.g., potatoes). Wein (1989) provides a consumption rate of 134 grams per day, which was adjusted by the frequency of 2% (i.e., 7 days in 365 days) at which wild mint and Labrador tea leaves were reportedly consumed in the Native households interviewed (Wein *et al.* 1991). From this, an adult consumption rate of 3 grams per day was assumed for traditional above-ground plants (e.g., wild mint and Labrador tea leaves). Wein *et al.* (1991) reports that wild roots were seldom used in the Native households interviewed and does not provide any consumption data for wild roots. As a result, the HHRA assumed that the consumption rates for traditional below-ground and above-ground plants were equivalent (i.e., 3 g/d).

Health Canada provides vegetable (root and other) ingestion rates for the Canadian general population based on 24-hour recall data collected in 1970 and 1972 as part of the Nutrition Canada Survey (Health Canada 1994, 2004). The dietary survey involved a statistically representative sample of the Canadian population, personal interviews conducted by trained interviewers, and 3-dimensional models of meal portions to assist in determining food portion sizes for some 180 different foods. Summary data are provided by Health Canada (2004) for vegetable (root and other) 'eaters only', which exclude individuals reporting no vegetable

consumption. Using statistics for ‘eaters only’ ensures that the consumption rates of the individuals who consume the majority of the vegetables are not under estimated. Health Canada’s vegetable ingestion rates were used to assess potential health risks associated with the consumption of garden vegetables.

Fruit consumption rates are reported by Health Canada (1994) based on the same Nutrition Canada Survey as garden vegetables, described above. These values include all fruit and fruit products such as tropical fruit and frozen concentrate juice. In order to estimate consumption rates for fruits potentially harvested from the area (i.e., wild berries and garden fruits), the overall fruit consumption rate can be broken down into its constituents. In this case, fruit consumption rates were based on a composite of apples, apple sauce, cherries, strawberries, blueberries, jams and honey.

Workers

Although people would likely only reside at the AltaGas, EnCana and MEG Energy housing complexes during their years of employment, it was conservatively assumed that workers would reside at these housing complexes during the time of employment. As a result, they would be exposed to the project emissions 24 hours per day, 365 days per year for the 56 years of their adult life. As such, workers were assessed on both an acute and chronic basis.

All workers were determined to potentially be exposed to project emissions via direct inhalation, inhalation of dust, inadvertent ingestion of soil, and dermal contact with soil. It was assumed, however, that workers would obtain 100% of their food and water from the housing complex, which in turn would obtain all food and water from off-site (see [Volume 4, Section 6.8.2.2](#)).

18.4.1.3 Exposure Pathway Identification

For human exposure to take place (and potential health risks to occur), a feasible and relevant route of exposure must exist from the project through the environmental media to the human receptor (i.e., recreational persons, residents or workers) (Health Canada 1995; US EPA 2002). Potential pathways of exposure were identified specific to the three previously described lifestyles.

Because the project will emit COPCs directly into air from various sources, people visiting or residing near the project could be directly exposed to the COPCs via the primary pathway of exposure (i.e., inhalation). As such, direct inhalation was deemed to be an applicable pathway of exposure for recreational persons, residents and workers.

As it was assumed that recreational persons would only be in the vicinity of the project on a short-term (acute) basis, inhalation of the COPCs emitted from the project to the air was deemed to be the only applicable pathway of exposure and these individuals were not included in the multiple pathway assessment.

For the residents and workers, potential long-term (chronic) exposures to the COPCs through multiple pathways (i.e., inhalation, ingestion and dermal contact) were considered. [Table 18.4-6](#) offers a summary of the exposure pathways assessed for each of the lifestyle categories. For modelling assumptions relating to the multiple pathway assessment, see [Appendix J2](#).

Table 18.4-6: Exposure Pathways Assessed for the Lifestyle Categories

Exposure Pathway	Lifestyle Categories		
	Recreational Persons	Residents	Workers
Inhalation			
Inhalation of air	√	√	√
Inhalation of dust	x	√	√
Ingestion			
Ingestion of soil (inadvertent)	x	√	√
Ingestion of local drinking water	x	√	x
Ingestion of local water during swimming	x	√	x
Ingestion of local wild game	x	√	x
Ingestion of local fish	x	√	x
Ingestion of local natural foods (i.e., berries, cattail roots and tea leaves)	x	√	x
Ingestion of local garden foods (i.e., fruits and vegetables)	x	√	x
Dermal Contact			
Dermal contact with soil	x	√	√
Dermal contact with water during swimming	x	√	x

Notes:

- √ Exposure pathway is applicable for the lifestyle category.
- x Exposure pathway is not applicable for the lifestyle category.

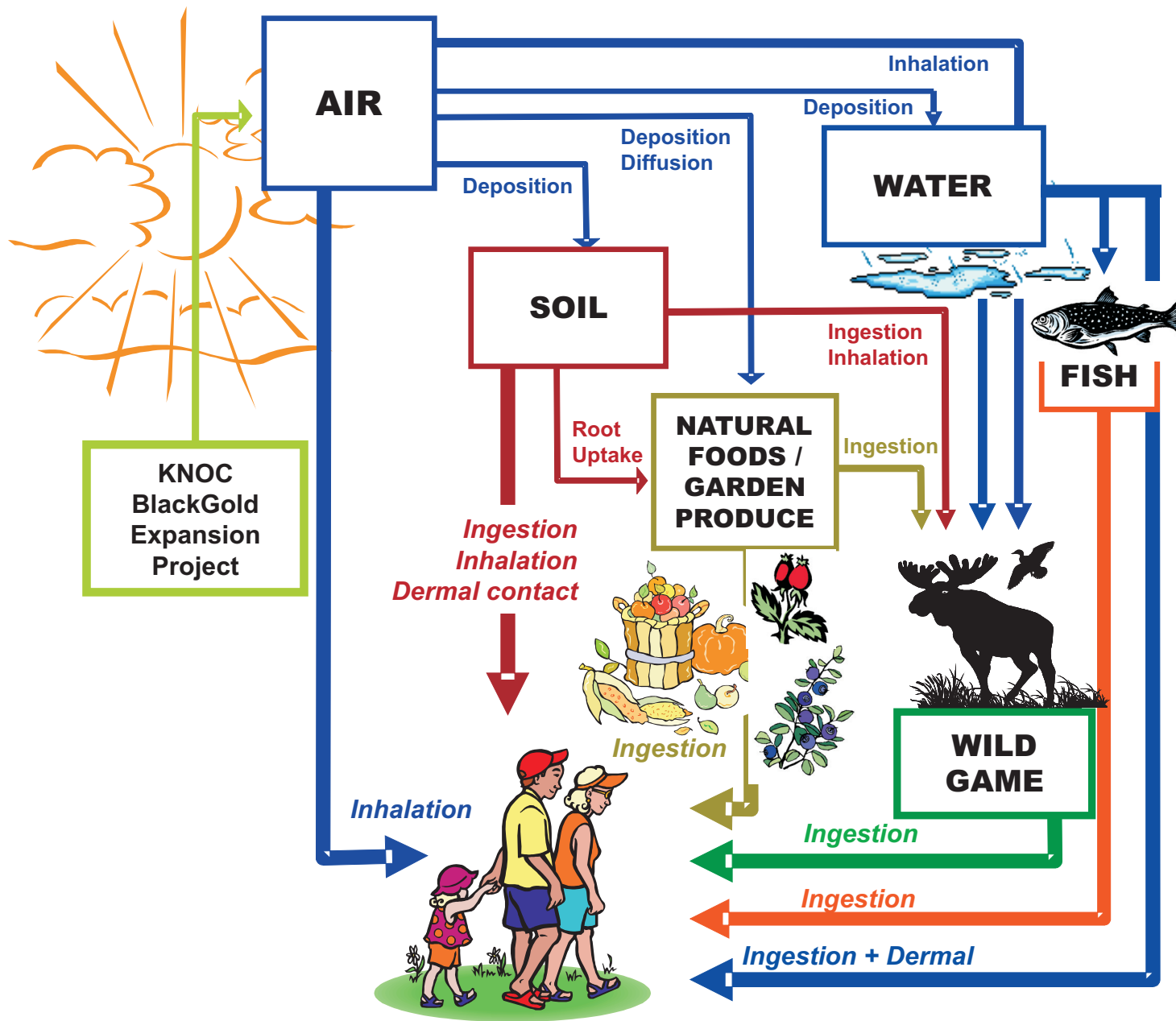
For an illustration of the exposure pathways considered in the multiple pathway assessments for the residents, see [Figure 18.4-3](#) and for the workers, see [Figure 18.4-4](#).

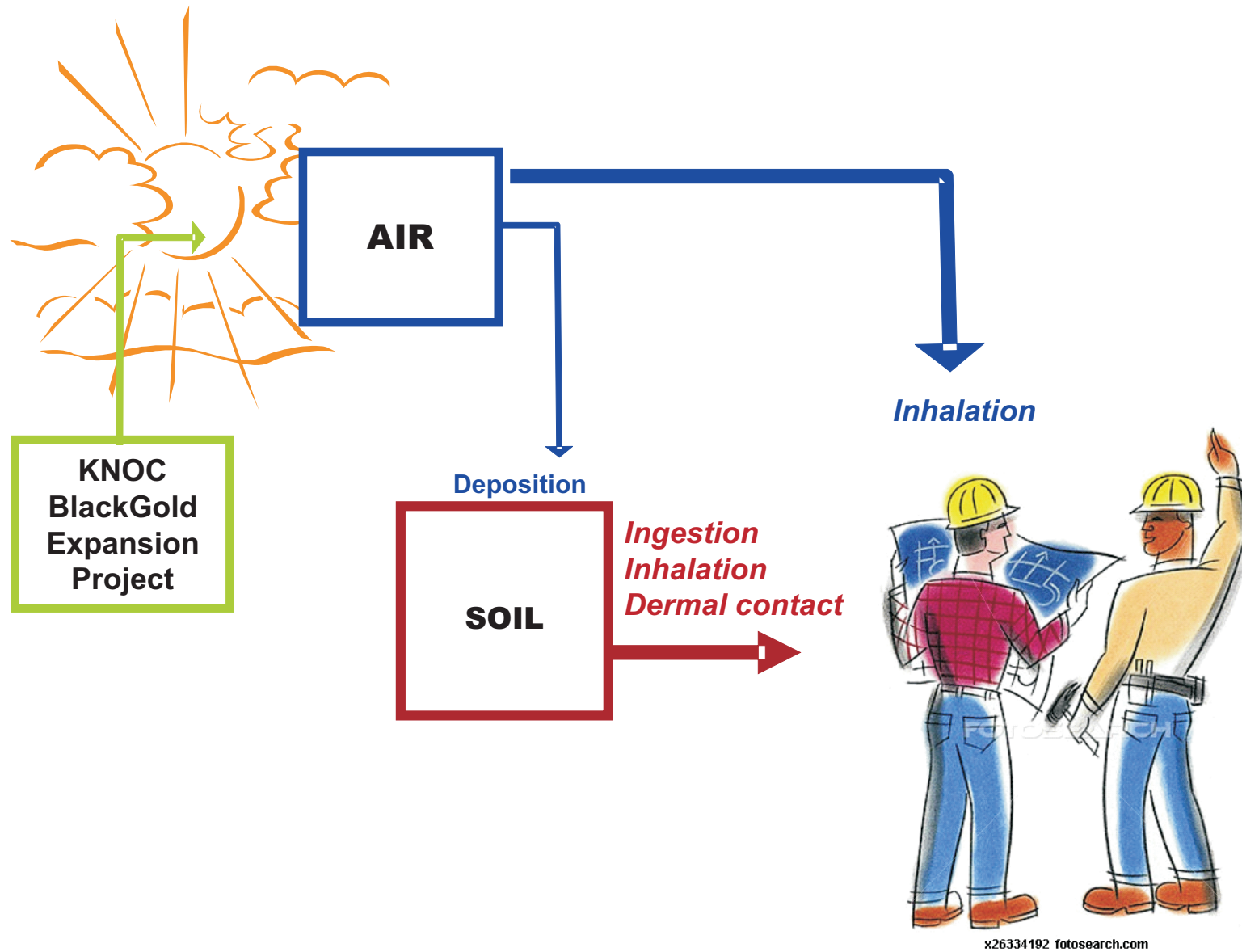
18.4.2 Exposure Assessment

The primary objective of the exposure assessment is to estimate, based on the use of “reasonable worst-case” assumptions, the potential COPC exposures received by the people identified in the problem formulation as being ‘at risk’. Because the project will emit COPCs directly to air from various sources, people residing or working near the project, as well as people visiting the area could be directly exposed to the COPCs via inhalation. All of the COPCs emitted to air were incorporated in the inhalation assessment, discussed in detail in the section that follows.

