HUMAN HEALTH RISK ASSESSMENT OF PIPELINE SPILL SCENARIOS TECHNICAL REPORT FOR THE TRANS MOUNTAIN PIPELINE ULC TRANS MOUNTAIN EXPANSION PROJECT

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Prepared for:

TRANSMOUNTAIN

Trans Mountain Pipeline ULC

Kinder Morgan Canada Inc.
Suite 2700, 300 – 5th Avenue S.W.
Calgary, Alberta T2P 5J2
Ph: 403-514-6400

Prepared by:

intrinsik

Intrinsik Environmental Sciences Inc.
Suite 1060, 736 - 8th Avenue S.W.
Calgary, Alberta T2P 1H4
Ph: 403-237-0275

EXECUTIVE SUMMARY

E1.0 Introduction

This report describes the assessment of the potential human health effects associated with a set of simulated pipeline oil spill scenarios that was completed on behalf of Trans Mountain Pipeline ULC ("Trans Mountain") in support of the proposed Trans Mountain Expansion Project (referred to as "TMEP" or "the Project"). It is meant to increase awareness and understanding of the nature and extent of any such effects, with the information to be used to help further inform emergency and spill response programs and other programs aimed at the protection of public health and safety. Emphasis is given to the types of health effects that people could potentially experience from exposure to hydrocarbon vapours released during the early stages of a spill, before the arrival of first responders and the implementation of emergency and spill response measures aimed at quickly isolating, containing and recovering the spilled oil.

E2.0 Methods

The overall approach involved identifying the potential health effects that could be experienced by people under each of the different spill scenarios, with emphasis placed on assessing the possible health-related consequences of such spills, without consideration of the low likelihood or probability of occurrence of such incidents. In this regard, the assessment differed from a conventional human health risk assessment (HHRA) in which some measure of the prospect for health effects to occur typically forms part of the analysis and the results are expressed in quantitative terms (*i.e.*, the results consist of numerical estimates of the likelihood that health effects will occur). The difference in approach is due principally to the fact that, unlike HHRAs that tend to focus on routine operations consisting of planned activities for which chemical exposures and any corresponding health risks can be anticipated and assessed on the basis of known or reasonably well defined exposure scenarios, spills represent low probability, unpredictable events for which the exposures and any associated risks must necessarily be assessed on the basis of strictly hypothetical scenarios.

For the purposes of the present assessment, rather than attempting to combine the probability of occurrence of these unpredictable events with the consequences of exposure, it was assumed *a priori* that the oil spill events had taken place, leaving the assessment to focus on the potential health effects that could occur under each simulated spill scenario. In this respect, the approach was very conservative in nature since it did not allow for the multitude of design, engineering, operational, administrative and other types of safeguards that will be in place as part of the Project to limit the prospect for oil spills to occur. These safeguards are described in Volume 7. The approach aligned with the objectives of the assessment as outlined above insofar as it not only allowed for the identification of the potential health effects that might be experienced by people in the event of an oil spill under the various simulated spill scenarios, but also served to inform Trans Mountain, the Project team and spill response authorities of the potential human health consequences that could result from such oil spills in order to assist in Project planning around emergency and spill response programs aimed at the protection of public health and safety.

The assessment followed a paradigm adapted from that used for conventional HHRAs to reflect the emphasis on identifying the potential health consequences that could occur under the different simulated oil spill scenarios based on the premise that the spills had taken place. The paradigm is illustrated in Figure 3.1 of Appendix A of the report. It consists of a series of steps in which consideration is given to both the toxicological properties of the chemicals of potential concern as well as the opportunities for exposure to these chemicals that might exist to arrive at an understanding of the types of health effects that people might experience. A brief description of the various steps is provided below. Complete details can be found in the main report.

- Problem Formulation – This step is concerned with defining the overall scope and boundaries of the assessment, and is meant to focus the work on the areas of principal interest and concern. It focuses on five major areas:

- Identification of the Project components to be examined, with a specific focus on identifying components that might reasonably be anticipated to contribute to chemical exposures through the emission, discharge or release of chemicals into the environment.

- Identification of the exposure scenarios under which humans might reasonably be anticipated to be exposed to the chemicals emitted, discharged or released from the various Project components.

- Identification of the chemicals of potential concern (COPC) found in the emissions, discharges and/or releases to which people could be exposed.

- Identification and characterization of the human "receptors" that could potentially be exposed to the COPC.

- Identification of the exposure routes and pathways by which humans might be exposed to the COPC.

The principal outcomes of the Problem Formulation step completed for the present assessment are summarized in Table E1.

TABLE E1

SUMMARY OF THE PROBLEM FORMULATION STEP FOR THE ASSESSMENT

Project Component		Exposure Scenario	COPC	Receptors	Exposure Pathway(s)
Spill Type	Spill Size				
Pipeline spill to an urban area caused by third-party damage	CWC – 1,558 m^3 oil spilled. Smaller – 1,012 m^3 oil spilled.	Exposures received during the early stages of the spill before the arrival of first responders and implementation of emergency and spill response measures.	Consisted principally of lighter-end, volatile and semi-volatile hydrocarbons (C_1 to C_{12}), including both aliphatic and aromatic constituents found in CLWB diluted bitumen. The latter constituents included BTEX (benzene, toluene, ethylbenzene and xylenes), alkyl substituted benzenes, and PAHs. The remaining COPC consisted of various combinations of sulphur-containing chemicals.	Members of the general public, including sensitive sub-populations, found along the pipeline corridor within Metro Vancouver, as well as emergency responders.	Inhalation

- Exposure Assessment – This step involved estimating the level of exposure to the COPC that might be received by the receptor(s) *via* different exposure pathways. The step often relies on one or more forms of predictive modelling to arrive at the exposure estimates, with specific reliance on air dispersion modelling in the case of chemical emissions to air. For the purposes of the present assessment, reliance was placed on the results of spill modelling simulations and air dispersion modelling performed by RWDI Air Inc. (RWDI) of the fate and behaviour of the spilled oil under each of the simulated spill scenarios. The model was used to predict the maximum one-hour average ground-level air concentrations of the COPC at progressively increasing distances from the pooled oil that people in the area might encounter as a result of the spill under each of the spill scenarios. The predicted distances referred specifically to the downwind distances along the centre-line of the plume of hydrocarbon vapours released from the surface of the spilled oil. The modelling results served as proxies for the exposures to the COPC that might be experienced by people in the area during the early stages of the spill event.

- Toxicity Assessment – This step is concerned with identifying and understanding the potential health effects that can be caused by each of the COPC (acting either singly or in combination), and the exposure conditions under which the effects can occur. The step revolves around the principle that the dose of a chemical largely dictates the nature and extent of any health effects that might be observed. Consideration is given to understanding the influence of the amount, duration and frequency of exposure on the types and severity of the health effects. The principal outcomes of this step were:

- The determination of Exposure Limits for the COPC, which refer to the levels of exposure that would not be expected to cause adverse health outcomes. The Exposure Limits are often based on guidelines, objectives or standards established by reputable government authorities charged with the protection of public health. The level of protection afforded by the Limits is set so as to be protective of even sub-populations who may show heightened responsiveness to chemical exposures. For the purposes of the present assessment, emphasis was placed on Exposure Limits intended to be protective against health effects resulting from short-term exposures (referred to as "acute Exposure Limits") since the focus of the work was on determining the nature and extent of health effects that could occur among people from short-term inhalation exposure to the COPC during the early stages of the oil spill before the arrival of first responders and the implementation of emergency and spill response measures.

- The identification of benchmarks other than conventional Exposure Limits, which may be better suited for health effects assessment purposes because of the particular exposure circumstances involved. For example, situations in which there can be rare, atypical accidental exposure of the general public to a chemical(s), such as spills, fires or explosions, may be better addressed using benchmarks such as the Acute Exposure Guideline Levels (AEGLs) developed by the United States Environmental Protection Agency (US EPA) or the Emergency Response Planning Guidelines (ERPGs) developed by the American Industrial Hygiene Association (AIHA) since these guidelines are specifically intended for use in determining the potential risks to the health of the general public from rare exposures to high concentrations of airborne chemicals for short durations. For the purposes of the present assessment, the one-hour AEGLs and ERPGs developed for the COPC were used as benchmarks to provide added perspective *vis-à-vis* the prospect for people's health to be adversely affected from exposure to the chemical vapours released from the surface of the pooled oil during the early stages of the spill(s).

- The determination of the relevant chemical mixtures given the fact that people are rarely exposed to chemicals in isolation, but rather exposure most commonly occurs to mixtures of chemicals. The latter situation applies to the oil spill scenarios in that the vapours released during the spill will consist of a mix of hydrocarbons and other chemicals emitted simultaneously from the surface of the pooled oil. Accordingly, it was necessary that the assessment consider the health effects that might be experienced by people in the area at the time of the spill not only from exposure to the COPC acting singly, but also in combination.

- Characterization of Health Effects – This step involves comparing the estimated exposures to the COPC that might be experienced by the receptor(s) against the corresponding Exposure Limits and/or other comparison benchmarks to determine whether health effects might occur, and if so, to assess the nature and extent of these effects across each of the Project components and exposure scenarios of interest. For the present assessment, the potential health effects were characterized using a multi-step approach: (i) screening against Exposure Limits; (ii) determination of the areal extent of any exceedances of the Exposure Limits; and, (iii) comparison against the one-hour AEGLs and ERPGs.

- Uncertainty Analysis – This step is concerned with acknowledging and understanding the uncertainties that can surround the assessment, with consideration given to the assumptions made to accommodate the uncertainties, which typically embrace a high degree of conservatism so as to minimize the likelihood of any health effects being overlooked or understated. The analysis forms part of the interpretation of the findings of the assessment, especially in terms of gauging their meaning and relevance. Care must be taken to distinguish health effects for which the prospect for occurrence is tangible from effects that represent hypothetical constructs only because of the conservatism incorporated into the assessment.

E3.0 Results

The results of the assessment are summarized below.

- For the majority of the COPC, the maximum predicted one-hour average airborne concentrations were lower than the corresponding acute inhalation Exposure Limits, signaling an absence of health risks from exposure to these chemicals. The exceptions included the aliphatic C_1-C_4 and aliphatic C_5-C_8 groups, benzene and toluene, for which exceedances of the Exposure Limits were predicted to occur downwind of the pooled oil, along the centre-line of the dispersing vapour plume, indicating some prospect for people's health to be affected, if they happened to be present at the time and located along or near the path followed by the plume. The interpretation of the meaning and relevance of the exceedances required further evaluation in which the conservatism incorporated into the assessment was necessarily considered.

- In both the CWC and smaller spill scenarios, the maximum predicted one-hour average airborne concentrations of the COPC were highest at the edge of the pooled oil and declined with increasing distance downwind from this point. As might be expected, the spatial extent of the exceedances was influenced by spill size, with the downwind distances from the spill source to which the exceedances extended being greater for the CWC spill scenario than for the corresponding smaller-size spill scenario.

- Comparison of the maximum predicted one-hour average airborne concentrations of the COPC against the corresponding one-hour AEGLs and ERPGs consistently revealed the levels of the COPC that people in the area might encounter during the early stages of the spill to be well below these guidelines, including the "Tier-1" values, indicating no obvious prospect for people's health to be seriously adversely affected under either of the simulated spill scenarios examined.

E4.0 Conclusions

The principal conclusions that emerged from the assessment are:

- Based on the weight-of-evidence, there is no obvious indication that people's health would be seriously adversely affected by acute inhalation exposure to the chemical vapours released from the pooled oil during the early stages of a spill.

- The evidence suggests the health effects that could be experienced by people in the area would be confined to minor, transient sensory and/or non-sensory effects, including minor discomfort, irritability, mild irritation of the eyes, nose and/or throat, mild cough, and symptoms consistent with CNS involvement such as mild headache, light headedness, minor vertigo, dizziness, and/or nausea.

- The evidence also indicates mild, transient, localized skin irritation could occur in the event that the spilled oil was to contact the skin.

- The evidence also indicates odours could be apparent to some individuals. The odours would be dominated by a hydrocarbon-like smell, with some potential for other distinct odours due to the presence of sulphur containing chemicals in the vapour mix. The odours could contribute to added discomfort and irritability among these people.

Although minor and transient, the effects would still be annoying and discomforting, indicating the need for and importance of the spill prevention programs described in Volume 7. Planning and preparedness around emergency and spill response also are critical to ensure timely and adequate response to any spill events to limit opportunities for chemical exposures such that public health and safety is not threatened, highlighting the need for and importance of the emergency and spill response programs described in Volume 7.

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DEFINITIONS AND ACRONYM LIST

Definition/Acronym	Full Name
°C	Degree(s) Celsius
µg/m³	microgram(s) per cubic metre
a priori	logic relating to or involving deductive reasoning from a general principle to the expected facts or effects
ACGIH	American Conference of Governmental Industrial Hygienists
AEGL	Acute Exposure Guideline Level(s)
AIHA	American Industrial Hygiene Association
ATSDR	Agency for Toxic Substances and Disease Registry
bbl/d	barrel(s) per day
BC	British Columbia
BC MOE	British Columbia Ministry of the Environment
bona fide	Latin for 'in good faith'
BTEX	Benzene, toluene, ethylbenzene and xylenes
CCME	Canadian Council of Ministers of the Environment
CLWB	Cold Lake Winter Blend
cm	centimetre(s)
CNS	Central nervous system
COPC	Chemical of potential concern
CPCN	Certificate of Public Convenience and Necessity
CWC	Credible worst-case
de novo	Latin expression meaning 'afresh', 'anew', 'beginning again'.
e.g.	Latin for 'for example'
EBA	EBA, A Tetra Tech Company
ECB	European Chemicals Bureau
ERPG	Emergency Response Planning Guidelines
ESA	Environmental and Socio-economic Assessment
ESRD	Alberta Environment and Sustainable Resource Development
et al.	Latin for 'and others'
FHA	Fraser Health Authority
FVRD	Fraser Valley Regional District
HHRA	Human Health Risk Assessment
i.e.	Latin for 'such as'
Intrinsik	Intrinsik Environmental Sciences Inc.
km	kilometre(s)
KMC	Kinder Morgan Canada Inc.
LOAEL	Lowest-observed-adverse-effect level
LSA	Local study area
m	metre(s)
m/s	metre(s) per second
m³	cubic metre(s)
m³/d	cubic metre(s) per day
NEB	National Energy Board
NEB Act	*National Energy Board Act*
NOAEL	No-observed-adverse-effect level
NRC	National Research Council
OEHHA	California's Office of Environmental Health Hazard Assessment
OMOE	Ontario Ministry of the Environment
PAH	Polycyclic aromatic hydrocarbon
per se	a Latin phrase meaning 'in itself'
PHAST	Program Hazard Analysis Software Tool
PPE	Personal protective equipment
RIVM	Rijksinstituut voor Volksgezondheid en Milieu (Netherlands National Institute of Public Health and the Environment)
RWDI	RWDI Air Inc.
TCEQ	Texas Commission of Environmental Quality

the Project	The Trans Mountain Expansion Project
TMEP	Trans Mountain Expansion Project
TMPL	Trans Mountain pipeline
TMPL system	Trans Mountain pipeline system
Trans Mountain	Trans Mountain Pipeline ULC
US	United States
US EPA	United States Environmental Protection Agency
VCHA	Vancouver Coastal Health Authority
via	Latin for 'by way of'
vis-à-vis	French literally 'face to face'. Often now used in the sense of 'in relation to'.
vs.	versus
WA DOE	Washington State Department of Ecology
WCMRC	Western Canada Marine Response Corporation
WHO	World Health Organization

1.0 INTRODUCTION

This report describes the assessment of the potential human health effects associated with a set of simulated pipeline oil spill scenarios that was completed on behalf of Trans Mountain Pipeline ULC ("Trans Mountain") in support of the proposed Trans Mountain Expansion Project (referred to as "TMEP" or "the Project"). It is aimed at increasing awareness and understanding of the nature and extent of any such effects, with the information meant, in part, to help further inform emergency and spill response programs and other programs aimed at the protection of public health and safety. Emphasis is given to the types of health effects that people could potentially experience from exposure to hydrocarbon vapours released during the early stages of a spill, before the arrival of first responders and the implementation of emergency and spill response measures aimed at quickly isolating, containing and recovering the spilled oil.

This assessment was completed, in part, to fulfill the information requirements outlined in Guide A.2 of the NEB *Filing Manual* for completion of an Environmental and Socio-Economic Assessment (ESA) in support of a facilities application (NEB 2013a). Additional guidance was provided by the NEB's (2013b) *Filing Requirements Related to the Potential Environmental and Socio Economic Effects of Increased Marine Shipping Activities, Trans Mountain Expansion Project* (September 10, 2013), notably the requirements related to the assessment of the potential socio-economic and environmental effects from accidents and malfunctions, including the need to examine the effects for both credible worst-case (CWC) spill scenarios and smaller spill scenarios.

This report begins with background information on the Project relevant to the assessment. It continues with a description of the overall approach used, including discussion of a number of guiding principles that were respected as part of the work. It then proceeds to describe the specific methodology that was followed for the assessment, and continues with discussion of the results that emerged. It concludes with a discussion of the findings, which includes a summary of the conclusions that were reached.

1.1 Project Overview

Trans Mountain Pipeline ULC (Trans Mountain) is a Canadian corporation with its head office located in Calgary, Alberta. Trans Mountain is a general partner of Trans Mountain Pipeline L.P., which is operated by Kinder Morgan Canada Inc. (KMC), and is fully owned by Kinder Morgan Energy Partners, L.P. Trans Mountain is the holder of the NEB certificates for the Trans Mountain pipeline system (TMPL system).

The TMPL system commenced operations 60 years ago and now transports a range of crude oil and petroleum products from Western Canada to locations in central and southwestern British Columbia (BC), Washington State and offshore. The TMPL system currently supplies much of the crude oil and refined products used in BC. The TMPL system is operated and maintained by staff located at Trans Mountain's regional and local offices in Alberta (Edmonton, Edson, and Jasper) and BC (Clearwater, Kamloops, Hope, Abbotsford, and Burnaby).

The TMPL system has an operating capacity of approximately 47,690 m^3/d (300,000 bbl/d) using 23 active pump stations and 40 petroleum storage tanks. The expansion will increase the capacity to 141,500 m^3/d (890,000 bbl/d).

The proposed expansion will comprise the following:

- Pipeline segments that complete a twinning (or "looping") of the pipeline in Alberta and BC with about 987 km of new buried pipeline.
- New and modified facilities, including pump stations and tanks.
- Three new berths at the Westridge Marine Terminal in Burnaby, BC, each capable of handling Aframax class vessels.

The expansion has been developed in response to requests for service from Western Canadian oil producers and West Coast refiners for increased pipeline capacity in support of growing oil production and access to growing West Coast and offshore markets. NEB decision RH 001 2012 reinforces market

support for the expansion and provides Trans Mountain the necessary economic conditions to proceed with design, consultation, and regulatory applications.

An application is being made pursuant to Section 52 of the *National Energy Board Act* (*NEB Act*) for the proposed Trans Mountain Expansion Project (referred to as "TMEP" or "the Project"). The NEB will undertake a detailed review and hold a Public Hearing to determine if it is in the public interest to recommend a Certificate of Public Convenience and Necessity (CPCN) for construction and operation of the Project. Subject to the outcome of the NEB Hearing process, Trans Mountain plans to begin construction in 2016 and go into service in 2017.

Trans Mountain has embarked on an extensive program to engage Aboriginal communities and to consult with landowners, government agencies (*e.g.*, regulators and municipalities), stakeholders, and the general public. Information on the Project is also available at www.transmountain.com.

1.2 Objectives

The primary objectives of the present assessment are to:

- Identify and understand the potential health effects that might be experienced by people under each of the simulated oil spill scenarios examined, with an emphasis on the effects that could potentially occur from short-term exposure to the chemical vapours that might be released from the surface of the pooled oil during the early stages of the incident before the arrival of first responders and the implementation of emergency and spill response measures.

- Address the information requirements outlined in Guide A.2 of the NEB *Filing Manual* for completion of an ESA in support of the Project (NEB 2013a), specifically the requirements relating to the assessment of the potential socio-economic and environmental effects that could result from Project-related accidents and malfunctions. (Additional guidance was provided in the NEB's (2013b) *Filing Requirements Related to the Potential Environmental and Socio-Economic Effects of Increased Marine Shipping Activities, Trans Mountain Expansion Project* (September 10, 2013), notably the requirements related to the assessment of the potential socio-economic and environmental effects from accidents and malfunctions along the pipeline, including the need to examine the effects for both CWC spill and smaller spill scenarios).

- Address concerns expressed by Aboriginal communities and stakeholders, including the public, emergency responders and regulatory authorities at the federal, provincial and regional levels, over the potential health effects of accidents and malfunctions associated with the Project. These concerns include the possible effects of oil spills on people's health.

- Provide further information to Trans Mountain, the Project team and spill response authorities on the nature and extent of potential human health effects that could result from oil spills under the simulated spill scenarios in order to help inform emergency and spill preparedness and response programs aimed at the protection of public health and safety.

2.0 CONSULTATION

Trans Mountain and its consultants have conducted a number of activities to inform Aboriginal communities, stakeholders, the public and regulatory authorities about the approach to assessing potential environmental and socio-economic effects of the Project, and to seek input throughout the Project planning process.

2.1 Public Consultation, Aboriginal Engagement and Landowner Relations

Trans Mountain has implemented and continues to conduct open, extensive and thorough public consultation, Aboriginal engagement and landowner relations programs. These programs were designed to reflect the unique nature of the Project as well as the diverse and varied communities along the proposed pipeline corridor. These programs were based on Aboriginal communities, landowner and stakeholder groups' interests and inputs, knowledge levels, time and preferred methods of engagement. In order to build relationships for the long-term, these programs were based on the principles of accountability, communication, local focus, mutual benefit, relationship building, respect, responsiveness, shared process, sustainability, timeliness, and transparency.

Feedback, related to the Project that was raised through various Aboriginal engagement and public consultation activities, including public open houses, ESA Workshops, Community Workshops and one-on-one meetings, is summarized below and was considered in the development of this technical report:

- Potential human health effects associated with the inhalation of chemical vapours that could result from accidents or malfunctions, including a pipeline spill,
- Potential effects of a pipeline spill on the health of Aboriginal peoples, including the potential effects of spills on traditional activities, and
- Potential effects of a pipeline spill on the health of emergency responders.

Full descriptions of the Public Consultation, Aboriginal Engagement and Landowner Relations programs, including the consultation and engagement activities that focused on identifying issues and concerns related to the potential effects of the Project on human health and that helped inform the present assessment, are provided elsewhere (see Volumes 3A, 3B and 3C of the Application filed December 2013, and the Consultation Update No. 1 and Errata, filed March 20, 2014).

2.2 Regulatory Consultation

Consultation with federal, provincial and regional regulatory authorities responsible for the protection of public health took place in which the authorities were introduced to the Project and in which the nature and scope of work to be completed to assess the potential Project-related human health effects were shared. Feedback received from the authorities helped inform the work, including the present assessment. The consultative activities are shown in Table 2–1.

TABLE 2–1

SUMMARY OF CONSULTATION ACTIVITIES RELATED TO THE ASSESSMENT

Stakeholder Group / Agency Name	Name and Title of Contact	Method of Contact	Date of Consultation Activity	Reason For Engagement	Issues / Concerns	Commitments / Follow-up Actions / Comments
FEDERAL CONSULTATION						
Health Canada (BC Region)	Dr. Carl Alleyne, BC Regional Environmental Assessment Coordinator Dr. Gladis Lemus, BC Regional Manager	Meeting	January 28, 2013	Project introduction. Discussion of the planned HHRA methodology.	Health Canada advised that they will be directing particular attention to Aboriginal health. Health Canada expressed an interest in knowing the potential health effects associated with any accidents and malfunctions. Health Canada will be interested in knowing the potential short-term as well as long-term health effects associated with the Project, with consideration given to all relevant exposure pathways.	None
PROVINCIAL CONSULTATION - ALBERTA						
Alberta Health	Dr. Karina Thomas, Environmental Health Scientist, Health Protection Branch Dr. James Talbot, Chief Medical Officer of Health for Alberta	Meeting	February 4, 2013	Project introduction. Discussion of the planned HHRA methodology.	No specific issues / concerns regarding the planned HHRA methodology were identified.	Alberta Health requested that the HHRA team keep them informed of progress as the HHRA is completed.
LOCAL CONSULTATION - BRITISH COLUMBIA						
Fraser Health Authority (FHA)	Dr. Paul Van Buynder, Chief Medical Health Officer Dr. Nadine Loewen, Medical Health Officer Dr. Goran Krstic, Human Health Risk Assessment Specialist, Health Protection Tim Shum, Regional Director	Meeting	January 28, 2013	Project introduction. Discussion of the planned HHRA methodology.	FHA and VCHA expressed an interest in knowing whether any long-term monitoring of health is planned. FHA and VCHA expressed an interest in knowing the historical effects of the Legacy Line. FHA and VCHA expressed an interest in knowing the potential health effects associated with a spill to an urban environment. FHA and VCHA is interested in knowing the potential short-term as well as long-term health effects associated with the Project, with consideration given to all relevant exposure pathways.	None
Vancouver Coastal Health Authority (VCHA)	Dr. Patricia Daly, Chief Medical Health Officer Dr. James Lu, Medical Health Officer, Richmond Public Health Dr. Richard Taki, Regional Director, Health Protection					

Stakeholder Group / Agency Name	Name and Title of Contact	Method of Contact	Date of Consultation Activity	Reason For Engagement	Issues / Concerns	Commitments / Follow-up Actions / Comments
Fraser Valley Regional District (FVRD)	Alison Stewart, Senior Planner, Strategic Planning and Initiatives	Telephone call	March 20, 2013	Project introduction. Discussion of the planned HHRA methodology.	FVRD expressed an interest in knowing the potential effects of the Project on air quality, and subsequently human health, in the FVRD. From a health perspective, Ms. Stewart indicated that the FVRD would be taking their direction from FHA.	None

3.0 GENERAL METHODS

3.1 Overall Approach

The general methodology adopted for the present assessment is discussed below. The overall approach involved identifying the potential health effects that could be experienced by people under each of the different spill scenarios, with emphasis placed on assessing the possible health-related consequences of such spills, without consideration of the low likelihood or probability of occurrence of such incidents. In this regard, the assessment differed from a conventional human health risk assessment (HHRA) in which some measure of the prospect for health effects to occur typically forms part of the analysis and the results are expressed in quantitative terms (*i.e.*, the results consist of numerical estimates of the likelihood that health effects will occur). The difference in approach is due principally to the fact that, unlike HHRAs that tend to focus on routine operations consisting of planned activities for which chemical exposures and any corresponding health risks can be anticipated and assessed on the basis of known or reasonably well defined exposure scenarios, spills represent low probability, unpredictable events for which the exposures and any associated risks must necessarily be assessed on the basis of strictly hypothetical scenarios.[1]

For the purposes of the present assessment, rather than attempting to combine the probability of occurrence of these unpredictable events with the consequences of exposure, it was assumed *a priori* that the oil spill events had taken place, leaving the assessment to focus on the potential health effects that could occur under each simulated spill scenario. In this respect, the approach was very conservative in nature since it did not allow for the multitude of design, engineering, operational, administrative and other types of safeguards that will be in place as part of the Project to limit the prospect for oil spills to occur. These safeguards are described in Volume 7. The approach aligned with the objectives of the assessment as outlined above insofar as it not only allowed for the identification of the potential health effects that might be experienced by people in the event of an oil spill under the various simulated spill scenarios, but also served to inform Trans Mountain, the Project team and spill response authorities of the potential human health consequences that could result from such oil spills in order to assist in Project planning around emergency and spill response programs aimed at the protection of public health and safety.

