Metro Vancouver

Waste-to-Energy Facility Public Health Risk Assessment

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Executive Summary

The Greater Vancouver Sewerage and Drainage District is the owner of the Metro Vancouver Waste-to-Energy Facility located in Burnaby, British Columbia. The facility's Operational Certificate 107051 (OC) was issued on December 15, 2016 by the British Columbia (BC) Ministry of Environment and Climate Change Strategy (MOE) and requires an "*Evaluation of Contaminant Dispersion and Public Health Risk Assessment*".

The first stage of the project was to undertake the Start-Up/Shutdown stack testing of the parameters with discharge limits. This was completed in November 2017. The second stage of the project was to conduct the Air Dispersion Modelling Study of contaminants under four scenarios – Permit, Operations, Start-Up and Shutdown conditions. The results of both of these phases of work were used as inputs to the public health risk assessment.

The background ambient air quality for criteria air contaminants and metal concentrations were obtained from the extensive regional air monitoring network. The Air Dispersion Modeling Study provided 1-hr, 24-hr and annual concentrations for contaminants of potential concern for the four scenarios. These concentrations of contaminants were used to assess the potential for public health risk from their exposure.

As expected, the highest ground level concentrations of contaminants were predicted for the Permitted Scenario. This is the maximum concentration of contaminants that can be emitted from the facility. There was a considerable decrease of maximum ground level contaminant concentrations for the Operations Scenario, based on the actual emissions that come from the facility. This is because the facility routinely emits considerably less of each contaminant than limited by the permit. For the first time, contaminants were directly monitored at the facility's stack during Start-up and Shutdown conditions. There was a slight increase in concentrations of some contaminants over the day-to-day Operations Scenario; however, these events did not materially impact the modelled ground level concentrations for most contaminants.

Public health risk assessment is the scientific approach to determine if a population's exposure to contaminants released to the environment could pose an undue risk to health. The results of the deposition analysis for the facility were consistent with those found in the scientific peer-reviewed literature. No appreciable or analytically detectable increase in soil contaminant concentrations was predicted. Therefore, the only appreciable exposure pathway for the facility is through inhalation of contaminants in air.

All contaminant concentrations were below their respective health-based benchmarks for the Operations, Start-up and Shutdown Scenarios and required no further evaluation. This means that the current emissions from the facility do not pose a health risk to people.

For the very conservative Permitted Scenario, the maximum concentrations of 1-hr nitrogen dioxide, 1-hr hydrogen chloride and 24-hr total polycyclic aromatic hydrocarbons immediately adjacent to the facility were above the respective background guidelines for a couple of hours a year.

Further spatial, temporal and toxicological exposure evaluation to the maximum predicted concentrations of all three of these contaminants close to the facility revealed that they do not pose an undue public health risk for those living, working or engaged in recreational activity surrounding the facility. Based on these results, additional monitoring of contaminants in air, soil,

water, vegetation or other environmental media are not recommended. Although there were minor temporal exceedances of the Permitted Scenario these Operational Certificate limits are reasonable, do not result in a public health risk and therefore no changes to the Operational Certificate limits are recommended. The findings of the PHRA are consistent with the past two decades of peer-reviewed scientific literature and government reports.

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1 Introduction

The Greater Vancouver Sewerage and Drainage District (Corporation) is the owner of the Metro Vancouver Waste-to-Energy Facility (WTEF) located in Burnaby, British Columbia. Covanta Burnaby Renewable Energy, ULC (Covanta) operates the plant on behalf of the Corporation. The emissions discharge limits and performance requirements for the air pollution control equipment for various parameters are listed in the WTEF's Operational Certificate 107051 (OC). It was issued on December 15, 2016 by the British Columbia (BC) Ministry of Environment and Climate Change Strategy (MOE) under the Provisions of the Environmental Management Act, and in accordance with the Integrated Solid Waste and Resource Management Plan.

Section 2.17 of the OC required the Holder to undertake an "*Evaluation of Contaminant Dispersion and Public Health Risk Assessment*". The evaluation must include:

- *characterization of contaminant emissions using site specific monitoring data, scientific literature review, and any other relevant sources of information, to determine potential environmental and health effects for all air contaminants of potential concern including dioxins and furans;*
- *updated and comprehensive site-specific air dispersion modelling to evaluate potential impacts on the local and regional air quality, and the potential for atmospheric deposition of air contaminants;*
- *a comprehensive public health risk assessment that takes into consideration multiple pathways of exposure and potentially sensitive receptors within the area of impact, and that covers long-term normal operation of the facility as well as short-term conditions anticipated at start up, shutdown, or during an upset;*
- *an assessment of the existing regional air quality monitoring network and program to confirm its appropriateness and effectiveness in assessing potential impacts from facility emissions; and*
- *based on the preceding, an assessment of the effectiveness of the monitoring requirements made in this Operational Certificate, and recommendations for sampling or evaluation of receptors such as soil, vegetation, or other media.*

It also required input from provincial health authorities and that the final report be provided to them for informational purposes. This evaluation must be completed and report acceptable to the Director within 24 months (December 15, 2018) of issuance of the OC.

The first stage of the project was to undertake the Start-Up/Shutdown stack testing of the parameters with discharge limits. This testing was conducted in November 2017. The second stage of the project was to conduct the Air Dispersion Modelling Study (RWDI, 2018) of contaminants under four scenarios – Permit, Operations, Start-Up and Shutdown conditions. The results of both of these phases of work were used as inputs to the public health risk assessment (PHRA), otherwise known as the human health risk assessment (HHRA).

This PHRA assessed both the short-term (Start-Up/Shutdown) and long-term (normal operations) potential exposure of the public to release of chemicals from the WTEF. It involved both a review of the existing scientific literature on chemical release, exposure and long-term deposition of chemicals from such facilities and the PHRA. Based on the findings of the PHRA requirements for additional monitoring are discussed.