In addition to the primary pathway of exposure (i.e., inhalation), people that live or work in the area might be exposed to the COPCs via secondary exposure pathways. For example:

- Some COPCs will be deposited onto soils surrounding the project. Depending on the fate, transport and persistence of the COPC in the environment, this chemical deposition could affect the chemical concentrations in local soil. Exposure through inhalation of dust, inadvertent ingestion of soil and dermal contact with soil were included in the HHRA;





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Exposure Pathways to be Considered for Workers

DATE: March 2010		Fig18.04-04 Exposure Pathways Workers 10-03-26	
PROJECT: CE03745		DRAWN BY: AMEC	
ANALYST: TM	QA/QC: KW EA DR	PREPARED BY: Intrinsic	

Figure 18.4-4

- Concentrations of some COPC in local vegetation could be affected by both direct deposition of atmospheric emissions onto plant surfaces and uptake of COPCs from soils. As a result, exposure through ingestion of local fruits and vegetables (root and leafy) was included in the HHRA;
- Some COPC concentrations in local wild game could be affected by both the direct inhalation of the atmospheric emissions and the ingestion of the COPCs in local soil, soil invertebrates, water, vegetation and prey. Exposure through ingestion of local wild game was included in the HHRA; and
- Although concentrations of the COPCs in local surface water and subsequently fish tissue were not predicted to change as a result of project releases directly to surface water, some deposition of COPCs onto surface waterbodies may occur. On this basis, exposure through ingestion of local surface water and fish were included in the HHRA. The COPCs that are expected to deposit nearby the project and possibly persist or accumulate in the environment are identified below.

These secondary pathways were incorporated into the multiple pathway assessment. Thus, it was necessary to identify those COPCs that, although only emitted into air, are expected to deposit near the project and possibly persist or accumulate in the environment in sufficient quantities for residents and workers to be exposed via secondary pathways. For this purpose, two categories of COPCs were identified:

- Gaseous COPCs (i.e., CO, NO₂ and SO₂), which are not likely to contribute to human exposure via secondary pathways as they will remain airborne for extended times and over extended distances. In addition, the health effects of these gaseous COPCs are strictly related to inhalation; and
- Non-gaseous COPCs (i.e., certain VOCs and PAHs), which might deposit in the vicinity of the project and persist or accumulate in the environment in sufficient quantities for residents and workers to be exposed via secondary pathways.

To identify the non-gaseous COPCs that could deposit near the project and persist or accumulate in the environment, consideration was given to the physical-chemical properties of the COPCs that influence their fate and persistence in the environment and subsequently their potential occurrence in the secondary pathways of exposure. For this, the physical-chemical properties (i.e., molecular weight, vapour pressure and Henry's Law Constant) of each of the VOCs and PAHs were compared against pre-established criteria to identify non-volatile substances.

The screening criteria used were recommended by a number of scientific authorities (Cal EPA 1994; US EPA 1998, 2003), who define non-volatile chemicals as those that satisfy one or more of the following criteria:

- Molecular weight >200 g/mol;
- Henry's Law Constant <0.00001 atm·m³/mol (or 1.0E-05 atm·m³/mol); and
- Vapour pressure <0.001 mmHg (or 1.0E-03 mmHg).

The premise of this exercise is that if a chemical that is emitted to the air does not meet any of the criteria, the potential for the chemical to deposit near the project and persist or accumulate in the environment is negligible, and only limited opportunity exists for exposure via secondary pathways. However, if a chemical meets any one of the criteria, sufficient opportunity could be presented for exposure via secondary pathways. Also, if a constituent of an aliphatic or aromatic group satisfied even one of the criteria, the entire group was included in the multiple pathway assessment.

[Table 18.4-7](#) summarizes the relevant physical-chemical properties of the COPCs.

The findings of the exercise indicate that 16 of the COPCs could contribute to human exposure via secondary pathways and thus were included in the multiple pathway assessment. Additionally, because at least one of the constituents of the aromatic C₉-C₁₆ group satisfied one or more of the criteria, the entire aromatic group was assessed as part of the multiple pathway assessment.

Table 18.4-7: Identification of Chemicals of Potential Concern to be Included in the Multiple Pathway Assessment

Chemical of Potential Concern ^{1,2}	Molecular Weight [g/mol]	Henry's Law Constant ³ [atm-m ³ /mol]	Vapour Pressure ³ [mmHg]	Reference
Criteria	>200	<1.0E-05	<1.0E-03	
2-Methylnaphthalene	142	4.0E-04	6.1E-02	Mackay <i>et al.</i> 1992
3-Methylcholanthrene	268	–	7.73E-10	Mackay <i>et al.</i> 1992
7,12-Dimethylbenz(a)anthracene	256	–	2.69E-08	Mackay <i>et al.</i> 1992
Acenaphthene	154	1.60E-04	2.50E-03	US EPA OSW 2005
Acenaphthylene	152	4.48E-04	1.27E-02	Mackay <i>et al.</i> 1992
Anthracene	178	6.50E-05	2.70E-06	US EPA OSW 2005
Benzene	78	5.60E-03	9.50E+01	US EPA OSW 2005
Benz(a)anthracene	228	3.40E-06	1.10E-07	US EPA OSW 2005
Benzo(a)pyrene	252	1.10E-06	5.50E-09	US EPA OSW 2005
Benzo(b)fluoranthene	252	1.10E-04	5.00E-07	US EPA OSW 2005
Benzo(g,h,i)perylene	276	1.82E-06	1.33E-09	Mackay <i>et al.</i> 1992
Benzo(k)fluoranthene	252	8.30E-07	2.00E-09	US EPA OSW 2005
Chrysene	228	9.50E-05	6.20E-09	US EPA OSW 2005
Dibenz(a,h)anthracene	278	1.50E-08	1.00E-10	US EPA OSW 2005
Dichlorobenzene	147	3.10E-03	2.15E+00	US EPA OSW 2005
Fluoranthene	202	1.60E-05	7.83E-06	US EPA OSW 2005
Fluorene	166	6.40E-05	6.30E-04	US EPA OSW 2005
Formaldehyde	30	3.36E-07	5.24E+03	US EPA OSW 2005
Indeno(1,2,3-cd)pyrene	276	1.60E-06	1.00E-10	US EPA OSW 2005
Naphthalene	128	4.80E-04	8.50E-02	US EPA OSW 2005
n-Hexane	86	1.47E+00	1.52E+02	Mackay <i>et al.</i> 1992
n-Pentane	72	1.14E+00	5.10E+02	Mackay <i>et al.</i> 1992
Phenanthrene	178	2.30E-05	1.10E-04	US EPA OSW 2005
Pyrene	202	1.10E-05	4.60E-06	US EPA OSW 2005
Toluene	92	6.60E-03	2.80E+01	US EPA OSW 2005

Notes:

- ¹ Gaseous COPCs (CO, NO₂, SO₂) were excluded from the physical-chemical screening process and evaluated on an inhalation basis only.
- ² PM_{2.5} was excluded from the screening as it is a mixture, for which the physical and chemical properties are not known.
- ³ With scientific notation, values too large or small to be conveniently written in standard decimal notation are expressed either to the negative power (i.e., E-x) or to the positive power (i.e., E+x). For example, Henry's Law Constant for 2-methylnaphthalene is 4.0E-04, which equates to 0.00040.

Bold values represent parameters that satisfy the screening criteria, and the chemicals carried forth in the multiple pathway exposure assessment.

– Indicates the value is not available.

Table 18.4-8 summarizes the final list of COPCs to be assessed in the inhalation and multiple pathway assessments.

Table 18.4-8: Chemicals of Potential Concern in the Inhalation and Multiple Pathway Assessments

Chemicals of Potential Concern ¹	Inhalation Assessment ²	Multiple Pathway Assessment
Aliphatic C ₅ -C ₈ group	√	x
Aromatic C ₉ -C ₁₆ group	√	√
Aromatic C ₁₇ -C ₃₄ group	x	√
Benzene	√	x
Benzo(a)pyrene and equivalents	√	√
CO	√	x
Dichlorobenzene	√	x
Formaldehyde	√	√
n-Hexane	√	x
Naphthalene	√	x
NO ₂	√	x
PM _{2.5}	√	x
Pyrene	x	√
SO ₂	√	x
Toluene	√	x

Notes:

- ¹ The chemical constituents of the aliphatic and aromatic groups, as well as the benzo(a)pyrene equivalents are provided in [Table 18.4-2](#).
- ² The aromatic C₁₇-C₃₄ group and pyrene were not included in the inhalation assessment as health-based exposure limits for inhalation exposure have not been developed or recommended by any of the scientific authorities examined.

18.4.2.1 Inhalation Assessment

Inhalation exposure estimates were based on the results of air dispersion modelling described in the air quality assessment (see [Volume 4, Section 4.0](#)). Predicted air concentrations were evaluated in association with different averaging periods (i.e., 10-minute, 1-hour, 8-hour, 24-hour and annual) to allow for the assessment of both acute and chronic inhalation health risks. Predicted ground-level air concentrations for the chemical groups were based on the addition of the air concentrations predicted at each location for each of the COPCs included in the chemical group. For example, the ground-level air concentrations predicted for n-hexane and n-pentane at R01 (Cabin A) were summed to derive a total air concentration for the aliphatic C₅-C₈ group at R01 (Cabin A).

Predicted ground-level air concentrations incorporated emissions associated with all major regional sources as well as background community concentrations (see [Volume 4, Section 4.5.4](#)). Because the air quality assessment enabled the existing conditions in the region to be adequately characterized, further background concentrations were not added to the predicted values in the HHRA.

18.4.2.2 Multiple Pathway Assessment

Determination of potential exposure to the COPCs through multiple pathways relied on both ambient measurements and predictive exposure modelling. The former approach involves the monitoring of the COPCs in environmental media, preferably in the area of the project, and is usually accomplished by the simple collection and quantification of the COPCs to provide estimates of ambient levels. Whenever possible, this approach was used to characterize the background concentrations of the COPCs in the environmental media. The second approach involved using predictive models to estimate the concentrations of the COPCs in media for each of the assessment cases (i.e., Baseline Case, Application Case and the Planned Development Case). Further details concerning each approach are provided below.

Ambient Measurements

As part of a baseline sampling program, concentrations of the COPCs were measured in surface water. Although samples of soil, sediment and groundwater were collected as part of the program, samples only underwent analysis for metals, which were not identified as COPCs for the project. On this basis, baseline data previously collected in support of other projects in the Conklin area were used to characterize baseline soil and vegetation data (Devon 2008; EnCana 2009; MEG Energy 2008).

Baseline soil and vegetation sampling data obtained from the EIAs for three neighbouring projects (i.e., Devon Jackfish 2, EnCana Christina Lake, and MEG Energy Christina Lake) were examined. In total, 37 samples of soil, 18 samples of alder leaves, 16 samples of berries, 22 samples of cattail roots, and 32 samples of Labrador tea leaves have previously been collected from the Conklin area and analyzed for a suite of PAHs. All soil and vegetation sampling data were below the method detection levels (MDLs) for PAHs (i.e., were non-detectable).

Surface Water Sampling Data

Surface water samples were collected from eight waterbodies within the surface water quality study area and analyzed for a suite of metals and PAHs. A total of 35 surface water samples were collected from three unnamed lakes, Christina Lake, three unnamed creeks and Sunday Creek between May 2005 and September 2008. PAH concentrations were largely below their MDLs, the exceptions being benz(a)anthracene, benzo(a)pyrene, pyrene and phenanthrene. [Table 18.4-9](#) provides the results of the PAHs analysis in surface water.