Having distinguished the overall approach used in the present assessment from that followed in conventional HHRAs, it is important to note that some similarities remain. In this regard, the assessment fully respected a number of guiding principles and incorporated a number of design features that are central to the conduct of any assessment of the human health consequences that can result from chemical exposures, be it qualitative or quantitative in nature. These items are introduced and discussed below.

3.2 Guiding Principles

A number of guiding principles that are fundamental to understanding and interpreting the health effects that can be caused by chemical exposures were fully respected by the assessment. These principles are:

- All chemicals, regardless of type or source, can be considered toxic since they all have the capacity to cause health effects. This principle applies to every chemical, including the various hydrocarbons and other chemical constituents of oil that could be released as vapours in the event of an oil spill. Each of these chemicals is potentially capable of causing health effects.

- Whether or not a chemical's potential to cause health effects will be realized depends on the amount or "dose" of the chemical received. The dose, in turn, depends on the concentration of the chemical encountered as well as the frequency and duration of exposure (*i.e.*, how much, how often, and how long). This principle forms the basis of the so-called "dose-response relationship" that defines the nature and extent of health effects that can be caused by a chemical as a function of both its intrinsic

[1] Estimates of pipeline failure frequency (expressed as units of failures per km-year) can be found in Section 3.1 of Volume 7.

toxicity and the exposure received. The relationship is fundamental to determining the prospect for health effects to occur in response to exposure to a chemical. In the absence of exposure, health effects will not occur, regardless of the toxicity of the chemical. If exposure takes place, some prospect for the occurrence of health effects will exist, with the likelihood and severity of these effects becoming progressively greater as the exposure increases. This principle, sometimes coined "the dose makes the difference", is important since it points to the fact that, simply because a chemical is known to be toxic, does not necessarily mean that it will cause health effects. It is the combination of toxicity and exposure that will ultimately determine whether or not health effects will occur.

- With few exceptions, a minimum or "threshold" dose exists below which a chemical's toxicity is not expressed. In other words, exposure to a chemical must reach a certain level before health effects begin to occur. At exposures below this threshold dose, the body can render the chemical harmless by detoxifying and eliminating it. The body also possesses a certain level of resilience, partly through: i) the physical barriers that are present to prevent or limit the absorption of chemicals, such as the skin and/or other membranes that chemicals must cross in order to reach the target tissues; ii) its ability to self-repair; and, iii) the redundancy of certain organ systems, that allow the body to tolerate low levels of chemical exposure without loss of function. Once the threshold dose is exceeded, health effects will begin to appear, with the response becoming increasingly more pronounced with increasing exposure (*i.e.*, consistent with the dose-response principle). The threshold dose will vary by chemical, by individual (see below), and by the type of response. The exceptions include chemical sensitization responses and certain types of cancer having a genetically-induced basis, for which the existence of a threshold dose may not be obvious.

- For any given chemical, the type and nature of health effects that can result from a short-term or "acute" exposure (*i.e.*, an exposure lasting several minutes to several hours) may differ from the effects caused by longer-term or "chronic" exposure (*i.e.*, repeated exposure over the course of several weeks or months or longer). Whether this difference applies is very much dependent on the chemical; however, there are many examples of chemicals for which the health effects from acute exposure differ from chronic exposure in terms of the tissue/organ(s) affected, the mechanism of toxicity, and the level of response. Accordingly, in assessing the potential health effects that may result from a chemical exposure, it is important to specify the type of exposure involved *vis-à-vis* its frequency and duration.

- The toxicity of any chemical is very much dependent on its molecular size and structure, with the type of functional groups present having a substantive influence on the manner and extent to which it may interfere with biological tissues and processes. Within limits, chemicals having similar structures and functional groups will often share a similar mechanism of toxic action and produce similar types of toxic responses. This principle allows the health effects of a chemical of unknown toxicity to be predicted on the basis of the toxicological properties of a second "surrogate" chemical having similar molecular characteristics. The term "read across" has been coined to describe the process by which the properties of the surrogate chemical are applied to other structurally-related compounds to predict the types of health effects the latter substances might cause.

- People may respond differently to the same chemical under the same exposure circumstances owing to differences in age, gender, lifestyle, health status and other characteristics affecting an individual's sensitivity and/or susceptibility to chemical exposures. Individuals with a high response threshold (see above) will be more tolerant of exposure than most people; whereas, persons having a lower response threshold than normal may be more susceptible to exposure. These differences should be acknowledged and respected as part of the assessment of the potential health effects associated with chemical exposures since they can affect the likelihood and extent to which a person might be affected. Infants, young children, the elderly and people whose health may be compromised as a result of pre-existing medical conditions (*e.g.*, asthma) are generally regarded as being sensitive sub-populations who may show heightened responsiveness to chemical exposures.

3.3 The Health Effects Assessment Paradigm

The overall approach used for the assessment followed a paradigm adapted from that used for conventional HHRAs to reflect the emphasis on identifying the potential health consequences that could occur under the different simulated oil spill scenarios based on the premise that the spills had taken place (*i.e.*, without regard for the low probability of occurrence of such spill events). The paradigm is shown in Figure 3.1 of Appendix A. It consists of a series of steps in which consideration is given to both the toxicological properties of the chemicals of potential concern as well as the opportunities for exposure to these chemicals that might exist to arrive at an understanding of the types of health effects that people might experience. A brief introduction to the paradigm and the steps involved is provided below. The manner in which the paradigm was applied for the purposes of the present assessment is described in Section 4.0 Specific Methods.

3.3.1 Problem Formulation

This step is concerned with defining the overall scope and boundaries of the assessment, and is meant to focus the work on the areas of principal interest and concern. In terms of the assessment, the intent was to strike an appropriate balance between the need to avoid overlooking any health effects that could potentially occur under the spill scenarios and the need to acknowledge and appreciate the various emergency and spill response measures that will be implemented in the event of a spill, with the understanding that these measures are aimed, in part, at limiting any chemical exposures and corresponding health effects that people might experience. The step focuses on five major areas:

- Identification of the Project components to be examined, with a specific focus on identifying components that might reasonably be anticipated to contribute to chemical exposures through the emission, discharge or release of chemicals into the environment.

- Identification of the exposure scenarios under which humans might reasonably be anticipated to be exposed to the chemicals emitted, discharged or released from the various Project components. In selecting the exposure scenarios, consideration is given to the overall exposure circumstances and exposure opportunities that could exist taking into account the quantities of chemicals that might be emitted or released, the expected manner in which the chemicals would behave in the environment, the expected duration of exposure, and other factors governing the extent to which exposures might occur. The aim is to focus the assessment on the exposure scenarios that best represent the conditions under which people might be exposed to the chemicals.

- Identification of the chemicals of potential concern (COPC) based on consideration of their toxic properties, their environmental fate and behavior, and the opportunities for exposure that might exist taking into consideration the amounts and the rates at which the chemicals might be released into the environment.

- Identification and characterization of the human “receptors” that could potentially be exposed to the COPC.

- Identification of the exposure routes and pathways by which the receptors might be exposed to the COPC, with the most common routes being inhalation, ingestion and/or dermal contact, and the pathways comprising either direct (or primary) and/or indirect (or secondary) avenues of exposure. As the name suggests, the former pathways are direct in nature with no intermediate steps. An example is inhaling chemicals that are emitted into the air. Secondary pathways involve one or more intermediate steps taking place before the chemical(s) reaches the receptor(s). For example, chemicals that are emitted into the air may deposit onto the ground, where they may be taken up by flora and/or fauna to become part of the “food chain”, with the chemicals eventually being ingested by the receptors.

3.3.2 Exposure Assessment

This step is concerned with estimating the level of exposure to the COPC that might be received by the receptor(s) *via* different exposure pathways. The step often relies on one or more forms of predictive modelling to arrive at the exposure estimates, with specific reliance on air dispersion modelling in the case of chemical emissions to air. Factors that can influence the amount of exposure received, such as the fate and behaviour of the COPC in the environment and the characteristics of the receptors (*e.g.*, age, body weight, breathing rate) are integrated into the assessment. Distinction is made between exposures received on a short-term basis and those that could be experienced on a longer-term basis to accommodate the fact that the health effects caused by the COPC from acute versus chronic exposure may differ (see Section 3.2 Guiding Principles). The distinction is needed to allow the exposure estimates to align with the health effects information and Exposure Limits revealed by the Toxicity Assessment (see below) such that the health effects and corresponding exposure circumstances (*i.e.*, acute *vs.* chronic) are kept separate.

3.3.3 Toxicity Assessment

This step is concerned with identifying and understanding the potential health effects that can be caused by each of the COPC (acting either singly or in combination), and the exposure conditions under which the effects can occur. The step revolves around the guiding principle that the dose of a chemical largely dictates the nature and extent of any health effects that might be observed (*i.e.*, "the dose makes the difference" – see Section 3.2 Guiding Principles). Careful consideration is given to understanding the influence of the amount, duration and frequency of exposure on the types and severity of the health effects (*i.e.*, the dose-response relationship). Much of the information is sourced from case studies involving accidental or deliberate exposure of people to the COPC, clinical investigations involving controlled exposure of human subjects to the chemicals and/or non-clinical studies involving controlled exposure of laboratory rodents. By design, the latter studies often involve exposure to the chemicals at dosages much greater than those that might be encountered in the environment.

A principal outcome of this step is the determination of Exposure Limits for the COPC, which refer to the levels of exposure that would not be expected to cause adverse health outcomes. The development of the Exposure Limits typically follows a standard protocol wherein the level of exposure that causes either no effects or minimal effects only on the most sensitive health endpoint in either humans or the most sensitive test species is identified (*i.e.*, the no-observed-adverse-effect level [NOAEL] or lowest-observed-adverse-effect level [LOAEL]), and then the NOAEL or LOAEL is adjusted downward using uncertainty factors[2] to accommodate possible differences in responsiveness to the chemical that may exist within and between species to arrive at the Limit. Additional uncertainty factors may be applied to allow for limitations in the extent to which health effects information exists for the chemical and/or to confer added protection if the critical endpoint is of particular concern. Examples of the use of uncertainty factors are provided in Table 3–1. Typically, the use of uncertainty factors results in at least a 100-fold downward adjustment of the NOAEL or LOAEL. The net result is that the Limit is often set at a level well below the levels at which health effects are observed.

The Exposure Limits chosen often correspond to guidelines, objectives or standards developed by reputable government authorities charged with the protection of public health. The level of protection afforded by the Exposure Limits is set so as to be protective of even sub-populations who may show heightened responsiveness to chemical exposures, such as infants, young children, the elderly and individuals who may be especially sensitive because of medical conditions. Distinction is made between Exposure Limits intended to be protective against health effects resulting from short-term exposures (referred to as "acute Exposure Limits") and health effects caused by longer-term exposure (referred to as "chronic Exposure Limits"). More specifically, the acute Exposure Limits are meant to provide protection against the occurrence of adverse health effects from exposures lasting for a few minutes to a few hours or longer (*i.e.*, for as long as 14 days); the chronic Exposure Limits are intended to be protective against

[2] Also referred to as "modifying factors" or "safety factors" by some scientific and regulatory authorities.

the occurrence of effects from exposures lasting from several months to several years or longer (*i.e.*, up to a lifetime).

TABLE 3–1

EXAMPLES OF COMMONLY-USED UNCERTAINTY FACTORS

Nature of Uncertainty	Magnitude of Factor	Comments
Differences in sensitivity between species	3 to10-fold	Used to accommodate the uncertainty surrounding the use of laboratory animal data to predict potential human responses. For example, an uncertainty factor of 10 assumes that humans are 10 times more sensitive to the chemical than the laboratory animal species studied.
Differences in sensitivity within a species	3 to10-fold	Used to account for individuals within the human population that may be more sensitive to a chemical than the average person. For example, an uncertainty factor of 10 assumes that the sensitive individual is 10 times more responsive than the average person.
LOAEL to a NOAEL	3 to10-fold	Used to account for the uncertainty surrounding the use of a LOAEL when a NOAEL is not available for the critical health endpoint in the most sensitive test species. For example, an uncertainty factor of 10 assumes that, at a dose 10 times lower than the lowest dose used in the most definitive toxicity study, no responses would be observed in the test species.
Duration of exposure	3 to 10-fold	Used to account for the uncertainty surrounding the use of data involving shorter exposure periods to predict the responses that might occur over longer periods of exposure.
Adequacy of database	3 to 10-fold	Used to account for a lack of toxicological information for one or more endpoints.

As part of the Toxicity Assessment step, consideration is given to the fact that people are rarely exposed to chemicals in isolation, but rather exposure occurs to mixtures of chemicals. The chemicals within a mixture may interact in different ways such that toxicity may be altered, possibly becoming enhanced (*i.e.*, additivity, potentiation or synergism) or reduced (*i.e.*, antagonism). The assessment of the health effects of chemical mixtures is challenging by virtue of the infinite number of chemical combinations that are possible. Recent efforts have been taken by several leading scientific and regulatory authorities to better understand the types of interactions involved and to develop methods for assessing mixtures (Boobis *et al*. 2011, European Commission 2012, Meek *et al*. 2011, Price *et al*. 2009, Price and Han 2011). These efforts have led to the following observations:

- Under certain conditions, chemicals can act in combination as a mixture in a manner that affects the overall level of toxicity.
- Chemicals with common modes of action can act jointly to produce combined effects that may be greater than the effects of each of the constituents alone. These effects are additive in nature.
- For chemicals having different modes of action, there is no robust evidence available to indicate that mixtures of such substances are of health or environmental concern provided the individual chemicals are present in amounts at or below their threshold dose levels.
- Interactions (including antagonism, potentiation and synergism) usually occur only at moderate to high dose levels (relative to the lowest effect levels), and are either unlikely to occur or to be of any toxicological relevance at low or “environmentally relevant” exposure levels.
- If information is lacking on the mode(s) of action of chemicals in a mixture, it should be assumed by default that they will act in an additive fashion, with the manner and extent to which they may interact act determined on a case-by-case basis using professional judgement.

Based on these observations and in accordance with Health Canada (2010) guidance, one approach to assessing chemicals mixtures is to combine those chemicals which act through a common or similar toxicological mechanism and/or affect the same target tissues and/or organs as a group, and assume that the overall toxicity of the group is equivalent to the sum of the toxicities of the individual chemicals comprising the group. In other words, consistent with the above observations, the chemicals are assumed

to interact in an additive fashion, with the net result being an enhancement of toxicity when assessed at the mixture level.

3.3.4 Characterization of Potential Health Effects

This step involves comparing the estimates of the exposures to the COPC that might be experienced by the receptor(s) on either a short-term and/or longer-term basis (as revealed by the Exposure Assessment) against the corresponding Exposure Limits and health effects information (revealed by the Toxicity Assessment) to determine whether health effects might occur, and if so, to assess the nature and extent of these effects across each of the Project components and exposure scenarios of interest. Unlike a conventional HHRA, for the purposes of the assessment, the prospect for health effects to occur under each simulated oil spill scenario was not quantified *per se* since the occurrence of such incidents is unpredictable, and to generate numerical risk estimates could be misleading since they would infer a higher degree of precision and certainty than actually surrounds such low probability, unpredictable events. Instead, the focus was placed on describing the types of health effects that might occur under the spill scenarios, assuming the spills had taken place without regard for their low probability and unpredictability.

3.3.5 Uncertainty Analysis

This step is concerned with acknowledging and understanding the uncertainties that can surround the assessment, with consideration given to the assumptions made to accommodate the uncertainties, which typically embrace a high degree of conservatism so as to minimize the likelihood of any health effects being overlooked or understated. The analysis forms part of the interpretation of the findings of the assessment, especially in terms of gauging their meaning and relevance. Care must be taken to distinguish health effects for which the prospect for occurrence is tangible from effects that represent hypothetical constructs only because of the conservatism incorporated into the assessment.

4.0 SPECIFIC METHODS

The methodology followed for the assessment was based on the health effects assessment paradigm discussed above, with some unique design features introduced to address elements specific to the simulated oil spill scenarios of interest. The specific methodology used is outlined below, with the topics arranged according to the steps of the paradigm.

Among the items that were considered in developing the specific approach to be used were:

- The type and volume of oil spilled;
- The types of chemicals contained in the spilled oil to which people could be exposed;
- The extent to which people could be exposed based on predictions of how the spilled oil and the chemicals would likely behave in the environment;
- The manner and pathways by which people might be exposed to the chemicals;
- The types of health effects that can be caused by the chemicals as a function of the amount, frequency and duration of exposure;
- The types of health effects that might be experienced by people exposed to the chemicals contained in the spilled oil, including individuals who may show heightened responsiveness to chemical exposures;
- The emergency and spill response measures that would be taken by Trans Mountain and other spill response authorities to limit people's exposure to the chemicals in the event of a spill; and
- The actions that can be taken by government authorities charged with the protection of human health and/or the environment to safeguard people's health in the event of an emergency or unplanned event, such as an oil spill.

4.1 Problem Formulation

The specific design features of the assessment related to the Problem Formulation step of the paradigm are discussed below. The information is summarized at the end of this section in Table 4–5.

4.1.1 Identification of Project Components

The proposed expansion includes the completion of a twinning (or "looping") of the existing pipeline in Alberta and BC with approximately 987 km of new buried pipeline. In order to address the information requirements outlined in Guide A.2 of the NEB *Filing Manual*, specifically the requirements relating to the assessment of the potential socio-economic and environmental effects that could result from Project-related accidents and malfunctions, the new pipeline segments were identified as Project components of interest.

The oil spill scenarios examined involved the spillage of oil to land in an urban area as a result of third-party damage to the pipeline. The scenarios represented hypothetical events and were based strictly on simulated conditions. All pipelines experience some level of threat due to third-party damage, the magnitude of this threat being a function of the effectiveness of damage prevention measures, adjacent land use, depth of cover, material properties and pipeline design. Although damage prevention measures can help to minimize this threat, the risk of third-party damage can never be fully neutralized. For the reader's information, initial estimates of the average frequency based on a preliminary threat assessment indicate that the threat of third-party damage over the pipeline is in the order of 5.1×10^{-6} failures/km-year (Section 3.1.3.5 of Volume 7). Despite a low probability of third-party damage to the pipeline, for the purpose of the assessment, it was assumed that the spills had taken place. The rationale surrounding the selection of the spill scenarios *vis-à-vis* spill location, spill circumstances, and spill volumes is described below.

The selection of the spill location was based, in part, on the fact that more people could be potentially affected by a spill occurring near an urban centre compared to a spill in a remote, largely uninhabited area along the pipeline corridor because of the higher population size and density involved. Moreover, the large population size found in urban centres better allows for the possibility that individuals showing heightened sensitivity to chemical exposures could be part of the exposed cohort compared to the sparser populations found in remote areas. In addition, stakeholders at various community meetings and the Fraser Health Authority (FHA) and Vancouver Coastal Health Authority (VCHA) expressed an interest in understanding the potential human health effects that could result from an oil spill in an urban area. That said, the outcomes of the assessment of the specific spill scenarios and location examined were judged to be representative of the types of health effects that might be experienced by people living in smaller communities, including Aboriginal communities, located along the pipeline route in the event that an oil spill was to occur in such neighbourhoods.

The circumstances under which the spill was predicted to occur involved a breach of the pipeline caused by third-party damage during the summer season. The summer season was selected as air temperatures facilitate more rapid volatilization of lighter hydrocarbons into air. At the same time, generally lower wind speeds during the summer months result in less dilution of any hydrocarbon vapours released from the surface of the spilled oil into the air. The combination of these factors will contribute to greater opportunity during the summer months for people in the area at the time of the oil spill to be exposed to the hydrocarbon vapours compared to other times of the year. In addition, more people are likely to be outdoors during the summer months compared to other seasons, again contributing to greater opportunity for people to be exposed to the hydrocarbon vapours. Thus, a simulation occurring during the summer season was considered most appropriate for the purposes of the assessment as it tends to reflect worst-case conditions.

As indicated previously, two different sized spills were assessed: one representing the volume of oil that potentially could be spilled under CWC conditions, and the second involving the spillage of a smaller amount of oil. For the purposes of the assessment, the volume of oil spilled under the CWC spill scenario was assumed to be 1,558 m^3. For the smaller release scenario, it was assumed that the volume of oil spilled was 1,012 m^3. The potential spill volumes were estimated taking into consideration the expected response time for initiation and completion of valve closure upon detecting a leak, the distance between valve locations, and include both the volume of oil that would be released under pressure before the valves close as well as the drain-down volume for the pipeline between valve locations.

4.1.2 Identification of Exposure Scenarios

The assessment focused on the chemical exposures that people might experience during the early stages of the oil spill incident, when they could be unaware of its occurrence and before the arrival of first responders and the implementation of emergency and spill response measures. The nature and extent of the emergency and spill response measures were important considerations in arriving at the choice of exposure scenarios to be assessed since they represent important determinants governing the chemical exposures that people might receive, not only in terms of amount, but also with respect to frequency and duration (which in turn, will govern the prospect for people's health to be affected – see Section 3.2 Guiding Principles). Details concerning these emergency and spill response measures can be found in Volume 7. The most likely avenue of exposure during this time would be *via* inhalation of the chemical vapours released from the surface of the spilled oil (see Section 4.1.5 Identification of Exposure Pathways).

4.1.3 Identification of Chemicals of Potential Concern

For the purposes of the assessment, Cold Lake Winter Blend (CLWB) diluted bitumen was chosen to represent the type of oil spilled, with its selection based, in part, on the fact that CLWB is currently, and is expected to remain, a major product carried by the TMEP. Accordingly, in the unlikely event of a spill occurring, there is a strong possibility that the spilled product will be CLWB. Another factor that contributed to its selection is the fact that the diluent in CLWB is a liquid condensate that is rich in light-end hydrocarbons that are volatile or semi-volatile in nature. These hydrocarbon components could potentially be released as vapours from the surface of the spilled oil.

The identification of the specific hydrocarbon components to be assessed as COPC proceeded step-wise, as outlined below:

- As a first step, reliance was placed on the results of a bulk liquid analysis of CLWB to determine its chemical make-up. The results are summarized in Table 4–1, arranged by chemical family.

- The second step involved screening the entire list of chemicals shown in Table 4–1 based on each component's physico-chemical properties, notably those properties, such as vapour pressure and Henry's Law Constant, that determine its tendency to partition into air and the ease with which it might volatilize from the surface of the spilled oil. The screening was performed by EBA, a Tetra Tech company (EBA) as described in Volume 8C. Due to their non-volatile nature, the metals/metalloids/minerals components were automatically removed from further consideration. A listing of the components that were carried forward to the next step of the chemical selection process based on the screening performed by EBA is provided in Table 4–2.

- In the third step, consideration was given to findings reported in *Flux Chamber Sampling Program in Support of Spill Modelling for the Trans Mountain Expansion Project completed in Gainford, Alberta* (TERMPOL 3.1 in Volume 8C). The aim of the study was to characterize the emissions off the surface of the CLWB in terms of the types and amounts of chemicals present. The study measured the emission flux rates of the chemical components from the surface of CLWB in a holding tank over a nine-day sampling period. Components containing more than 12 carbon atoms were not detected in air samples collected from the holding tank, suggesting that despite the fact that they were identified as being semi-volatile based on the EBA analysis (see above), these compounds would not be expected to partition to air from the surface of the spilled oil; hence, they were excluded from the assessment. A listing of the components that were carried forward to the next step of the chemical selection process based on the results of the flux chamber study is provided in Table 4–3.

- The final step of the selection process involved refining the list of chemicals by combining and re-naming certain of the components to better align with chemical nomenclature and naming conventions in common use by health authorities and regulatory agencies involved in the development of Exposure Limits. In some cases, "surrogate" chemicals were used to represent the CLWB components, consistent with the "read across" principle mentioned earlier (see 3.2 Guiding Principles). The final outcome of the screening process was the list of COPC shown in Table 4–4. Examination of the list reveals that the COPC consisted principally of lighter-end, volatile and semi-volatile hydrocarbons (C_1 to C_{12}), including both aliphatic and aromatic constituents. The latter constituents included BTEX (benzene, toluene, ethylbenzene and xylenes), alkyl substituted benzenes, and polycyclic aromatic hydrocarbons (PAHs). The remaining COPC consisted of various combinations of sulphur-containing chemicals.