2 Literature Review

A number of comprehensive scientific literature reviews have been conducted in this field over the past decade. In 2014, Metro Vancouver commissioned a study "*Literature Review of Potential Health Risk Issues Associated with New Waste-to-Energy Facilities*" (Intrinsik, 2014). This review focused on PHRAs, human biomonitoring studies and epidemiological studies for those living in close proximity to WTE facilities. The overall conclusion from this report was:

> *"Out of the 21 peer-reviewed articles included for detailed review, 14 were risk assessments, 3 were human biomonitoring studies, and 4 were epidemiological studies. Although there were some limitations and uncertainties associated with each of the studies, overall these articles best represented the available scientific knowledge on modern WTE facilities and potential health impacts. The results from these studies collectively indicate that there are no unacceptable health risks to residents living in the immediate vicinity of a modern, well- maintained and properly operated WTE facility equipped with the best available pollution control technologies."*

The Metro Vancouver 2014 review built on the comprehensive reviews undertaken for Ontario in "*Halton Region Energy-from-Waste Literature Review*" (Jacques Whitford, 2007) and the Durham Region "*Review of International Best Practices of Environmental Surveillance for Energy-From-Waste Facilities Literature Review of Waste-to-Energy Issues"* (Jacques Whitford, 2009). The findings of these reports are consistent with the the Metro Vanouver (2014) review. A key finding of the Jacques Whitford (2009) report was:

> *"It is concluded from the scientific literature that an ongoing soil monitoring program would not be required for the proposed Durham/York EFW facility to ensure the protection of human or environmental health. This conclusion was reached on the basis that a modern incineration facility that employs current pollution control technology should not impact local soil quality."*

This conclusion was reached after review of numerous soil monitoring programs around WTE Facilities indicate that loading of contaminants (including dioxins and furans) did not occur above background conditions.

In 2017, Metro Portland as part of their long-term strategic planning effort for municipal solid waste (MSW) commissioned a *Literature Review of WTE Issues* (HDR, 2017). This review included an update to the health literature from the Metro Vancouver review (Intrinsik, 2014) and issues surrounding environmental monitoring for impacts. It concluded:

> *"Overall, the published scientific literature on potential health concerns living in proximity to WTE facilities indicates that modern facilities with appropriate air pollution control technology can be safely sited."*

The peer-reviewed published literature indicates that the primary concern for modern WTE Facilities is the potential for airborne emissions to impact local air quality, and thus lead to inhalation exposure. There is no indication in the literature that emissions measurably impact local soil quality or vegetation, even after a decade or more of facility operation. In addition, risk assessments, biomonitoring and epidemiological studies have indicated that there are no adverse effects on local populations living and working near such modern facilities.

An updated literature search was conducted for 2017-2018, since the time the last comprehensive review was conducted for Metro Portland. It included a search for peer-reviewed scientific articles on potential health impacts and exposure pathways (air, soil and vegetation) for WTE facilities. Four papers were retrieved (one epidemiology, one biomonitoring and two HHRA) for current technology WTE facilities. The following provides a brief overview of conclusions of these papers.

Epidemiology

Vinceti et. al. (2018) Adverse pregnancy outcomes in women with changing patterns of exposure to the emissions of a municipal waste incinerator. Environ Res. 164:444-451.

Overall, these results do not suggest an effect of exposure to the emissions of the municipal solid waste incinerator we investigated on two indicators of reproductive health.

Biomonitoring

Gatti et al. (2018) Human biomonitoring of polycyclic aromatic hydrocarbons and metals in the general population residing near the municipal solid waste incinerator of Modena, Italy. Chemosphere. 186:546-557

The study indicates that the emissions were very low and highlights that specific urinary PAHs provided useful information about the internal dose arising from incinerator emission.

Risk Assessment

Zhang et al. (2018) The health risk levels of different age groups of residents living in the vicinity of municipal solid waste incinerator posed by PCDD/Fs in atmosphere and soil. Sci Total Environ 631-632:81-91

The carcinogenic risk (CR) values of PCDD/Fs in surrounding atmosphere and soil for children, teens and adults were 1.24E-06, 9.06E-07 and 4.41E-06, respectively, suggesting that the potential cancer risk occurred but the risk was at acceptable levels for both children and adults (<1.00E-05), and the cancer risk for teens was negligible (<1.00E-06). The non-carcinogenic risk (non-CR) values of three age groups were lower than 1, indicating that no obvious non-carcinogenic effects occurred.

Rovira et al. (2018) Concentrations of trace elements and PCDD/Fs around a municipal solid waste incinerator in Girona (Catalonia, Spain). Human health risks for the population living in the neighborhood. Sci Total Environ. 630:34-45.

The concentrations of trace elements and PCDD/Fs were similar -or even lower- than those reported around other MSWIs in Catalonia and various countries. Non-carcinogenic risks were below the safety limit (HQ<1). In turn, carcinogenic risks due to exposure to trace elements and PCDD/Fs were in acceptable ranges, according to national and international standard regulations.

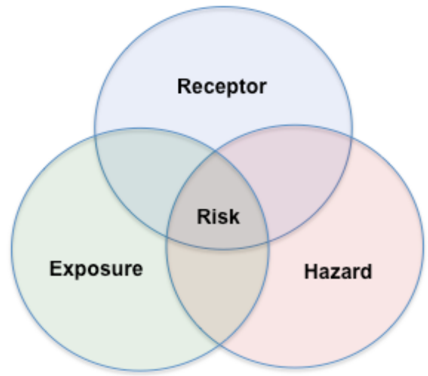
The updated review of the literature is consistent with the findings of previous published scientific research and results in the field, and taken together suggest that it is unlikely that the WTEF would adversely impact health of nearby receptors (people). However, this PHRA will assess the health risks associated with inhalation exposure of air emissions from the facility to determine that this is indeed the case. In addition, the literature remains consistent that operation of modern WTE facilities are not expected to measurably increase the concentration of chemicals in soils or other environmental media, suggesting that a multi-media PHRA is likely not required. The deposition assessment conducted in this PHRA will examine whether this is the case for the WTEF.

3 Methodology for the Public Health Risk Assessment of WTEF Emissions

Public health risk assessment (PHRA) is the scientific approach to determining if a population's exposure to chemicals released to the environment could pose an undue risk to health. This approach is based on decades of research and the development of standard protocols and approaches to assessing risk.

All chemicals have the potential to interact with people, but it is the level, route and duration of exposure that determine if it could cause harm to health. For a potential undue risk to exist from emissions from the WTEF, one must understand:

- The nature in which people use the surrounding environment, for work, living and recreational purposes (receptors);
- The extent to which people may come into contact with the emitted chemicals (exposure); and
- The chemicals must be emitted at a high enough level to pose a risk to these people (hazard).



It is a combination of these elements that determine if an unacceptable risk to human health may exist.

The British Columbia (BC) Ministry of Environment and Climate Change Strategy (MOE) has no specific guidance on how to conduct a PHRA for facility air emission risk assessments. This is similar across Canada in other provincial and federal jurisdictions. However, BCMOE *Technical Guidance 7, on Contaminated Sites* (V5, November 2017) provides general guidance for risk assessment in BC.