Table 18.4-9: Concentrations of the Chemicals of Potential Concern Measured in Surface Water

Chemical of Potential Concern	Detection Limit [µg/L]	# of Samples	# of Non-Detectables	% of Non-Detectables	Detected Values [µg/L]
Acenaphthene	<0.01 to <0.1	35	35	100%	n/a
Acenaphthylene	<0.01 to <0.2	16	16	100%	n/a
Anthracene	<0.007 to <0.1	35	35	100%	n/a
Benz(a)anthracene	<0.006 to <0.05	35	33	94%	Two detected values of 0.02
Benzo(a)pyrene	<0.005 to <0.05	35	33	94%	Two detected values of 0.01
Benzo(b)fluoranthene	<0.01 to <0.1	24	24	100%	n/a
Benzo(g,h,i)perylene	<0.05	15	15	100%	n/a
Benzo(k)fluoranthene	<0.01 to <0.1	24	24	100%	n/a
Chrysene	<0.05	31	31	100%	n/a
Dibenz(a,h)anthracene	<0.01 to <0.1	24	24	100%	n/a
Fluoranthene	<0.04	35	35	100%	n/a
Fluorene	<0.02 to <0.05	35	35	100%	n/a
Indeno(1,2,3-cd)pyrene	<0.1	24	24	100%	n/a
Phenanthrene	<0.01 to <0.05	35	31	88%	Four detected values of 0.05
Pyrene	<0.02	35	34	97%	One detected value of 0.02

Notes:

n/a – not applicable

The maximum measured benz(a)anthracene, benzo(a)pyrene, pyrene and phenanthrene concentrations obtained during the surface water sampling program were used to characterize background or ambient exposures for the residents in the multiple pathway assessment. For the surface water concentrations used in the multiple pathway exposure models, see [Appendix J2](#).

Predictive Exposure Modelling

Predictive exposure models rely on the use of mathematical equations (algorithms) that define the movement of the COPCs from the point of release of the chemicals into the air (i.e., from the project) to the point of contact with humans (Health Canada 1995; US EPA 2002).

The following data were considered as part of the predictive exposure modelling:

- the maximum ground-level air concentrations of a COPC as a result of atmospheric emissions from the project, in combination with those from other regional sources;
- the various physical and chemical characteristics (e.g., water solubility, volatility, deposition rates), which determine the fate and transport of the COPC in various environmental media and the food chain;
- the concentration of each COPC transported from air to other environmental media (e.g., soil, vegetation, wildlife);

- the concentration of each COPC measured in environmental media from the project area (e.g., surface water);
- the various exposure pathways identified in the problem formulation that could potentially contribute to uptake by humans;
- absorption characteristics of each COPC once exposure has occurred; and
- the activity patterns and characteristics of human receptors (e.g., respiration rate, food consumption).

Additional details regarding the predictive exposure models used in the HHRA are provided in [Appendix J2](#).

Concentrations of the Chemicals of Potential Concern in Environmental Media

Measured concentrations were only obtained for four of the COPCs in local waterbodies. The maximum measured concentrations were used to characterize potential background exposures in the multiple pathway assessment associated with drinking local water. Measured surface water concentrations also were used to predict concentrations in fish and wild game tissue. From this, potential background exposures associated with fish and wild game ingestion were predicted ([Table 18.4-10](#)).

The multiple pathway exposure models predicted lifestyle-specific concentrations of the COPCs in environmental media (i.e., soil, vegetation, water, wild game and fish) under the Baseline Case, Application Case and the Planned Development Case based on the atmospheric deposition of the maximum predicted annual average air concentrations for each lifestyle category (i.e., resident and worker).

To compensate, in part, for the uncertainty surrounding the use of modelled predictions of exposure, “reasonable worst-case” assumptions were applied to describe the movement of the COPCs to ensure that the predictions do not underestimate potential exposure.

18.4.3 Toxicity Assessment

The toxicity assessment involves identifying and understanding potential health effects that can result from exposure to each COPC, and the conditions under which the effects might be observed. The assessment relied on the following guiding principles that have been proven through years of scientific investigation and observation:

- All chemicals, regardless of type or source, possess some degree of intrinsic toxicity (i.e., all chemicals have the capacity to cause some level of harm or injury);
- The health effects produced by any chemical depend on both the intrinsic toxicity of the substance and the exposure, or dose, of the chemical that is received. Potential health effects associated with exposures to the COPCs, and the basis of the individual COPC exposure limits, are described in [Appendix J1](#);

Table 18.4-10: Concentrations of the Chemicals of Potential Concern in Environmental Media

Media	Description
Air	Air dispersion modelling incorporated meteorological data that represented conditions contributing to maximum predicted ground-level air concentrations of the COPCs. The maximum annual average air concentrations were predicted for each location at which people are known or anticipated to spend time on a long-term basis. Ground-level air concentrations, including background community sources, were predicted as part of the air quality assessment (see Volume 4, Section 4.0).
Soil	Background concentrations of the COPCs were non-detectable in soils, thus no background concentrations were used in the multiple pathway models. Soil concentrations were predicted for each lifestyle category (i.e., residents and workers) based on: <ul style="list-style-type: none"> the direct deposition of the highest annual average air concentrations of the locations within each lifestyle category; and chemical losses due to degradation and volatilization.
Vegetation	Background concentrations of the COPCs were non-detectable in vegetation, thus no background concentrations were incorporated in the multiple pathway models. Above-ground plant (i.e., alder, Labrador tea leaves and above-ground garden vegetables) concentrations were predicted for the residents based on: <ul style="list-style-type: none"> the direct deposition of the highest annual average air concentrations of the 37 resident locations; direct vapour uptake from the atmosphere; and root uptake from soil. Below-ground plant (i.e., cattail roots and below-ground garden vegetables) as well as fruit and berry concentrations were predicted for the residents using the highest predicted soil concentration of the 37 resident locations (described above). Following US EPA guidance (US EPA OSW 2005), direct deposition and vapour uptake were not incorporated in the prediction of the COPC concentrations in fruits and berries. The HHRA did not make any adjustments for washing or peeling of garden produce, fruits or berries.
Water	In surface water, background concentrations of the COPCs were non-detectable for the majority of COPCs, the exceptions being benz(a)anthracene, benzo(a)pyrene, pyrene and phenanthrene. From this, background concentrations were incorporated in the multiple pathway models for these PAHs. In addition, concentrations of the COPCs were predicted in surface water based on: <ul style="list-style-type: none"> the direct deposition of the highest annual average air concentrations of the 37 resident locations; the physical dimensions of Christina Lake; and chemical losses due to degradation and volatilization.
Wild Game	Concentrations of the COPCs in wild game tissues (i.e., moose, snowshoe hare and ruffed grouse) were predicted for the residents based on: <ul style="list-style-type: none"> the highest annual average air concentrations of the 37 resident locations and the local MPOI; ingestion of soil and alder leaves; ingestion of water and aquatic plants from the unnamed lake located within the project area; and chemical losses due metabolism of the COPCs.
Fish	Concentrations of the COPCs in fish tissues were predicted for the residents based on predicted surface water concentrations for the closest waterbody known to contain sport fish (i.e., Christina Lake).

- With few exceptions, the intrinsic toxicity of a chemical (i.e., the capacity to produce a harmful effect or physiological injury) is only expressed if the exposure exceeds a critical threshold level. Below this threshold dose, injury does not occur and health effects are not observed. A possible exception to this principle involves the actions of certain chemical carcinogens that act via genetically mediated mechanisms to produce certain forms of cancer. Some scientists contend that no safe dose levels exist for these carcinogens (Health Canada 2004). Other scientific authorities disagree and argue that the threshold phenomenon applies equally to carcinogens and non-carcinogens; often this approach to carcinogens is chemical dependent (Health Canada 2006; Klassen 1996). Debate also surrounds whether or not the threshold phenomenon applies to particulate matter (PM) and some other forms of air pollution (Health Canada 2004; US EPA 2004; WHO 2000, 2006). In each case, experimental data demonstrating the absence of a threshold dose are lacking, and the exceptions represent theoretical arguments only;
- If the threshold dose is exceeded, health effects can occur. The severity of these effects will depend on the level of exposure received, with more severe effects occurring with increasing dose;
- The toxicity of a chemical depends on its molecular structure. Within limits, chemicals with similar structures will produce similar evidence of toxicity. This principle allows the health effects of a chemical of unknown toxicity to be predicted by comparison with known health effects produced by a second chemical of similar molecular structure; and
- The health effects produced by a chemical depend on the nature, extent and duration of exposure. It is important to distinguish between the health effects that might result from acute exposures of short duration and effects that might occur following chronic or long-term exposure. Also, health effects might differ according to the route of exposure (e.g., inhalation rather than oral exposure).

Chemicals may differ not only with respect to the dosage required to cause an adverse effect, but also in the mechanism by which the adverse effect is elicited. For this reason, two general categories were used to evaluate the COPCs based upon their mode of action or mechanism of toxicity: threshold and non-threshold.

In the case of threshold chemicals, which are generally non-carcinogenic chemicals, a benchmark or threshold level must be exceeded for toxicity to occur. The degree of toxicity expressed then increases with increasing dose. The threshold phenomenon applies to virtually all types of toxic responses and chemicals, with the exception of some carcinogens and some forms of cancer. For these chemicals, a no-observed-adverse-effects-level (NOAEL) can be identified. A NOAEL is the dose or amount of the chemical that results in no obvious response in the most sensitive test species and test endpoint. In some cases, a benchmark dose or concentration (BMD or BMC) is derived, which represents the dose associated with a specific magnitude of response (i.e., 5 or 10% incidence within the study population). In the derivation of exposure limits by leading regulatory and scientific agencies, uncertainty factors are applied to the NOAEL or BMD/BMC to provide protection for the most sensitive subjects following exposure over a prescribed period.

Non-threshold chemicals are capable of producing cancer through one or more of a number of possible mechanisms (e.g., mutagenicity, cytotoxicity, inhibition of programmed cell death, mitogenesis [uncontrolled cell proliferation] and immune suppression) that, in theory, do not require the exceedance of a threshold (US EPA 2005). In general, tumourigenicity data from animals or human epidemiological studies are evaluated and examined using mathematical models to determine the chemical-specific unit risks or slope factors, which are in turn used to develop applicable exposure limits. Regulatory agencies, such as Health Canada and the US EPA, assume that any level of long-term exposure to carcinogenic chemicals is associated with some “hypothetical cancer risk”. As a result, Health Canada and AENV have specified an incremental (i.e., over and above background) lifetime cancer risk of one in 100 000, which these agencies consider acceptable, tolerable or essentially negligible (AENV 2009b; Health Canada 2004). The regulatory benchmark of an acceptable cancer risk of one in 100 000 is policy-based (CCME 2006), and its interpretation by various regulatory agencies differs.

An assumed incremental cancer risk of one in 100 000 increases a person’s lifetime cancer risk from 0.40000 (based on the 40% lifetime probability of developing cancer in Canada) to 0.40001 (CCS/NCIC 2006). Because this assumed “acceptable” cancer risk level was specifically developed to address cancer risks over and above background cancer incidence, a portion of which includes background exposure to environmental pollutants, background exposures were not included in the assessment of potential cancer risks for non-threshold (i.e., carcinogenic) chemicals (Wilson 2005).