TABLE 4–1

STEP 1: FULL LIST OF CHEMICAL COMPONENTS OF CLWB DILUTED BITUMEN

Metals/Metalloids /Minerals	Petroleum Hydrocarbons	Polycyclic Aromatic Hydrocarbons	Sulphur-Containing Compounds	Volatile Organic Compounds	Other
Boron	Aliphatics C_6-C_8	Acenaphthene	n-Butanethiol	1,2,4-Trimethylbenzene	2,4-Dimethylphenol
Calcium	Aliphatics >C_8-C_{10}	Acridine	Dibenzothiophene	Benzene	3 & 4-Methylphenol
Iron	Aliphatics >C_{10}-C_{12}	Anthracene	C1-Dibenzothiophene	iso-Butane	Asphaltenes
Mercury	Aliphatics >C_{12}-C_{16}	Benzo(a)anthracene	C2-Dibenzothiophene	n-Butane	Polars
Molybdenum	Aliphatics >C_{16}-C_{21}	C1-Benzo(a)anthracene / chrysene	C3-Dibenzothiophene	Cyclohexane	Saturates
Nickel	Aliphatics >C_{21}-C_{34}	C2-Benzo(a)anthracene / chrysene	C4-Dibenzothiophene	Ethylbenzene	
Phosphorus	Aliphatics >C_{34}-C_{50}	C3-Benzo(a)anthracene / chrysene	Dimethyl sulphide	Methylcyclohexane	
Potassium	Aromatics >C_8-C_{10}	C4-Benzo(a)anthracene / chrysene	Ethanethiol	Methylcyclopentane	
Silicon	Aromatics >C_{10}-C_{12}	Benzo(a)pyrene	n-Hexanethiol	iso-Pentane	
Sodium	Aromatics >C_{12}-C_{16}	Benzo(b&j)fluoranthene	iso-Propanethiol	n-Pentane	
Sulphur	Aromatics >C_{16}-C_{21}	C1-Benzo(b,j,k)fluoranthene / benzo(a)pyrene	Methyl ethyl sulphide	Propane	
Titanium	Aromatics >C_{21}-C_{34}	C2-Benzo(b,j,k)fluoranthene / benzo(a)pyrene	Thiophene / sec-Butanethiol	Toluene	
Vanadium	Aromatics >C_{34}-C_{50}	Benzo(e)pyrene		Xylenes	
		Benzo(g,h,i)perylene			
		Biphenyl			
		C1-Biphenyl			
		C2-Biphenyl			
		Chrysene			
		Fluoranthene			
		C1-Fluoranthene / pyrene			
		C2-Fluoranthene / pyrene			
		C3-Fluoranthene / pyrene			
		C4-Fluoranthene / pyrene			
		Fluorene			
		C1-Fluorene			
		C2-Fluorene			
		C3-Fluorene			
		Naphthalene			
		C1-Naphthalene			
		C2-Naphthalene			
		C3-Naphthalene			
		C4-Naphthalene			
		Perylene			
		Phenanthrene			
		C1-Phenanthrene / anthracene			
		C2-Phenanthrene / anthracene			
		C3-Phenanthrene / anthracene			
		C4-Phenanthrene / anthracene			
		Retene			

TABLE 4–2

STEP 2: LIST OF CHEMICAL COMPONENTS OF CLWB REMAINING AFTER SCREENING BASED ON VOLATILITY

Petroleum Hydrocarbons	Polycyclic Aromatic Hydrocarbons	Sulphur-Containing Compounds	Volatile Organic Compounds
Aliphatics C_6-C_8	Acenaphthene	n-Butanethiol	1,2,4-Trimethylbenzene
Aliphatics >C_8-C_{10}	Acridine	Dibenzothiophene	Benzene
Aliphatics >C_{10}-C_{12}	Anthracene	C1-Dibenzothiophene	iso-Butane
Aliphatics >C_{12}-C_{16}	Biphenyl	C2-Dibenzothiophene	n-Butane
Aliphatics >C_{16}-C_{21}	C1-Biphenyl	C3-Dibenzothiophene	Cyclohexane
Aromatics >C_8-C_{10}	C2-Biphenyl	C4-Dibenzothiophene	Ethylbenzene
Aromatics >C_{10}-C_{12}	Fluoranthene	Dimethyl sulphide	Methylcyclohexane
Aromatics >C_{12}-C_{16}	Fluorene	Ethanethiol	Methylcyclopentane
	C1-Fluorene	n-Hexanethiol	iso-Pentane
	C2-Fluorene	Methyl ethyl sulphide	n-Pentane
	C3-Fluorene	iso-Propanethiol	Propane
	Naphthalene	Thiophene / sec-Butanethiol	Toluene
	C1-Naphthalene		Xylenes
	C2-Naphthalene		
	C3-Naphthalene		
	C4-Naphthalene		
	Phenanthrene		
	C1-Phenanthrene / anthracene		
	C2-Phenanthrene / anthracene		

TABLE 4–3

STEP 3: LIST OF CHEMICAL COMPONENTS OF CLWB REMAINING AFTER SCREENING BASED ON FLUX CHAMBER SAMPLING STUDY

Petroleum Hydrocarbons	Polycyclic Aromatic Hydrocarbons	Sulphur-Containing Compounds	Volatile Organic Compounds
Aliphatics C_6-C_8	Acenaphthene	n-Butanethiol	1,2,4-Trimethylbenzene
Aliphatics >C_8-C_{10}	Biphenyl	Dibenzothiophene	Benzene
Aliphatics >C_{10}-C_{12}	Naphthalene	Dimethyl sulphide	iso-Butane
Aromatics >C_8-C_{10}	C1-Naphthalene	Ethanethiol	n-Butane
Aromatics >C_{10}-C_{12}	C2-Naphthalene	n-Hexanethiol	Cyclohexane
		Methyl ethyl sulphide	Ethylbenzene
		iso-Propanethiol	Methylcyclohexane
		Thiophene / sec-Butanethiol	Methylcyclopentane
			iso-Pentane
			n-Pentane
			Propane
			Toluene
			Xylenes

TABLE 4–4

STEP 4: LIST OF COPC EXAMINED AS PART OF THE ASSESSMENT

COPC	CLWB Chemical Components
Aliphatic C_1-C_4 group	iso-Butane, n-Butane, Propane
Aliphatic C_5-C_8 group	iso-Pentane, n-Pentane, Aliphatics C_6-C_8[1]
Aliphatic C_9-C_{12} group	Aliphatics >C_8-C_{10}, Aliphatics >C_{10}-C_{12}
Aromatic C_9-C_{12} group	Aromatics >C_8-C_{10}[2], Aromatics >C_{10}-C_{12}[3]
Benzene	Benzene
Dibenzothiophene	Dibenzothiophene
Dimethyl sulphide group	Dimethyl sulphide, Methyl ethyl sulphide
Ethanethiol group	Ethanethiol, iso-Propanethiol, Thiophene/sec-Butanethiol, n-Butanethiol, n-Hexanethiol
Ethylbenzene	Ethylbenzene
Toluene	Toluene
Trimethylbenzenes	1,2,4-Trimethylbenzene
Xylenes	Xylenes

Notes:

1 Cyclohexane, methylcyclohexane and methylcyclopentane were assigned to the aliphatics C_6-C_8, and ultimately assessed as part of the aliphatic C_5-C_8 group since health-based Exposure Limits intended to be protective against the occurrence of health effects from acute inhalation exposure are not currently available for these chemicals.

2 Naphthalene was assigned to the aromatics >C_8-C_{10}, and ultimately assessed as part of the aromatic C_9-C_{12} group since the health-based Exposure Limit for naphthalene was used to assess the group.

3 Acenaphthene, biphenyl, C1-naphthalene and C2-naphthalene were assigned to the aromatics >C_8-C_{10}, and ultimately assessed as part of the aromatic C_9-C_{12} group since health-based Exposure Limits intended to be protective against the occurrence of health effects from acute inhalation exposure are not currently available for these chemicals.

4.1.4 Identification of Receptors

The assessment was directed at identifying and understanding the nature and extent of health effects that humans might experience from exposure to the COPC under each of the simulated oil spill scenarios. The selection of the specific human receptors to be assessed was based on consideration of the following:

- It is reasonable to assume that members of the general public could be in the area at the time of a spill and unaware of its occurrence, at least in the short-term before the arrival of first responders and the implementation of emergency and spill response measures. These people could include individuals who might reside in the area or be frequenting the area for work, recreation or other reasons. Given that opportunity could exist for these people to be exposed to chemical vapours released from the spilled oil during the early stages of an incident, they were chosen as the human receptors to be assessed. It was recognized that, as members of the general public, these human receptors could include people who may be especially responsive to chemical exposures, including young children, the elderly, people with compromised health, and other sensitive sub-populations. The assessment necessarily allowed for the fact that these types of individuals could be among people found in the area at the time of the spill.

- In the event of a spill, emergency and spill response personnel would be dispatched to the scene. These personnel will be trained in emergency preparedness and response, would be equipped with appropriate personal protective equipment (PPE), would be trained and prepared for such situations, and would take appropriate precautions to avoid physical contact with the spilled oil itself as well as to limit exposure to any chemical vapours that might be present. These measures would act to limit any chemical exposures and corresponding health effects that might be experienced by first responders and other response personnel. In light of the limited exposure opportunities that would exist for these individuals, they were not specifically identified and assessed as a separate sub-population.

4.1.5 Identification of Exposure Pathways

The assessment focused on the potential health effects that could occur among people found in the area at the time of the spill from inhalation exposure to the hydrocarbon and other chemical vapours released

from the surface of the spilled oil, with a specific focus on exposures that could be received on a short-term basis during the early stages of the incident. The choice of this exposure pathway is explained below:

- Opportunity exists for people located downwind of the oil spill to be exposed to chemical vapours released from the surface of the spilled oil during the early stages of the incident because some time will elapse between the first reporting of a spill, the arrival of first responders and the implementation of the emergency response measures. Exposure to the vapours would be *via* inhalation on a short-term basis, with the likelihood and extent of exposure declining as responders arrive on scene and emergency response measures are taken. It is expected that Trans Mountain and other response personnel will first arrive on-scene within as little as one hour after receiving notification.

- Direct physical contact with the spilled oil was considered possible during the early stages of the incident; however, the time that the oil might remain in contact with the skin would be expected to be limited since as part of the emergency response measures, people would be advised to remove any oiled clothing and/or wash any exposed skin with soap and water. These measures would limit the opportunity for the chemical components of the oil to penetrate the skin. In addition, the actions taken by first responders would include notifying the public, securing the area, restricting access, and containing the oil, all of which will act to limit direct physical contact with the spilled oil.

- In addition to the implementation of the emergency and spill response measures discussed above (see Section 4.1.2 Identification of Exposure Scenarios) and described in Volume 7, if conditions warrant, local and/or provincial authorities can implement controls or issue advisories to protect public health. Examples of such controls include forced evacuation of people if public health and safety are threatened, and/or the issuance of food advisories recommending that local foodstuffs, such as home-grown produce, meat and dairy products, not be consumed until further notice. These measures will further reduce the potential opportunities for exposure of people to the chemicals released during a spill not only *via* inhalation, but also through secondary pathways on both a short- and long-term basis.

- As part of the spill response measures, monitoring programs would be initiated to track both the movement of the oil itself as well as the presence of any spill-related chemical residues in different environmental media, including the water, air, soils and/or sediment, and extending to possible foodstuffs if necessary to protect public health. The results of the monitoring program(s) will be used, in part, to guide decision-making opposite the need for control measures such as food advisories. These controls will remain in place until the results of the monitoring program(s) indicate that public health and safety is not at risk. The implementation of the monitoring programs and introduction of such control measures will serve to reduce the opportunities for exposure of the public to the chemicals, especially any exposures that could be received through secondary pathways on a longer-term basis.

Justification for focusing the assessment on the chemical exposures that people might experience *via* inhalation during the early stages of the oil spill incident, with less concern over exposures that might be received on a longer-term basis also was provided by the fact that, in some cases, exposure of people might reasonably be expected to be self-limiting owing to the irritant properties of a number of the hydrocarbon components of the spilled oil as well as the odours that might be noticed. Both of these properties would provide warning of the presence of the chemicals such that individuals could take action to remove and/or distance themselves from the source, thereby limiting the amount and duration of any exposure that might be experienced.

TABLE 4–5

SUMMARY OF THE PROBLEM FORMULATION STEP FOR THE ASSESSMENT

Project Component		Exposure Scenario	COPC	Receptors	Exposure Pathway(s)
Spill Type	Spill Size				
Pipeline spill to an urban area caused by third-party damage	CWC – 1,558 m^3 oil spilled. Smaller – 1,012 m^3 oil spilled.	Exposures received during the early stages of the spill before the arrival of first responders and implementation of emergency and spill response measures.	Consisted principally of lighter-end, volatile and semi-volatile hydrocarbons (C_1 to C_{12}), including both aliphatic and aromatic constituents found in CLWB diluted bitumen (see Table 4–4). The latter constituents included BTEX (benzene, toluene, ethylbenzene and xylenes), alkyl substituted benzenes, and PAHs. The remaining COPC consisted of various combinations of sulphur containing chemicals.	Members of the general public, including sensitive sub-populations, found along the pipeline corridor within Metro Vancouver, as well as emergency responders.	Inhalation

4.2 Exposure Assessment

The Exposure Assessment step involved estimating the potential short-term exposure to the chemical vapours released from the surface of the spilled oil that people might experience during the early stages of the incident before the arrival of first responders and the implementation of the emergency response measures. The assessment relied on the results of air dispersion modelling of the chemical vapours performed by RWDI Air Inc. (RWDI) for each of the simulated spill scenarios, with the findings consisting of predictions of the airborne concentrations of the COPC at varying distances from the spill. The predicted concentrations were used as proxies of the exposures that people might experience during the early stages of each incident. The modelling accounted for a number of different parameters affecting the fate and behaviour of the COPC in the spilled oil, including time of year and weather patterns. Highlights of the general modelling approach used by RWDI are presented below; full details can be found in Appendix B.

4.2.1 Oil Spill Modelling

The oil spill modelling assumed third-party damage to the pipeline segment within Metro Vancouver (*i.e.*, from RK 1137.5 to RK 1181.7). The determination of the spill volumes used in the assessment proceeded step-wise.

- First, spill volumes were calculated by the Trans Mountain pipeline engineering team as part of the semi-quantitative risk assessment for more than 2,000 locations along the Metro Vancouver segment of pipeline (see Application, Volume 7, Section 3.1 for additional information). The majority of the locations were found on land, with a small number located beneath the Fraser River (in the vicinity of the proposed horizontal directional drill).

- Second, the locations were screened for relevance, with the on-land locations determined to be of principal interest as the primary objective of the assessment was to assess the potential health effects that could result from short-term inhalation exposure to chemical vapours released from the surface of the spilled oil. This type of exposure would most likely be realized in an urban area when a spill occurs from a segment of the pipeline crossing land where residences are located nearby. On this basis, the locations found beneath the Fraser River were removed from further consideration.

- Lastly, the 95^{th} percentile and the average of the spill volumes predicted for the on-land locations were calculated and used to represent the CWC and smaller oil spill volumes, respectively. These volumes were determined to be 1,558 m^3 and 1,012 m^3.

The key assumptions of the oil spill modelling are presented below:

- It was assumed that the pipeline release would occur in a populated area.

- It was assumed that the breach of the pipeline would be the result of the third-party damage and that released oil from the buried pipeline would flow to ground level.

- For each of the spill scenarios, it was assumed that the entire spill volume would be released over a one-hour period at a constant rate.

- In terms of the movement and pooling of the spilled oil, it was assumed that the release would occur on level terrain.

- It was assumed that the depth of the pool of oil would be uniform at 10 cm based on US EPA Evaporation from Liquid Pool Equation described in Appendix A.

These assumptions resulted in a predicted pool radius of 70 m for the CWC spill scenario, and 57 m for the smaller spill scenario. The PHAST (Program Hazard Analysis Software Tool) model was used by RWDI to determine the emission rates of the COPC from the pool of spilled oil.

4.2.2 Determination of Exposure Estimates

The air dispersion modelling relied on site-specific meteorological data drawn from records for the Vancouver International Airport between 1971 and 2000. Emphasis was given to data gathered during the summer months for the reasons outlined earlier (see Section 4.1.1 Identification of Project Components). The modelling assumed an ambient temperature of 21°C, a relative humidity of 75%, and a wind speed of 3 m/s at the time of the spill (Appendix B).

The US EPA AERSCREEN dispersion model was used to predict the maximum one-hour average ground-level air concentrations of the COPC at progressively increasing distances from the pooled oil that people in the area might encounter as a result of the spill under each of the spill scenarios. The predicted vapour concentrations were modelled at 25 m intervals. The predicted distances referred specifically to the downwind distances along the centre-line of the vapour plume released from the surface of the spilled oil. The modelling results served as proxies for the highest exposures to the COPC that might be experienced by people in the area during the early stages of the spill event.

4.3 Toxicity Assessment

4.3.1 Selection of Exposure Limits

As indicated earlier, this step of the paradigm is concerned with identifying and understanding the potential health effects that can be caused by the COPC (acting either singly or in combination) as a function of the amount, frequency and duration of exposure, with a principal outcome of the step being the determination of Exposure Limits for the COPC. These Exposure Limits refer to the levels of exposure that would not be expected to cause adverse health outcomes. As mentioned already, the Exposure Limits are typically based on guidelines, objectives or standards established by reputable government authorities charged with the protection of public health, with the level of protection afforded by the Exposure Limits set so as to be protective of even sub-populations who may show heightened responsiveness to chemical exposures, such as infants, young children, the elderly and individuals who may be especially sensitive because of medical conditions. In order to achieve the level of protection demanded, the Exposure Limits are derived on the basis of the most sensitive health endpoint affected in humans or the most sensitive test species, with uncertainty factors then applied to account for possible differences in sensitivity to the chemical(s) between and within species. Distinction is made between Exposure Limits intended to be protective against health effects resulting from short-term exposures (referred to as “acute Exposure Limits”) and health effects caused by longer-term exposures (referred to as “chronic Exposure Limits”). For the purposes of the present assessment, emphasis was placed on the former type Exposure Limits since the focus of the work was on determining the nature and extent of health effects that could occur among people from short-term inhalation exposure to the COPC during the early stages of the oil spill before the arrival of first responders and the implementation of emergency and spill response measures. The manner by which the acute inhalation Exposure Limits were selected is described below. More complete details surrounding the basis of selection of the individual COPC are presented in the “Toxicity Profiles” found in Appendix C.

Key features surrounding the choice of Exposure Limits were:

- The Exposure Limits were chosen on the basis of a pre-defined series of selection criteria to ensure consistency, relevance and technical defensibility. The criteria specified that the Exposure Limits be:

  - Health-based (as opposed to being based on a non-health endpoint, such as odour perception or damage to physical materials);

  - Protective of the health of the general population, including the health of sub-populations who may be especially responsive to chemical exposures, such as infants and young children, the elderly, and people with compromised health because of medical conditions);

  - Established by reputable scientific authorities or government agencies whose primary mandate includes the protection of public health; and

  - Supported by documentation outlining the manner by which the Limit was developed.

- A search and comparison of Exposure Limits established by a number of reputable scientific and regulatory authorities was completed, the supporting documentation was reviewed, and a choice was made of the Limit to be used based on relevance, scientific robustness and technical defensibility. The search extended to the following authorities:

  - Metro Vancouver
  - British Columbia Ministry of the Environment (BC MOE)
  - Alberta Environment and Sustainable Resource Development (ESRD)
  - Agency for Toxic Substances and Disease Registry (ATSDR)
  - American Conference of Governmental Industrial Hygienists (ACGIH)
  - Canadian Council of Ministers of the Environment (CCME)
  - Health Canada and Environment Canada
  - Netherlands National Institute of Public Health and the Environment (RIVM)
  - California's Office of Environmental Health Hazard Assessment (OEHHA)
  - Ontario Ministry of the Environment (OMOE)
  - Texas Commission of Environmental Quality (TCEQ)
  - United States Environmental Protection Agency (US EPA)
  - Washington State Department of Ecology (WA DOE)
  - World Health Organization (WHO)

- Certain of the COPC were discrete chemical substances (*e.g.*, benzene, toluene); whereas, other COPC consisted of families of structurally-similar chemicals (*e.g.*, aliphatic C_1-C_4 hydrocarbons). For the former COPC, Exposure Limits developed for the specific chemicals were chosen. For the latter COPC, a "surrogate" chemical was used to represent the group as a whole, and the Exposure Limits chosen were those developed for the surrogate substance. In all cases, the surrogate chemicals were members of the chemical families being represented. For example, *iso*-butane was identified as one of the chemicals comprising the aliphatic C_1-C_4 group based on the bulk analysis of the crude CLWB, and was used to represent the group. Similarly, *n*-pentane was identified as a constituent of the aliphatic C_5-C_8 group, and was chosen to represent the group as a whole. The use of surrogate chemicals was dictated, in part, by the fact that Exposure Limits were unavailable for the chemical families *per se*, but did exist for one or more of the chemical constituents of the group. The use of such surrogate chemicals to represent the latter-type COPC is consistent with the "read across" principle that was mentioned earlier (see Section 3.2 Guiding Principles). The principle is accepted by most leading scientific and regulatory authorities as a means to accommodate the absence of health effects information and/or lack of availability of Exposure Limits that may apply to some chemicals or chemical groups, with the understanding that because of the structural similarities involved, the toxicity of the surrogate chemical is likely to be representative of the toxicity of the group as a whole.

- In some cases, Exposure Limits satisfying the above selection criteria could not be located, nor was sufficient health effects information available to develop *bona fide* "provisional" Exposure Limits on a *de novo* basis. In these instances, the COPC was removed from further consideration.

A list of the Exposure Limits chosen for use in the assessment is provided in Table 4–6. The basis of each Limit (*i.e.*, the critical health endpoint affected), together with the identity of the scientific/regulatory authority responsible for its development are shown. More complete details concerning the Exposure Limits and the manner in which they were developed are available in Appendix C. Again, it is important to note that a high degree of conservatism is incorporated into the Exposure Limits by virtue of reliance on the most sensitive endpoint in humans or the most sensitive test species as the primary determinant, coupled with the use of uncertainty factors to arrive at the value. Because of this conservatism, the Exposure Limits represent exposure levels that are well below those known to cause adverse health effects.

TABLE 4–6

SUMMARY OF ACUTE INHALATION EXPOSURE LIMITS

COPC	Duration	Value (µg/m³)	Critical Health Endpoint	Authority
Aliphatic C_1-C_4 group[1] (surrogate: iso-butane)	1-Hour	78,000	Neurological effects	TCEQ (2012)
Aliphatic C_5-C_8 group[1] (surrogate: n-pentane)	1-Hour	200,000	—	TCEQ (2011)
Aliphatic C_9-C_{12} group	—	—	—	—
Aromatic C_9-C_{12} group[1] (surrogate: naphthalene)	1-Hour	2,000 (adjusted)	Eye irritation	ACGIH (2013)
Benzene	1-Hour	580	Immunological effects	TCEQ (2007)
Dibenzothiophene[1]	—	—	—	—
Dimethyl sulphide group[1]	—	—	—	—
Ethanethiol group[1] (surrogate: ethanethiol)	1-Hour	2,500	Respiratory irritation	US EPA (2013)
Ethylbenzene	1-Hour	21,700	Neurological effects	ATSDR (2010)
Toluene	1-Hour	15,000	Eye and nasal irritation, Neurological effects	TCEQ (2008)
Trimethylbenzenes[2]	1-Hour	690,000	Neurological effects	US EPA (2007)
Xylenes	1-Hour	7,400	Respiratory irritation, Neurological effects	TCEQ (2009)

Notes:
— not available
1 Refer to Table 4–4 for the chemical components comprising the chemical groups.
2 Trimethylbenzenes was assessed as an individual COPC as well as part of the aromatic C_9-C_{12} group.

4.3.2 Assessment of Chemical Mixtures

As stated earlier, people are rarely exposed to chemicals in isolation, but rather exposure most commonly occurs to mixtures of chemicals. The latter situation applies to the oil spill scenarios in that the vapours released during the spill will consist of a mix of hydrocarbons and other chemicals emitted simultaneously from the surface of the spilled oil. Accordingly, it was necessary that the assessment consider the health effects that might be experienced by people in the area at the time of the spill not only from exposure to the individual COPC acting singly, but also in combination. In accordance with the approach outlined earlier and recommended by Health Canada (2010), the COPC acting through a similar mechanism of toxicity and/or affecting the same target tissues/organs (*i.e.*, sharing a so-called “commonality of effect”) were combined and assumed to act in an additive fashion. A series of different chemical mixtures were developed. Each mixture was assigned a specific designation (*e.g.*, eye irritants, respiratory irritants, neurotoxicants) based on the common critical health endpoint affected by the COPC comprising the mixture that served as the basis for the development of their Exposure Limits. The specific mixtures examined as part of the assessment are listed in Table 4–7.

TABLE 4–7

CHEMICAL MIXTURES EXAMINED

Chemical Mixture Designation	Critical Health Endpoint	COPC Comprising Mixture
Eye irritants	Eye irritation	Aromatic C_9-C_{12} group, Toluene
Respiratory irritants	Respiratory irritation	Ethanethiol group, Xylenes
Neurotoxicants	Neurological effects	Trimethylbenzenes, Aliphatic C_1-C_4 group, Ethylbenzene, Toluene, Xylenes

4.4 Characterization of Potential Health Effects

The approach taken to characterize the potential health effects that might be experienced by people in the area from exposure to the COPC vapours during the early stages of the oil spill proceeded step-wise, as outlined below:

Step 1: Comparison Against Exposure Limits

The predicted maximum one-hour average airborne concentrations of the COPC that people in the area might encounter during the early stages of the spill were compared to the corresponding acute inhalation Exposure Limits, and any exceedances of the Exposure Limits were noted. These exceedances signalled the possibility of occurrence of adverse health effects. Any COPC for which exceedances were noted were carried forward for further evaluation aimed, in part, at understanding the exact nature and extent of the health effects, and the actual prospect for the effects to occur. Any COPC for which exceedances of the Exposure Limits were not revealed by the comparison were removed from further consideration, with the understanding that even the maximum concentrations of these COPC that people might encounter were below those associated with adverse health outcomes. Because of the high degree of conservatism incorporated into both the exposure estimates (*i.e.*, use of the predicted maximum airborne concentrations for comparison) and the Exposure Limits (*i.e.*, deliberately set to afford a high degree of protection against the occurrence of adverse health effects), the decision to remove the latter COPC from further evaluation was made with confidence.

Step 2: Determination of the Areal Extent of the Exceedances

The areal extent of the exceedances was determined by RWDI for each of the COPC for which exceedances of the Exposure Limit was identified in Step 1, which in turn, provided an indication of the area surrounding the spilled oil where the airborne concentrations of the COPC could reach levels potentially capable of causing health effects among people. The information was used to help interpret the relevance of the exceedances *vis-à-vis* assessing the actual prospect for people to be found within the area in which exceedances were predicted to occur, with the understanding that the larger the area, the greater r the prospect for people to be present whose health could potentially be affected.