This risk assessment follows the general risk assessment paradigm of

- Problem formulation
- Exposure assessment
- Toxicity assessment
- Risk characterization

In keeping with BC guidance, the following was be the primary guidance document relied on in the PHRA:

- *Part V: Guidance on Complex Human Health Detailed Quantitative Risk Assessment for Chemicals (Health Canada, 2010)*

Figure 1 provides a flow diagram of the process by which the inhalation and the multi-media risk assessments were conducted. This will be referred to throughout the PHRA. In general, the Tier 1 inhalation assessment evaluated if concentrations of chemicals of potential concern (COPC) in air at the maximum point of impingement (MPOI) pose an unacceptable non-cancer risk (concentration ratio (CR) >1 for criteria air contaminants (CAC); >0.2 other COPCs) or cancer risk (incremental lifetime cancer risk (ILCR) $>10^{-5}$) for a hypothetical resident living at the MPOI 24 hours a day throughout their entire lifetime. For any COPC that failed the Tier 1 assessment failed, a Tier 2 assessment that considered frequency of exceedance, actual land use and time activity patterns was conducted.

For the multi-media PHRA, a 10-year deposition analysis was conducted for those COPCs that could persist in the environment when deposited in soil. For COPCs that showed no significant increase over background conditions or laboratory reporting limits, no multi-media assessment was conducted. Had a COPC failed the deposition analysis, then a more detailed multi-media PHRA would have been conducted.

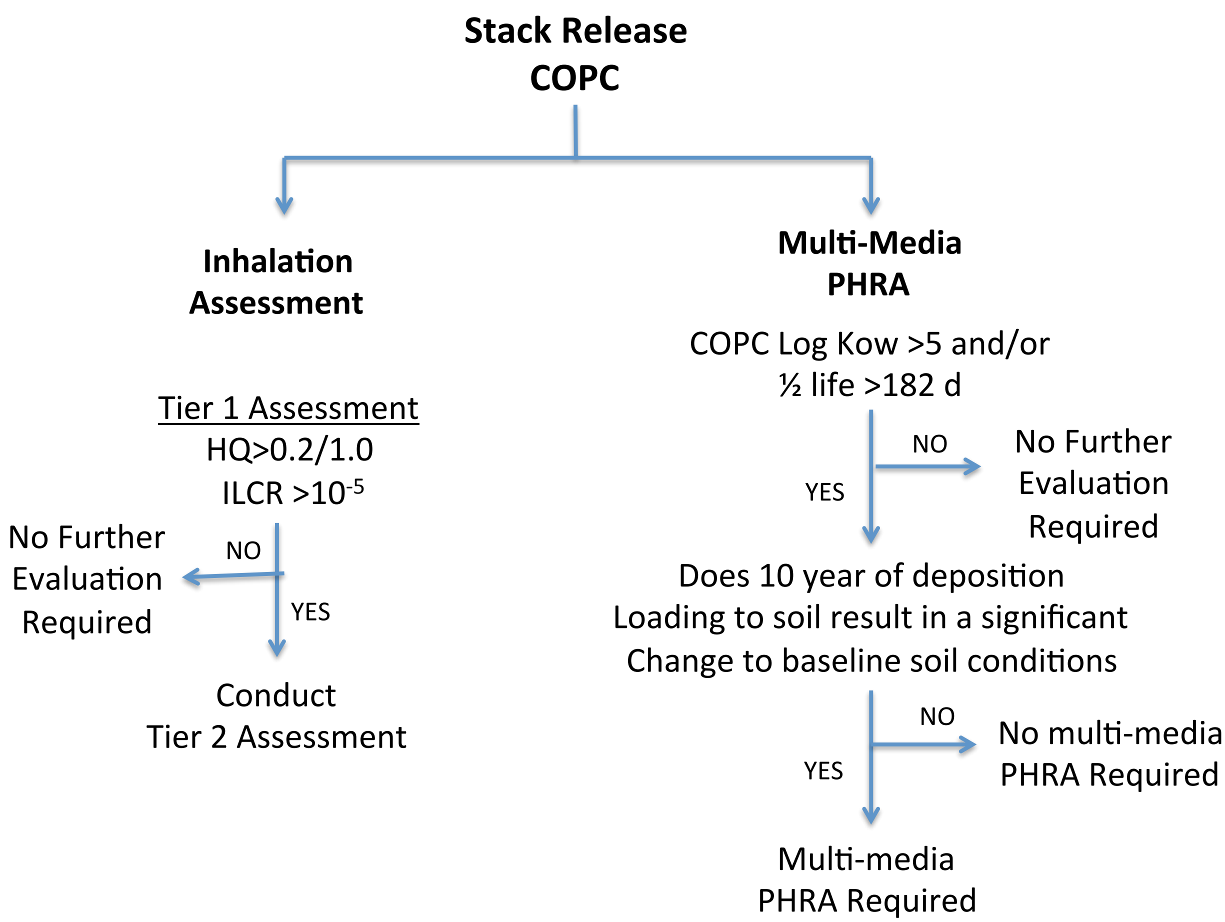


Figure 1. Public Health Risk Assessment Framework for Metro Vancouver Waste-to-Energy Facility

4 Problem Formulation

4.1 Site Characterization

The WTEF is located at 5150 Riverbend Drive, Burnaby, British Columbia. In operation since 1988, the WTEF is a 310,000 tonne per year (permitted capacity) MSW mass-burn facility that processes 260,000 tonnes per year, equivalent to a quarter of the region's municipal solid waste annually. Over the past 30 years, the facility has made continuous operational improvements and upgrades to its air pollution control (APC) technology. It routinely operates with emission levels considerably better than required by its OC (Permitted Scenario). The PHRA will provide information on recent emissions performance for the facility that will aid in understanding of annual emissions of key chemical constituents.

4.2 Operational Air Dispersion Modeling Scenarios

The primary source of COPC from the WTEF is airborne emissions from the facility stack. These emissions have the potential to result in ground-level exposure in areas surrounding the facility. The OC describes a number of emission conditions that need to be considered in the PHRA, as follows:

> *"long-term normal operation of the facility as well as short-term conditions anticipated at start up, shutdown, or during an upset."*

For the purposes of the Air Dispersion Modelling Study (RWDI, 2018) and the PHRA, these conditions have been assessed as five different scenarios: baseline (existing ambient air quality), Permit, Operations, Start-up and Shutdown, which are detailed in Table 1. For each scenario, the WTEF resulting ground level chemical concentrations were evaluated alone, and then together with baseline / background airborne concentrations. These scenarios are further detailed in the Air Dispersion Modelling Study.