The general terminology used to define threshold and non-threshold exposure limits differs according to the source and type of exposure. Also, it often varies between regulatory jurisdictions. Generic nomenclature has been developed, with the following terms and descriptions commonly used:

- *Reference Concentration (RfC)* – refers to the safe level of an airborne chemical for which the primary avenue of exposure is inhalation. It is expressed as a concentration of the chemical in air (i.e., $\mu\text{g}/\text{m}^3$) and applies only to threshold chemicals;
- *Reference Dose (RfD)* – refers to the safe level or dose of a chemical for which exposure occurs through multiple pathways (i.e., inhalation, ingestion and dermal). It is most commonly expressed in terms of the total intake of the chemical per unit of body weight (i.e., $\mu\text{g}/\text{kg bw}/\text{d}$). This term applies only to threshold chemicals;
- *Risk-specific Concentration (RsC)* – reserved for non-threshold or carcinogenic chemicals and refers to the level of an air-borne carcinogen for which the primary route of exposure is inhalation that results in a “regulatory acceptable” incremental increase in cancer (typically one in 100 000). It is expressed as a concentration of the chemical in air (i.e., $\mu\text{g}/\text{m}^3$); and
- *Risk-specific Dose (RsD)* – reserved for non-threshold or carcinogenic chemicals and refers to the dose of a carcinogen for which exposure occurs through multiple pathways that results in a “regulatory acceptable” increased incidence of cancer (typically one in 100 000). It is expressed in terms of the total intake of the chemical (i.e., $\mu\text{g}/\text{kg bw}/\text{d}$).

18.4.3.1 Exposure Limits

For the purpose of the HHRA, reliance was placed on exposure limits developed by regulatory or reputable scientific agencies as criteria (i.e., objectives, guidelines or standards) for the protection of air quality and human health. Exposure limits were sourced from:

- provincial regulatory agencies, including AENV;
- federal regulatory agencies, including Health Canada and CCME; and
- international regulatory and reputable scientific agencies, including the ATSDR, ACGIH, OEHHA, RIVM, TCEQ, US EPA and the WHO.

These exposure limits typically incorporate a high level of conservatism, in view of the mandate of the authorities to offer guidance aimed at the protection of public health. That said, the basis of these exposure limits might differ depending on the responsible regulatory jurisdiction or scientific authority charged with developing the safe or acceptable level of exposure. The limits also might differ in terms of the primary determinant(s) of concern (e.g., direct health effects versus odour) and the level of protection required. For inclusion in the HHRA, exposure limits were required to be:

- established or recommended by a reputable scientific or regulatory agency;
- protective of the health of the general public based on current scientific knowledge of the health effects associated with exposure to the COPC;
- protective of sensitive individuals (i.e., children and the elderly) through the incorporation of uncertainty or safety factors; and
- supported by adequate documentation.

Emphasis was given to those limits, which had adequate supporting documentation so that the limits could be evaluated to ensure that their basis was relevant and sufficient. When these criteria were satisfied by more than one objective, guideline or standard, the most scientifically defensible limit was selected. The scientific rationale for the exposure limit selection process is provided in [Appendix J1](#).

Because the toxicity and critical endpoint of a chemical has been observed to vary between short-term (acute) and long-term (chronic) exposure, it is important to differentiate exposure limits on the basis of exposure duration. The two exposure limit durations that will be used in the HHRA can be described as follows:

- *Acute Exposure Limit* – the amount or dose of a chemical that can be tolerated without evidence of adverse health effects on a short-term basis. These limits are routinely applied to conditions in which exposures extend over several hours or several days only; and
- *Chronic Exposure Limit* – the amount of a chemical that is expected to be without effect, even when exposure occurs continuously or regularly over extended periods, lasting for periods of at least a year, and possibly extending over an entire lifetime.

A complete list of the exposure limits selected for use in the HHRA is presented in [Table 18.4-11](#).

Table 18.4-11: Exposure Limits for the Chemicals of Potential Concern

Chemical of Potential Concern	Exposure Limits					
	Acute Inhalation		Chronic Inhalation		Chronic Multiple Pathway	
	Type	Value [µg/m ³]	Type	Value [µg/m ³]	Type	Value [µg/kg bw/d]
Aliphatic C ₅ -C ₈ group	–	–	RfC	18 400	n/a	n/a
Aromatic C ₉ -C ₁₆ group	1-hour	2 000	RfC	50	RfD	40
Aromatic C ₁₇ -C ₃₄ group	–	–	–	–	RfD	30
Benzene	1-hour	580	RsC	1.3	n/a	n/a
Benzo(a)pyrene and equivalents ¹	–	–	RsC RsC	0.00012 0.32	RsD	0.0014
CO	1-hour 8-hour	15 000 6 000	–	–	n/a	n/a
Dichlorobenzene	1-hour	3 000	RfC	60	n/a	n/a
Formaldehyde	1-hour	50	RfC	11	RfD	200
n-Hexane	–	–	RfC	670	n/a	n/a
Naphthalene	–	–	RfC	3	n/a	n/a
NO ₂	1-hour 24-hour	400 200	RfC	60	n/a	n/a
PM _{2.5}	24-hour	30	RfC	12	n/a	n/a
Pyrene	–	–	–	–	RfD	30
SO ₂	10-minute 1-hour	500 450	RfC	30	n/a	n/a
Toluene	1-hour	1 500	RfC	5 000	n/a	n/a

Note:

¹ Potential chronic inhalation health risks associated with benzo(a)pyrene and the other carcinogenic PAHs were evaluated using two different approaches, as described in [Appendix J1](#). The two RsC values provided above reflect these two approaches.

– Indicates value is not available.

n/a Not applicable; chronic oral exposure limits were only required for those COPCs that were deemed to be non-volatile and were thus included in the multiple pathway assessment.

RfC = Reference Concentration; RfD = Reference Dose; RsC = Risk-specific Concentration; RsD = Risk-specific Dose

18.4.3.2 Chemical Mixtures

Given that chemical exposures rarely occur in isolation, the potential health risks associated with mixtures of the COPCs were assessed in the HHRA. Although the interaction between chemicals can take many forms, additive interactions were assumed for the HHRA (Health Canada 2004). Additive interactions apply most readily to chemicals that are structurally similar, act toxicologically through similar mechanisms or affect the same target tissue in the body (i.e., share commonality in effect) (Health Canada 2004).

Potential additive interactions were identified for specific COPCs that may cause:

- irritation of the eyes, nose or respiratory tract;
- kidney toxicity; and
- neurotoxicity.

The endpoints of the exposure limits used in the HHRA provided the basis for an individual chemical's inclusion in a chemical mixture. For example, the acute inhalation exposure limit for formaldehyde is based on its ability to cause eye and nasal irritation, thus formaldehyde was included in both the acute inhalation "eye irritants" and "nasal irritants" mixtures. For details concerning the critical endpoints of the chemicals included in each of the mixtures, see [Appendix J1](#).

The chemical constituents of the mixtures are listed in [Table 18.4-12](#).

Table 18.4-12: Potential Additive Interactions of the Chemicals of Potential Concern

Exposure	Designation	Chemical Constituents ²
Acute Inhalation	Eye irritants	Aromatic C ₉ -C ₁₆ group; Dichlorobenzene; Formaldehyde
	Nasal irritants	Dichlorobenzene; Formaldehyde
	Respiratory irritants ¹	NO ₂ ; SO ₂
Chronic Inhalation	Nasal irritants	Dichlorobenzene; Formaldehyde; Naphthalene
	Respiratory irritants	Formaldehyde; Naphthalene; NO ₂ ; SO ₂
	Neurotoxicants	Aliphatic C ₅ -C ₈ group; n-Hexane; Toluene
Chronic Multiple Pathway	Kidney toxicants	Aromatic C ₉ -C ₁₆ group; Aromatic C ₁₇ -C ₃₄ group; Formaldehyde; Pyrene

Note:

¹ The highest risk quotient (RQ) values of the different averaging times for NO₂ (i.e., 1-hour and 24-hour) and SO₂ (i.e., 10-minute and 1-hour) were used in the prediction of potential health risks for the acute respiratory irritants mixture.

² Because some COPCs were assessed both individually and as part of a chemical group, the corresponding risk estimates were likely exaggerated due to the "double counting" of these chemicals in the mixtures. For example, the chronic risk estimate for n-hexane was added to the chronic risk estimate for the aliphatic C₅-C₈ group, which includes n-hexane, in the assessment of the chronic health risks associated with neurotoxicants.

Chemical interactions were not assessed for recreational persons because the exact locations within the health LSA where the maximum chemical concentrations would occur differed between the COPCs. For example, the precise location where the maximum 1-hr ground-level air concentration for the aromatic C₉-C₁₆ group was predicted to occur did not correspond to the location at which the maximum dichlorobenzene concentration was predicted to occur.

18.4.4 Risk Characterization

This final step of the assessment involves comparison of the estimated exposures with the selected exposure limits to determine potential health risks for the different assessment cases. In addition, sources of uncertainty and how uncertainties were addressed is discussed.

The uncertainty associated with the prediction of potential health risks is mitigated, in part, through the use of “reasonable worst-case” assumptions. Using this approach, any health risks identified by the assessment are unlikely to be understated, but may instead be overstated. Thus, it is important that the uncertainties and assumptions underlying the potential health risks be known and understood.

18.4.4.1 Non-Cancer Risks

Risk quotients (RQ values) were calculated by comparing the predicted levels of exposure for the non-carcinogenic COPCs to their respective exposure limits (described in [Section 18.4.3.1](#) and [Appendix J1](#)) that have been developed by regulatory and scientific authorities. Risk quotients were calculated using as follows:

$$RQ = \frac{\text{Predicted Exposure } (\mu\text{g} / \text{m}^3 \text{ or } \mu\text{g} / \text{kg bw} / \text{d})}{\text{Exposure Limit } (\mu\text{g} / \text{m}^3 \text{ or } \mu\text{g} / \text{kg bw} / \text{d})}$$

Interpretation of the RQ values proceeded as follows:

- $RQ \leq 1.0$ – Indicates that the estimated exposure is less than or equal to the exposure limit (i.e., the assumed safe level of exposure). RQ values less than or equal to 1.0 are associated with negligible health risks, even in sensitive individuals given the level of conservatism incorporated in the derivation of the exposure limit and exposure estimate; and
- $RQ > 1.0$ – Indicates that the exposure estimate exceeds the exposure limit. This suggests an elevated level of risk, the significance of which must be balanced against the degree of conservatism incorporated into the risk assessment.

18.4.4.2 Cancer Risks

As previously mentioned, regulatory agencies such as Health Canada, AENV and the US EPA assume that any level of long-term exposure to carcinogenic chemicals is associated with some “hypothetical cancer risk”. On this basis, Health Canada and AENV have specified an incremental (i.e., over and above background) lifetime cancer risk of one in 100 000, which these agencies consider acceptable, tolerable or essentially negligible (AENV 2009b; Health Canada 2004). Because this assumed “acceptable” cancer risk level was specifically developed to address cancer risks over and above background cancer incidence, a portion of which includes background exposure to environmental pollutants, background exposures were not included in the assessment of potential health risks for non-threshold (i.e., carcinogenic) chemicals.

Further, Health Canada (2004) requires that carcinogens be assessed on an incremental basis, and mandate an “acceptable” incremental lifetime cancer risk (ILCR) of one in 100 000. For the purposes of this assessment, ILCR estimates have been determined for the project alone as well as the incremental contribution of the future emission sources. Interpretation of these ILCR

values was based on comparison of the ILCR associated with the project alone against the Health Canada (2004) *de minimus* risk level of one in 100 000 (i.e., one extra cancer case in a population of 100 000 people).

The ILCR values were calculated for the project alone and future emission sources as follows:

$$ILCR = \frac{\text{Incremental Exposure } (\mu\text{g} / \text{m}^3 \text{ or } \mu\text{g} / \text{kg bw} / \text{d})}{\text{Carcinogenic Exposure Limit } (\mu\text{g} / \text{m}^3 \text{ or } \mu\text{g} / \text{kg bw} / \text{d})}$$

Interpretation of the ILCR values proceeded as follows:

- ILCR \leq 1.0 – Denotes an incremental lifetime cancer risk that is below the benchmark ILCR of one in 100 000 (i.e., within the accepted level of risk set by provincial and federal regulatory agencies); and
- ILCR $>$ 1.0 – Indicates an incremental lifetime cancer risk that is greater than the *de minimus* risk level of one in 100 000, the interpretation of which must consider the conservatism incorporated into the assessment.