Step 3: Comparison Against Other Health-Based Benchmarks

Finally, in order to provide additional perspective opposite the prospect for adverse health effects to occur from acute inhalation exposure to the COPC for which exceedances were noted, additional health-based comparison “benchmarks” apart from the Exposure Limits were introduced for assessment purposes. Two sets of additional benchmarks were used: i) Acute Exposure Guideline Levels (AEGLs) developed by the US Environmental Protection Agency (US EPA); and, ii) Emergency Response Planning Guidelines (ERPGs) developed by the American Industrial Hygiene Association (AIHA). Both types of benchmarks correspond to guideline levels for use in situations where rare, unintended exposure of the general public to hazardous chemicals may occur for short durations, such as accidents involving chemical spills, industrial explosions or fires. In this respect, the AEGLs and ERPGs are particularly well suited for use in the present assessment for which the focus is on identifying and understanding the nature and extent of health effects that could occur among people from exposure to the chemical vapours released from the surface of the pooled oil during the early stages of an accidental oil spill, with the accident having a low probability of occurrence qualifying it as a rare event (see Section 4.1.1 Identification of Project Components). The AEGLs and ERPGs differ from conventional Exposure Limits insofar as they apply to

rare, unpredictable situations in which some prospect exists for short-term exposures to relatively high airborne concentrations of chemicals; whereas, Exposure Limits are intended to provide protection against more commonly encountered exposures associated with more routine circumstances quite apart from accidents or malfunctions.

Both the AEGLs and ERPGs are constructed around three "tiers" distinguished by varying degrees of severity of health effects, with each tier representing a short-term exposure value corresponding to a threshold concentration below which specific categories or types of effects would not be expected to occur among members of the general public. With progressively increasing airborne concentrations above each tier, the prospect for occurrence of the particular effects becomes greater. The definitions of the various tiers are similar between the AEGLs and the ERPGs, as evidenced by the descriptions provided below. The AEGLs differ from the ERPGs in at least two respects: i) although both benchmarks are geared toward rare, accidental exposures of short-term duration, the ERPGs are based on a one-hour averaging period only; whereas, the AEGLs are often developed for a range of exposure times, from 10 minutes to eight hours; and, ii) although both benchmarks are intended to be protective of the health of the general public, the protection afforded by the AEGLs extends to sub-populations that may be especially sensitive to chemical exposures, such as infants, young children, the elderly and the infirm; whereas, the ERPGs are developed without specific consideration of these sensitive individuals. Complete details concerning the AEGLs and ERPGs, including their meaning, derivation and use can be found elsewhere (AIHA 2013, NRC 2001, US EPA 2013).

The AEGLs are defined as follows:

- **AEGL-1** is the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.

- **AEGL-2** is the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

- **AEGL-3** is the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

The ERPGs are defined as follows:

- **ERPG-1** is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing other than mild, transient health effects or perceiving a clearly defined, objectionable odour.

- **ERPG-2** is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action.

- **ERPG-3** is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.

As part of the characterization of the potential health effects that people might experience from exposure to the chemical vapours released during the early stages of the simulated oil spills, the predicted maximum one-hour average airborne concentrations of the COPC were compared to the corresponding AEGLs and ERPGs to determine if any of the tiered threshold exposure values were exceeded, and if so, to identify the potential health implications involved. Comparison of the predicted concentrations against the AEGLs and ERPGs was meant to provide added perspective beyond the comparisons based on the acute Exposure Limits in those instances in which exceedances of the Exposure Limits were noted. In this regard, the use of the Exposure Limits as the initial comparison benchmarks was performed by default as part of a screening-level exercise, with the premise being that, because of the high degree of conservatism incorporated into the Exposure Limits, comparisons showing no exceedances could be

accepted with confidence as indicating that very little, if any, prospect for the occurrence of health effects exists, effectively ruling out any need for further assessment. However, for cases in which exceedances were noted, reliance also was placed on the AEGLs and/or ERPGs as the comparison benchmarks since, unlike the Exposure Limits which are meant to provide protection against exposures received on a routine basis, the AEGLs and ERPGs are meant to be applied to rare, unpredictable exposure circumstances, such as accidents or malfunctions, that better match the simulated oil spill scenarios. Note that AEGLs and ERPGs were only identified for COPC for which exceedances of the Exposure Limits were noted. A listing of the AEGLs and ERPGs that were used for comparison purposes is provided in Table 4–8.

TABLE 4–8

SUMMARY OF 1-HOUR AEGLS AND ERPGS

COPC	1-Hour AEGL (µg/m³)			1-Hour ERPG (µg/m³)		
	1	2	3	1	2	3
Aliphatic C_1-C_4 group[1]	13,074,703	—	—	—	—	—
Aliphatic C_5-C_8 group	—	—	—	—	—	—
Benzene	166,131	2,555,858	12,779,288	159,741	479,223	3,194,822
Toluene	753,703	4,522,218	16,958,319	188,426	1,130,555	3,768,515

Notes:
— not available
1 AEGL-1 based on n-butane.

For certain of the COPC for which exceedances of the Exposure Limits were noted, neither AEGLs nor ERPGs were available (*i.e.*, aliphatic C_5-C_8 group). In these instances, added perspective was provided by comparison of the predicted airborne concentrations against concentrations reported to cause adverse effects in case studies and/or controlled exposure studies in humans, with the outcomes serving as another means to gauge the conservatism built into the Exposure Limits and to assess the meaning and relevance of the exceedances. Again, these comparisons enabled better understanding of the actual nature, extent and prospect of occurrence of any health effects among people who might be in the area at the time of an oil spill.

4.5 Uncertainty Analysis

Uncertainties surrounded some of the information that was relied upon as part of the assessment as might be expected for the analysis of low probability events of a rare and unpredictable nature. The uncertainty was accommodated, in part, by the use of conservative assumptions aimed at ensuring that assessment would not overlook or understate any health effects that people might experience in the event that a spill was to occur. The use of the conservative assumptions can present challenges when interpreting the meaning and relevance of the assessment findings insofar as the assumptions may be needed to rule out the possibility that the prospect for the occurrence of health effects has been underestimated, but the assumptions, especially when compounded, may lead to the creation of "phantom" effects that represent hypothetical constructs only that are of little, if any, practical meaning. As a result, the interpretation of the findings must necessarily consider not only the uncertainties surrounding the assessment, but also the conservatism incorporated into the work, with some measure of professional judgement included. To facilitate the interpretation of the results, the major conservative assumptions that formed part of the assessment are listed below, followed by a list of the principal uncertainties that remained.

For the purposes of the assessment, it was conservatively assumed that:

- The oil spills had occurred despite being rare, unpredictable events, and without regard for the multitude of design, engineering, construction, inspection, maintenance and other spill prevention programs described in Volume 7 that will be in place to minimize the prospect for spills to occur.

- People may be especially responsive to chemical exposures, including the COPC vapours that could be released from the surface of the spilled oil. In this regard, reliance was placed on the use of health-based Exposure Limits developed by reputable scientific and regulatory authorities as

comparison benchmarks to determine the nature and extent of any health effects that might be experienced by people from exposure to the vapours. As mentioned already, the Exposure Limits are deliberately set to afford a high degree of protection to the general public, including protection of sub-populations who may be particularly responsive to chemical exposures such as infants, young children, the elderly and individuals with compromised health. Because of the protection demanded, the Exposure Limits correspond to levels of exposure that are well below those known to cause health effects.

- People in the area at the time would be located outdoors and downwind of the pool of spilled oil along the centre-line of the vapour plume, and would be exposed to the maximum one-hour average concentrations of the COPC vapours predicted during the first hour following the spill. At other locations, the concentrations of the COPC that would be encountered would be lower than those that were assessed.

The principal uncertainties that remained were:

- The oil spills that were examined reflected specific scenarios *vis-à-vis* spill circumstances and size, as well as meteorological conditions and other physical parameters (*e.g.*, surface roughness, atmospheric turbulence) affecting the fate and movement of the spilled oil and/or the dispersion of the chemical vapours released from the surface of the pooled oil. The results of the assessment necessarily apply to the specific scenarios that were chosen. Uncertainty remains as to how well the results reflect the potential exposures to the COPC vapours and associated health effects that could be experienced by people under different spills scenarios because of differences in circumstances. However, despite the uncertainty, the potential health effects revealed by the assessment of the specific spill scenarios and location chosen for examination, namely a heavily-populated urban area, were considered representative of the types of effects that might be experienced by people living in smaller communities, including Aboriginal communities, located along the pipeline route in the event an oil spill was to occur.

- Certain of the COPC comprising the vapours that could be released from the surface of the pooled oil lacked acute inhalation Exposure Limits, AEGLs, ERPGs and/or health effects information on which to predict the types of health effects that could result from short-term exposure to them under the simulated oil spill scenarios. Surrogate chemicals to represent these COPC could not be identified from the inventory of volatile and/or semi-volatile chemicals that could be emitted from the pooled oil. As a result, they were removed from further consideration and not assessed. Other COPC required grouping on the basis of molecular/structural similarities to create a chemical group that could be represented by a surrogate chemical. These groups were assessed, but with some uncertainty surrounding how well their toxicity was reflected in the toxicological properties of the surrogate chemical.

5.0 RESULTS

The results that emerged from the assessment are presented below. They are arranged according to spill size, with the findings for the CWC spill scenario presented first, followed by those for the smaller-sized spill. The results are further differentiated between the findings that apply to the individual COPC and those pertaining to the chemical mixtures.

The presentation of the results for the individual COPC follows the sequence described earlier in Section 4.4 Characterization of Potential Health Effects, beginning with the comparison of the maximum predicted one-hour average COPC vapour concentrations against the corresponding acute inhalation Exposure Limits; proceeding to the assessment of the areal extent of the exceedances; and, continuing with the comparison of the vapour concentrations against the corresponding AEGL and ERPG guidelines. The results presented for the chemical mixtures consist primarily of discussion of the areal extent where people's health potentially could be affected by exposure to the combined vapours of the COPC comprising the mixtures.

5.1 CWC Spill Scenario

5.1.1 Individual COPC

5.1.1.1 Comparison Against Exposure Limits

The predicted maximum one-hour average airborne concentrations of the COPC that might be encountered downwind of the pooled oil together with the corresponding acute inhalation Exposure Limits are provided in Table 5–1 for the CWC spill scenario. Examination reveals that exceedances of the Exposure Limits were predicted to occur for the following COPC: aliphatic C_1-C_4 and aliphatic C_5-C_8 groups, benzene, and toluene. The exceedances indicate the possibility that people exposed to each of these COPC during the early stages of the spill incident could potentially experience adverse health effects. The nature, extent and relevance of the exceedances are examined in the following subsections. The predicted concentrations for the remaining COPC were consistently lower than the corresponding Exposure Limits, indicating no obvious prospect for people's health to be affected by exposures to these chemicals. As a result, these COPC were removed from further consideration.

TABLE 5–1

CWC SIMULATED SPILL SCENARIO – MAXIMUM PREDICTED 1-HOUR COPC VAPOUR CONCENTRATIONS AND CORRESPONDING EXPOSURE LIMITS

COPC[1]	Maximum Predicted 1-Hour Vapour Concentration (µg/m³)	Acute Inhalation Exposure Limit (µg/m³)
Aliphatic C_1-C_4 group	4,619,949	78,000
Aliphatic C_5-C_8 group	7,632,661	200,000
Aromatic C_9-C_{12} group	6.72	2,000
Benzene	58,582	580
Ethanethiol group	516	2,500
Ethylbenzene	889	21,700
Toluene	23,058	15,000
Trimethylbenzenes	221	690,000
Xylenes	7,153	7,400

Note:
1 COPC for which the maximum predicted one-hour average vapour concentrations exceeded the Exposure Limits are shown in bold font.

5.1.1.2 Areal Extent of Exceedances

The areal extent of the predicted exceedances (*i.e.*, the distances to which the maximum predicted downwind one-hour average concentrations of the COPC were shown to exceed the corresponding Exposure Limits) are provided as Table 5–2. Examination of the data revealed that the predicted one-hour average concentrations were seen to exceed the corresponding Exposure Limits at distances ranging from 100 m to approximately 1 km from the surface of the pooled oil, depending on the COPC. As

indicated earlier, these exceedances are based on concentrations that were predicted to occur directly downwind and along the centre-line of the vapour plume.

TABLE 5–2

CWC SIMULATED SPILL SCENARIO – MAXIMUM AREAL EXTENT OF EXCEEDANCES FOR THE COPC

COPC[1]	Maximum Predicted Distance from Damaged Pipeline (m)
Aliphatic C_1-C_4 group	750
Aliphatic C_5-C_8 group	550
Benzene	1,050
Toluene	100

5.1.1.3 Comparison Against Other Health Based Benchmarks

The predicted maximum one-hour average airborne concentrations of the COPC together with the corresponding AEGL and ERPG guidelines are provided in Table 5–3. Examination reveals that the predicted concentrations were consistently lower than these guidelines, including the Tier 1 values, indicating that people in the area would not be expected to experience health effects other than minor transient sensory and/or non sensory effects. Examples of these effects are: minor discomfort, irritability, mild irritation of the eyes, nose and/or throat, mild cough, and symptoms consistent with central nervous system (CNS) involvement such as mild headache, light headedness, minor vertigo, dizziness, and/or nausea. Odours could be apparent to some individuals. The odours would be dominated by a hydrocarbon like smell, with some potential for other distinct odours due to the presence of sulphur containing chemicals in the vapour mix. The odours could contribute to added discomfort and irritability among these people.

TABLE 5–3

CWC SIMULATED SPILL SCENARIO – MAXIMUM PREDICTED 1-HOUR AVERAGE COPC VAPOUR CONCENTRATIONS AND CORRESPONDING AEGLS AND ERPGS

COPC	Predicted Maximum 1-Hour Average Vapour Concentration (µg/m³)	1-Hour AEGL (µg/m³)			1-Hour ERPG (µg/m³)		
		1	2	3	1	2	3
Aliphatic C_1-C_4 group	4,619,949	13,074,703	—	—	—	—	—
Aliphatic C_5-C_8 group	7,632,661	—	—	—	—	—	—
Benzene	58,582	166,131	2,555,858	12,779,288	159,741	479,223	3,194,822
Toluene	23,058	753,703	4,522,218	16,958,319	188,426	1,130,555	3,768,515

In the case of the aliphatic C_5-C_8 group, AEGLs and ERPGs have not been developed; however, evidence indicates that adverse health effects from exposure to this COPC would not be expected to occur, even at the maximum predicted concentrations that people in the area may experience during the early stages of the spill. More specifically, acute inhalation exposure of human subjects to a mixture of n-pentane, iso-pentane, hexane, and butane at concentrations up to 15,000,000 µg/m³ (*i.e.*, approximately two-fold higher than the maximum concentration for this group predicted to occur from the spill) resulted in no observed effects (ECB 2003).

5.1.2 Chemical Mixtures

As outlined in Section 4.0 Specific Methods, the intent of the chemical mixtures assessment was to allow for the fact that the COPC could possibly interact in an additive fashion, potentially increasing the prospect for people's health to be adversely affected by exposure to the vapours released from the pooled oil. A series of chemical mixtures were defined based on commonality of effects, namely eye irritants, respiratory irritants and neurotoxicants. The assessment focused on establishing the area in

which people's health could potentially be affected by exposure to these mixtures. Table 5–4 provides the predicted maximum areal extent from the spill source where people's health could potentially be affected from the combined vapour concentrations of the COPC comprising each of these mixtures. Examination of the table reveals the following:

- The areal extent was greatest for the neurotoxicant mixture, less for the eye irritants and respiratory irritants.
- For the eye and respiratory irritant mixtures, the maximum area that could be potentially affected was predicted to occur within 100 m of the pipeline. The maximum area predicted to be affected by the neurotoxicant mixture extended up to approximately 750 m from the pipeline.
- People in the area exposed to the mixtures would not be expected to experience health effects other than the mild, transient sensory and non-sensory effects described above for the individual COPC. Because the maximum predicted one-hour average concentrations of the individual COPC comprising the mixtures were well below the corresponding acute inhalation Exposure Limits or the Tier-1 AEGL and/or ERPG guidelines, even combining the COPC and assuming they would interact in an additive fashion would not materially change the manner and extent to which people would be affected.

TABLE 5–4

CWC SIMULATED SPILL SCENARIO – MAXIMUM AREAL EXTENT OF EXCEEDANCES FOR THE CHEMICAL MIXTURES

Chemical Mixture	Maximum Predicted Distance from Damaged Pipeline (m)
Eye Irritants	75
Respiratory Irritants	75
Neurotoxicants	750

5.2 Smaller Spill Scenario

As already indicated in Section 4.0 Specific Methods, the smaller spill scenario was assumed to result from third-party damage to the pipeline, with the pool of spilled oil extending out 57 m. Due to the lesser amount of spilled oil, the predicted maximum one-hour average vapour concentrations released from the pooled oil would be expected to be lower than those predicted for the CWC spill scenario. The areal extent of exceedances also would be reduced. The predicted COPC vapour concentrations were examined following the same step-wise approach used for the CWC spill scenario, and are discussed in the subsections below.

5.2.1 Individual COPC

5.2.1.1 Comparison Against Exposure Limits

The maximum predicted one-hour average airborne concentrations of the COPC together with the corresponding acute inhalation Exposure Limits are provided in Table 5–5 for the smaller spill scenario. Examination reveals that exceedances of the Exposure Limits were predicted to occur for the following COPC: aliphatic C_1-C_4 and aliphatic C_5-C_8 groups, benzene, and toluene. The exceedances indicate the possibility that people exposed to each of these COPC during the early stages of the spill incident could potentially experience adverse health effects. The nature, extent and relevance of the exceedances are examined in the following subsections. The predicted concentrations for the remaining COPC were consistently lower than the corresponding Exposure Limits, indicating that no obvious prospect for people's health to be affected by exposures to these chemicals exists. As a result, these COPC were removed from further consideration.

TABLE 5–5

SMALLER SIMULATED SPILL SCENARIO – MAXIMUM PREDICTED 1-HOUR AVERAGE COPC VAPOUR CONCENTRATIONS AND CORRESPONDING EXPOSURE LIMITS

COPC[1]	Maximum Predicted 1-Hour Average Vapour Concentration (µg/m³)	Acute Inhalation Exposure Limit (µg/m³)
Aliphatic C_1-C_4 group	4,330,336	78,000
Aliphatic C_5-C_8 group	7,154,189	200,000
Aromatic C_9-C_{12} group	6.30	2,000
Benzene	54,910	580
Ethanethiol group	484	2,500
Ethylbenzene	833	21,700
Toluene	21,613	15,000
Trimethylbenzenes	207	690,000
Xylenes	6,705	7,400

Note:
1 COPC for which the maximum predicted one-hour average vapour concentrations exceeded the Exposure Limits are shown in bold font.

5.2.1.2 Areal Extent of Exceedances

The areal extent of the predicted exceedances (*i.e.*, the distances to which the maximum predicted downwind one-hour average concentrations of the COPC were shown to exceed the corresponding Exposure Limits) are provided as Table 5–6. Examination of the data revealed that the predicted one-hour average concentrations were seen to exceed the corresponding Exposure Limits at distances ranging from 50 m to approximately 800 m from the surface of the pooled oil, depending on the COPC. As indicated earlier, these exceedances are based on concentrations that were predicted to occur directly downwind and along the centre-line of the vapour plume.

TABLE 5–6

SMALLER SIMULATED SPILL SCENARIO – MAXIMUM AREAL EXTENT OF EXCEEDANCES FOR THE COPC

COPC	Maximum Predicted Distance from Damaged Pipeline (m)
Aliphatic C_1-C_4 group	575
Aliphatic C_5-C_8 group	425
Benzene	825
Toluene	50

5.2.1.3 Comparison Against Other Health-Based Benchmarks

The maximum predicted one-hour average airborne concentrations of the COPC together with the corresponding AEGL and ERPG guidelines are provided in Table 5–7. Examination reveals that the predicted concentrations were consistently lower than these guidelines, including the Tier-1 values, indicating that people in the area would not be expected to experience health effects other than minor transient sensory and/or non-sensory effects, such as those described above for the CWC spill scenario. Odours could be apparent to some individuals. The odours would be dominated by a hydrocarbon-like smell, with some potential for other distinct odours due to the presence of sulphur containing chemicals in the vapour mix. The odours could contribute to added discomfort and irritability among these people.

TABLE 5–7

SMALLER SIMULATED SPILL SCENARIO - MAXIMUM PREDICTED 1-HOUR AVERAGE COPC VAPOUR CONCENTRATIONS AND CORRESPONDING AEGLS AND ERPGS

COPC	Predicted Maximum 1-Hour Average Vapour Concentration (µg/m³)	1-Hour AEGL (µg/m³)			1-Hour ERPG (µg/m³)		
		1	2	3	1	2	3
Aliphatic C_1-C_4 group	4,330,336	13,074,703	—	—	—	—	—
Aliphatic C_5-C_8 group	7,154,189	—	—	—	—	—	—
Benzene	54,910	166,131	2,555,858	12,779,288	159,741	479,223	3,194,822
Toluene	21,613	753,703	4,522,218	16,958,319	188,426	1,130,555	3,768,515

As previously stated, AEGLs and ERPGs have not been developed the aliphatic C_5-C_8 group. Evidence indicates, however, that adverse health effects from exposure to this COPC would not be expected to occur for the same reasons outlined above for the CWC spill scenario.

5.2.2 Chemical Mixtures

As with the CWC spill scenario, the chemical mixtures that were examined as part of the smaller spill scenario were the eye irritant, respiratory irritant, and neurotoxicant mixtures. The predicted maximum areal extent from the spill source where people's health could potentially be affected from the combined vapour concentrations of the COPC comprising each of these mixtures are provided in Table 5–8. Examination of the table reveals the following:

- The areal extent was greatest for the neurotoxicant mixture, less for the eye irritant and respiratory irritant mixture.
- As described above for the CWC spill scenario, people in the area exposed to the mixtures would not be expected to experience health effects other than the mild, transient sensory and non-sensory effects.

TABLE 5–8

SMALLER SIMULATED SPILL SCENARIO – MAXIMUM AREAL EXTENT OF EXCEEDANCES FOR THE CHEMICAL MIXTURES

Chemical Mixture	Maximum Predicted Distance from Damaged Pipeline (m)
Eye Irritants	50
Respiratory Irritants	50
Neurotoxicants	450

6.0 DISCUSSION

The assessment was completed in order to permit understanding of the nature and extent of health effects that people in the area of a pipeline oil spill could experience from exposure to the hydrocarbon and other chemical vapours released from the surface of the pooled oil during the early stages of the incident under each of the simulated oil spill scenarios examined. The assessment focused on a set of simulated spill scenarios involving different-sized spills resulting from third-party damage to a segment of the pipeline in an urban area. The spill sizes corresponded to the volumes of oil that could be released under a CWC spill scenario and a smaller-sized spill scenario. For the purposes of the assessment, it was conservatively assumed that the oil spill(s) had taken place despite a low probability of occurrence, and without regard for the spill prevention programs described in Volume 7 that would be in effect to minimize the prospect for spills to occur along the entire length of the pipeline.

The assessment focused on the health effects that people might experience from inhalation of the COPC vapours released from the surface of the pooled oil during the early stages of the spill event before the arrival of first responders and the implementation of emergency and spill response measures aimed at quickly isolating, containing and recovering the spilled oil. The assessment followed a paradigm adapted from that used for conventional HHRAs to accommodate the specific focus of the present work. The characterization of the health effects followed a multi-tiered approach, beginning with comparison of the maximum predicted one-hour average COPC vapour concentrations against the corresponding acute inhalation Exposure Limits, with the relevance and meaning of any exceedances explored through examination of the areal extent of the predicted exceedances as well as further comparison of the maximum predicted vapour concentrations against the corresponding AEGLs and ERPGs.

The principal findings that emerged from the assessment are:

- For the majority of the COPC, the maximum predicted one-hour average airborne concentrations of the COPC were below the corresponding acute inhalation Exposure Limits. The exceptions included the aliphatic C_1-C_4 and aliphatic C_5-C_8 groups, benzene and toluene, for which exceedances of the Exposure Limits were predicted to occur downwind of the pooled oil, along the centre-line of the dispersing vapour plume, indicating some prospect for people's health to be affected. The interpretation of the relevance and meaning of these exceedances formed part of the characterization of the potential health effects (*i.e.*, Step 4 of the paradigm), and was reserved until the assessment was complete.

- In both the CWC and smaller spill scenarios, the maximum predicted one-hour average airborne concentrations of the COPC were highest at the edge of the pooled oil and declined with increasing distance downwind from this point. As might be expected, the spatial extent of the exceedances was influenced by spill size, with the downwind distances from the spill source to which the exceedances extended being greater for the CWC spill scenario than for the corresponding smaller-size spill scenario.

- Comparison of the maximum predicted one-hour average airborne concentrations of the COPC against the corresponding one-hour AEGLs and ERPGs consistently revealed the levels of the COPC that people in the area might encounter during the early stages of the spill to be well below these guidelines, including the "Tier-1" values, indicating no obvious prospect for people's health to be seriously adversely affected under either of the simulated spill scenarios examined.

Although the assessment revealed exceedances of the Exposure Limits on occasion for some COPC, the interpretation of the relevance and meaning of these exceedances required consideration of the conservatism incorporated into the assessment, including the Exposure Limits themselves. In this regard, by virtue of the level of protection demanded of the Exposure Limits, these guidelines correspond to exposure levels well below those known to cause adverse health outcomes. For this reason, an exceedance of an Exposure Limit does not necessarily indicate an imminent health risk, but rather only infers some prospect for health effects to occur, the interpretation of which requires further analysis. As part of this further analysis, reliance was placed on the AEGLs and ERPGs since these guidelines are deliberately intended for use in assessing the potential health effects that might occur among the general

public from exposure to relatively high concentrations of chemicals for short duration under rare, accidental circumstances, such as chemical spills.