Table 1. Project Inhalation Scenarios Evaluated in the Public Health Risk Assessment

Project Scenario	Scenario	Description
Existing Conditions	Baseline	Available observation data from existing Metro Vancouver air quality monitoring stations - Burnaby South (T18) and North Delta – are used to provide baseline concentrations of COPC. The 98th percentile of observed data to determine baseline air quality for 1-hour, 8-hour, 24-hour and annual averaging periods.
Operational	Permitted	Allowable emissions levels permitted in the OC were considered in this scenario. Emissions were considered to be continuous for all operation periods, meaning that the same emission rate was used to assess acute (1-hour average) and chronic (annual average) exposure periods. As the facility would not likely emit at permitted levels for 24 hours a day, each day of the year, this scenario represents a highly conservative emissions scenario.
	Operations	Actual facility emissions during normal operations measured by the Continuous Emissions Monitoring Systems (CEMS) and manual stack emissions testing were considered in this scenario. CEMS data were taken from 2017, while stack testing data were taken from 2016 and 2017 regulatory tests. This scenario provides a more realistic representation of actual facility emissions than the Permitted Scenario, but it is still somewhat conservative because it considers all three facility boilers to be continuous sources emitting at the same rate for 24 hours per day, each day of the year.
Start-Up and Shutdown	Start-up/Shutdown + Operational	These scenarios considered emissions from one boiler starting up or shutting down added emissions from the other two boilers operating normally as defined in the Operational Scenario. A series of specialized stack tests were conducted on November 28-30, 2017 (A. Lanfranco, 2017) to obtain emission rates during Start-Up and Shutdown conditions. Start-Up and Shutdown emission rates for pollutants measured by the facility CEMS were determined from data gathered during start-up and shut down periods throughout 2017. For the purposes of this emissions scenario, a single WTEF boiler starting up and shutting down was modelled as a constant point source representing the maximum emissions measured during start-up and shutdown testing. Air quality dispersion model predictions from this scenario will always be equal to or greater than concentrations from the Operational Scenario.

The OC for the WTEF does not have an expiration date, so a 10-year period of operations with emissions continuously at OC Permitted levels was used to assess the potential long-term cumulative effects of facility emissions. Deposition of persistent and bioaccumulative chemicals onto soil surround the facility was conducted over this 10 year period.

4.3 Chemicals of Potential Concern

The chemicals of potential concern (COPCs) for the WTEF are those that are governed by the OC. Although it is acknowledged that there are several other contaminants that are released from the facility, those requiring monitoring in the OC represent those that are: the most toxic, released at the highest levels, are of concern in airshed management, or are of particular concern to the public. The results of the literature review indicated that these are the appropriate COPCs and those that are studied most in this field of research (Table 2).

Table 2. Chemicals of Potential Concern for the Public Health Risk Assessment

Discharge Limit Parameter	PHRA COPC and/or Surrogate	Inhalation	Deposition
Criteria Air Contaminants (CAC)	Particulate Matter: All PM emitted from the facility was conservatively estimated to be as $PM_{2.5}$. This is the smallest size fraction and that which is of most concern for health.	X	
	Carbon Monoxide (CO), Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2)	X	
Halogen Acid Gases	Hydrogen Chloride (HCl), Hydrogen Fluoride (HF)	X	
Metals	Cadmium (Cd), Mercury (Hg), Lead (Pb), Arsenic (As), Chromium (Cr) (evaluated separately]	X	X
Organic Compounds	Total Dioxins and Furans (as 2,3,7,8-TCDD TEQ)	X	X
	Total Chlorophenols [surrogates 2,4,6-Trichlorophenol (carc), Pentachlorophenol (non-carc)	X	X
	Total Chlorobenzenes (surrogate Hexachlorobenzene (carc and non-carc)	X	X
	Total Polycyclic Aromatic Hydrocarbons (PAHs) (surrogate Benzo(a)pyrene TEQ (carc))	X	X
	Total Polychlorinated Biphenyls (PCBs)	X	X

Guidance for the characterization of persistence and bioaccumulation is provided in detail within Environment Canada's Existing Substances Program and the Health Canada and Environment Canada's Domestic Substances List Categorization, under the Canadian Environmental Protection Act (CEPA) (http://www.ec.gc.ca/ese-ees/). Persistence refers to the length of time a chemical resides in the environment and is measured by its half-life. This is the time required for the quantity of a chemical to diminish or degrade to half of its original amount within a particular environment or medium. A chemical is considered persistent if its half-life in soil is greater than or equal to (≥) six months (182 days).

Bioaccumulation is a general term used to describe the process by which chemicals are accumulated in an organism directly from exposure to water, soil, or through consumption of food containing the substances. A chemical's potential to bio-accumulate is approximated by its octanol-water partition coefficient (K_{ow}), which refers to the ratio of distribution of a substance in octanol compared to that in water. A chemical is considered bioaccumulative if its Log K_{ow} is greater than or equal to five.

Therefore, COPC retained for consideration of deposition in the PHRA had:

- A half-life in soil greater than or equal to six months; and/or
- Log K_{ow} greater than or equal to 5.

Published results in the scientific literature suggest that the cumulative deposition will not significantly increase soil concentrations over baseline outside of the margin of analytical error. As indicated in Figure 1, a multi-media risk assessment for a given COPC would not be undertaken if there was no significant increase in baseline soil concentration at the maximally impacted receptor location. However, a limited multi-media risk assessment would be completed if there was a significant loading (e.g., above standard analytical error and above soil quality guidelines).