18.4.4.3 Major Assumptions of the Human Health Risk Assessment

In an attempt to ensure that health risks would not be underestimated, “reasonable worst-case” assumptions were incorporated into the HHRA. A summary of the various assumptions that were incorporated into the HHRA is provided in [Table 18.4-13](#), arranged according to the steps of the risk assessment paradigm ([Figure 18.2-1](#)).

18.5 Mitigative Measures

Other than the mitigation measures already planned for air quality, surface water quality and groundwater quality, no additional measures are considered necessary for the protection of human health. A summary of the measures designed to manage potential impacts to air quality, surface water quality and groundwater quality is provided below.

18.5.1 Air Quality

Measures to manage combustion emissions from the project (see [Volume 4, Section 4.6](#)) include:

- centralization of emissions from the field (e.g., individual well pad flares) to the CPF will increase the dispersion potential of the emissions and reduce the impact to air quality in the area;
- combustion of produced gas in the boilers, as opposed to flaring, offers the advantage of more reliable and complete combustion, reducing the opportunity for the formation of incomplete combustion products;
- steam boilers will use low NO_x burners that meet the NO_x emission levels currently specified by the CCME;

Table 18.4-13: Major Assumptions Used in the Human Health Risk Assessment

Risk Assessment Step	Assumption	Discussion of Uncertainty
Exposure Assessment	Air dispersion modelling incorporated meteorological data that represented conditions contributing to maximum predicted ground-level air concentrations of the COPCs.	Use of the maximum predicted ground-level air concentrations of the COPCs likely contributed to the exaggeration of the exposures that might be received by people residing or visiting the area under most circumstances.
	Recreational persons might be found at the local MPOI, presenting the possibility that they could be exposed to the maximum predicted ground-level air concentrations of the COPCs within the health LSA.	The choice of these locations is expected to contribute to the exaggeration of the exposures that might be received by the recreational persons under most circumstances, as it is unlikely that individuals will be engaged in traditional or recreational activities at the MPOI at the exact time when the meteorological conditions contributing to the maximum concentrations occur.
	The people with the highest predicted exposures within each lifestyle category (i.e., recreational persons, residents and workers) were used to characterize the potential exposures for all people represented by the lifestyle category.	Potential exposure assumed for each lifestyle category represents a “reasonable worst-case” scenario. This contributes to the exaggeration of the potential risks other people in the lifestyle category may be presented with.
	Predicted chronic exposures for the residents were based on the assumption that individuals would be exposed 24 hours per day, 365 days per year to the maximum predicted ground-level air concentrations of the COPCs for the entire duration of their lives (i.e., 75 years).	The operating “life” of the project is expected to be 25 years; thus, assuming 75 years of COPC emissions into the air and water as well as 75 years of deposition is likely to contribute to the exaggeration of actual levels of exposures. Furthermore, residents would not be expected to maintain year-round occupancy at the camps, cabins, fire lookout towers and lodges in the area.
	Predicted chronic multiple pathway exposures associated with the non-carcinogens were estimated for all life stages, but only the results of the most sensitive age groups were reported.	Predicted exposures for the other life stages are anticipated to be lower than those reported.
	Residents were assumed to obtain 100% of their food from local food sources (e.g., berries and plants, wild game, fish and garden produce) and drinking water from local waterbodies.	The assumption that the residents obtain all of their food over their lifetime from the area is likely to contribute to the exaggeration of the exposures that might be received by these people under actual circumstances.
	Predicted environmental media concentrations (i.e., soil, plant, wild game, water and fish) were based on 75 years of continuous project emissions and associated chemical deposition, to represent an individual’s assumed lifespan.	The operating “life” of the project is expected to be 25 years; thus, assuming 75 years of COPC emissions into the air and water as well as 75 years of deposition is expected to contribute to the exaggeration of the exposures by both primary and secondary pathways.
	Tissue concentrations from local wild game, such as moose, snowshoe hare, and ruffed grouse, were based on the maximum predicted ground-level air concentrations of the MPOI locations and all resident locations.	Apart from the fact that it is unlikely that wild game will forage at one discrete location over their entire lifetime, assuming that wild game will forage at the location where the maximum concentrations are predicted in air, soil, water and vegetation over their lifetime is likely to contribute to the exaggeration of the exposures to people that consume wild game.

Risk Assessment Step	Assumption	Discussion of Uncertainty
Toxicity Assessment	Exposure limits were developed to be protective of the sensitive and more susceptible individuals within the general population (e.g., infants and young children, the elderly, individuals with compromised health) (ATSDR 2009; US EPA 2002, 2010).	A considerable amount of conservatism is incorporated in the exposure limits. Limits are deliberately set to be protective of sensitive individuals. The limits were derived from the most sensitive endpoints, and then adjusted to account for differences in sensitivity to chemicals among individuals. The use of uncertainty factors is already directed, in part, toward the protection of sensitive individuals.
	The findings from toxicity studies with laboratory rodents can be used to gauge the types of responses and health effects that the chemicals may cause in humans and the findings from the laboratory rodent studies can be used, in part, to determine exposure limits for the chemicals.	Laboratory rodents have traditionally served as suitable surrogate species for humans. The use of uncertainty factors accounts for the possible differences in responses to chemicals that might be observed between laboratory rodents and other species, such as humans (see Appendix J1). However, recent evidence suggests that rodents might be more sensitive to nasal effects than humans as a result of higher doses reaching the critical target site in rodents.
	The exposure limits for surrogate chemicals adequately represent the toxicity of the chemicals being represented.	In the absence of toxicity data for a number of the individual chemicals in the initial inventory, it was necessary to assume that structural similarity to the surrogate was a sufficient basis for the assumption of toxicological similarity.
	Possible interactions of the COPCs released by the project, which might lead to enhanced toxicity, were adequately addressed in the assessment.	Consistent with Health Canada (2004) guidance, potential health risks associated with the COPCs were considered to be additive if the exposure limit for the COPCs had the same toxicological endpoint. In some instances, it is possible that components of a mixture may have different mechanisms of effect, contributing some uncertainty in the predicted risk estimates for mixtures.

- steam generators will be designed to operate at a high efficiency (i.e., above 84% on a high heating value basis) and steam lines will be insulated to minimize heat losses associated with the transport of steam to the pads, thereby reducing the amount of fuel gas used; and
- continuous flaring will be limited to a pilot in the high pressure flare at the CPF and flaring due to upset/emergency conditions, start-up and commissioning will be minimized for the project.

During upset conditions, a flare stack will be used to dispose of unwanted gas streams. Upset flaring will be infrequent and short in duration. Two upset scenarios were modelled as part of the air quality assessment (see [Volume 4, Section 4.6.3](#)):

- *Upset Scenario 1* – flaring of gas vented in the event of vapour recovery unit (VRU) failure; and
- *Upset Scenario 2* – steam generator shutdown where the produced gas is diverted to the flare at the CPF.

The following section provides a detailed analysis of the “worst-case” upset scenario described above: Upset Scenario 2. From this, the predicted 9th highest 1-hour SO₂ concentration associated with emergency flare emissions would be 25.5 µg/m³. Comparison against the 1-hour SO₂ Alberta Ambient Air Quality Objective (AAAQO) of 450 µg/m³ results in an RQ of 0.057. Concentrations at other averaging periods were not predicted as emergency flaring is not expected to occur frequently, nor will it last for more than a few hours per occurrence.

To account for the influence of background concentrations of SO₂ that were not incorporated in the SO₂ predictions for the “worst-case” upset scenario, ambient air concentrations of SO₂ measured at the closest ambient air monitoring station in Anzac, Alberta were obtained. Between 2006 and 2009, hourly ambient SO₂ concentrations ranging from 2.6 to 180.5 µg/m³ have been measured in Anzac. Incorporation of the maximum hourly SO₂ concentration of the four consecutive years of data (180.5 µg/m³) represents a conservative estimate of ambient SO₂ concentrations in the region. Comparison of the cumulative SO₂ concentration (i.e., 25.5 µg/m³ + 180.5 µg/m³ = 206 µg/m³) against the 1-hour AAAQO results in an RQ of 0.45. Thus, despite these worst-case assumptions, health risks from SO₂ associated with the upset scenarios for the project are considered negligible.

Fugitive hydrocarbon emissions can result from various connection leaks (i.e., valve packing and pipe flanges), venting associated with maintenance activities or venting associated with short-duration outages of vapour-recovery compressors. The following mitigative measures will be taken to reduce any fugitive emissions from the project:

- a VRU will be installed to capture vapours from the storage tanks thereby reducing fugitive tank emissions; and
- partial redundancy in compressors for the plant vapour recovery system will minimize fugitive emissions in the event of a compressor upset.

18.5.2 Surface Water Quality

Mitigation measures will be employed to reduce the potential for project-related impacts to surface water from construction activities and runoff from well pads, roads and utility corridors (see [Volume 4, Section 8.6](#)).

Appropriate technologies and best management practices will be used to minimize erosion and sediment loadings to streams during construction. These include:

- selection of pipeline and road routes to minimize area disturbance by maximizing the use of existing corridors, minimizing habitat disruption, minimizing watercourse crossings;
- use of common corridors for both pipelines and roads;
- minimization of site disturbance by using existing disturbed or cleared sites for the project facilities, wherever possible;
- a 100 m buffer zone applied to waterbodies;
- design and installation of pipeline and road crossings in accordance with AENV's *Code of Practice for Pipelines and Telecommunications Line Crossing a Water Body* and *Code of Practice for Watercourse Crossings* under the *Water Act*;
- pipeline crossings will be located above ground;
- water quality will be monitored during construction of watercourse crossings;
- use of appropriate sediment control techniques, such as silt fences, during construction of roads, drainage ditches and pipelines to minimize sediment runoff;
- use of appropriate stabilization techniques during soil stockpiling to minimize deposition from wind and water erosion; and
- all drilling waste will be disposed of in accordance with ERCB Directive 58 and Directive 50.

During operations, mitigation measures will be in place to reduce runoff from the well pads, roads and utility corridors that could directly affect surface waters by introducing sediments. These measures include:

- all well pads will be surrounded by ditches;
- in the event of a spill at a well pad, a spill contingency plan will be implemented;
- contaminated runoff from well pads will be taken to the CPF for recycling;
- roadside ditches will be constructed to collect and contain local road runoff; and
- installation of bridges, culverts and/or rock drains at drainage lows, wetlands and watercourse crossings.

18.5.3 Groundwater Quality

Potential impacts to shallow groundwater as a result of new surface facilities, including a CPF, well pads, source wells and associated pipelines, will be managed using the following mitigative strategies (see [Volume 4, Section 6.6](#)):

- flowlines and storage tanks will be located above ground to facilitate leak detection;
- storage tanks will be designed to meet ERCB Directive 55;
- the development of a comprehensive spill response plan;
- groundwater monitoring program will be implemented;
- site will be constructed over low permeability clayey soils; and
- adhering to best management practices and meeting or exceeding industry standards.

18.6 Results

Given that health effects are dependent, in part, on the duration of exposure, separate assessments were completed for acute and chronic exposures. Since the pathway of exposure will also influence the potential chronic health effects associated with each of the COPCs, the chronic assessment is further divided into those exposures received from direct inhalation versus multiple pathway exposures (e.g., food, soils, water, etc.).

In all, predicted risk estimates were segregated into:

- acute inhalation;
- chronic inhalation; and
- chronic multiple pathways.

The acute and chronic risk estimates are presented in scientific notation as many of the calculated numerical values are well below 1.0. For instance, the acute risk estimate for the recreational persons exposed to the maximum air concentration for the aromatic C₉-C₁₆ group under the Baseline Case is 9.5E-06, which is equivalent to a RQ of 0.0000095 ([Table 18.6-1](#)).

18.6.1 Acute Inhalation

Acute inhalation risk estimates, expressed as RQ values, were based on assumed exposure periods that range from a few minutes (e.g., 10-minute SO₂) to a day (e.g., 24-hours PM_{2.5}). The maximum acute RQ values for the recreational persons, residents and workers are presented in [Tables 18.6-1](#) through [18.6-3](#). Risk quotients for all 40 locations are presented in [Appendix J3](#).