The weight-of-evidence gathered from the characterization of the potential health effects as outlined above showed no obvious prospect for people's health to be seriously adversely affected by exposure to the COPC vapours during the early stages of the spill events. Using the tiered AEGL and ERPG health effects criteria for guidance, the evidence revealed that people in the area would not be expected to experience health effects other than minor, transient sensory and/or non-sensory effects, related largely to the irritant properties and/or CNS effects of the COPC. Odours could be apparent to some individuals. The odours would be dominated by a hydrocarbon-like smell, with some potential for other distinct odours due to the presence of sulphur containing chemicals in the vapour mix. The odours could contribute to added discomfort and irritability among these people.

6.1 Other Considerations

Other considerations bearing on the interpretation of the relevance and meaning of the results of the assessment are:

- As outlined earlier, an appreciable degree of conservatism was incorporated into the assessment (see Section 4.5 Uncertainty Analysis), consisting, in part, of a number of conservative assumptions that could contribute to heightened exposure of people to the hydrocarbon and other chemical vapours released from the surface of the spilled oil in the event of a pipeline release compared to actual exposures that might be experienced. The reliance on these conservative assumptions was meant to avoid underestimating or overlooking any potential health effects that people could experience. By the same token, the conservatism incorporated into the assessment may have contributed to overstatement of the manner and extent to which people's health might be affected. Examples of the conservatism employed in the assessment are:

    - It was conservatively assumed that the spill(s) had occurred despite a low probability of occurrence and without regard to the spill prevention programs described in Volume 7 that will be in place.

    - In determining the manner and extent to which people's health might be affected by exposure to the COPC vapours, reliance was placed on the maximum predicted one-hour average concentrations that people in the area might encounter downwind of the pooled oil, along the centre-line of the dispersing vapour plume. At other locations, the COPC concentrations would be lower.

    - The assessment relied, in part, on Exposure Limits as comparison benchmarks to gauge the prospect for people's health to be adversely affected by exposure to the COPC vapours. The Exposure Limits are deliberately set to afford a high degree of protection with respect to the health of the general public, extending to sub-populations who may be especially sensitive to chemical exposures. By virtue of the manner in which the Exposure Limits are developed, including reliance on the most sensitive endpoint affected by the chemical in humans or the most sensitive test species as their basis, coupled with the application of uncertainty factors to confer added protection, the Exposure Limits correspond to exposure levels well below those at which adverse health effects have actually been observed.

- Exposure of people might reasonably be expected to be self-limiting owing to the irritant properties of a number of the COPC as well as the odours that might be noticed. Both of these properties would provide warning of the presence of the chemicals such that people could take action to remove or distance themselves from the source, thereby reducing the amount and duration of any exposure received. With respect to these actions that people could take to limit exposures, it is noteworthy that the maximum predicted one-hour average concentrations of the COPC were considerably below the Tier-2 AEGL and ERPG guidelines, indicating that any health effects that they might experience would not impair their ability to remove themselves from the area.

- The oil spills reflected specific scenarios *vis-à-vis* spill size, as well as meteorological conditions and other physical parameters affecting the fate and movement of the pooled oil and/or the dispersion of the chemical vapours released from the surface of the spilled oil. The results of the assessment necessarily apply to the specific scenarios that were chosen. Uncertainty remains as to how well the results reflect the potential exposures to the COPC vapours and associated health effects that could be experienced by people under different spills scenarios because of differences in circumstances. In this regard, there is need for recognition of the multitude of factors that can act as determinants of the exact nature and severity of any health effects that could potentially result from an oil spill, as well as the variability that can surround these factors. Examples of these factors and the manner by which they were addressed in the present assessment include:

    - The circumstances surrounding the spill, including the time of year and the meteorological conditions in effect at the time. These circumstances will affect the extent to which chemical vapours are released from the surface of the pooled oil and the manner in which these vapours disperse. For the purposes of the assessment, the potential exposures to the COPC vapours that people in the area could experience were based on circumstances that reflected seasonal and weather conditions favouring the volatilization of the hydrocarbons from the pooled oil.

    - The person's whereabouts in relation to the spill, including their distance from the source and their orientation to the pooled oil with respect to wind direction. The prospect for people's health to be affected by acute inhalation exposure to the hydrocarbon and other chemical vapours released from the spilled oil will be greatest at locations close to and downwind of the pooled oil, where the highest concentrations of the vapours will be encountered. The assessment relied on the maximum one-hour average COPC vapour concentrations predicted to occur downwind of the pooled oil, along the centre of the dispersing vapour plume as proxies for the exposures that people might experience.

    - The timeliness of emergency response measures. Measures taken to either remove the hazard from the general public (*e.g.,* spill isolation, containment) or to remove the general public from the hazard (*e.g.,* securing the spill area, restricting access, notifying the public to avoid the area, evacuation of people from the area) would reduce the prospect for exposure and any associated health effects. The sooner these measures can be implemented, the lower the likelihood of any effects. Prompt measures taken by Trans Mountain and other spill response agencies would serve to protect public health and safety.

- A person's sensitivity to chemical exposures. The manner and extent to which people in the area at the time of an oil spill may respond to the chemical vapours released from the surface of the pooled oil will depend, in part, on their age and health status, with the young, the elderly and people with compromised health possibly showing heightened sensitivity. The assessment allowed for the possibility that these sensitive sub-populations might be exposed to the COPC vapours by using the Exposure Limits and AEGLs as comparison benchmarks. Both types of guidelines afford protection to these sub-populations.

- Some prospect exists for people in close proximity to the damaged segment of the pipeline at the time of the spill to experience physical contact with the spilled oil, either through direct contact of the oil with any exposed skin and/or indirectly in the event of oil soaking through their clothing. The time that the oil might remain in contact with the skin would be expected to be limited since as part of the emergency response measures, people would be advised to wash any exposed skin with soap and water and/or remove any oiled clothing. These measures would limit the opportunity for the chemical components of the oil to penetrate the skin, effectively removing any prospect of systemic toxicity. However, because of the irritant properties of certain components, some prospect exists for people to experience some mild, transient, localized skin irritation.

7.0 SUMMARY AND CONCLUSIONS

An assessment was completed of the potential health effects that might be experienced by people from exposure to hydrocarbon and other chemical vapours released during the course of an oil spill caused by third-party damage to a segment of the pipeline in an urban area. The assessment relied on predictions of the maximum one-hour average airborne concentrations of a number of COPC as proxies for the acute inhalation exposures that people might experience. The predictions were made at downwind locations along the centre-line of the dispersing vapour plume. The predicted concentrations were compared to the corresponding health-based acute inhalation Exposure Limits, which correspond to the levels of the COPC that would not be anticipated to cause adverse health effects among the general public, including people who might be especially sensitive to chemical exposures. The results of the comparison were used to assess the nature and extent of any potential health effects that the people could experience. For added perspective, the predicted concentrations also were compared to the corresponding one-hour AEGL and ERPG guidelines. These latter guidelines were considered to be especially relevant benchmarks since they are intended for use in situations involving rare, unpredictable exposure of the general public to chemicals, such as accidental spills.

The major conclusions that emerged from the assessment are:

- Based on the weight-of-evidence, there is no obvious indication that people's health would be seriously adversely affected by acute inhalation exposure to the chemical vapours released from the pooled oil during the early stages of a spill.

- The evidence suggests that the health effects that could be experienced by people in the area would be confined to minor, transient sensory and/or non-sensory effects, including minor discomfort, irritability, mild irritation of the eyes, nose and/or throat, mild cough, and symptoms consistent with CNS involvement such as mild headache, light headedness, minor vertigo, dizziness, and/or nausea.

- The evidence also indicates that mild, transient, localized skin irritation could occur in the event that the spilled oil was to contact the skin.

- The evidence also indicates that odours could be apparent to some individuals. The odours would be dominated by a hydrocarbon-like smell, with some potential for other distinct odours due to the presence of sulphur containing chemicals in the vapour mix. The odours could contribute to added discomfort and irritability among these people.

Although minor and transient, the effects would still be annoying and discomforting, indicating the need for and importance of the spill prevention programs described in Volume 7. Planning and preparedness around emergency and spill response also are critical to ensure timely and adequate response to any spill events to limit opportunities for chemical exposures such that public health and safety is not threatened, highlighting the need for and importance of the emergency and spill response programs described in Volume 7.

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APPENDIX A FIGURES

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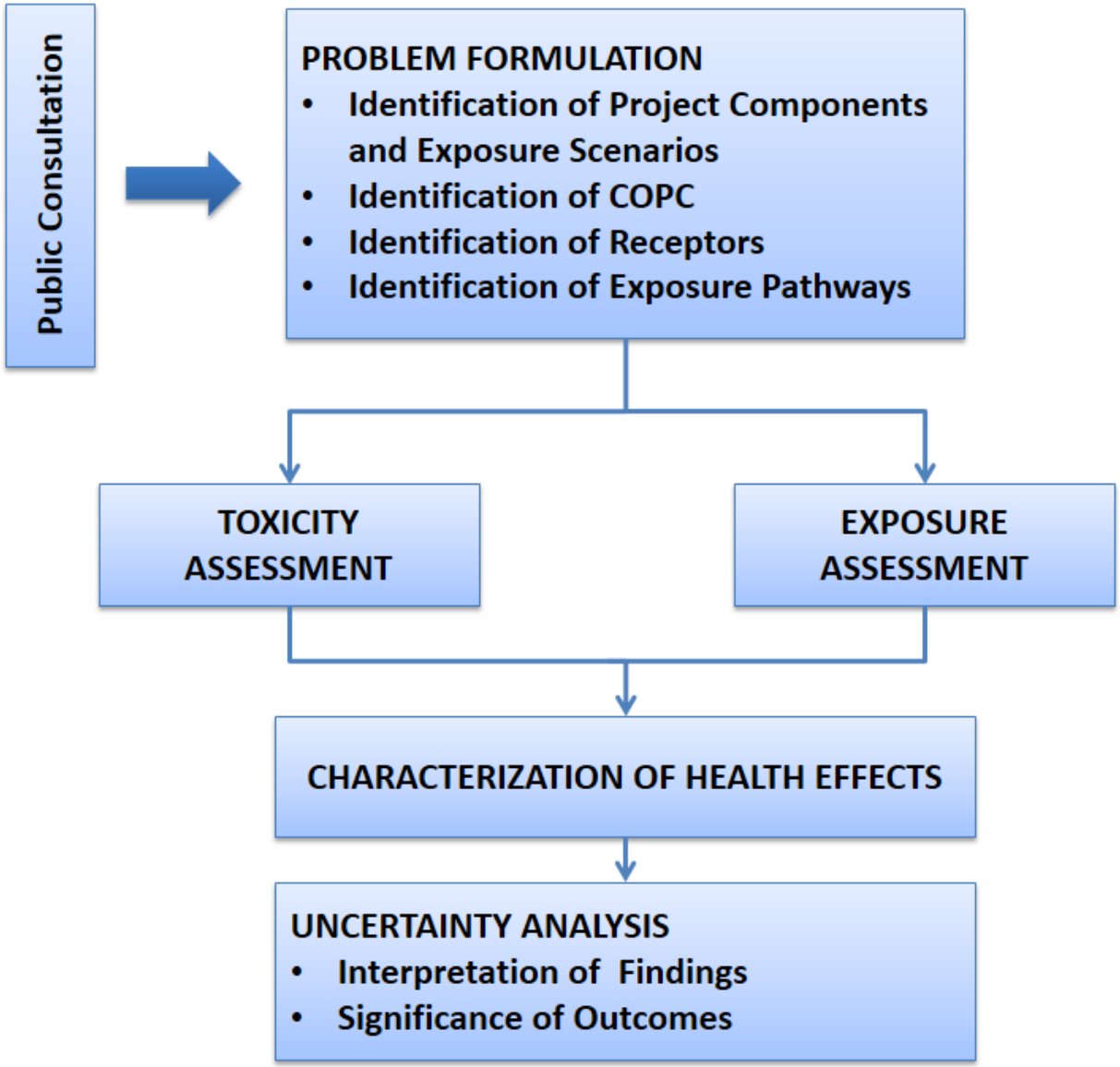

Figure 3.1 The Health Effects Assessment Paradigm

APPENDIX B RWDI URBAN SPILL REPORT

CONSULTING ENGINEERS & SCIENTISTS

Tel: 403.232.6771
Fax: 403.232.6762

RWDI AIR Inc.
#1000, 736-8th Avenue S.W.
Calgary, Alberta, Canada
T2P 1H4
Email: solutions@rwdi.com

HHRA Urban Pipeline Spill Consequence Modelling for the Trans Mountain Pipeline ULC Trans Mountain Expansion Project

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SUBMITTED TO
Jason Smith M.Sc.
Vice President Consulting Services - Principal
TERA Environmental Consultants
jsmith@teraenv.com

SUBMITTED BY
David Chadder Hon. B.Sc., QEP
Senior Project Director/Principal
David.Chadder@rwdi.com

Craig Vatcher, CET
Senior Project Manager/Associate
Craig.Vatcher@rwdi.com

Michael Ratcliff, Ph.D., P.E.
Technical Director
Michael.ratcliff@rwdi.com

Bryce Dawson, B.Sc., EPt
Project Manager
Bryce.dawson@rwdi.com

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Appendices

1. INTRODUCTION

RWDI AIR Inc. (RWDI) was retained by TERA Environmental Consultants (TERA) to perform consequence modelling to determine potential hazard extents resulting from a failure in the proposed Trans Mountain Expansion Project (TMEP); herein referred to as "The Project", as a result of third party damage. Accidental damage and failure of the pipeline would create the potential for a pool of the crude oil product transported in the pipeline to form on the ground after a failure, from which Chemicals of Potential Concern (COPC) could evaporate and become airborne. Emissions of total volatiles from the pool were calculated and dispersion modelling was conducted to examine maximum predicted hazard extents of various COPC, based on an accidental failure of the proposed addition of 914 mm (NPS 36) outside diameter pipeline located in Metro Vancouver. The results of this assessment were provided to Intrinsik Environmental Sciences Ltd. (Intrinsik) as a component of the Human Health Risk Assessment (HHRA).

This report describes the assessment methodology, including the technical guidance and assumptions related to decision making, and maximum predicted extents of hazardous concentrations of the COPC.

2. CHEMICALS OF POTENTIAL CONCERN

The COPC from a human health perspective were identified by Intrinsik based on bulk liquid analysis conducted by Maxxam Analytics for Cold Lake Winter Blend (CLWB) and representative petroleum hydrocarbon samples. The 1-hour exposure limit concentrations were supplied by Intrinsik, and are summarized in Table 1. The bulk liquid analysis and composition data of representative hydrocarbons are provided in Appendix A.

Table 1: Chemicals of Potential Concern and Corresponding 1-hour Exposure Limits (in µg/m^3)

Chemical of Potential Concern	1-hour Exposure Limit
Aliphatic C1-C4 Group	78,000
Aliphatic C5-C8 Group	200,000
Aromatic C9-C12 Group	2000
Benzene	580
Ethanethiols Group	2500
Ethylbenzene	21,700
Toluene	15,000
Trimethylbenzenes	690,000
Xylenes	7400

3. ASSESSMENT APPROACH

To conduct this assessment, RWDI used guidance from the U.S. Environmental Protection Agency (EPA) 1999 *Risk Management Program Guidance for Offsite Consequence Analysis* (RMP) to develop the emission scenarios and emission rates for the COPC (U.S. EPA, 1999). To conduct the dispersion modelling, the U.S. EPA AERSCREEN model and the PHAST (Process Hazard Analysis Software Tool) accidental release discharge and consequence model, developed by DNV GL Software Norway.

3.1 Product Parameters and Release Scenarios

The accidental spill was assumed to result from third-party damage to the NPS 36 pipe. The rupture of the pipeline was assumed to occur at any point within Metro Vancouver. Two release volumes were considered. The first was the 95th percentile, or "credible worst case", volume of oil at any point in the pipeline. The second was the arithmetic mean, or "smaller spill", volume of oil in the pipeline. The volume of material to be released was calculated based on data supplied by KMC. As a simplifying assumption, the spill was assumed to release the entire volume over the period of one hour at a constant (uniform) release rate that would produce a pool of material. The product and release parameters are presented in Table 2.

Table 2: Product and Release Parameters

Parameter	Value
Product	Cold Lake Winter Blend
Density (kg/m^3)	926.7
Credible Worst Case Spill Volume (m^3)	1558
Smaller Spill Volume (m^3)	1012
Product Temperature (°C)	25

3.2 Dispersion Scenarios and Meteorology

The accidental release scenario was developed following guidance presented by the U.S. EPA RMP (U.S. EPA, 1999) and followed the approach recommended for the alternate release scenario. The EPA RMP identifies parameters such as the meteorological conditions to be considered, and provides guidance on the minimum depth of the liquid pool to use. The alternative scenario as outlined by the EPA RMP considers Pasquill-Gifford (PG) atmospheric stability class D, which represents a neutral atmosphere, with a wind speed of 3 m/s and typical high ambient temperature. The EPA RMP indicates that site specific meteorological data can be used in this scenario. As such, the alternative scenario considered a typical summer day (i.e., 21°C) based on Canadian climate normals (1971-2000) from the Vancouver International Airport. This meteorological station was selected as it meets the United Nation's WMO standards and offered the most complete set of data for the region. Under this approach, the ambient temperature and relative humidity were modified relative to EPA defaults to reflect site specific conditions. A summary of the meteorological parameters used are presented in Table 3.

Table 3: Summary of Meteorological Parameters used in the Model

Parameter	Value
PG Stability Class	D
Wind Speed (m/s)	3
Ambient Temperature (°C)	21
Relative Humidity (%)	75
Minimum Pool Depth (m)	0.01
Maximum Pool Depth (m)	0.1

3.3 Emissions Characterization

To calculate the emissions of volatiles from the pool, a simplified representation of the CLWB product was entered into the PHAST model to determine the effect of evaporative cooling, and to predict the temperature of the liquid pool during the evaporation. The PHAST model contains a module to determine the total evaporation rate off of a pool for a single product. The simplified CLWB assumed that the product was composed entirely of a single hydrocarbon product, represented as n-decane, with a weighted average molecular weight based on the bulk liquid analysis, and with a vapour pressure based on typical characteristics for CLWB (Enbridge, 2014). The meteorological and pool depth parameters used in the PHAST model mirrored those presented in Table 3. This final estimated temperature was then used to determine the vapour pressure of the respective COPC to characterize the emission rate. Figure 1 presents the change in pool temperature over the assumed 1-hour spill.

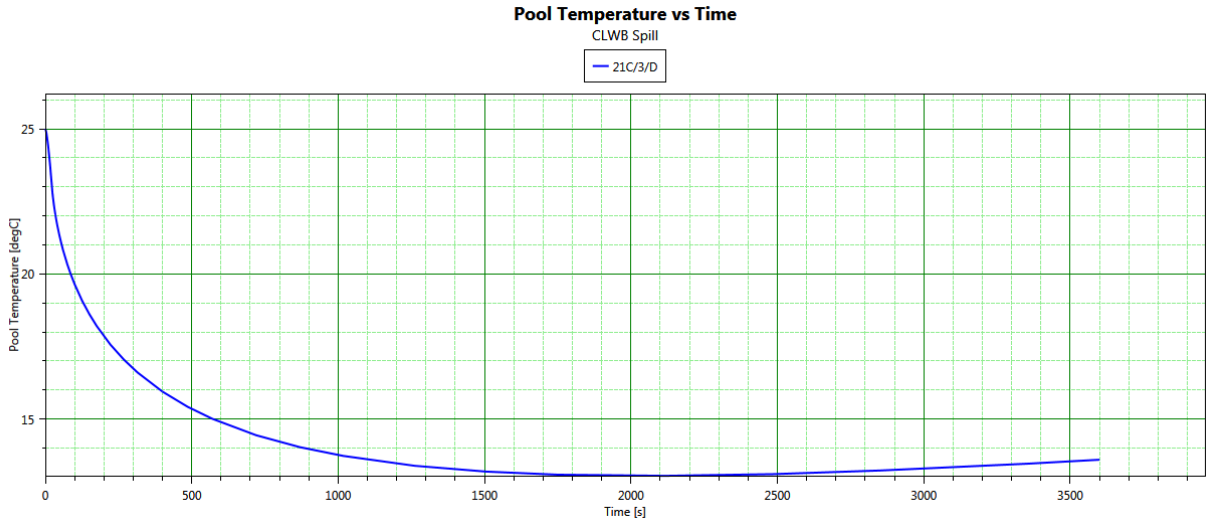

Figure 1: Pool Temperature over Time due to Evaporative Cooling of a CLWB Spill Calculated in PHAST

Based on the results of the PHAST model, emission rates for each COPC from the pool were calculated using equation D-2 for evaporation from a liquid pool in the U.S. EPA RMP, which considers mole fraction, molecular weight, wind speed, ambient temperature, vapour pressure and pool area. The equation is re-produced below in Equation 1.

$$QR = \frac{0.284\ x\ U^{0.78}\ x\ MW^{2/3}\ x\ A\ x\ VP}{82.05\ x\ T}$$

Where:

QR	Evaporation Rate (pounds per minute)
U	Wind Speed (m/s)
MW	Molecular Weight
A	Surface Area (square feet)
VP	Vapour Pressure (mmHg)
T	Temperature (K)

Equation 1: U.S. EPA Evaporation from Liquid Pool Equation

The parameters for meteorological conditions (wind speed and ambient temperature) are as outlined in Table 3. For the pool area, it was assumed that the entire inventory for both spill volumes was at a uniform depth of 0.1 m, giving a pool radius of 70 m and 57 m for the credible worst case and smaller spill volumes, respectively. As a conservatism, and to account for any peaks in the emission rates during the first few minutes of the spill, which would not be reflected by the lower vapour pressures associated with the lower pool temperatures, the temperature used in the equation was assumed to be ambient (21°C), rather than the temperature of the pool. Additionally, it was assumed that the spill occurred on a flat surface, absent of topographic features such as hill or valleys, allowing the pool to spread to a maximum diameter based on pool depth. In this case, the surface area and wind speed under which the spill occurred would remain constant and uniform for the assumed spill and the associated calculated emission rates.

The relative percentages (mole fraction) of each COPC were determined based on the bulk liquid composition and the representative hydrocarbon analysis that was provided by Stantec Consulting Ltd. (2013) in Volume 7 of The Application by Trans Mountain for Approval of the Trans Mountain Expansion Project. For COPC representing a group of compounds, simplifying assumptions were used to determine the percentage of the group in the CLWB product. For the Aliphatic C5-C8 group, it was assumed that all chemicals with the same number of carbons, as presented in the bulk liquid analysis, were included in this group, and a representative vapour pressure based on a weighted average molecular weight for the group was adopted. For the Aliphatic C5-C8 group, the vapour pressure of n-hexane was assumed. For the Aromatic C9-C12 group, the mole fraction was based on representative hydrocarbon analysis provided by Stantec, and included the Aromatic>C8-C10 and the Aromatic>C10-C12 groups. The vapour pressure for this group (Aromatic C9-C12) was assumed to be equivalent to that of naphthalene. The percentages of each COPC used in the U.S. EPA equation and the calculated emission rates are presented in Table 4. Not all compounds included in the CLWB composition are listed in Table 4; only

COPC identified by Intrinsik were evaluated. Detailed calculations for the credible worst case and smaller spill volumes are provided in Tables B-1 and B-2, respectively, as found in Appendix B.

Table 4: Percentages of each Chemical of Potential Concern in the CLWB Product and Calculated Emission Rates for each Spill Scenario

Chemical of Potential Concern	Mole Percentage in CLWB (%)	Emission Rate for Credible Worst Case Spill Volume (g/s)	Emission Rate for Smaller Spill Volume (g/s)
Aliphatic C1-C4 Group	2.64	10,919	7240
Aliphatic C5-C8 Group	55.8	18,040	11,962
Aromatic C9-C12 Group	5.07	0.016	0.011
Benzene	0.85	138	91.8
Ethanethiols Group	2.36E-05	1.22	0.808
Ethylbenzene	0.07	2.10	1.39
Toluene	1.07	54.5	36.1
Trimethylbenzenes	0.06	0.52	0.35
Xylenes	1.32	16.9	11.2

3.4 Dispersion Modelling

The U.S. EPA AERSCREEN dispersion model was used to determine maximum predicted downwind distances to the respective 1-hour exposure limits (see Table 1) for the COPC. The model was applied using an area source for each of the spill volumes and a wind speed of 3 m/s. The model was also used to calculate maximum predicted concentrations of each COPC at various downwind distances.

The terrain, or characteristics of the surface cover, over which an accidental release disperses will influence the dispersing plume. Surface characteristics affect the degree of turbulence experienced by the wind, or contaminant plume, as it disperses along a surface. For modelling purposes, surface cover is quantified as surface roughness length which corresponds to typical land use categories (e.g., forest, urban, grassland, etc.). For this assessment, the surface roughness length was set to 1 m, which corresponds to regular occurrence of large obstacles, as would be expected in a populated area, such as in Metro Vancouver.

Finally, the dispersion modelling results are peak centerline concentrations for the worst hour following the spill for receptors located directly downwind of the spill, with the assumption of constant and uniform wind speed and direction for the entire hour. This approach does not take into account plume meander that may be associated with changing wind directions or gusting winds over the 1-hour period.

4. RESULTS

The maximum predicted downwind extents for the 1-hour exposure limit for the COPC are presented in Tables 5 and 6 for the credible worst case and smaller spill volumes, respectively. The maximum

predicted concentrations for each contaminant of potential concern at numerous distances from the failure are presented in Tables 7 and 8 for the credible worst case and smaller spill volumes, respectively.