4.4 Receptor Characterization

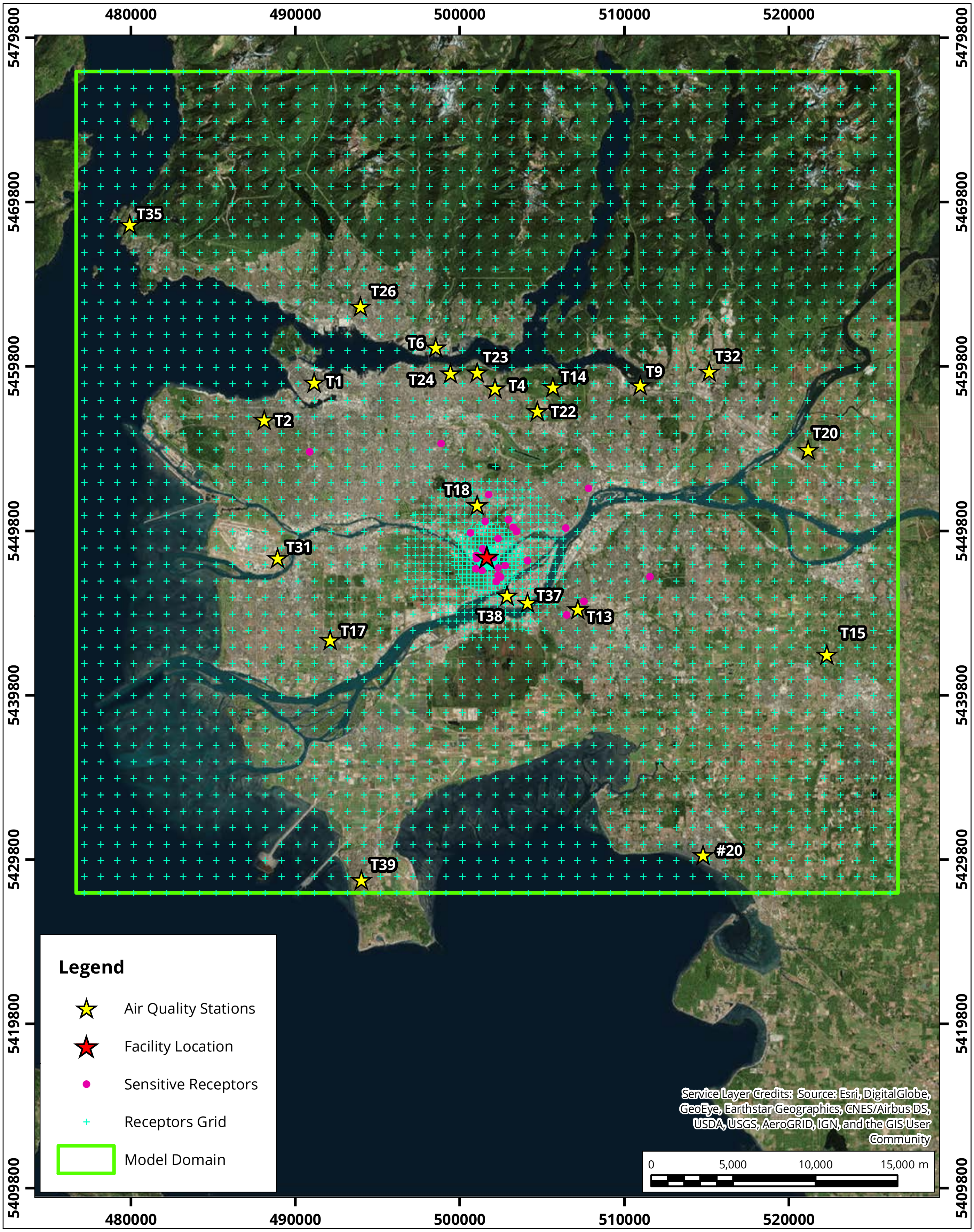
The WTEF is surrounded by mixed land use including:

- Urban;
- Agricultural;
- Industrial/Commercial; and,
- Fraser River.

Selection of potential receptor locations was done in consort with the Air Quality Team at RWDI and Metro Vancouver staff. Although the area surrounding the WTEF is largely industrial and commercial, there are local residential and agricultural land uses (primarily cranberry farming) in the area. In addition, Special Receptors were selected based on potential vulnerable populations, including residential neighborhoods, schools, old age homes, hospitals and recreational areas (Table 3).

Table 3. Special Receptor Locations

ID	Type	Receptor
1	Business	Tippet-Richardson
2		BC Roofing Products
3		Strip Mall
4		Vanguard Steel
5	Residence	River Rd
6		Queensborough
7		New Westminster
8	School	Hamilton Elementary
9		Glenwood Elementary
10		Taylor Park Elementary
11		Queen Elizabeth Elementary
12		Burnaby South
13		Connaught Heights Elementary
14	Child Care	Cranberry Children's Centre
15		Betheny Child Care Centre
16		Happy Learning Child Centre
17		Burnaby Children's Centres Society
18	Senior Center	Seniors Services Society
19		Seniors Services Society
20		Kennedy Senior Recreation Center
21	Hospital	RYT Medical Centre
22		Royal Columbian
23		Surrey Memorial Hospital
24		Burnaby Hospital
25		Womens and Childrens
26	Other	Burnaby Youth Custody Centre
27		RichBerry Cranberry Farm
28		Farm
29		Riverway Golf Course



Study area, receptors, and meteorological stations used for dispersion modelling

Map Projection: NAD 1983 UTM Zone 10N

Waste-To-Energy Facility - Burnaby, British Columbia

True North

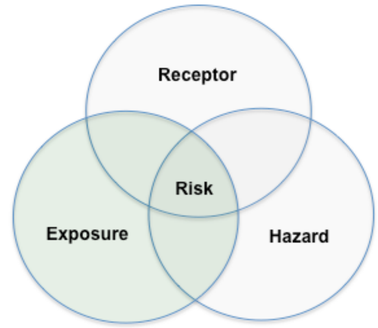
Project #: 1702445

Drawn by: DJH	Figure: 2-1
Approx. Scale: 1:320,000	
Date Revised: Mar 21, 2018	

Map Document: C:\Users\djh\Desktop\GIS Temp\1702445\WTE Domain Receptor Figure.mxd

5 Exposure Assessment

The exposure assessment determines the degree to which people come into contact with airborne concentrations of chemicals released from the WTEF. This includes consideration of age, physiological parameters (e.g., inhalation rate, body weight) and duration of exposure.



5.1 Tier 1 Exposure Assessment

The Tier 1 exposure assessment assumes that an exposed individual lives at the Maximum Point of Impingement (MPOI), 24 hours a day for an entire 80 year lifespan. Even if the MPOI occurs in the residential area, this is a highly conservative approach, because an individual is very unlikely to spend their entire life in one location, and the WTEF is similarly unlikely to operate in its current configuration for 80 years. However, if there is no undue risk at the MPOI for this ever-present individual, than there would not be an increased risk for any of the other Special Receptors (Figure 1).

The Tier 1 assessment includes consideration of health risks due to acute (short-term; 1-hr and 24-hr) and chronic (long-term; annual average) exposures to ground-level airborne concentrations of COPCs.

5.2 Tier 2 Exposure Assessment

For COPC exposures where the Tier 1 assessment showed a health risk great than guideline levels, a Tier 2 assessment would be performed to evaluate three primary age groups at the Special Receptor locations:

- Toddlers (non-carcinogenic)
- Lifetime (carcinogenic)
- Adult Workers (non-carcinogenic / carcinogenic)

Standard practice is to assess toddler exposure for non-carcinogens given that their inhalation rate to body weight ratio is higher than that for adults, resulting in greater exposure dose.