Predicted acute RQ values did not exceed 1.0 for any of the COPCs or mixtures for any of the three assessment cases (i.e., Baseline Case, Application Case and the Planned Development Case). This demonstrates that in all cases, predicted COPC air concentrations were less than their health-based guidelines and that the additive interactions of the COPCs are not predicted to result in health-related impacts. Therefore, potential acute health risks associated with the COPCs and mixtures are predicted to be negligible at these locations.

Table 18.6-1: Acute Inhalation Risk Quotients – Recreational Persons

Chemical of Potential Concern ^{1,2}	Averaging Period	Risk Quotient ³		
		Baseline Case	Application Case	Planned Development Case
Aromatic C ₉ -C ₁₆ group	1-hour	9.5E-06	6.9E-02	6.9E-02
Benzene	1-hour	2.3E-04	2.3E-04	3.5E-04
CO	1-hour	7.6E-02	7.6E-02	7.6E-02
	8-hour	7.8E-02	7.8E-02	7.9E-02
Dichlorobenzene	1-hour	4.4E-06	1.3E-05	1.3E-05
Formaldehyde	1-hour	1.6E-02	1.6E-02	1.6E-02
NO ₂	1-hour	4.6E-01	4.6E-01	4.6E-01
	24-hour	5.5E-01	5.5E-01	5.5E-01
PM _{2.5}	24-hour	1.0E-01	1.3E-01	1.7E-01
SO ₂	10-minute	5.7E-01	5.7E-01	5.7E-01
	1-hour	4.4E-01	4.4E-01	4.4E-01
Toluene	1-hour	1.0E-04	1.0E-04	1.2E-04

Notes:

- ¹ Aliphatic C₅-C₈ group, aromatic C₁₇-C₃₄ group, benzo(a)pyrene, benzo(a)pyrene and equivalents, n-hexane, naphthalene, and pyrene were not included in the acute inhalation assessment due to the lack of an adequate acute inhalation exposure limit for the COPCs or, in the case of naphthalene, it was assessed used as the surrogate for the aromatic C₉-C₁₆ group.
- ² Mixtures were not assessed for recreational persons because the local MPOI locations are chemical-specific; that is to say, the location within the health LSA at which the maximum ground-level air concentration for NO₂ was predicted did not correspond to the location at which the maximum ground-level air concentration for SO₂ was predicted.
- ³ An RQ equal to or less than 1.0 signifies that the estimated exposure is equal to or less than the exposure limit and no health effects are expected. Values in bold show an RQ of greater than 1.0. With scientific notation, any value expressed to the negative power (i.e., E-x) shows that predicted exposures were less than the exposure limit; whereas, a value expressed to the positive power (i.e., E+x) shows exposure estimates exceeded the exposure limit.

Table 18.6-2: Acute Inhalation Risk Quotients – Residents

Chemical of Potential Concern ¹	Averaging Period	Risk Quotient ⁴		
		Baseline Case	Application Case	Planned Development Case
Aromatic C ₉ -C ₁₆ group	1-hour	6.4E-05	3.5E-02	3.5E-02
Benzene	1-hour	1.2E-03	1.2E-03	2.4E-03
CO	1-hour	4.2E-02	4.2E-02	4.2E-02
	8-hour	3.6E-02	3.6E-02	3.6E-02
Dichlorobenzene	1-hour	2.1E-06	6.4E-06	6.4E-06
Formaldehyde	1-hour	1.1E-02	1.1E-02	2.3E-02
NO ₂	1-hour	2.8E-01	2.8E-01	2.8E-01
	24-hour	2.4E-01	2.4E-01	2.7E-01
PM _{2.5} ²	24-hour	1.9E-01	1.9E-01	3.4E-01
SO ₂	10-minute	2.3E-01	2.3E-01	2.3E-01
	1-hour	1.8E-01	1.8E-01	1.8E-01
Toluene	1-hour	1.7E-04	1.7E-04	3.2E-04
Mixtures³				
Eye irritants	n/a	1.1E-02	4.0E-02	4.0E-02
Nasal irritants	n/a	1.1E-02	1.1E-02	2.3E-02
Respiratory irritants	n/a	4.4E-01	4.5E-01	4.5E-01

Notes:

- ¹ Aliphatic C₅-C₈ group, aromatic C₁₇-C₃₄ group, benzo(a)pyrene, benzo(a)pyrene and equivalents, n-hexane, naphthalene, and pyrene were not included in the acute inhalation assessment due to the lack of an adequate acute inhalation exposure limit for the COPCs or, in the case of naphthalene, it was assessed used as the surrogate for the aromatic C₉-C₁₆ group.
- ² Health Canada's SUM15 method, which is different from more recent methods and calculates excess health risk when PM_{2.5} air concentrations exceed a daily threshold of 15 µg/m³ (Health Canada 1999), is provided for R19 (Janvier IR 194) in [Appendix J4](#). Janvier IR 194 was assessed using Health Canada's SUM15 approach since daily PM_{2.5} concentrations were predicted to exceed 15 µg/m³ on one or more days during a year. Janvier IR 194 was the only location for which PM_{2.5} concentrations were predicted to exceed 15 µg/m³.
- ³ Individual constituents of the chemical mixtures are identified in [Table 18.4-12](#). Note that addition of the individual RQ values provided in the above table for a mixture's chemical constituents might not equate to the RQ value provided for the mixture because the RQ values in the table represent the highest RQ for each lifestyle category. For example, in the Baseline Case, the dichlorobenzene RQ in the above table is based on predictions at R09 (Metis Trailer Camp), while the RQ for the formaldehyde is based on R19 (Janvier IR 194), and the RQ for the "eye irritants" mixture is based on R09 (Metis Trailer Camp).
- ⁴ An RQ equal to or less than 1.0 signifies that the estimated exposure is equal to or less than the exposure limit and no health effects are expected. Values in bold show an RQ of greater than 1.0. With scientific notation, any value expressed to the negative power (i.e., E-x) shows that predicted exposures were less than the exposure limit; whereas, a value expressed to the positive power (i.e., E+x) shows exposure estimates exceeded the exposure limit.

Table 18.6-3: Acute Inhalation Risk Quotients – Workers

Chemical of Potential Concern ¹	Averaging Period	Risk Quotient ³		
		Baseline Case	Application Case	Planned Development Case
Aromatic C ₉ -C ₁₆ group	1-hour	6.1E-06	1.5E-02	1.5E-02
Benzene	1-hour	1.5E-04	1.5E-04	2.4E-04
CO	1-hour	6.1E-03	6.1E-03	7.0E-03
	8-hour	6.8E-03	6.8E-03	9.1E-03
Dichlorobenzene	1-hour	3.0E-06	3.7E-06	3.7E-06
Formaldehyde	1-hour	1.1E-02	1.1E-02	1.1E-02
NO ₂	1-hour	2.8E-01	2.8E-01	2.8E-01
	24-hour	2.0E-01	2.0E-01	2.3E-01
PM _{2.5}	24-hour	4.1E-02	7.2E-02	1.3E-01
SO ₂	10-minute	6.2E-01	6.2E-01	6.2E-01
	1-hour	4.8E-01	4.8E-01	4.8E-01
Toluene	1-hour	8.5E-05	8.5E-05	9.3E-05
Mixtures²				
Eye irritants	n/a	1.1E-02	2.6E-02	2.6E-02
Nasal irritants	n/a	1.1E-02	1.1E-02	1.1E-02
Respiratory irritants	n/a	9.0E-01	9.0E-01	9.0E-01

Notes:

¹ Aliphatic C₅-C₈ group, aromatic C₁₇-C₃₄ group, benzo(a)pyrene and equivalents, n-hexane, naphthalene, and pyrene were not included in the acute inhalation assessment due to the lack of an adequate acute inhalation exposure limit for the COPCs or, in the case of naphthalene, it was assessed used as the surrogate for the aromatic C₉-C₁₆ group.

² Individual constituents of the chemical mixtures are identified in [Table 18.4-12](#). Note that addition of the individual RQ values provided in the above table for a mixture's chemical constituents might not equate to the RQ value provided for the mixture because the RQ values in the table represent the highest RQ for each lifestyle category.

³ An RQ equal to or less than 1.0 signifies that the estimated exposure is equal to or less than the exposure limit and no health effects are expected. Values in bold show an RQ of greater than 1.0. With scientific notation, any value expressed to the negative power (i.e., E-x) shows that predicted exposures were less than the exposure limit; whereas, a value expressed to the positive power (i.e., E+x) shows exposure estimates exceeded the exposure limit.

18.6.2 Chronic Inhalation

Chronic inhalation health risks were estimated based on the assumption that residents would be continuously exposed to maximum predicted annual average air concentrations for an assumed lifespan of 75 years (Health Canada 2004), while workers would be continuously exposed over the 56 years of their adult life. Chronic inhalation health risks were calculated and evaluated for the residents and workers. Recreational persons were not included in the chronic inhalation assessment as it was assumed that they would not be exposed on a continuous basis. Refer to [Appendix J3](#) for the risk estimates for each of the 40 individual locations assessed on a chronic basis.

Separate assessments were conducted for the non-carcinogens and carcinogens to encompass the different approaches used in calculating and interpreting risk estimates.

18.6.2.1 Non-Carcinogens

Chronic inhalation health risks, expressed as RQ values, for the maximums of the residents and workers are presented in [Table 18.6-4](#) and [Table 18.6-5](#).

Predicted chronic RQ values did not exceed 1.0 for any of the COPCs or mixtures for any of the three assessment cases (i.e., Baseline Case, Application Case and the Planned Development Case). This demonstrates that, in all cases, predicted COPC air concentrations were less than their health-based guidelines and that the additive interactions of the COPCs are not predicted to result in health-related impacts. Therefore, potential chronic health risks for these COPCs and associated mixtures are predicted to be negligible.

Table 18.6-4: Chronic Inhalation Risk Quotients – Residents

Chemical of Potential Concern ¹	Risk Quotient ³		
	Baseline Case	Application Case	Planned Development Case
Aliphatic C ₅ -C ₈ group	4.4E-05	4.4E-05	8.2E-05
Aromatic C ₉ -C ₁₆ group	1.5E-04	2.2E-02	2.2E-02
Dichlorobenzene	3.7E-06	1.1E-05	1.1E-05
Formaldehyde	3.9E-03	3.9E-03	7.9E-03
n-Hexane	5.0E-04	5.0E-04	9.2E-04
Naphthalene	1.9E-03	1.9E-03	3.9E-03
NO ₂	1.1E-01	1.2E-01	1.4E-01
PM _{2.5}	1.3E-01	1.3E-01	2.5E-01
SO ₂	1.1E-01	1.1E-01	1.2E-01
Toluene	4.6E-06	4.6E-06	8.3E-06
Mixtures²			
Nasal irritants	5.8E-03	5.8E-03	1.2E-02
Respiratory irritants	1.9E-01	2.0E-01	2.3E-01
Neurotoxicants	5.5E-04	5.5E-04	1.0E-03

Notes:

- ¹ Aromatic C₁₇-C₃₄ group, CO, and pyrene were not included in the chronic inhalation assessment due to the lack of an adequate chronic inhalation exposure limit for the COPCs.
- ² Individual constituents of the chemical mixtures are identified in [Table 18.4-12](#). Note that addition of the individual RQ values provided in the above table for a mixture's chemical constituents might not equate to the RQ value provided for the mixture because the RQ values in the table represent the highest RQ for each lifestyle category.
- ³ An RQ equal to or less than 1.0 signifies that the estimated exposure is equal to or less than the exposure limit and no health effects are expected. Values in bold show an RQ of greater than 1.0. With scientific notation, any value expressed to the negative power (i.e., E-x) shows that predicted exposures were less than the exposure limit; whereas, a value expressed to the positive power (i.e., E+x) shows exposure estimates exceeded the exposure limit.