Table 5: Maximum Predicted Downwind Extents to 1-hour Exposure Limits for the Chemicals of Potential Concern for the Credible Worst Case Spill Volume

Chemical of Potential Concern	Maximum Predicted Distance to Exposure Limit (m)
Aliphatic C1-C4 Group	750
Aliphatic C5-C8 Group	550
Aromatic C9-C12 Group	0
Benzene	1050
Ethanethiols Group	0
Ethylbenzene	0
Toluene	100
Trimethylbenzenes	0
Xylenes	0

Table 6: Maximum Predicted Downwind Extents to 1-hour Exposure Limits for the Chemicals of Potential Concern for the Smaller Spill Volume

Chemical of Potential Concern	Maximum Predicted Distance to Exposure Limit (m)
Aliphatic C1-C4 Group	575
Aliphatic C5-C8 Group	425
Aromatic C9-C12 Group	0
Benzene	825
Ethanethiols Group	0
Ethylbenzene	0
Toluene	50
Trimethylbenzenes	0
Xylenes	0

Table 7: Maximum Predicted Concentrations for the Chemicals of Potential Concern for the Credible Worst Case Spill Volume at Downwind Distances (in µg/m^3)

COPC	Downwind Distance (m)												
	1	4	9	25	50	75	100	150	300	450	600	750	900
Aliphatic C1-C4	3.97E+06	4.01E+06	4.08E+06	4.25E+06	4.48E+06	4.62E+06	1.79E+06	7.18E+05	2.78E+05	1.61E+05	1.07E+05	7.69E+04	5.81E+04
Aliphatic C5-C8	6.56E+06	6.63E+06	6.74E+06	7.02E+06	7.40E+06	7.63E+06	2.95E+06	1.19E+06	4.60E+05	2.66E+05	1.77E+05	1.27E+05	9.61E+04
Aromatic C9-C12	5.78E+00	5.84E+00	5.93E+00	6.18E+00	6.51E+00	6.72E+00	2.60E+00	1.04E+00	4.05E-01	2.34E-01	1.56E-01	1.12E-01	8.45E-02
Benzene	5.04E+04	5.09E+04	5.17E+04	5.39E+04	5.68E+04	5.86E+04	2.26E+04	9.11E+03	3.53E+03	2.04E+03	1.36E+03	9.75E+02	7.37E+02
Ethanethiols	4.44E+02	4.48E+02	4.55E+02	4.75E+02	5.00E+02	5.16E+02	1.99E+02	8.02E+01	3.11E+01	1.80E+01	1.20E+01	8.59E+00	6.49E+00
Ethylbenzene	7.65E+02	7.72E+02	7.85E+02	8.18E+02	8.62E+02	8.89E+02	3.44E+02	1.38E+02	5.35E+01	3.10E+01	2.06E+01	1.48E+01	1.12E+01
Toluene	1.98E+04	2.00E+04	2.03E+04	2.12E+04	2.23E+04	2.31E+04	8.91E+03	3.58E+03	1.39E+03	8.04E+02	5.34E+02	3.84E+02	2.90E+02
Trimethyl-benzenes	1.90E+02	1.92E+02	1.95E+02	2.03E+02	2.14E+02	2.21E+02	8.53E+01	3.43E+01	1.33E+01	7.70E+00	5.12E+00	3.67E+00	2.78E+00
Xylenes	6.15E+03	6.21E+03	6.31E+03	6.58E+03	6.93E+03	7.15E+03	2.76E+03	1.11E+03	4.31E+02	2.50E+02	1.66E+02	1.19E+02	9.00E+01

Table 8: Maximum Predicted Concentrations for the Chemicals of Potential Concern for the Smaller Spill Volume at Downwind Distances (in µg/m^3)

COPC	Downwind Distance (m)												
	1	4	9	25	50	75	100	150	300	450	600	750	900
Aliphatic C1-C4	3.75E+06	3.80E+06	3.87E+06	4.07E+06	4.33E+06	2.43E+06	1.03E+06	4.64E+05	1.90E+05	1.10E+05	7.26E+04	5.20E+04	3.92E+04
Aliphatic C5-C8	6.19E+06	6.27E+06	6.40E+06	6.72E+06	7.15E+06	4.01E+06	1.71E+06	7.67E+05	3.15E+05	1.82E+05	1.20E+05	8.60E+04	6.48E+04
Aromatic C9-C12	5.45E+00	5.52E+00	5.63E+00	5.92E+00	6.30E+00	3.53E+00	1.50E+00	6.75E-01	2.77E-01	1.60E-01	1.06E-01	7.56E-02	5.70E-02
Benzene	4.75E+04	4.81E+04	4.91E+04	5.16E+04	5.49E+04	3.08E+04	1.31E+04	5.88E+03	2.42E+03	1.39E+03	9.21E+02	6.60E+02	4.98E+02
Ethanethiols	4.18E+02	4.24E+02	4.32E+02	4.54E+02	4.84E+02	2.71E+02	1.16E+02	5.18E+01	2.13E+01	1.23E+01	8.11E+00	5.81E+00	4.38E+00
Ethylbenzene	7.21E+02	7.30E+02	7.45E+02	7.83E+02	8.33E+02	4.67E+02	1.99E+02	8.93E+01	3.67E+01	2.11E+01	1.40E+01	1.00E+01	7.55E+00
Toluene	1.87E+04	1.89E+04	1.93E+04	2.03E+04	2.16E+04	1.21E+04	5.16E+03	2.32E+03	9.51E+02	5.49E+02	3.62E+02	2.60E+02	1.96E+02
Trimethyl-benzenes	7.21E+02	7.30E+02	7.45E+02	7.83E+02	8.33E+02	4.67E+02	1.99E+02	8.93E+01	3.67E+01	2.11E+01	1.40E+01	1.00E+01	7.55E+00
Xylenes	5.80E+03	5.88E+03	5.99E+03	6.30E+03	6.70E+03	3.76E+03	1.60E+03	7.19E+02	2.95E+02	1.70E+02	1.12E+02	8.06E+01	6.07E+01

5. CONCLUSIONS

RWDI was retained to perform accidental release and consequence modelling to determine potential hazard extents resulting from a failure in the proposed Trans Mountain Expansion Project (TMEP). To perform this modelling, an accidental failure of the pipeline was assumed to create a pool of the crude oil product transported in the pipeline anywhere in Metro Vancouver, from which chemicals of potential concern (COPC) could evaporate and become airborne. Based on the guidance from the U.S. EPA, release scenarios were developed which included typical summer day meteorological conditions based on climate normals from Vancouver International Airport. Emissions of volatiles from the pool were calculated and dispersion modelling was conducted to examine maximum predicted hazard extents of various COPC to support a Human Health Risk Assessment (HHRA).

For the credible worst case spill volume, the downwind distance extents to reach the 1-hour COPC exposure limits ranged from 0 to 1050 m from the pool. As expected for the smaller spill volume, which was lesser than the credible worst case volume, the distance extents ranged from 0 to 825 m from the pool.

6. REFERENCES

Enbridge Pipelines Inc., 2014. 2013 Crude Characteristics No. 44. Retrieved online from: http://www.enbridge.com/~/media/www/Site%20Documents/Delivering%20Energy/2013%20Crude%20Characteristics.pdf

Stantec Consulting Ltd. (2013) Qualitative Ecological Risk Assessment of Pipeline Spills. Technical Report for the Trans Mountain Pipeline ULC Trans Mountain Expansion Project. Volume 7: Risk Assessment & Management of Pipeline and Facility Spills.

United States Environmental Protection Agency (U.S. EPA), 1999. *Risk Management Program Guidance for Offsite Consequence Analysis.*

APPENDIX A

Maxxam Analytics Inc

Success Through Science

C30+ / C100 RECOMBINED LIQUID HYDROCARBON ANALYSIS

Laboratory Number B311691 : GB6706
Operator Name KINDER MORGAN CANADA
Well Name TRANSMOUNTAIN TERMINAL
Well I.D. N/A
Sample Point CL
Sample Point Maxx I.D. N/A

Source Pressure N/A kPag
Source Temperature N/A °C

Prepared by: Monika Majerova

COMPOSITION

Component	Mole Fraction	Mass Fraction	Volume Fraction
N2	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000
C1	0.0000	0.0000	0.0000
C2	0.0002	TRACE	TRACE
C3	0.0021	0.0004	0.0007
IC4	0.0042	0.0010	0.0016
NC4	0.0222	0.0051	0.0081
IC5	0.1106	0.0316	0.0468
NC5	0.1198	0.0342	0.0502
C6	0.1258	0.0430	0.0599
C7+	0.6151	0.8847	0.8328
TOTAL	1.0000	1.0000	1.0000

PROPERTIES

RESIDUE	RELATIVE DENSITY @ 15°C		RELATIVE MOLECULAR MASS		DATA SUMMARY		
	Observed	Calculated	Observed	Calculated	Mole Fraction	Mass Fraction	Volume Fraction
C5+		0.9296		258	0.9713	0.9935	0.9896
C6+		0.9624		316	0.7409	0.9277	0.8926
C7+		0.9838		363	0.6151	0.8847	0.8327
C10+		1.0276		543	0.3642	0.7831	0.7056
C12+		1.0415		606	0.3144	0.7547	0.6709
Total		0.9259		252	1.0000	1.0000	1.0000

Calculated Absolute Density Total Sample	926.7	kg/m^3 @ 15°C
Observed Absolute Density Total Sample	926.7	kg/m^3 @ 15°C
Gas Equivalency Factor	86.6	m^3 Gas / m^3 Liquid

Maxxam Analytics Inc

Success Through Science

C30+ / C100 RECOMBINED LIQUID HYDROCARBON ANALYSIS

Laboratory Number B311691 : GB6706
Operator Name KINDER MORGAN CANADA
Well Name TRANSMOUNTAIN TERMINAL
Well I.D. N/A
Sample Point CL
Sample Point Maxx I.D. N/A

Source Pressure N/A kPag
Source Temperature N/A °C

Prepared by: Monika Majerova

Component	Boling Point (°C)	Mole Fraction	Mass Fraction	Volume Fraction
Nitrogen	-196	0.0000	0.0000	0.0000
Carbon Dioxide	-79	0.0000	0.0000	0.0000
Hydrogen Sulfide	-60	0.0000	0.0000	0.0000
Methane	-162	0.0000	0.0000	0.0000
Ethane	-90	0.0002	TRACE	TRACE
Propane	-42	0.0021	0.0004	0.0007
Iso-Butane	-12	0.0042	0.0010	0.0016
n-Butane	0	0.0222	0.0051	0.0081
Iso-Pentane	28	0.1106	0.0316	0.0468
n-Pentane	36	0.1198	0.0342	0.0502
Hexanes	37-69	0.1258	0.0430	0.0599
Heptanes	70-98	0.1182	0.0427	0.0541
Octanes	99-126	0.0834	0.0351	0.0438
Nonanes	127-151	0.0493	0.0238	0.0292
Decanes	152-174	0.0278	0.0156	0.0196
Undecanes	175-196	0.0220	0.0128	0.0150
Dodecanes	197-216	0.0228	0.0146	0.0168
Tridecanes	217-236	0.0254	0.0176	0.0201
Tetradecanes	237-253	0.0254	0.0191	0.0215
Pentadecanes	254-271	0.0281	0.0229	0.0255
Hexadecanes	272-287	0.0220	0.0194	0.0214
Heptadecanes	288-302	0.0202	0.0189	0.0207
Octadecanes	303-317	0.0204	0.0203	0.0221
Nonadecanes	318-331	0.0174	0.0182	0.0196
Eicosanes	332-343	0.0173	0.0189	0.0203
Heneicosanes	344-357	0.0136	0.0157	0.0168
Docosanes	358-369	0.0150	0.0182	0.0193
Tricosanes	370-380	0.0151	0.0190	0.0200
Tetracosanes	381-391	0.0134	0.0176	0.0185
Pentacosanes	392-402	0.0114	0.0156	0.0164
Hexacosanes	403-412	0.0103	0.0146	0.0152
Heptacosanes	413-422	0.0107	0.0158	0.0164
Octacosanes	423-432	0.0111	0.0170	0.0176
Nonaconsanes	433-441	0.0108	0.0172	0.0178
Triacontanes+	442-449+	0.0040	0.4342	0.3251
Total		1.0000	1.0000	1.0000
Neo-Hexane	50	0.0000	0.0000	0.0000
Methylcyclopentane	70	0.0241	0.0080	0.0099
Benzene	80	0.0085	0.0026	0.0028
Cyclohexane	81	0.0300	0.0100	0.0118
Methylcyclohexane	101	0.0269	0.0105	0.0125
Toluene	111	0.0107	0.0039	0.0041
Ethylbenzene	136	0.0007	0.0003	0.0003
M&P Xylene	139	0.0094	0.0039	0.0042
O-Xylene	144	0.0038	0.0016	0.0017
1,2,4-Trimethylbenzene	169	0.0006	0.0003	0.0003

APPENDIX B

Table B-1: Calculated Emission Rates for Chemicals of Potential Concern for the Credible Worst Case Spill Volume of Cold Lake Winter Blend using the U.S. EPA Evaporation from a Liquid Pool Equation

COPC		Aliphatic C1-C4 Group	Aliphatic C5-C8 Group	Aromatic C9-C16 Group	Benzene	Ethanethiols Group	Ethyl-benzene	Toluene	Trimethyl-benzenes	Xylenes
VP	mmHg	774	46	0.00032	25	78	3.75	7	1	1.6
Effect. VP	mmHg	20.4336	25.6588	1.62E-05	0.2125	0.00184	0.002625	0.0749	0.0006	0.02112
Mole frac.	-	0.0264	0.5578	0.05073	0.0085	2.36E-05	0.0007	0.0107	0.0006	0.0132
Radius	m	70	70	70	70	70	70	70	70	70
A	m^2	15,394	15,394	15,394	15,394	15,394	15,394	15,394	15,394	15,394
	ft^2	165,714	165,714	165,714	165,714	165,714	165,714	165,714	165,714	165,714
MW	g/mol	58.1	87.5	143.2	78.11	80	106.2	92.1	120.19	106.2
U	m/s	3	3	3	3	3	3	3	3	3
T	K	294	294	294	294	294	294	294	294	294
QR	lb/min	1,444	2,386	0.002	18.3	0.16	0.278	7.21	0.069	2.24
	g/s	10,919	18,040	0.016	139	1.22	2.1	54.5	0.522	16.9

Table B-2: Calculated Emission Rates for Chemicals of Potential Concern for the Smaller Spill Volume of Cold Lake Winter Blend using the U.S. EPA Evaporation from a Liquid Pool Equation

COPC		Aliphatic C1-C4 Group	Aliphatic C5-C8 Group	Aromatic C9-C16 Group	Benzene	Ethanethiols Group	Ethyl-benzene	Toluene	Trimethyl-benzenes	Xylenes
VP	mmHg	774	46	0.00032	25	78	3.75	7	1	1.6
Effect. VP	mmHg	20.4336	25.6588	1.62E-05	0.2125	0.00184	0.002625	0.0749	0.0006	0.02112
Mole frac.	-	0.0264	0.5578	0.05073	0.0085	2.36E-05	0.0007	0.0107	0.0006	0.0132
Radius	m	57	57	57	57	57	57	57	57	57
A	m^2	10,207	10,207	10,207	10,207	10,207	10,207	10,207	10,207	10,207
	ft^2	109,878	109,878	109,878	109,878	109,878	109,878	109,878	109,878	109,878
MW	g/mol	58.1	87.5	143.2	78.11	80	106.2	92.1	120.19	106.2
U	m/s	3	3	3	3	3	3	3	3	3
T	K	294	294	294	294	294	294	294	294	294
QR	lb/min	957	1,582	0.001	12.1	0.11	0.184	4.78	0.046	1.48
	g/s	7,240	11,962	0.011	91.8	0.81	1.393	36.1	0.346	11.2

APPENDIX C ACUTE TOXICITY PROFILES

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1.0 INTRODUCTION

This appendix describes the scientific basis for the acute (short-term) exposure limits used to assess potential human health effects associated with the chemicals of potential concern (COPC). An overview of the general process used to evaluate and select exposure limits or toxicity reference values for use in the assessment is provided. As well, this appendix presents a series of individual profiles for the COPC, wherein the available values are summarized and information regarding the selected exposure limits is provided.

1.1 Exposure Limit Selection

A tiered approach was used in the review and selection of available exposure limits for each of the COPC. If a suitable exposure limit could not be identified from one of the regulatory agencies in the first tier, the search was then expanded to the second tier of agencies.

To ensure that the most defensible and appropriate exposure limit was selected for each chemical in the assessment, consideration was given only to exposure limits meeting the following criteria:

- Established or recommended by reputable scientific authorities.
- Protective of the health of the general public based on the current scientific understanding of the health effects known to be associated with exposures to the COPC.
- Protective of sensitive individuals through the use of appropriate uncertainty factors.
- Supported by adequate and available documentation.

All supporting documents were critically evaluated to identify the most appropriate and defensible value for use in the assessment. In the case that the above criteria were supported by more than one standard, guideline or objective, the most scientifically defensible limit was selected and the rationale for the decision is provided in the toxicity profile.

The process and resources used in selecting exposure limits varied slightly between the acute inhalation, chronic inhalation and chronic oral sections, due to the types of information available for these values. For all three categories of exposure limits, a tiered process of limit review and selection was utilized.

Two ‘Tiers’ of sources for exposure limits have been identified. The resources in Tier 1 represent reputable governmental agencies or established organizations, generally have supporting documentation available, and are generally recognized by governmental agencies. In the event that a defensible value with available supporting documentation was not available from Tier 1, the search for exposure limits was extended to include the agencies and organizations listed as Tier 2.

For some chemicals, our approach for Tier 1 can vary slightly due to the nature of the information available. The Tier 1 sources for acute inhalation exposure limits are as follows:

- Metro Vancouver – AAQOs;
- British Columbia Ministry of the Environment (BC MOE) – AAQOs;
- Alberta Environment and Sustainable Resource Development (ESRD) - Ambient Air Quality Objectives (1-hour, 8-hour, 24-hour);
- Agency for Toxic Substances and Disease Registry (ATSDR) – Minimal Risk Levels (MRLs), Acute inhalation;
- California Office of Environmental Health Hazard Assessment (OEHHA) – Acute Reference Exposure Levels (RELs);

- Ontario Ministry of the Environment (OMOE) – Air Quality Standards and Guidelines (1-hour, 24-hour guidelines);
- Texas Commission for Environmental Quality (TCEQ) – Acute Reference Values (ReV);
- United States Environmental Protection Agency (US EPA). Integrated Risk Information System (IRIS) – Acute Reference Concentrations; and
- World Health Organization (WHO) – Air Quality Guidelines for Europe.

In the event that a defensible value with adequate supporting documentation could not be identified from the Tier 1 sources, the search for acute exposure limits was expanded to include the following Tier 2 sources:

- American Conference for Governmental and Industrial Hygienists (ACGIH). Only Short-term Exposure Limits (STELs) and ceiling values; and
- US EPA Acute Exposure Guideline Levels (AEGLs) Level 1 (*i.e.*, AEGL-1 values).

TABLE 1.1

SUMMARY OF ACUTE INHALATION EXPOSURE LIMITS

COPC	Averaging Period	Value [µg/m³]	Authority	Critical Health Endpoint	Species and Sex Studied	Dosing/Exposure Characteristics	Point of Departure	Uncertainty Factors and Adjustments
Aliphatic C_1-C_4 group (surrogate: iso-butane)	1-Hour	78,000	TCEQ	Neurological effects	Human, male and female (n=8)	0, 250, 500 or 1,000 ppm (592, 1,185, or 2,370 mg/m³) of isobutene within a controlled chamber for various exposure durations in a series: 1-minute, 2-minute, 10-minute, 1-hour, 2-hours, or 8-hours	NOAEL : 1,000 ppm (2,370,000 µg/m³)	Uncertainty factor of 30 applied (10 for intraspecies differences,3 for database limitations)
Aliphatic C_5-C_8 group[1] (surrogate: n-pentane)	1-Hour	200,000	TCEQ	—	Male WAG/RijCHBR rats (n=8 per group)	0, 2,000, 6,500, or 20,000 mg/m³ of n-pentane for 8 hours per day for 3-days	NOAEL: 20,000,000 µg/m³	Uncertainty factor of 100 applied (10 for intraspecies differences, 3 for interspecies differences, 3 for database limitations)
Aliphatic C_9-C_{12} group	—	—	—	—	—	—	—	—
Aromatics C_9-C_{12} group (Surrogate: naphthalene)	1-Hour	2,000	ACGIH (adjusted)	Eye irritation	Human (limited information available)	Limited information available	Limited information available	• The STEL derived by ACGIH was adjusted from a 15-minute averaging period to a 1-hour averaging period. • Uncertainty factor of 10 applied for intraspecies variability.
Benzene	1-Hour	580	TCEQ	Immunological effects	Male C57BL/6J mice (n=7 or 8 per group)	0, 10.2, 31, 100, or 301 ppm (0, 32.6, 99, 320, or 960 mg/m³) benzene in whole-body dynamic inhalation chambers for 6 hours/day for 6 days	LOAEL: 10.2 ppm (33,000 µg/m³)	• POD adjusted for continuous exposure (6/24 hours x 5/7 days/week) • Uncertainty factor of 300 applied (10 for intraspecies differences, 10 for the use of a LOAEL, 3 for interspecies differences
Dibenzothiophene	—	—	—	—	—	—	—	—
Dimethyl sulphide group[1]	—	—	—	—	—	—	—	—
Ethanethiol group (surrogate: ethanethiol)	1-Hour	2,500	US EPA AEGL	Respiratory irritation	Male rabbits (n=6/group)	0, 10, 100, or 1,000 ppm (0, 25,000, 250,000 or 2,500,000 µg/m³) ethanethiol through a breathing mask for 20 minutes	NOAEL: 10 ppm (25,000 µg/m³)	Uncertainty factor of 10 applied (3 for intraspecies differences, and 3 for interspecies differences)
Ethylbenzene	1-Hour	21,700	ATSDR	Neurological effects	Wag/Rij rats (limited information available)	0, 300, 400, or 550 ppm (0, 1,302, 1,736, or 2,387 mg/m³) ethylbenzene for 8 hours/day for 5 days	• $BMDL_{1SD}$: µmol/L blood • Converted to a HEC of 154.26 ppm (669,000 µg/m³) using PBPK model	Uncertainty factor of 30 applied (10 for intraspecies differences, 3 for interspecies differences)

COPC	Averaging Period	Value [µg/m³]	Authority	Critical Health Endpoint	Species and Sex Studied	Dosing/Exposure Characteristics	Point of Departure	Uncertainty Factors and Adjustments
Toluene	1-Hour	15,000	TCEQ	Eye and nasal irritation Neurological effects	Human (n=16)	• 0, 10, 40, or 100 ppm for 6 hours/day • Subjects exposed to different concentration each of 4 days	NOAEL: 40 ppm (150,000 µg/m³)	Uncertainty factor of 10 applied for intraspecies differences
Trimethylbenzenes[1]	1-Hour	690,000	US EPA	Neurological effects	Rats (limited information available)	• 0, 250 to 2,000 ppm (individual doses not specified) within a controlled chamber for a duration of 4 hours • Animals exposed to 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, and 1,2,3-trimethylbenzene	EC_{50}: 900 ppm (4,435,714 µg/m3)	• POD adjusted from a 4-hour exposure to a 1-hour exposure • Uncertainty factor of 10 applied (3 for intraspecies differences, 3 for interspecies differences)
Xylenes	1-Hour	7,400	TCEQ	Respiratory irritation Neurological effects	Human (n=56)	0 or 50 ppm (200,000 µg/m³) for 2 hours within a controlled inhalation chamber	LOAEL: 50 ppm (200,000 µg/m³)	Uncertainty factor of 30 applied (10 for intraspecies variability, 3 for the use of a minimal LOAEL)

Notes:
− = Not available
1 Trimethylbenzenes was assessed as an individual COPC as well as part of the aromatic C_9-C_{12} group.

2.0 ALIPHATIC C_1 - C_4 GROUP

2.1 Acute Inhalation Exposure Limit

TABLE 2.1

ACUTE INHALATION EXPOSURE LIMITS FOR THE ALIPHATIC C_1-C_4 GROUP

Regulatory Agency	Type	Value (µg/m³)	Reference
ATSDR	–	–	ATSDR 2013
BC MOE	–	–	BC MOE 2013
ESRD	–	–	ESRD 2013
Metro Vancouver	–	–	Metro Vancouver 2011
OEHHA	-	-	OEHHA 2014
OMOE	-	-	OMOE 2012
TCEQ	ReV	78,000 (isobutane) 220,000 (butane) 570,000 (ethylene)	TCEQ 2013, 2012, 2008
US EPA	-	-	US EPA 2014
WA DOE	–	–	WA DOE 2011
WHO	-	-	WHO 2000

Notes:
- = Not available

As no limits were available for the aliphatic C_1-C_4 group as a whole, the search was expanded to include values from the individual constituents of the group from the agencies listed in the table above.

For isobutane, the TCEQ (2013, 2012) has developed an acute 1-hour ReV of 78,000 µg/m³. In the key study, healthy adult male and female volunteers (8 total) were exposed to 0, 250, 500 or 1,000 ppm (592, 1,185, or 2,370 mg/m³) of isobutene within a controlled chamber for various exposure durations in a series: 1-minute, 2-minute, 10-minute, 1-hour, 2-hour, or 8-hour. Following the first series of exposure, the volunteers were exposed to isobutane at 500 ppm for 1, 2 or 8 hours per day, 5 days/week for a duration of 2 weeks. Clinical evaluations of respiratory and cardiac responses to the exposures were conducted, as well as neurological measurements including spontaneous electroencephalograms (EEG) and visual evoked response (VER). No adverse effects on physiology, lung or cardiac function, neurological or adrenocortical function were observed at any exposure concentration for the first set of exposures. Significant reductions in VER were observed at 500 ppm in the second series during the second week of exposure. The TCEQ identified a NOAEL of 1,000 ppm (2,370 mg/m³) for exposures less than 8 hours, and a LOAEL for neurological effects of 500 ppm (1,185 mg/m³). The TCEQ selected the NOAEL of 1,000 ppm (2,370 mg/m³) as the POD for the exposure limit. No adjustments were applied to the POD. An uncertainty factor of 30 was applied to account for intraspecies differences (10) and database limitations (3), resulting in the ReV of 78,000 µg/m³. This value was selected for use in the assessment

The TCEQ (2013, 2012) has derived an acute 1-hour ReV of 220,000 µg/m³ for n-butane. In the key study, male and female Sprague Dawley CD rats (10 per sex/group) were exposed to 0, 90, 900 or 9,000 ppm (0, 213, 2,133, 21,330 mg/m³), via whole body inhalation for 6 hours per day, 7 days per week for a duration of 2 weeks. The average measured exposure concentrations were determined to be 0, 91.3, 910.5, 9,197 ppm (0, 216, 2,158, 21,797 mg/m³). No significant adverse effects on viability, body weights, feed intake, clinical observations, organ weights or macroscopic observations were observed at any concentration, and the TCEQ identified the highest measured concentration (9,197 ppm or 21,797 mg/m³) as a free-standing NOAEL. No adjustment for exposure duration was applied, as the TCEQ notes that the effects of n-butane are concentration-dependent rather than duration-dependent. A default RGDR of 1 was applied to convert the NOAEL into a POD_{HEC}. The TCEQ applied an uncertainty factor of 100 to account for interspecies differences (3), intrahuman variability (10), and limitations in the toxicological database (3). This ReV was not selected for use in the assessment, as the ReV for isobutane is more conservative.