As with the Tier 1 assessment, the Tier 2 assessment includes consideration of health risks due to acute (short-term; 1-hr and 24-hr) and chronic (long-term; annual average) exposures to ground-level airborne concentrations of COPCs.

5.3 Airborne Chemicals of Potential Concern Concentrations

Airborne COPC concentrations were reported in the Air Dispersion Modeling Study (RWDI, 2018). Table 4 provides the COPC concentrations for the 1-hr, 24-hr and annual average concentrations at the MPOI for the five scenarios evaluated, including background concentrations where available. The potential for impact of these concentrations on health is provided in Section 7 Risk Characterization.

Background concentrations were obtained for the criteria air contaminants from the Metro Vancouver Burnaby South and North Delta stations, while the metals were obtained from the National Air Pollution Surveillance stations in the general area of the WTEF. Given that the WTEF volatile organic compound and halogen acid gases that are not routinely monitoring at air stations, no baseline or background concentrations could be obtained for these chemicals.

The Permitted emissions scenario resulted in the highest predicted ground-level concentrations of COPCs. This is not unexpected, as this scenario represents upper limits at which the facility is permitted to operate. In contrast, Operations emissions scenario resulted in predicted ground level concentrations of COPCs at the MPOI that were typically far less than those under the Permitted Scenario. For example, dioxin and furan (PCDD/F) concentrations at the MPOI were four (4) orders of magnitude lower for the Operations Scenario. The exception was NO_2, where concentrations predicted for the Operations scenario were approximately 90% of those predicted for the Permitted Scenario.

A major focus of the *"Evaluation of Contaminant Dispersion and Public Health Risk Assessment"* required by the OC was to determine how Start-up and Shutdown conditions at the WTEF affect emission levels, ground level COPC concentrations, and associated human health risk. Of key interest was how these start-up and shutdown conditions would impact predicted PCDD/F emissions and exposure relative to the Operations scenario. Relative to the Operations scenario, results for the Shutdown scenario show only a slight increase in PCDD/F concentrations at the MPOI, while Start-up conditions resulted in a two orders of magnitude concentration increase. However, the concentrations predicted for the Operations, Start-up and Shutdown scenarios all remained below those predicted for the Permitted Scenario. Similar trends were seen for the other organic chemicals and the metals.

Table 4. Airborne Concentrations of Chemicals of Potential Concern at the Maximum Point of Impingement.

Air Contaminant	Averaging Period	*Background (ug/m3)*	WTEF Alone				WTEF + Background			
			Permitted Model Concentrations	Operational Model Concentrations	Start-up Boiler Model Concentrations + other 2 boilers	Shut-down Boiler Model Concentrations + other 2 boilers	Permitted (with background; ug/m3)	Operational (with background; ug/m3)	Start-up I (with background; ug/m3)	Shut-down (with background; ug/m3)
$PM_{2.5}$	24-hour	*17*	2.0	0.46	0.46	0.46	18	17	17	17
	Annual	*5.9*	0.19	0.03	0.03	0.03	6.1	6.0	6.0	6.0
Carbon Monoxide (CO)	1-hour	*607*	105	53	60	125	712	660	667	732
	8-hour	*560*	19	10	11	24	579	570	571	584
Hydrogen Chloride (HCl)	1-hour	*NV*	115	41	41	45	115	41	41	45
	24-hour	*NV*	9.5	3.8	3.8	4.3	9.5	3.8	3.8	4.3
	Annual	*NV*	1.1	0.41	0.43	0.43	1.08	0.41	0.43	0.43
Hydrogen Fluoride (HF)	1-hour	*NV*	2.1	0.03	0.05	0.03	2.09	0.03	0.05	0.03
Sulphur Dioxide (SO_2)	1-hour	*5.24*	155	53	53	53	160	59	59	59
	24-hour	*3.70*	35	12	12	12	38	16	16	16
	Annual	*1.07*	3.9	1.3	1.3	1.3	5.0	2.4	2.4	2.4
Nitrogen Dioxide (NO_2) (Converted from NO_X)	1-hour	62	73	66	66	66	135	129	129	129
	24-hour	29	33	23	23	23	33	23	23	23
	Annual	25	3.7	2.6	2.6	2.6	29	28	28	28
Total Dioxins and Furans (as PCDD/F TEQ)	24-hour	*NV*	1.4E-08	1.4E-12	5.440E-10	9.3E-11	1.4E-08	1.4E-12	5.440E-10	9.3E-11
	Annual	*NV*	1.6E-09	1.6E-13	5.6E-12	1.1E-12	1.6E-09	1.6E-13	5.6E-12	1.1E-12
Cadmium (Cd)	1-hour	*9.2E-04*	1.5E-02	4.4E-04	4.427E-04	5.8E-04	1.6E-02	1.4E-03	1.366E-03	1.5E-03
	24-hour	*3.7E-04*	1.2E-03	4.1E-05	4.074E-05	5.5E-05	1.6E-03	4.1E-04	4.099E-04	4.2E-04
	Annual	*7.3E-05*	1.4E-04	4.5E-06	4.482E-06	4.8E-06	2.1E-04	7.7E-05	7.728E-05	7.8E-05
Mercury (Hg)	1-hour	*NV*	4.2E-02	2.9E-03	2.940E-03	2.9E-03	4.2E-02	2.9E-03	2.940E-03	2.9E-03
	24-hour	*NV*	3.5E-03	2.7E-04	2.705E-04	2.7E-04	3.5E-03	2.7E-04	2.705E-04	2.7E-04
	Annual	*NV*	3.9E-04	3.0E-05	2.976E-05	3.0E-05	3.9E-04	3.0E-05	2.976E-05	3.0E-05
Lead (Pb)	1-hour	*2.2E-02*	NV	2.5E-03	2.659E-03	2.5E-03	NV	2.4E-02	2.432E-02	2.4E-02
	24-hour	*8.7E-03*	NV	2.3E-04	2.528E-04	2.3E-04	NV	8.9E-03	8.919E-03	8.9E-03
	Annual	*1.9E-03*	NV	2.5E-05	2.626E-05	2.5E-05	NV	2.0E-03	1.958E-03	2.0E-03
Arsenic (As)	1-hour	*3.0E-03*	NV	7.4E-04	9.912E-04	7.4E-04	NV	3.7E-03	3.967E-03	3.7E-03
	24-hour	*1.2E-03*	NV	6.8E-05	9.528E-05	6.8E-05	NV	1.3E-03	1.286E-03	1.3E-03
	Annual	*4.0E-04*	NV	7.5E-06	7.993E-06	7.5E-06	NV	4.0E-04	4.043E-04	4.0E-04
Chromium (Cr)	1-hour	*5.4E-03*	NV	4.2E-03	4.163E-03	4.2E-03	NV	9.6E-03	9.607E-03	9.6E-03
	24-hour	*2.2E-03*	NV	3.8E-04	3.830E-04	3.8E-04	NV	2.6E-03	2.561E-03	2.6E-03
	Annual	*5.5E-04*	NV	4.2E-05	4.214E-05	4.2E-05	NV	5.9E-04	5.921E-04	5.9E-04
Chlorophenols	1-hour	*NV*	2.1E-03	1.8E-07	1.146E-04	5.9E-05	2.1E-03	1.8E-07	1.146E-04	5.9E-05
Pentachlorophenol	1-hour	*NV*	NV	3.8E-07	2.451E-06	1.4E-06	NV	3.8E-07	2.451E-06	1.4E-06
Pentachlorophenol	24-hour	*NV*	NV	3.5E-08	2.436E-07	1.4E-07	NV	3.5E-08	2.436E-07	1.4E-07
Pentachlorophenol	Annual	*NV*	NV	3.9E-09	6.069E-09	5.0E-09	NV	3.9E-09	6.069E-09	5.0E-09
Chlorobenzenes	1-hour	*NV*	2.1E-03	1.5E-05	8.903E-04	1.2E-03	2.1E-03	1.5E-05	8.903E-04	1.2E-03
Pentachlorobenzene	1-hour	*NV*	NV	4.2E-07	1.878E-06	2.1E-06	NV	4.2E-07	1.878E-06	2.1E-06
Pentachlorobenzene	Annual	*NV*	NV	4.3E-09	5.872E-09	6.1E-09	NV	4.3E-09	5.872E-09	6.1E-09
Hexachlorobenzene	1-hour	*NV*	NV	7.6E-08	4.102E-07	2.8E-07	NV	7.6E-08	4.102E-07	2.8E-07
Hexachlorobenzene	Annual	*NV*	NV	7.7E-10	1.133E-09	1.0E-09	NV	7.7E-10	1.133E-09	1.0E-09
Polycyclic Aromatic Hydrocarbons (PAHs)	24-hour	*NV*	8.7E-04	2.5E-07	8.537E-06	5.1E-05	8.7E-04	2.5E-07	8.537E-06	5.1E-05
	Annual	*NV*	9.8E-05	2.8E-08	1.120E-07	5.3E-07	9.8E-05	2.8E-08	1.120E-07	5.3E-07
Polychlorinated Biphenyls (PCBs)	1-hour	*NV*	2.1E-03	4.4E-09	1.396E-08	2.6E-08	2.1E-03	4.4E-09	1.396E-08	2.6E-08
	24-hour	*NV*	1.7E-04	4.0E-10	1.375E-09	2.5E-09	1.7E-04	4.0E-10	1.375E-09	2.5E-09
	Annual	*NV*	2.0E-05	4.4E-11	5.516E-11	6.7E-11	2.0E-05	4.4E-11	5.516E-11	6.7E-11