Table 18.6-5: Chronic Inhalation Risk Quotients – Workers

Chemical of Potential Concern ¹	Risk Quotient ³		
	Baseline Case	Application Case	Planned Development Case
Aliphatic C ₅ -C ₈ group	5.4E-05	5.5E-05	5.5E-05
Aromatic C ₉ -C ₁₆ group	6.1E-06	1.0E-02	1.0E-02
Dichlorobenzene	4.5E-06	8.4E-06	8.4E-06
Formaldehyde	1.6E-03	1.6E-03	1.6E-03
n-Hexane	6.0E-04	6.2E-04	6.3E-04
Naphthalene	8.9E-05	9.0E-05	1.2E-04
NO ₂	1.3E-01	1.4E-01	1.6E-01
PM _{2.5}	5.0E-02	5.2E-02	7.0E-02
SO ₂	1.7E-01	1.7E-01	1.7E-01
Toluene	1.0E-06	1.1E-06	1.1E-06
Mixtures²			
Nasal irritants	1.7E-03	1.7E-03	1.8E-03
Respiratory irritants	2.9E-01	3.0E-01	3.3E-01
Neurotoxicants	6.6E-04	6.8E-04	6.9E-04

Notes:

- ¹ Aromatic C₁₇-C₃₄ group, CO, and pyrene were not included in the chronic inhalation assessment due to the lack of an adequate chronic inhalation exposure limit for the COPCs.
- ² Individual constituents of the chemical mixtures are identified in [Table 18.4-12](#). Note that addition of the individual RQ values provided in the above table for a mixture's chemical constituents might not equate to the RQ value provided for the mixture because the RQ values in the table represent the highest RQ for each lifestyle category.
- ³ An RQ equal to or less than 1.0 signifies that the estimated exposure is equal to or less than the exposure limit and no health effects are expected. Values in bold show an RQ of greater than 1.0. With scientific notation, any value expressed to the negative power (i.e., E-x) shows that predicted exposures were less than the exposure limit; whereas, a value expressed to the positive power (i.e., E+x) shows exposure estimates exceeded the exposure limit.

18.6.2.2 Carcinogens

Chronic inhalation health risks for the carcinogenic COPCs, expressed as ILCR values, are presented in [Tables 18.6-6](#) and [18.6-7](#) for the maximum of the residents and workers, respectively. As discussed previously, the regulatory benchmark of an acceptable ILCR of one in 100 000 is policy-based (AENV 2009b; CCME 2006; Health Canada 2004). The assessment focused on ILCR values from the project alone and future emission sources in the area (i.e., the Planned Development Case minus Baseline Case).

Table 18.6-6: Chronic Inhalation Incremental Lifetime Cancer Risks – Residents

Chemical of Potential Concern	Incremental Lifetime Cancer Risk ¹	
	Project Alone	Future Emission Sources
Benzene	8.0E-06	4.0E-02
Benzo(a)pyrene and equivalents ²	4.3E-03 2.2E-04	8.5E-02 2.3E-04

Notes:

- ¹ An ILCR equal to or less than 1.0 signifies an incremental lifetime cancer risk that is below the benchmark ILCR of one in 100 000 (i.e., within the generally accepted limit deemed to be protective of public health). Boldface values show an ILCR of greater than the *de minimus* risk level of one in 100 000. With scientific notation, any value expressed to the negative power (i.e., E-x) shows that predicted exposures were less than the exposure limit; whereas, a value expressed to the positive power (i.e., E+x) shows exposure estimates exceeded the exposure limit.
- ² The two ILCR values reflect for benzo(a)pyrene and equivalents reflect the two distinct approaches used to assess potential chronic inhalation health risks associated with benzo(a)pyrene and the other carcinogenic PAHs, as described in [Appendix J1](#).

Table 18.6-7: Chronic Inhalation Incremental Lifetime Cancer Risks – Workers

Chemical of Potential Concern	Incremental Lifetime Cancer Risk ¹	
	Project Alone	Future Emission Sources
Benzene	2.7E-06	5.2E-04
Benzo(a)pyrene and equivalents ²	1.4E-03 7.4E-05	2.3E-03 7.6E-05

Notes:

- ¹ An ILCR equal to or less than 1.0 signifies an incremental lifetime cancer risk that is below the benchmark ILCR of one in 100 000; i.e., within the generally accepted limit deemed to be protective of public health). Boldface values show an ILCR of greater than the *de minimus* risk level of one in 100 000. With scientific notation, any value expressed to the negative power (i.e., E-x) shows that predicted exposures were less than the exposure limit; whereas, a value expressed to the positive power (i.e., E+x) shows exposure estimates exceeded the exposure limit.
- ² The two ILCR values reflect for benzo(a)pyrene and equivalents reflect the two distinct approaches used to assess potential chronic inhalation health risks associated with benzo(a)pyrene and the other carcinogenic PAHs, as described in [Appendix J1](#).

As shown in [Tables 18.6-6](#) and [18.6-7](#), the maximum predicted ILCR values associated with the project alone and future emission sources in the area (i.e., the PDC minus Baseline Case) are all less than one in 100 000 indicating that the incremental cancer risk from the project and planned development is predicted to be “essentially negligible” (Health Canada 2004).

18.6.3 Chronic Multiple Pathway

As in the chronic inhalation assessment, health risks were estimated for the residents exposed via multiple exposure pathways over their entire lifespan of 75 years (Health Canada 2004). In the case of the workers, it was assumed that multiple pathway exposures would be limited to the 56 years of their adult life. As such, chronic health risks associated with multiple pathways of exposure were calculated and evaluated for the maximums of the residents and workers. Recreational persons were not included in the chronic multiple pathway assessment as it was assumed that they would not be exposed on a continuous basis.

Again, separate assessments were conducted for the non-carcinogens and carcinogens to encompass the different approaches used in calculating and interpreting risk estimates.

18.6.3.1 Non-Carcinogens

For the residents, chronic multiple pathway risk estimates, presented as RQ values, are provided for the most sensitive life stage. The most sensitive life stage is defined as the life stage with the greatest exposure per unit body weight per day (Health Canada 2004). On this basis, young children (i.e., infants and toddlers) were typically identified as the most sensitive on a per unit body weight basis. In the case of the workers, it was assumed that the housing complexes would be occupied by adult employees only. [Tables 18.6-8](#) and [18.6-9](#) present the maximum predicted RQ values for the residents and workers, respectively.

Table 18.6-8: Chronic Multiple Pathway Risk Quotients – Residents

Chemical of Potential Concern ¹	Risk Quotient ³		
	Baseline Case	Application Case	Planned Development Case
Aromatic C ₉ -C ₁₆ group	1.2E-04	1.9E-02	1.9E-02
Aromatic C ₁₇ -C ₃₄ group	8.3E-06	2.4E-05	2.4E-05
Formaldehyde	3.4E-06	3.4E-06	6.9E-06
Pyrene	8.2E-05	8.2E-05	8.9E-05
Mixtures²			
Renal toxicants	2.1E-04	1.9E-02	2.0E-02

Notes:

- ¹ Only those COPCs deemed to be non-volatile were included in the multiple pathway assessment.
- ² Individual constituents of the chemical mixtures are identified in [Table 18.4-12](#). Note that addition of the individual RQ values provided in the above table for a mixture's chemical constituents might not equate to the RQ value provided for the mixture because the RQ values in the table represent the highest RQ for each lifestyle category.
- ³ An RQ equal to or less than 1.0 signifies that the estimated exposure is equal to or less than the exposure limit and no health effects are expected. Values in bold show an RQ of greater than 1.0. With scientific notation, any value expressed to the negative power (i.e., E-x) shows that predicted exposures were less than the exposure limit; whereas, a value expressed to the positive power (i.e., E+x) shows exposure estimates exceeded the exposure limit.

Table 18.6-9: Chronic Multiple Pathway Risk Quotients – Workers

Chemical of Potential Concern ¹	Risk Quotient ³		
	Baseline Case	Application Case	Planned Development Case
Aromatic C ₉ -C ₁₆ group	1.1E-08	1.6E-06	1.6E-06
Aromatic C ₁₇ -C ₃₄ group	3.8E-09	7.1E-09	7.1E-09
Formaldehyde	6.6E-14	6.6E-14	6.8E-14
Pyrene	1.4E-08	1.6E-08	2.6E-08
Mixtures²			
Renal toxicants	2.9E-08	1.7E-06	1.7E-06

Notes:

- ¹ Only those COPCs deemed to be non-volatile were included in the multiple pathway assessment.
- ² Individual constituents of the chemical mixtures are identified in [Table 18.4-12](#). Note that addition of the individual RQ values provided in the above table for a mixture's chemical constituents might not equate to the RQ value provided for the mixture because the RQ values in the table represent the highest RQ for each lifestyle category.
- ³ An RQ equal to or less than 1.0 signifies that the estimated exposure is equal to or less than the exposure limit and no health effects are expected. Values in bold show an RQ of greater than 1.0. With scientific notation, any value expressed to the negative power (i.e., E-x) shows that predicted exposures were less than the exposure limit; whereas, a value expressed to the positive power (i.e., E+x) shows exposure estimates exceeded the exposure limit.

Predicted chronic multiple pathway RQ values did not exceed 1.0 for any of the COPCs or mixtures for any of the three assessment cases (i.e., Baseline Case, Application Case and the Planned Development Case). This demonstrates that in all cases, predicted exposures to the COPCs were less than their health-based guidelines and that the additive interactions of the COPCs are not predicted to result in health-related impacts. Therefore, potential chronic health risks for these COPCs and associated mixtures are predicted to be negligible.

18.6.3.2 Carcinogens

For the assessment of carcinogens, a “composite individual” who represents all life stages (e.g., from infant to adult) was used to represent cumulative exposure over a 75 year lifespan of a resident. Again, multiple pathway exposures for workers were assumed to be limited to the 56 years of their adult life. The carcinogenic PAHs, including benzo(a)pyrene and equivalents, were the only carcinogens to be assessed through multiple routes of exposure. Chronic multiple pathway health risks for the carcinogenic COPCs, expressed as ILCR values, are presented in [Tables 18.6-10](#) and [18.6-11](#) for the maximums of the residents and workers. As discussed previously, the regulatory benchmark of an acceptable incremental lifetime cancer risk or ILCR of one in 100 000 is policy-based (AENV 2009b; CCME 2006; Health Canada 2004). The assessment focused on ILCR values from the project alone and future emission sources in the area (i.e., the Planned Development Case minus Baseline Case).

Table 18.6-10: Chronic Multiple Pathway Incremental Lifetime Cancer Risks – Residents

Chemical of Potential Concern	Incremental Lifetime Cancer Risks ¹	
	Project Alone	Future Emission Sources
Benzo(a)pyrene and equivalents	3.1E-01	4.3E-01

Note:

¹ An ILCR equal to or less than 1.0 signifies an incremental lifetime cancer risk that is below the benchmark ILCR of one in 100 000 (i.e., within the generally accepted limit deemed to be protective of public health). Boldface values show an ILCR of greater than the *de minimus* risk level of one in 100 000. With scientific notation, any value expressed to the negative power (i.e., E-x) shows that predicted exposures were less than the exposure limit; whereas, a value expressed to the positive power (i.e., E+x) shows exposure estimates exceeded the exposure limit.

Table 18.6-11: Chronic Multiple Pathway Incremental Lifetime Cancer Risks – Workers

Chemical of Potential Concern	Incremental Lifetime Cancer Risks ¹	
	Project Alone	Future Emission Sources
Benzo(a)pyrene and equivalents	1.4E-03	1.5E-03

Note:

¹ An ILCR equal to or less than 1.0 signifies an incremental lifetime cancer risk that is below the benchmark ILCR of one in 100 000 (i.e., within the generally accepted limit deemed to be protective of public health). Boldface values show an ILCR of greater than the *de minimus* risk level of one in 100 000. With scientific notation, any value expressed to the negative power (i.e., E-x) shows that predicted exposures were less than the exposure limit; whereas, a value expressed to the positive power (i.e., E+x) shows exposure estimates exceeded the exposure limit.