For ethylene, the TCEQ (2013, 2008) has derived an acute 1-hour ReV of 570,000 µg/m³. Male Holtzmann rats were exposed to 0, 10,000, 25,000 or 50,000 ppm of ethylene for a duration of 4 hours. A second group of rats were exposed via oral gavage to 300 µmol of polychlorinated biphenyls for a duration of 3 days, and then were exposed to the same ethylene concentrations as the other group for 4 days. Histopathological evaluations of the livers of animals were conducted, and concentration of various hepatic enzymes, including sorbitol dehydrogenase (SDH) and serum alpha-ketoglutarate transaminase (SAKT) were measured. Severe degenerative necrosis of hepatocytes was observed in rats that were exposed to PCBs and then ethylene only, with no significant effects in rats exposed to only ethylene. The TCEQ (2008) identified the highest exposure concentration, 50,000 ppm, as a free-standing NOAEL. No adjustments were made to convert the 4-hour exposure to a 1-hour exposure, on the basis of the relatively high exposure concentrations and the lack of observed adverse effects in the ethylene-only exposure group. The NOAEL was converted to a $NOAEL_{HEC}$ of 50,000 ppm, using a default RGDR value of 1, given the documented similarities in ethylene disposition between animals and humans. An uncertainty factor of 300 was applied to the $NOAEL_{HEC}$ to account for interspecies differences (3), intraspecies variability (10), and database deficiencies (3). Due to the availability of a more conservative ReV for 2-butene that is based upon a lower NOAEL, the 1-hour ReV for ethylene was not selected for use in the acute effects assessment.

TABLE 2.2

SUMMARY OF EXPOSURE LIMITS SELECTED FOR THE ALIPHATIC C_1-C_4 GROUP

Duration	Averaging-Time	Exposure Pathway	Type	Value	Units	Reference	Endpoint Relevant to Mixtures
Acute	1-hour	Inhalation	ReV	78,000	µg/m³	TCEQ 2012	Neurological effects

2.2 References

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3.0 ALIPHATIC C_5-C_8 GROUP

3.1 Acute Inhalation Exposure Limit

TABLE 3.1

ACUTE INHALATION EXPOSURE LIMITS FOR ALIPHATIC C_5-C_8 GROUP

Regulatory Agency	Type	Value (µg/m³)	Reference
ATSDR	–	–	ATSDR 2013
BC MOE	–	–	BC MOE 2013
ESRD	AAQO	21,000 (n-hexane)	ESRD 2013
Metro Vancouver	–	–	Metro Vancouver 2011
OEHHA	–	–	OEHHA 2014
OMOE	24-hour Standard	2,500 (n-hexane mixture) 6,100 (cyclohexane) 11,000 (heptane) 50,000 (1-octene)	OMOE 2012, 2005a OMOE 2012, 2005b OMOE 2012 OMOE 2012
TCEQ	1-hour ReV	200,000 (n-pentane)	TCEQ 2013, 2011
US EPA	–	–	US EPA 2014
WA DOE	–	–	WA DOE 2011
WHO	–	–	WHO 2000

Notes:
– = Not available

The aliphatic C_5-C_8 group was created for comparison against limits recommended by the CCME (2008), MA DEP (2003), RIVM (2001) and TPHCWG (1997) for the petroleum hydrocarbon (PHC) fractions. These agencies, however, have only developed chronic limits, and not acute limits, for the PHC fractions. As a result, the search for acute limits was necessarily expanded to include limits for the individual constituents of the aliphatic C_5-C_8 group.

The TCEQ (2013, 2011) has derived a 1-hour ReV of 200,000 µg/m^3 for n-pentane. In the key study by Lammers *et al*. (2011), two acute experiments were conducted. In the first experiment, male WAG/RijCHBR rats (8 per group) were exposed to 0, 2,000, 6,500, or 20,000 mg/m^3 of n-pentane for 8 hours per day for 3 consecutive days. An assessment of motor activity and neurobehavioral functions was conducted using a standardized functional observational battery of tests. No significant adverse neurological effects were observed in any of the exposure groups.

In the second experiment, male WAG/RijCHBR rats (8 per group) were exposed to the same concentrations of n-pentane for the same amount of time, with tests for cognitive performance being conducted after exposure. Mild, reversible changes in performance speed were observed in the two lowest exposure groups, but not in the high-exposure group. Tests conducted one day post-exposure revealed no adverse effects due to n-pentane exposure. The TCEQ (2013) identified 20,000 mg/m^3 (19,872 mg/m^3 average measured concentration) as a free-standing NOAEL. The recommended default RGDR of one (TCEQ 2006) was applied to account for the ratio of the blood: gas coefficients of rats to humans being less than one, resulting in a POD of 19,872 mg/m^3 (equivalent to the NOAEL). An uncertainty factor of 100 was applied to the POD to account for interspecies differences (3, due to the use of an RGDR), intraspecies differences (10), and database deficiencies (3). The resulting 1-hour ReV of 200,000 µg/m^3 was used to assess the aliphatic C_5-C_8 group in the acute inhalation assessment.

Although the TCEQ (2013) provides supporting documents for hexane and pentene isomers, no acute ReVs have been derived for these chemicals due to a lack of sufficient information (TCEQ 2007a,b).

ESRD (2013) presents a 1-hour AAQO for n-hexane of 21,000 µg/m³, and indicates that this value is based on a 24-hour California air quality objective. However, a search of the OEHHA (2013) did not

reveal a 24-hour value for n-hexane, only a chronic value. As a result, this value was not considered further.

The OMOE (2012, 2005a) developed a 24-hour standard of 2,500 µg/m³ for an n-hexane mixture. This standard was developed from a LOAEL of 58 ppm (204 mg/m³) for polyneuropathy in humans (Sanagi *et al*. 1980). Workers were exposed to low concentrations of n-hexane and acetone in a tungsten carbide alloys facility for an average of 6.2 years. This value is based on chronic exposures that are not relevant to acute assessment. As such, this value was not considered suitable as an acute exposure limit.

In addition, the OMOE (2012, 2005b) has established a 24-hour standard of 6,100 µg/m³ for cyclohexane based on a NOAEL of 6,886 mg/m³ for reduced pup weights in the F1 and F2 generations in a reproductive and developmental inhalation study (Kreckmann *et al*. 2000; OMOE 2005b). The NOAEL was revised to an HEC of 1,722 mg/m³ and the lower confidence of the benchmark concentration (BMCL) was then derived (1,822 mg/m³). An uncertainty factor of 300 was applied to the BMCL to account for intraspecies variability (10), interspecies variability (3), and database deficiencies due to the lack of chronic studies specifically examining developmental neurotoxicity and hepatic effects (10) (OMOE 2005b). Due to the long-term study duration and the uncertainty factor applied for subchronic exposure, this value was not selected for use.

TABLE 3.2

SUMMARY OF EXPOSURE LIMITS SELECTED FOR ALIPHATIC C_5-C_8 GROUP

Duration	Averaging-Time	Exposure Pathway	Type	Value	Units	Reference	Endpoint Relevant to Mixtures
Acute	1-hour	Inhalation	ReV	200,000	µg/m³	TCEQ 2013, 2011	–

Notes:
– = Not available

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4.0 ALIPHATIC C_9-C_{12} GROUP

4.1 Acute Inhalation Exposure Limit

TABLE 4.1

ACUTE INHALATION EXPOSURE LIMITS FOR ALIPHATIC C_9-C_{12} GROUP

Regulatory Agency	Type	Value (µg/m³)	Reference
ATSDR	–	–	ATSDR 2013
BC MOE	–	–	BC MOE 2013
ESRD	–	–	ESRD 2013
Metro Vancouver	–	–	Metro Vancouver 2011
OEHHA	–	–	OEHHA 2014
OMOE	24-hour Standard	60,000 (1-decene)	OMOE 2012
TCEQ	–	–	TCEQ 2013
US EPA	–	–	US EPA 2014
WA DOE	–	–	WA DOE 2011
WHO	–	–	WHO 2000

Notes:
– = Not available

The aliphatic C_9-C_{12} group was created for comparison against limits recommended by the CCME (2008), MA DEP (2003), RIVM (2001) and TPHCWG (1997) for the petroleum hydrocarbon (PHC) fractions. These agencies, however, have only developed chronic limits, and not acute limits, for the PHC fractions. As a result, the search for acute limits was necessarily expanded to include limits for the individual constituents of the aliphatic C_9-C_{12} group.

The OMOE (2012) presents a 24-hour health-based guideline for 1-decene of 60,000 µg/m^3. However, no supporting documentation is available for this value. As a result, the OMOE guideline was not used to characterize the acute health risks.

No defensible exposure limits were identified for the individual constituents that make up the aliphatic C_9-C_{12} group. The search was further expanded to include STEL and Ceiling values from the ACGIH (2013) and AEGL-1 values from the US EPA 2013. As no limits were identified, the aliphatic C_9-C_{12} group could not be evaluated in the acute inhalation assessment.

TABLE 4.2

SUMMARY OF EXPOSURE LIMITS SELECTED FOR ALIPHATIC C_9-C_{12} GROUP

Duration	Averaging-Time	Exposure Pathway	Type	Value	Units	Reference	Endpoint Relevant to Mixtures
Acute	1-hour	Inhalation	–	–	–	–	–

Notes:
– = Not available

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5.0 AROMATIC C_9-C_{12} GROUP

5.1 Acute Inhalation Exposure Limit

TABLE 5.1

ACUTE INHALATION EXPOSURE LIMITS FOR AROMATIC C_9-C_{12} GROUP

Regulatory Agency	Type	Value (µg/m³)	Reference
ATSDR	–	–	ATSDR 2013
BC MOE	–	–	BC MOE 2013
ESRD	–	–	ESRD 2013
Metro Vancouver	–	–	Metro Vancouver 2011
OEHHA	–	–	OEHHA 2014
OMOE	24-hour Guideline	220 (trimethylbenzene) 400 (isopropylbenzene)	OMOE 2012 OMOE 2012
TCEQ	–	–	TCEQ 2013
US EPA	–	–	US EPA 2014
WA DOE	–	–	WA DOE 2011
WHO	–	–	WHO 2000

Notes:
– = Not available

The aromatic C_9-C_{12} group was created for comparison against limits recommended by the CCME (2008), MA DEP (2003), RIVM (2001) and TPHCWG (1997) for the petroleum hydrocarbon (PHC) fractions. These agencies, however, have only developed chronic limits, and not acute limits, for the PHC fractions. As a result, the search for acute limits was necessarily expanded to include limits for the individual constituents of the aromatic C_9-C_{12} group.

The OMOE (2012) presents 24-hour values of 220 µg/m³ for trimethylbenzenes and 400 µg/m³ for isopropylbenzene; however, as no supporting documentation is available, these values were not considered in the acute assessment.

As no acute exposure limits with adequate supporting documentation were identified from the above listed sources for the individual constituents of the aromatic C_9-C_{12} group, the search for was further expanded to include STEL and Ceiling values from the ACGIH (2013) and AEGL-1 values from the US EPA (2013).

The ACGIH (2013) recommends a STEL of 15 ppm (79 mg/m³) based on eye irritation as a result of occupational exposure to naphthalene. The STEL equates to a 15-minute air concentration that should not be exceeded at any time during a workday. The 15-minute STEL can be adjusted to an equivalent 1 hour concentration using a modified Haber's Law.

$$C_{ADJ}^{\ n} \times T_{ADJ} = C^n \times T$$

$$C^1 \times 60 \text{ minutes} = (79 \text{ mg/m}^3)^1 \times 15 \text{ minutes}$$

Where:

C_{ADJ} = duration adjusted concentration

T_{ADJ} = desired time of exposure (60 minutes)

C = concentration of exposure (79 mg/m³)

T = time of exposure (15 minutes)

n = chemical specific modification factor designed to account for the toxicity of a chemical being concentration and/or duration dependent. The OEHHA recommends using a default n value of 1 in the adjustment for less than 1 hour exposure.

Based on the above conversion factor, the STEL was adjusted to a concentration of 20 mg/m³. A cumulative uncertainty factor of 10 was applied to the duration adjusted STEL to account for intraspecies variability (10). The result is a 1-hour exposure limit of 2,000 µg/m³ based on eye irritation. This value was selected for use in the assessment to evaluate the aromatic C_9-C_{12} group.

The US EPA (2007a) has derived a 1-hour AEGL-1 of 250 mg/m^3 for isopropylbenzene (cumene). This value is based on what appears to be an anecdotal report from an occupational environment (Dow 1948) that was published but has since been withdrawn, according to the US EPA (2007a) reference list. This value was not considered in the acute assessment as the supporting information could not be verified.

The US EPA (2007b) has derived a 1-hour AEGL-1 for all isomers of trimethylbenzene of 140 ppm (690,000 µg/m³). Due to a lack of available human data for acute trimethylbenzene exposure, the AEGL-1 was derived from an analysis of several animal studies. Korsak and Rydzynski (1996) conducted a study involving acute (4-hour) exposure to 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene and 1,2,3-trimethylbenzene at concentrations ranging from 250 to 2,000 ppm (individual doses not specified) within a controlled chamber. Concentration-related changes were observed in rotarod performance in the exposed rats (male only). EC_{50} values for each isomer based on disturbances in rotarod function were determined to be: 4,693 mg/m³ (95% CI 3,891 to 5,493 mg/m³) for 1,2,4-trimethylbenzene; 4,738 mg/m³ (95% CI 3,675 to 5,453 mg/m³) for 1,3,5-trimethylbenzene; and 3,779 mg/m³ (95% CI 2,832 to 4,615 mg/m³) for 1,2,3-trimethylbenzene. Changes in pain sensitivity also were observed for the three isomers in the acute study. EC_{50} values for pain sensitivity (demonstrated by the paw lick response) were determined to be the following: 5,682 mg/m³ (95% CI 2,715 to 7,596 mg/m³) for 1,2,4-trimethylbenzene; 5,938 mg/m³ (95% CI of 5,194 to 6,512 mg/m³) for 1,3,5-trimethylbenzene; and 4,155 mg/m³ (3,400 to 4,811 mg/m³ for 1,2,3-trimethylbenzene. Of the two endpoints, rotarod disturbance seems to be the more sensitive effect. Korzack and Rydzynski (1996) note that the 1,2,3-trimethylbenzene isomer appeared to demonstrate more neurotoxic potential than the other two isomers.

Also cited as a key study by US EPA (2007c), Korsak *et al*. (1995) conducted a similar study with only 1,2,4-trimethylbenzene in male rats. Rats were exposed for a duration of 4 hours to 250 to 2,000 ppm (individual dose levels not specified) within a controlled chamber. Altered rotorod activity indicative of neurotoxicity, altered pain response and decreased respiratory rate were observed in association with concentration-dependent responses. EC_{50} values for rotorod performance, pain sensitivity and respiratory depression were determined to be 4,693 mg/m³ (95% CI 3,891 to 5,493 mg/m³), 5,682 mg/m³ (95% CI 2,715 to 7,596 mg/m³) and 2,840 mg/m³ (95%,CI 1,500 to 3,900 mg/m³), respectively. Although it is not clear how the US EPA calculated the value, an average of 900 ppm was calculated to be the average EC_{50} for neurological effects from the animal data, and served as the point of departure for the derivation of the AEGL. The Haber's Law approach was used by the US EPA (2007c) to convert the 4-hour concentration to a 1-hour concentration of 1,429 mg/m³. A total uncertainty factor of 10 was applied to account for interspecies differences (3), and intraspecies differences (3), to result in the 1-hour AEGL of 690 mg/m³ (690,000 µg/m³). This value was not selected for use in the assessment, as it is much higher than the adjusted STEL for naphthalene.

TABLE 5.2

SUMMARY OF EXPOSURE LIMITS SELECTED FOR AROMATIC C_9-C_{12} GROUP

Duration	Averaging-Time	Exposure Pathway	Type	Value	Units	Reference	Endpoint Relevant to Mixtures
Acute	1-hour	Inhalation	STEL (adjusted)	2,000	µg/m³	ACGIH 2013	Eye irritation

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6.0 BENZENE

6.1 Acute Inhalation Exposure Limit

TABLE 6.1

ACUTE INHALATION EXPOSURE LIMITS FOR BENZENE

Regulatory Agency	Type	Value (µg/m³)	Reference
ATSDR	24-hour MRL	30	ATSDR 2013, 2007
BC MOE	–	–	BC MOE 2013
ESRD	1-hour AAQO	30	ESRD 2013
Metro Vancouver	–	–	Metro Vancouver 2011
OEHHA	6-hour REL	1,300	OEHHA 2014, 2008
OMOE	24-hour	2.3	OMOE 2012
TCEQ	1-hour ReV	580	TCEQ 2013, 2007
US EPA	–	–	US EPA 2014
WA DOE	–	–	WA DOE 2011
WHO	–	–	WHO 2000

Notes:
– = Not available

The TCEQ (2013, 2007) has derived an acute ReV of 580 µg/m³ for benzene. Review of the supporting documentation for this value indicates that TCEQ used the same key study (Rozen *et al*. 1984) as the ATSDR. As well, the TCEQ identified the same LOAEL value of 10.2 ppm. The difference between the ATSDR and TCEQ values originates from the adjustment of the LOAEL for continuous exposure and the uncertainty factors applied.

The TCEQ (2007) established that the $LOAEL_{ADJ}$ for benzene in the Rozen *et al*. (1984) study was 18.5 ppm (59 mg/m³), using Haber's law and a default approach for converting exposures of more than one hour to a 1-hour exposure level from TCEQ (2007). The $LOAEL_{ADJ}$ was converted to a $LOAEL_{HEC}$ using a regional gas dose ratio (RGDR). In the case that the animal blood to gas partition coefficient is greater than the human blood to gas partition coefficient, a default value of 1 is used for the RGDR. Thus, the $LOAEL_{HEC}$ was calculated to be 18.5 ppm. A cumulative uncertainty factor of 100 was applied by the TCEQ (2007) to the $LOAEL_{HEC}$ to account for interspecies differences (3), intraspecies variability (10), and the use of a LOAEL (3). A factor of 3 was applied for extrapolation of animal data to humans since dosimetric adjustments were conducted to address toxicokinetic differences. In addition, studies indicate that benzene is metabolized along similar pathways in animals and humans and data suggests that mice are relatively sensitive in regards to hematotoxic effects of benzene (TCEQ 2007). A factor of 3 was applied for extrapolation from a LOAEL to a NOAEL on the basis that the LOAEL used to derive the acute ReV is lower than other LOAELs observed in animal and human studies, and the LOAEL is similar to NOAELs observed in mouse studies (TCEQ 2007). In addition, benchmark dose modelling of estimated lymphocyte count depression data produces a BMCL of 4 ppm, which supports a factor of 3 as being sufficiently conservative (TCEQ 2007). The TCEQ (2007) also states that lymphocyte count depression is a sensitive sentinel effect that is not a serious nature, and the reported decreased lymphocyte count at 10.2 ppm appears to be within the normal range. The result is an acute ReV of 580 µg/m³ based on immunological effects, which was used as a 1-hour limit in the acute effects assessment of benzene.

The ATSDR (2013, 2007) presents an acute MRL of 0.009 ppm (30 µg/m³) based on immunological effects. Male C57BL/6J mice (7 or 8 per concentration) were exposed to 0, 10.2, 31, 100, or 301 ppm (0, 32.6, 99, 320, or 960 mg/m³) benzene in whole-body dynamic inhalation chambers for 6 hours/day on six consecutive days (ATSDR 2007). The control group was exposed to filtered, conditioned air only. Significant depression of femoral lipopolysaccharide induced B-colony-forming ability was observed at the 10.2 ppm exposure level in the absence of a significant depression of total number of B cells. Peripheral lymphocyte counts were depressed at all exposure levels. The ATSDR (2007) adjusted a LOAEL of

10.2 ppm (32.6 mg/m³) from intermittent to continuous exposure (6/24 hours) to a concentration of 2.55 ppm (8.16 mg/m³). The duration-adjusted LOAEL ($LOAEL_{ADJ}$) was converted to a HEC ($LOAEL_{HEC}$) for a category 3 gas causing respiratory effects. The average ratio of the animal blood: air partition coefficient would be greater than 1; thus, a default value of 1 was used in calculating the HEC (ATSDR 2007). As a result, a $LOAEL_{HEC}$ of 2.55 ppm (8.16 mg/m³) was identified. The ATSDR (2007) applied a cumulative uncertainty factor of 300 to the $LOAEL_{HEC}$ to account for interspecies variability (3), intraspecies variability (10) and use of a LOAEL (10). A factor of 3 was applied for the extrapolation of laboratory animal data to humans since the calculation of a HEC addressed the pharmacokinetic aspects of the interspecies uncertainty factor. This value was not selected, as the time-adjustment process applied by TCEQ (2007) was more defensible given the dose-response and duration-related effects observed for benzene.

ESRD (2013) also provides a 1-hour AAQO of 30 µg/m³ for benzene based on hematological effects. However, detailed supporting documentation is lacking. As a result, it was not used in the acute effects assessment.

The OMOE (2012) presents a 24-hour criterion of 2.3 µg/m³, however, no supporting documentation for this value is available. As a result, this value was not selected for use in the assessment.

The OEHHA (2014, 2008) presents a 6-hour acute REL of 1,300 µg/m³, based on reproductive effects. The key study (Coate *et al*. 1984) involved the exposure of pregnant female rats (40 per group) to 0, 1, 10, 40 or 100 ppm (0, 3.2, 32, 130 or 324 mg/m³) for 6 hours/day on days 6 to 15 of gestation. Significantly decreased mean fetal weights were observed at the highest (100 ppm) exposure level. No fetotoxic, teratogenic or maternal toxicity was observed in the 40 ppm group. The study NOAEL was identified as 40 ppm for reduced fetal weight. An uncertainty factor of 100 was applied to account for interspecies differences (10) and intraspecies variability (10). The OEHHA (2008) notes that the NOAEL was not adjusted to a 1-hour exposure due to the uncertainty associated with extrapolating data from repeated exposures to a 1-hour concentration. As a result of this uncertainty, the 6-hour REL of 1,300 µg/m³ may be considered equivalent to a 1-hour REL. This value was not selected, as reproductive effects do not appear to be the most sensitive endpoint in association with acute benzene exposure.

TABLE 6.2

SUMMARY OF EXPOSURE LIMITS SELECTED FOR BENZENE

Duration	Averaging-Time	Exposure Pathway	Type	Value	Units	Reference	Endpoint Relevant to Mixtures
Acute	1-hour	Inhalation	ReV	580	µg/m³	TCEQ 2013, 2007	Immunological effects

6.2 References

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7.0 DIBENZOTHIOPHENE

7.1 Acute Inhalation Exposure Limit

TABLE 7.1

ACUTE INHALATION EXPOSURE LIMITS FOR DIBENZOTHIOPHENE

Regulatory Agency	Type	Value (µg/m³)	Reference
ATSDR	–	–	ATSDR 2013
BC MOE	–	–	BC MOE 2013
ESRD	–	–	ESRD 2013
Metro Vancouver	–	–	Metro Vancouver 2011
OEHHA	–	–	OEHHA 2014
OMOE	–	–	OMOE 2012
TCEQ	–	–	TCEQ 2013
US EPA	–	–	US EPA 2014
WA DOE	–	–	WA DOE 2011
WHO	–	–	WHO 2000

Notes:
– = Not available

An acute criterion or guideline has not been established by any of the above regulatory agencies for dibenzothiophene. The search was expanded to include short term occupational limit values (*i.e.*, STEL or Ceiling) developed by ACGIH (2013) and AEGL-1 values from US EPA (2013b). No values were available from these sources. Given the lack of a defensible limit, dibenzothiophene was not included in the acute inhalation assessment.

TABLE 7.2

SUMMARY OF EXPOSURE LIMITS SELECTED FOR DIBENZOTHIOPHENE

Duration	Averaging-Time	Exposure Pathway	Type	Value	Units	Reference	Endpoint Relevant to Mixtures
Acute	1-hour	Inhalation	–	–	–	–	–

Notes:
– = Not available

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8.0 DIMETHYL SULPHIDE

8.1 Acute Inhalation Exposure Limit

TABLE 8.1

ACUTE INHALATION EXPOSURE LIMITS FOR DIMETHYL SULPHIDE

Regulatory Agency	Type	Value (µg/m³)	Reference
ATSDR	–	–	ATSDR 2013
BC MOE	–	–	BC MOE 2013
ESRD	–	–	ESRD 2013
Metro Vancouver	–	–	Metro Vancouver 2011
OEHHA	–	–	OEHHA 2014
OMOE	–	–	OMOE 2012
TCEQ	–	–	TCEQ 2013
US EPA	–	–	US EPA 2014
WA DOE	–	–	WA DOE 2011
WHO	–	–	WHO 2000

Notes:
– = Not available

An acute criterion or guideline has not been established by any of the above regulatory agencies for dimethyl sulphide. The search was expanded to include short-term occupational limit values (*i.e.*, STEL or Ceiling) developed by ACGIH (2013) and AEGL-1 values from the US EPA (2013). No values were available from these sources. Given the lack of a defensible limit, dimethyl sulphide was not included in the acute inhalation assessment.

TABLE 8.2

SUMMARY OF EXPOSURE LIMITS SELECTED FOR DIMETHYL SULPHIDE

Duration	Averaging-Time	Exposure Pathway	Type	Value	Units	Reference	Endpoint Relevant to Mixtures
Acute	1-hour	Inhalation	–	–	–	–	–

Notes:
– = Not available

8.2 References

Agency for Toxic Substances and Disease Registry. 2013. Minimal Risk Levels (MRLs) for Hazardous Substances. US Department of Health and Human Services, Public Health Service. Atlanta, GA. July 2013. Website: http://www.atsdr.cdc.gov/mrls/mrllist.asp

American Conference of Governmental Industrial Hygienists. 2013. TLVs® and BEIs® Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. ISBN: 978-1-607260-59-2. ACGIH®, Cincinnati. OH.