The Literature Reviews suggest that the maximum ground level point of impingement (MPOI) for modern waste to energy facilities typically occur less than 1 km from facilities. The MPOI for the WTEF differs based on averaging time used to assess ground level concentrations, but in all cases occurs very near the facility in the adjacent Burnaby Fraser Foreshore Park (Table 5). The furthest MPOI was for the annual average concentrations at a distance of just under 400 m from the WTEF to the southwest in the park.

Table 5. Maximum Point of Impingement Distances and Direction from the WTEF Property

Averaging time	MPOI Distance from Property Line (m)	Direction of MPOI from Stack
1 hr	39 to 62	SW to NW
24 hr	106	SW
Annual	377	SW

COPC concentrations at these MPOI locations are used to characterize human exposure in the Tier 1 PHRA. Although no one lives or works at the MPOI locations, they provide a conservative estimate of exposure for surrounding land uses. Although the MPOI was located close to the WTEF, special receptors out several kilometers from the WTEF have been included in the PHRA (Table 3).

5.4 Multi-Media Exposure Pathway Risk Assessment Evaluation of Deposition of Chemicals of Potential Concern

The Literature Review suggests that the primary exposure pathway for COPCs from modern WTE facilities is ground level airborne inhalation. Numerous PHRAs and post-construction monitoring programs for other modern facilities have been demonstrated no significant health risk associated with other routes of exposure such as soil ingestion, dermal contact, and food ingestion. To determine if this is the case for the WTEF, deposition of COPCs to soil over a 10 year period were calculated. This is a standard approach for such facilities, as outlined in the Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities (UEPEA, 2005). Details on the methodology and calculation for deposition of persistent and bioaccumulative COPCs are provided in Appendix A.

The first step in assessing deposition for WTEF emissions was determination of background concentrations of COPCs in soil. Where possible, BC background soil concentrations were obtained from the BC MOE. However, a number of chemicals do not have analytical data for background available for BC, so Ontario background soil concentrations were obtained from Ontario Ministry of the Environment, Conservation and Parks (MECP), Ontario Regulation 153/04. In addition, Ontario MECP provides default chemical analytical reporting limits (RL), which were used for evaluation of the significance of soil loading of COPCs.

Table 6 provides the predicted deposition of COPCs to soil at the MPOI over a 10 year period for the Permitted scenario, as well as percentage change in loading relative to background levels. Ten year deposition of WTEF emissions resulted in changes from background soil levels of 15% or less. However, soil loading of each COPC was either at (PCDD/F) or well below (all other COPCs) the analytical reporting limits. This means that after 10 years of WTEF emissions deposition in soil at the MPOI, the change in COPC concentration would be analytically insignificant, and likely not detectable. This indicates that there would be no appreciable increase in human health risk due to deposited COPC. In addition, an increase in all other multi-media pathway (e.g., vegetation, Fraser River, vegetables, or fish) would depend on an appreciable increase in COPC concentrations in soil (USEPA, 2005).