As shown in [Tables 18.6-10](#) and [18.6-11](#), the maximum predicted ILCR values associated with the project alone and future emission sources in the area (i.e., the Planned Development Case minus Baseline Case) are all less than one in 100 000 indicating that the incremental cancer risk from the project and planned development is predicted to be “essentially negligible” (Health Canada 2004).

18.7 Monitoring

As part of ongoing stakeholder consultation, KNOC will continue to engage and consult with stakeholders and potentially affected communities (see [Volume 1, Section 4.5](#)). Measures designed to manage potential impacts to air, groundwater and surface water, and the associated monitoring, are discussed in [Volume 4 sections 4.8, 6.8, and 8.8](#) respectively. No additional monitoring is deemed necessary for the protection of human health.

18.8 Summary

The impact of the project’s emissions, either alone or in combination with other sources of COPCs, is predicted to be negligible. Similarly, increases in health risks associated with the project alone are predicted to be very small, indicating that the project is not anticipated to contribute to health risks in the area. Changes in health risks between the Baseline Case to the Planned Development Case are also generally small. No measurable increase in health effects is predicted from the cumulative health risks associated with the additional projects and activities planned for the region.

Inhalation health risks associated with the air emissions from the project were characterized by comparing predicted maximum short-term (i.e., 10-minute, 1-hour, 8-hour or 24-hour) and long-term (i.e., annual) air concentrations with health-based criteria (i.e., exposure limits) considered protective of the most sensitive individuals. Predicted acute (short-term) and chronic (long-term) inhalation risk estimates did not exceed 1.0 for any of the individual COPCs and chemical mixtures for any of the three assessment cases (i.e., Baseline Case, Application Case and the Planned Development Case) or the “worst-case” upset scenario. All incremental lifetime cancer risks also were predicted to be less than one in 100 000 – the benchmark considered to be ‘essentially negligible’ by Health Canada (2004). This demonstrates that in all cases, predicted COPC air concentrations were less than their health-based guidelines and the additive interactions of the COPCs are not predicted to result in health-related impacts. Therefore, inhalation health risks for the COPCs and mixtures are predicted to be negligible, and short-term and long-term impacts of the COPCs via are not expected.

Health risks associated with multiple pathways of exposure were estimated by comparing exposure estimates with health-based oral guidelines. For the residents, exposure estimates were based on:

- inhalation of dust;
- ingestion of soil (inadvertent);
- dermal contact with soil;
- ingestion of local wild game;
- ingestion of local fish;
- ingestion of local natural foods (i.e., berries, cattail roots and tea leaves);
- ingestion of local garden foods (i.e., fruits and vegetables);
- ingestion of local surface water during swimming (inadvertent);
- ingestion of local water; and
- dermal contact with surface water during swimming.

Exposure estimates for the workers were restricted to the inhalation of dust, inadvertent ingestion of soil, and dermal contact with soil as it was assumed that workers would obtain all of their food and water from the housing complex, which in turn would obtain all food and water from off-site.

Similar to the inhalation assessment, predicted chronic multiple pathway risk estimates did not exceed 1.0 for any of the individual COPCs and chemical mixtures for any of the three assessment cases (i.e., Baseline Case, Application Case and the Planned Development Case). All incremental lifetime cancer risks also were predicted to be less than one in 100 000 – the benchmark considered to be ‘essentially negligible’ by Health Canada (2004). This demonstrates that predicted exposures associated with the COPCs were less than their health-based guidelines and the additive interactions of the COPCs are not predicted to result in health-related impacts. From this, the long-term consumption of local foods and water is not anticipated to have an adverse impact on human health.

18.9 Literature Cited

- AENV (Alberta Environment). 2009a. Proposed Terms of Reference the Environmental Impact Assessment (EIA) Report for the Proposed BlackGold SAGD Project, Approximately 10 km Southeast of the Community of Conklin, Alberta.
- AENV (Alberta Environment). 2009b. Alberta Tier 1 Soil and Groundwater Remediation Guidelines. Climate Change, Air, and Land Policy Branch, Environmental Assurance Division, Alberta Environment. Edmonton, Alberta. February 2009.
- AHW (Alberta Health and Wellness). 1997. Swan Hills Special Waste Treatment Centre Human Health Impact Assessment. Health Surveillance Branch, Alberta Health and Wellness. October 1997.
- AHW (Alberta Health and Wellness). 2009. Human Health Risk Assessment Mercury in Fish in Central Alberta. Surveillance and Environmental Health, Alberta Health and Wellness. Edmonton, Alberta. March 2009. ISBN 978-0-7785-7427-9.
- ATSDR (Agency for Toxic Substances and Disease Registry). 2009. Minimal Risk Levels (MRLs) for Hazardous Substances (website). Public Health Service, US Department of Health and Human Services. Atlanta, GA. December 2009. Available at: <http://www.atsdr.cdc.gov/mrls/index.html>.
- BCS (Bureau of Chemical Safety), Health Canada. 2004. Fish Consumption: Review and Recommendation of Current Intake Figures for Canadian Consumers. Available at: http://www.hc-sc.gc.ca/fn-an/pubs/mercur/merc_fish_poisson-eng.php
- Cal EPA (California Environmental Protection) 1994. Preliminary Endangered Assessment Guidance Manual. January. Cited in: US EPA 2003.
- CCME (Canadian Council of Ministers of the Environment). 1996. A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines. The National Contaminated Sites Remediation Program, Canadian Council for Ministers of the Environment. March 1996.
- CCME (Canadian Council of Ministers of the Environment). 2006. A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines. Canadian Council of Ministers of the Environment. ISBN – 10 1-896997-45-7 PDF.
- CCME (Canadian Council of Ministers of the Environment). 2008. Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil: Scientific Rationale. Supporting Technical Document. January 2008. ISBN 978-1-896997-77-3.
- CCS/NCIC (Canadian Cancer Society/National Cancer Institute of Canada). 2006. Canadian Cancer Statistics 2006. Toronto, ON. April 2006. ISSN 0835-2976.
- Devon ARL Corporation. 2008. Application for the Approval of the Devon Jackfish 2 Project Including Supplementary Information Requests (SIRs) ALL ROUNDS. Submitted to: Alberta Energy and Utilities Board and Alberta Environment. January 2008.

- Earth Tech and Conor Pacific. 1998. Initial CALGRID Ozone Modelling in the Athabasca Oil Sands Region. Prepared for Syncrude Canada Ltd.
- EnCana FCCL Ltd. 2009. Christina Lake Thermal Expansion Project Phases 1E, 1F and 1G: Joint Application to the Alberta Energy Resources Conservation Board for an Amendment to Approval No. 8591 and Alberta Environment for an Amendment to Approval No. 48522-00-09. October 2009.
- Health Canada. 1994. Human Health Risk Assessment for Priority Substances. Ottawa, ON: Canadian Communication Group Publishing.
- Health Canada. 1995. Investigating Human Exposure to Contaminants in the Environment: A Handbook for Exposure Calculations. Volume 1–3. Ottawa, ON: Minister of National Health and Welfare.
- Health Canada. 1999. Lesser Slave Lake Health Study. Unpublished. Medical Service Branch, Health Canada. Cited in: AHW 2009.
- Health Canada. 2004. Federal Contaminated Site Risk Assessment in Canada. Part I: Guidance on Human Health Preliminary Quantitative Risk Assessment (PQRA). Environmental Health Assessment Services Safe Environments Programme. ISBN 0-662-38244-7. September 2004.
- Health Canada. 2006. Federal Contaminated Site Risk Assessment in Canada. Part I: Guidance on Human Health Preliminary Quantitative Risk Assessment (PQRA). Environmental Health Assessment Services Safe Environments Programme. Draft for Comment.
- Health Canada. 2007. Human Health Risk Assessment of Mercury in Fish and Health Benefits of Fish Consumption. Ottawa, ON: Bureau of Chemical Safety, Food Directorate, Health Products and Food Branch, Health Canada.
- Klassen, C.D. 1996. Casarett and Doull's Toxicology – the Basic Science of Poisons. 5th ed. McGraw Hill New York: 1996.
- Mackay, D, W.C. Shiu and K.C. Ma. 1992. Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals: Volumes I-IV.: Lewis Publishers. Chelsea, Michigan.
- Market Facts of Canada. 1991. Research Report: National Seafood Consumption Study. Conducted for: Health and Welfare Canada. #C388/JdeB.
- MEG Energy Corporation. 2008. Application for Approval of The Christina Lake Regional Project Phase 3 Integrated Application and Environmental Impact Assessment. April 2008.
- O'Connor and Richardson (O'Connor Associates Environmental Inc. and G Mark Richardson). 1997. Compendium of Canadian Human Exposure Factors for Risk Assessment. 1155-2720 Queensview Dr., Ottawa, ON.

- RMWB (Regional Municipality of Wood Buffalo). 2009. Municipal Census 2008. Planning and Development Department, Regional Municipality of Wood Buffalo. Fort McMurray, AB. June 1, 2009.
- US EPA (United States Environmental Protection Agency). 1987. Risk Assessment Guidelines of 1986. Office of Health and Environmental Assessment. Washington, DC.
- US EPA (United States Environmental Protection Agency). 1991. Guidance for Risk Assessment. Environmental Protection Agency, US (EPA). Risk Assessment Council, Washington, DC.
- US EPA (United States Environmental Protection Agency). 1998. Preliminary Remediation Goals, Region IX. Technical Memorandum from Stan Smucker. Cited in: US EPA 2003.
- US EPA (United States Environmental Protection Agency). 2002. A Review of the Reference Dose and Reference Concentration Process: Risk Assessment Forum. December 2002. Washington, DC.
- US EPA (United States Environmental Protection Agency). 2003. Attachment 1-3 Guidance for Developing Ecological Soil Screening Levels (Eco-SSLs) Evaluation of Dermal Contact and Inhalation Exposure Pathways for the Purpose of Setting Eco-SSLs. OSWER Directive 92857-55. November 2003.
- US EPA (United States Environmental Protection Agency). 2004. Air Quality Criteria for Particulate Matter, Volume I. October 2004. EPA/600/P 99/002aF. National Centre for Environmental Assessment-RTP Office, Office of Research and Development, US Environmental Protection Agency. Triangle Park, North Carolina.
- US EPA (United States Environmental Protection Agency). 2005. Guidelines for Carcinogen Risk Assessment. Risk Assessment Forum. EPA/630/P-03/001F.
- US EPA (United States Environmental Protection Agency). 2010. IRIS Glossary. Available at: http://www.epa.gov/ncea/iris/help_gloss.htm.
- US EPA OSW (United States Environmental Protection Agency's Office of Solid Waste). 2005. Screening Level Ecological Risk Assessment Protocol for Hazardous Waste Combustion Facilities, Final. United States Environmental Protection Agency Region 6. Multimedia Planning and Permitting Division. Center for Combustion Science and Engineering, Office of Solid Waste.
- US NRC (United States National Research Council). 1983. Risk Assessment in the Federal Government): Managing the Process. National Academy Press, Washington, DC.
- US NRC (United States National Research Council). 1994. Science and Judgment in Risk Assessment. Taylor and Francis. Washington, DC.

- Wein, E.E, J.H. Sabry and F.T. Evers. 1991. Food Consumption Patterns and Use of Country Foods by Native Canadians near Wood Buffalo National Park, Canada. *Arctic* 44(3):196-205.
- Wein, E.E. 1989. Nutrient Intakes and Use of Country Foods by Native Canadians Near Wood Buffalo National Park. Thesis presented to the Faculty of Graduate Studies, University of Guelph. February 1989.
- WHO (World Health Organization). 2000. Air Quality Guidelines for Europe, Second Edition. World Health Organization, Regional Office for Europe, Copenhagen. WHO Regional Publications, European Series, No. 91. Available at:
<http://www.euro.who.int/document/e71922.pdf>
- WHO (World Health Organization). 2006. Air Quality Guidelines: Global Update. 2005. Particulate matter, ozone, nitrogen dioxide and sulphur dioxide. ISBN 92 890 2192 6.
- Wilson, R.M. 2005. Guidance on Air Quality Risk Assessment, Version 1. Prepared for Health Canada. HECS-SEP-BC/Yukon-04/05-06. August 8, 2005.