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Environment and Sustainable Resource Development. 2013. Alberta Ambient Air Quality Objectives and Guidelines. Air Policy Branch. ISBN: 978-1-4601-1253-3. Issued August 2013. Website: http://environment.gov.ab.ca/info/library/5726.pdf

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United States Environmental Protection Agency. 2014. Integrated Risk Information System (IRIS) database on-line search. A-Z List of Substances. Website: http://cfpub.epa.gov/ncea/iris/index.cfm?fuseaction=iris.showSubstanceList&list_type=alpha&view

United States Environmental Protection Agency. 2013. Acute Exposure Guideline Levels (AEGL) Chemicals. Website: http://www.epa.gov/opptintr/aegl/pubs/chemlist.htm

Washington State Department of Ecology. 2011. Ambient Air Quality Standards in Washington State. Website: http://www.ecy.wa.gov/programs/air/sips/WA_Stds_August2011.pdf

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. ISBN 92 890 1358 3 ISSN 0378-2255

9.0 ETHANETHIOL (OR ETHYL MERCAPTAN)

9.1 Acute Inhalation Exposure Limit

TABLE 9.1

ACUTE INHALATION EXPOSURE LIMITS FOR ETHANETHIOL

Regulatory Agency	Type	Value (µg/m³)	Reference
ATSDR	–	–	ATSDR 2013
BC MOE	–	–	BC MOE 2013
ESRD	–	–	ESRD 2013
Metro Vancouver	–	–	Metro Vancouver 2011
OEHHA	–	–	OEHHA 2014
OMOE	–	–	OMOE 2012
TCEQ	–	–	TCEQ 2013
US EPA	–	–	US EPA 2014
WA DOE	–	–	WA DOE 2011
WHO	–	–	WHO 2000

Notes:
– = Not available

An acute criterion or guideline has not been established by any of the regulatory agencies listed in the above table for ethanethiol. The search was expanded to include short-term occupational limit values (*i.e.*, STEL or Ceiling) developed by ACGIH (2013) and AEGL-1 values from US EPA (2013). Exposure limits were not available from ACGIH, however, US EPA has developed an AEGL-1 value for ethanethiol of 2.5 mg/m^3 (or 1 ppm).

According to the US EPA (2013), human ethanethiol studies have primarily focused on odour, as opposed to toxic endpoints. As such, the US EPA based its AEGL-1 value on an acute animal, wherein six male rabbits were exposed to 10, 100, or 1,000 ppm ethanethiol through a breathing mask for 20 minutes. Breathing rate (measured by observed thorax movement) and minute expiratory volume (measured by wet spirometry) were monitored throughout the exposure periods and were significantly affected in the rabbits exposed to 100 and 1,000 ppm ethanethiol. The researchers identified the 10 ppm exposure level as a study NOAEL for respiratory irritation in rabbits. The US EPA applied a three-fold uncertainty factor for interspecies differences and a three-fold uncertainty factor for intraspecies differences, for a combined uncertainty factor of 10. The resultant AEGL-1 value of 1 ppm or 2500 µg/m^3 was used to characterize the acute health effects associated with short-term inhalation of ethanethiol.

TABLE 9.2

SUMMARY OF EXPOSURE LIMITS SELECTED FOR ETHANETHIOL

Duration	Averaging-Time	Exposure Pathway	Type	Value	Units	Reference	Endpoint Relevant to Mixtures
Acute	1-hour	Inhalation	AEGL-1	2,500	µg/m³	US EPA 2013	Respiratory irritation

Notes:
– = Not available

9.2 References

Agency for Toxic Substances and Disease Registry. 2013. Minimal Risk Levels (MRLs) for Hazardous Substances. US Department of Health and Human Services, Public Health Service. Atlanta, GA. July 2013. Website: http://www.atsdr.cdc.gov/mrls/mrllist.asp

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BC MOE (British Columbia Ministry of the Environment). 2013. Ambient Air Quality Objectives – Updated August 12, 2013. Website: http://www.bcairquality.ca/reports/pdfs/aqotable.pdf

California Office of Environmental Health Hazard Assessment. 2014. Acute, 8-hour and Chronic Reference Exposure Level (REL) Summary. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. Sacramento, CA. Website: http://www.oehha.ca.gov/air/allrels.html

Environment and Sustainable Resource Development. 2013. Alberta Ambient Air Quality Objectives and Guidelines. Air Policy Branch. ISBN: 978-1-4601-1253-3. Issued August 2013. Website: http://environment.gov.ab.ca/info/library/5726.pdf

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Texas Commission on Environmental Quality. 2013. Final Development Support Documents (DSDs). Website: http://www.tceq.state.tx.us/implementation/tox/dsd/final.html

United States Environmental Protection Agency. 2014. Integrated Risk Information System (IRIS) database on-line search. A-Z List of Substances. Website: http://cfpub.epa.gov/ncea/iris/index.cfm?fuseaction=iris.showSubstanceList&list_type=alpha&view

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WA DOE (Washington State Department of Ecology). 2011. Ambient Air Quality Standards in Washington State. Website: http://www.ecy.wa.gov/programs/air/sips/WA_Stds_August2011.pdf

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. ISBN 92 890 1358 3 ISSN 0378-2255

10.0 ETHYLBENZENE

10.1 Acute Inhalation Exposure Limit

TABLE 10.1

ACUTE INHALATION EXPOSURE LIMITS FOR ETHYLBENZENE

Regulatory Agency	Type	Value (µg/m³)	Reference
ATSDR	acute MRL	21,700	ATSDR 2013, 2010
BC MOE	–	–	BC MOE 2013
ESRD	1-hour AAQO	2,000	ESRD 2013
Metro Vancouver	–	–	Metro Vancouver 2011
OEHHA	–	–	OEHHA 2013
OMOE	24-hour Standard	1,000	OMOE 2013
TCEQ	acute ReV	86,000	TCEQ 2013
US EPA	–	–	US EPA 2013
WA DOE	–	–	WA DOE 2011
WHO	–	–	WHO 2000

Notes:
– = Not available

The ATSDR (2013, 2010) provides an acute inhalation MRL of 5 ppm (21,700 µg/m³) based on neurological effects in rats. Wag/Rij rats were exposed to 0, 300, 400, or 550 ppm (0, 1,302, 1,736, or 2,387 mg/m³) ethylbenzene (99% pure) for 8 hours/day for 5 days (Cappaert *et al*. 2000). Three to six weeks following cessation of exposure, Measurement of Distortion Product Otoacoustic Emissions (DPOAE), Compound Action Potential (CAP), and hair cell counts were conducted. Although Cappaert *et al*. (2000) only provided the results of the study graphically the ATSDR was able to obtain the individual animal data directly from Cappaert *et al*., allowing for use of the BMD model approach. Benchmark dose modelling was completed using the CAP auditory threshold data, where the largest effects were observed in response to 8, 12 and 16 kHz stimuli. The BMD model estimated $BMDL_{1SD}$ values of 102.3, 89.47, and 81.10 µmol/L at 8, 12 and 16 kHz, respectively. The lowest $BMDL_{1SD}$ of 81.10 µmol/L was used as the POD for the acute inhalation MRL. A HEC of 154.26 ppm (669.49 mg/m³) was calculated using the human PBPK model, a human body weight of 70 kg, and the assumption of 14-day continuous exposure. A cumulative uncertainty factor of 30 was applied to the $BMDL_{HEC}$ to account for extrapolation from animals to humans with dosimetric adjustment (3) and for human variability (10). The result is an acute inhalation MRL of 21,700 µg/m³ which was used as a 1-hour exposure limit in the acute effects assessment of ethylbenzene.

The TCEQ (2013) provides an acute ReV of 86,000 µg/m³ based on the same key study as the ATSDR (*i.e.*, Cappaert *et al*. 2000). However, the TCEQ did not obtain the individual animal data directly from Cappaert *et al*. and thus used the NOAEL/LOAEL approach over the BMD model approach to determine the POD for the development of the acute ReV. A NOAEL of 300 ppm (1,302 mg/m³) and a LOAEL of 400 ppm (1,736 mg/m³) were identified for significant deterioration in CAP auditory thresholds and significant outer hair cell losses. The 8-hour NOAEL was adjusted to a 1-hour NOAEL using modified Haber's law.

$$C_{ADJ}^{\,n} \times T_{ADJ} = C^n \times T$$
$$C^3 \times 1 \text{ hour} = (1{,}302 \text{ mg/m}^3)^3 \times 8 \text{ hours}$$

Where:

C_{ADJ} = duration-adjusted concentration

T_{ADJ} = desired time of exposure (1 hour)

C = concentration of exposure (1,302 mg/m³)

T = time of exposure (8 hours)

n = chemical-specific modification factor designed to account for the toxicity of a chemical being concentration and duration dependent (3).

The HEC was calculated from the $NOAEL_{ADJ}$ of 600 ppm (2,604 mg/m³) using the recommended equation for category 3 gases. The TCEQ notes, however, that ethylbenzene is classified as a category 2 gas since it is relatively soluble in water and produces both local and systemic effects, but category 2 gases are still under review by the US EPA.

$$RGDR = (H_{b/g})_A / (H_{b/g})_H$$

Where:

RGDR = regional gas dosimetry ratio

$H_{b/g}$ = ratio of blood:gas partition coefficient

A = animal

H = human

The TCEQ (2013) assumed an $H_{b/g}$ for rats of 42.7 and a mean $H_{b/g}$ for humans of 28.0. When the $(H_{b/g})_A/(H_{b/g})_H$ is greater than 1, a default value of 1 is used for the RGDR. The RGDR was then multiplied by the $NOAEL_{ADJ}$, resulting in a $NOAEL_{HEC}$ of 600 ppm (2,604 mg/m³). The TCEQ (2013) applied a cumulative uncertainty factor of 30 to the $NOAEL_{HEC}$ to account for interspecies variability with dosimetric adjustment (3) and intraspecies variability (10). The result is an acute ReV of 86,000 µg/m³ for ethylbenzene. The TCEQ acute ReV was not used in the acute effects assessment for ethylbenzene because: (a) the TCEQ did not provide sufficient evidence to justify the use of this less conservative (*i.e.*, higher) limit over the ATSDR acute MRL of 21,700 µg/m³ that is based on the same key study; and (b) the ATSDR obtained the individual animal data, and applied the BMD and PBPK models in the development of its acute MRL.

The OMOE (2013) has established a health-based 24-hour standard of 1,000 µg/m³ for ethylbenzene. However, no scientific basis or supporting document is provided for this standard. As a result, this limit was not used in the acute effects assessment of ethylbenzene.

ESRD (2013) presents an AAQO of 2,000 µg/m³ for a 1-hour average exposure. This limit was adopted from the TCEQ based on odour perception, but no specific basis was provided. As well, the TCEQ (2013) recently revised its acute odour-based acute ESL to a value of 740 µg/m³. Given that this objective is not health-based and does not reflect TCEQ's most current odour-based acute ESL, the ESRD AAQO was not used in the acute effects assessment of ethylbenzene.

TABLE 10.2

SUMMARY OF EXPOSURE LIMITS SELECTED FOR ETHYLBENZENE

Duration	Averaging-Time	Exposure Pathway	Type	Value	Units	Reference	Endpoint Relevant to Mixtures
Acute	1-hour	Inhalation	MRL	21,700	µg/m³	ATSDR 2013, 2010	Neurological effects

10.2 References

Agency for Toxic Substances and Disease Registry. 2010. Toxicological Profile for Ethylbenzene. Atlanta, GA: US Department of Health and Human Services, Public Health Service.

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11.0 TOLUENE

11.1 Acute Inhalation Exposure Limit

TABLE 11.1

ACUTE INHALATION EXPOSURE LIMITS FOR TOLUENE

Regulatory Agency	Type	Value (µg/m³)	Reference
ATSDR	24-hour MRL	3,800	ATSDR 2013, 2000
BC MOE	–	–	BC MOE 2013
ESRD	1-hour AAQO 24-hour AAQO	1,880 400	ESRD 2013, Alberta Environment 2004
Metro Vancouver	–	–	Metro Vancouver 2011
OEHHA	1-hour REL	37,000	OEHHA 2014, 2008
OMOE	–	–	OMOE 2012
TCEQ	1-hour ReV	15,000	TCEQ 2013, 2008
US EPA	–	–	US EPA 2014
WA DOE	–	–	WA DOE 2011
WHO	–	–	WHO 2000

Notes:
– = Not available

The same key study (Anderson *et al*. 1983) was chosen by the TCEQ, the ATSDR and OEHHA as the basis for their values.

As reported by Andersen *et al*. (1983), 16 healthy subjects with no previous exposure to organic solvents were exposed to toluene for 6 hours/day over 4 consecutive days. The concentration of toluene was 0, 10, 40, or 100 ppm with each group exposed to a different toluene concentration each day. After 1 hour of exposure to the desired toluene concentration, physiological measurements and performance assessments test were carried out on all subjects. The tests were repeated in the 5th and 6th hours of exposure. No adverse effects were reported at the 10 and 40 ppm levels, but statistically significant increased irritation was experienced in the eyes and nose at the 100 ppm concentration. There was also a statistically significant increase in the occurrence of headaches, dizziness, and feeling of intoxication. A NOAEL of 40 ppm (150 mg/m³) was identified.

The TCEQ, ATSDR and OEHHA share the opinion that the NOAEL of 40 ppm (150 mg/m³) is appropriate for short-term inhalation of toluene and that an uncertainty factor of 10 is sufficiently protective of the general population. The discrepancies between the limits derived arise from the duration adjustments applied by the individual regulatory agencies.

The TCEQ (2008) elected not to adjust the exposure duration based on a weight of evidence that suggests that concentration rather than duration is the primary determinant of the effects of toluene. The TCEQ (2008) only applied the uncertainty factor of 10 for intraspecies variability to the NOAEL of 40 ppm (150 mg/m³). The result is an acute ReV of 15,000 µg/m³, which was selected as the 1-hour exposure limit in the acute effects assessment of toluene, as it represents the most conservative value that takes into account the short-term, concentration-related effects of toluene. The toxicological basis of this value includes neurological effects and both eye and nasal irritation.

The ATSDR (2000) adjusted the NOAEL of 40 ppm to account for intermittent exposure (8/24 hours × 5/7 days). An uncertainty factor of 10 was applied to the adjusted NOAEL to account for intraspecies variability, resulting in an MRL 0f 0.95 ppm, which was rounded to 1 ppm (3,800 µg/m³). This value was not selected due to the adjustment to a 24 hour MRL.

The OEHHA (2014, 2008) converted the 6-hour exposure duration to a 1-hour REL of 98 ppm (370 mg/m³) based on a modified Haber's Law, and applied an uncertainty factor for intraspecies

variability (10), resulting in an acute 1-hour REL of 37,000 µg/m³. This value was not used as the TCEQ value is more conservative.

ESRD 2013 has established a 1-hour AAQO of 1,880 µg/m³, which was adopted from the TCEQ ESL. However, TCEQ has since updated their health based acute ReVs and ESLs and therefore the ESRD limit is not up to date. The ESRD also provides a 24-hour AAQO of 400 µg/m³ adopted from the Michigan Department of Environmental Quality and the Washington Department of Ecology (ESRD 2013, Alberta Environment 2004). These regulatory agencies based their 24-hour guidelines on the US EPA chronic inhalation RfC of 400 µg/m³ which has since been revised to be 5,000 µg/m³. As the ESRD values are based on out-dated chronic information, they were not considered further for use in the assessment.

TABLE 11.2

SUMMARY OF EXPOSURE LIMITS SELECTED FOR TOLUENE

Duration	Averaging-Time	Exposure Pathway	Type	Value	Units	Reference	Endpoint Relevant to Mixtures
Acute	1-hour	Inhalation	ReV	15,000	µg/m³	TCEQ 2013, 2008	Eye and nasal irritation, neurological effects

11.2 References

Agency for Toxic Substances and Disease Registry. 2000. Toxicological Profile for Toluene. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. September 2000.

Agency for Toxic Substances and Disease Registry. 2013. Minimal Risk Levels (MRLs) for Hazardous Substances. US Department of Health and Human Services, Public Health Service. Atlanta, GA. July 2013. Website: http://www.atsdr.cdc.gov/mrls/mrllist.asp

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12.0 TRIMETHYLBENZENES

12.1 Acute Inhalation Exposure Limit

TABLE 12.1

ACUTE INHALATION EXPOSURE LIMITS FOR TRIMETHYLBENZENES

Regulatory Agency	Type	Value (µg/m³)	Reference
ATSDR	–	–	ATSDR 2013
BC MOE	–	–	BC MOE 2013
ESRD	–	–	ESRD 2013
Metro Vancouver	–	–	Metro Vancouver 2011
OEHHA	–	–	OEHHA 2014
OMOE	24-hour	220	OMOE 2012
TCEQ	–	–	TCEQ 2013
US EPA	–	–	US EPA 2014
WA DOE	–	–	WA DOE 2011
WHO	–	–	WHO 2000

Notes:
– = Not available

The OMOE (2012) presents a 24-hour value of 220 µg/m³ for trimethylbenzenes; however, as no supporting documentation is available, this value was not considered in the assessment. Due to a lack of available limits from other agencies listed in the table above, the search was expanded to include values from the US EPA AEGL-1 (US EPA 2013) list, and the ACGIH (2013) STEL or ceiling values.

The US EPA (2007) has derived an acute AEGL-1 of 140 ppm (690,000 µg/m³) for all isomers of trimethylbenzene. Due to a lack of available human data for acute trimethylbenzene exposure, the AEGL-1 was derived from an analysis of several animal studies. Korsak and Rydzynski (1996) conducted a study involving acute (4-hour) exposure to 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene and 1,2,3-trimethylbenzene at concentrations ranging from 250 to 2,000 ppm (individual doses not specified) within a controlled chamber. Concentration-related changes were observed in rotarod performance in the exposed rats (male only). EC_{50} values for each isomer based upon disturbances in rotarod function were determined to be: 4,693 mg/m³ (95% CI 3,891 to 5,493 mg/m³) for 1,2,4-trimethylbenzene; 4,738 mg/m³ (95% CI 3,675 to 5,453 mg/m³) for 1,3,5-trimethylbenzene; and 3,779 mg/m³ (95% CI 2,832 to 4,615 mg/m³) for 1,2,3-trimethylbenzene. Changes in pain sensitivity also were observed for the three isomers in the acute study. EC_{50} values for pain sensitivity (demonstrated by the paw lick response) were determined to be the following: 5,682 mg/m³ (95% CI 2,715 to 7,596 mg/m³) for 1,2,4-trimethylbenzene; 5,938 mg/m³ (95% CI of 5,194 to 6,512 mg/m³) for 1,3,5-trimethylbenzene; and 4,155 mg/m³ (3,400 to 4,811 mg/m³ for 1,2,3-trimethylbenzene. Of the two endpoints, rotarod disturbance seems to be the more sensitive effect. Korzack and Rydzynski (1996) note that the 1,2,3-trimethylbenzene isomer appeared to demonstrate more neurotoxic potential than the other two isomers.

Also cited as a key study by US EPA (2007), Korsak *et al*. (1995) conducted a similar study with only 1,2,4-trimethylbenzene in male rats. Rats were exposed for a duration of 4 hours to 250 to 2,000 ppm (individual dose levels not specified) within a controlled chamber. Altered rotorod activity indicative of neurotoxicity, altered pain response and decreased respiratory rate were observed in association with concentration-dependent responses. EC_{50} values for rotorod performance, pain sensitivity and respiratory depression were determined to be 4,693 mg/m³ (95% CI 3,891 to 5,493 mg/m³), 5,682 mg/m³ (95% CI 2,715 to 7,596 mg/m³) and 2,840 mg/m³ (95%,CI 1,500 to 3,900 mg/m³), respectively.

Although it is not clear how the US EPA calculated the value, the average EC_{50} for neurological effects was determined to be 900 ppm from the animal data, and served as the point of departure for the

derivation of the AEGL. The Haber's Law approach was used by the US EPA (2007) to convert the 4-hour concentration to a 1-hour concentration:

$$(C_1)^n \times T_1 = (C_2)^n \times T_2$$

Where:

C_1 = 4-hour concentration (mg/m³)

T_1 = 4 hours

C_2 = converted 1-hour concentration (mg/m³)

T_2 = 1 hour

n = 3 (US EPA 2007)

A 1-hour concentration of 1,429 mg/m³ was calculated, and then adjusted by a total uncertainty factor of 10 to account for interspecies differences (3), and intraspecies differences (3), to result in the 1-hour AEGL of 690 mg/m³ (690,000 µg/m³).

The ACGIH (2013) has not derived a STEL for acute exposures.

As a result, the 1-hour AEGL from the US EPA (2007) of 690,000 µg/m³ based on neurotoxic effects was selected for use as a 1-hour exposure limit in the acute inhalation assessment.

TABLE 12.2

SUMMARY OF EXPOSURE LIMITS SELECTED FOR TRIMETHYLBENZENES

Duration	Averaging-Time	Exposure Pathway	Type	Value	Units	Reference	Endpoint Relevant to Mixtures
Acute	1-hour	Inhalation	AEGL-1	690,000	µg/m³	US EPA 2007	Neurological effects

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13.0 XYLENES

13.1 Acute Inhalation Exposure Limit

TABLE 13.1

ACUTE INHALATION EXPOSURE LIMITS FOR XYLENES

Regulatory Agency	Type	Value (µg/m³)[1]	Reference
ATSDR	1-hour MRL	8,700	ATSDR 2013, 2007
BC MOE	–	–	BC MOE 2013
ESRD	1-hour AAQO 24-hour AAQO	2,300 700	ESRD 2013
Metro Vancouver	–	–	Metro Vancouver 2011
OEHHA	1-hour REL	22,000	OEHHA 2014, 2008
OMOE	24-hour standard	730	OMOE 2012, 2005
TCEQ	1-hour ReV	7,400	TCEQ 2013, 2009
US EPA	–	–	US EPA 2014
WA DOE	–	–	WA DOE 2011
WHO	–	–	WHO 2000

Notes:
1 Exposure limit provided for m-xylene, o-xylene, p-xylene or mixed isomers.
– = Not available

The TCEQ (2013, 2009) has derived an acute ReV of 1.7 ppm (7,400 µg/m³) for xylenes based on mild respiratory effects and subjective symptoms of neurotoxicity. Ernstgard *et al*. (2002) was selected as the key study for the derivation of the acute ReV. In this study, 56 human volunteers were exposed to 50 ppm *m*-xylene, clean air, or 150 ppm 2-propanol for 2 hours in an inhalation chamber (TCEQ 2009). The TCEQ (2009) identified a LOAEL of 50 ppm based on breathing difficulty in both sexes and discomfort in the throat and airways of females. In addition, symptoms of neurotoxicity were reported, including fatigue, headache, dizziness, and a feeling of intoxication. All of these effects were considered minimal (TCEQ 2009). The LOAEL was not adjusted to a 1-hour exposure duration because the exposure concentration, as opposed to the duration of exposure, was identified as the primary determinant of the adverse effects of xylene (TCEQ 2009). An uncertainty factor of 10 was applied to the LOAEL to account for intraspecies variability and an uncertainty factor of 3 was applied to the LOAEL to account for use of a minimal LOAEL.

The ATSDR (2013, 2007) also selected the study by Ernstgard *et al*. (2002) as the basis of their MRL. A concentration of 50 ppm (200 mg/m³) was designated as a LOAEL for slight respiratory effects (*e.g.*, reduced forced vital capacity, increased discomfort in throat and airways in women and breathing difficulties in both sexes) and subjective symptoms of neurotoxicity (*e.g.*, headache, dizziness, feelings of intoxication). The LOAEL was considered minimal due to the minor nature of the effects observed (ATSDR 2007). The ATSDR (2007) applied an uncertainty factor of 30 for intraspecies variability (10) and use of a (minimal) LOAEL (3), resulting in an acute MRL of 2 ppm (8,700 µg/m³).

Although the TCEQ and ATSDR selected the same study and LOAEL based on respiratory irritation and neurological effects, the exposure limits are slightly different due to rounding differences. Given that the TCEQ provides a lower limit, this acute ReV of 7,400 µg/m³ was used as a 1-hour exposure limit in the acute assessment.

The OEHHA (2014, 2008) has derived a REL for 1-hour exposure of 22,000 µg/m³ based on irritation of the eyes, nose, and throat. In the study by Hastings *et al*. (1984), 50 healthy human volunteers were exposed for 30 minutes to concentrations of 430, 860, or 1,720 mg/m³ of technical grade (mixed) xylene. A NOAEL of 100 ppm (430 mg/m³) was identified by Hastings *et al*. (1984) as it was observed that the incidence of eye irritation was comparable to what was reported in the control group. The NOAEL was adjusted to a 1-hour exposure of 50 ppm (C × 60 minutes = 100 ppm × 30 minutes). A cumulative

uncertainty factor of 10 was applied to the NOAEL to account for intraspecies variation. The result is an acute REL of 5 ppm (22,000 µg/m³). As the OEHHA limit is less conservative than the limit provided by TCEQ (2013, 2009) this exposure limit was not selected for use in the acute assessment.

ESRD 2013 adopted the OMOE's half-hour point-of-impingement of 2,300 µg/m³ as its 1-hour AAQO. However, this POI was based on odour perception and has since been updated (OMOE 2012). ESRD (2013) also provides a 24-hour AAQO of 700 µg/m³ which was adopted from the OEHHA. However, as the OEHHA value is based on chronic studies, it was not considered appropriate for use in the acute assessment.

The OMOE (2012, 2005) has derived a 24-hour criteria of 730 µg/m³ based on adverse neurological effects. A LOAEL of 62 mg/m³ was established for headaches, eye and nasal irritation and light headedness (floating sensation) in approximately 300 workers, 175 of whom were occupationally exposed for an average of 7 years. The LOAEL was adjusted by the OMOE (2005) to account for discontinuous exposure to a concentration of 22.1 mg/m³. As this 24-hour value is based on chronic exposure, it was not used in the assessment.

TABLE 13.2

SUMMARY OF EXPOSURE LIMITS SELECTED FOR XYLENES

Duration	Averaging-Time	Exposure Pathway	Type	Value	Units	Reference	Endpoint Relevant to Mixtures
Acute	1-hour	Inhalation	ReV	7,400	µg/m³	TCEQ 2013, 2009	Respiratory irritation, neurological effects

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