Table 6. Deposition of Chemicals of Potential Concern to Soil from the Permitted Scenario at the Maximum Point of Impingement

Parameter	Description /Surrogate	Ontario MOE Soil RL mg/kg	Ontario Soil Bkgrd mg/kg	BC Bkgrd mg/kg	Background Data Source	Soil Concentration mg/kg	% Change from Background	Soil Loading Concentration Relative to Reporting Limit (RL)
2,3,7,8-TCDD Equivalent	Total Dioxins and Furans expressed as 2,3,7,8-TCDD TEQ	5.40E-07	7.00E-06		Ontario	5.40E-07	7.7%	At RL
Cadmium (Cd)		1	1	0.8	Burnaby Report	0.02	2.2%	<RL
Mercury (Hg)	Total modeled as (inorganic) - divalent Mg2+	0.1	0.16	0.33	Ontaro	0.04	13.0%	<RL
Lead (Pb)	Sum of Lead, Arsenic and Chromium applied to Each Metal	10	45	80.7	SALM data	0.29	0.4%	<RL
Arsenic (As)		1	11	5.7	SALM data	0.08	1.4%	<RL
Chromium (Cr)		5	67	14.1	SALM data	0.05	0.4%	<RL
Total Chlorophenols	Total Chlorophenols modeled as 2,4,6-Trichlorophenol	0.1	0.1			5.01E-05	0.1%	<RL
Total Chlorobenzenes	Total Chlorobenezesmodeled as hexachlorobeneze	0.05	0.05			3.19E-03	6.4%	<RL
Total PAHs	Total PAHs Modelled as Benzo(a)pyrene	0.05	0.05	0.063	Data received from BCMOE	7.09E-03	11.3%	<RL
Total PCB	Modelled as AROCLOR 1254	0.3	0.3			6.75E-03	2.3%	<RL

The Operations Scenario (Table 7) indicate that after 10 years of deposition of WTEF emissions, all soil COPC concentrations were less than the analytical reporting limit. Further, the increase in soil COPC concentrations over 10 years was <0.35%.

Table 7. Deposition of Chemicals of Potential Concern to Soil from the Operations Scenario at the Maximum Point of Impingement

Parameter	Description /Surrogate	Ontario MOE Soil RL mg/kg	Ontario Soil Bkgrd mg/kg	BC Bkgrd mg/kg	Background Data Source	Soil Concentration mg/kg	% Change from Background	Soil Loading Concentration Relative to Reporting Limit (RL)
2,3,7,8-TCDD Equivalent	Total Dioxins and Furans expressed as 2,3,7,8-TCDD TEQ	5.40E-07	7.00E-06		Ontario	4.83E-11	<0.01%	<RL
Cadmium (Cd)		1	1	0.8	Burnaby Report	2.08E-04	0.026%	<RL
Mercury (Hg)	Total modeled as (inorganic) - divalent Mg2+	0.1	0.16	0.33	Ontaro	1.16E-03	0.35%	<RL
Lead (Pb)	Sum of Lead, Arsenic and Chromium applied to Each Metal	10	45	80.7	SALM data	6.13E-03	<0.01%	<RL
Arsenic (As)		1	11	5.7	SALM data	1.72E-03	<0.01%	<RL
Chromium (Cr)		5	67	14.1	SALM data	1.15E-03	<0.01%	<RL
Total Chlorophenols	Total Chlorophenols modeled as 2,4,6-Trichlorophenol	0.1	0.1			4.06E-09	<0.01%	<RL
Total Chlorobenzenes	Total Chlorobenezesmodeled as hexachlorobeneze	0.05	0.05			2.07E-07	<0.01%	<RL
Total PAHs	Total PAHs Modelled as Benzo(a)pyrene	0.05	0.05	0.063	Data received from BCMOE	1.82E-06	<0.01%	<RL
Total PCB	Modelled as AROCLOR 1254	0.3	0.3			1.36E-08	<0.01%	<RL

The results of the deposition analysis for the WTEF are consistent with those found in the scientific peer-reviewed literature. No appreciable or analytically detectable increase in soil COPC concentrations was predicted, indicating that the only significant exposure pathway for WTEF PHRA is ground-level inhalation of airborne COPCs. Following the PHRA Framework methodology (Figure 1), it was concluded that no multi-media PHRA was required.

6 Hazard Assessment

All chemicals (anthropogenic and natural) have the potential to induce toxicological effects in people; however, it is the chemical concentration, the route of exposure, the duration of exposure, and the inherent toxicity of the chemical that determines the level of effect. Toxicity reference values (TRVs) are defined as doses of chemicals or regulatory benchmarks that people can be exposed to without developing unacceptable health effects. For the PHRA both non-carcinogenic (threshold) and carcinogenic (non-threshold) exposure to chemicals were evaluated. Chemicals that have the potential to elicit both endpoints were assessed against both non-carcinogenic and carcinogenic TRVs where available.

No guidance exists in BC for the selection of TRVs for a facility emissions risk assessment. However, BCMOE *Technical Guidance 7, on Contaminated Sites* (V5, November 2017) recommends the following hierarchy of TRV sources be followed:

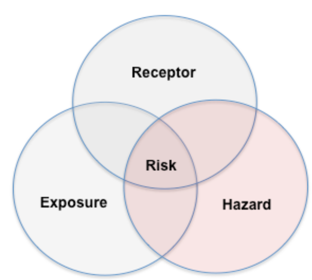
1. *BC Ministry of Environment derived and approved TRVs, including TRVs for:*
    a. *Sodium ion, Chloride ion, and Lead (toddler and adult)*
2. *US EPA: Integrated Risk Information System (IRIS) toxicity reference values in human health risk assessment, for all but the following:*
    a. *Chlorinated dioxins and furans, PCBs*

    For the above substances and classes of substances, the ministry recommends use of the most recently published or publicly available Health Canada TRVs.
3. *Health Canada: Toxicological Reference Values (TRVs) and Chemical-Specific Factors, Version 2.0.*
4. *UN World Health Organization: International Programme on Chemical Safety, INCHEM.*

The guidance indicates that where TRVs from these agencies are lacking for a substance, other credible international scientific agencies should be considered for TRV adoption.

In addition, the toxicity of a chemical depends on whether the exposure is acute (short-term) or chronic (long-term) in duration and TRVs need to be differentiated accordingly. This is particularly true for the inhalation exposure pathway.

Acute: The amount or dose of a chemical that can be tolerated without evidence of adverse health outcomes on a short-term basis. These limits are routinely applied to conditions in which exposures extend from minutes through several hours or several days only (ATSDR, 2006). For the PHRA, acute risks will be evaluated based upon 1- or 24-hour inhalation exposure periods. Acute exposures are applicable only for non-carcinogenic endpoints.



Chronic: The amount or dose of a chemical that is expected to be without health outcomes, even when exposure occurs continuously or regularly over extended periods, possibly lasting for periods of at least a year, and possibly extending over an entire lifetime (ATSDR, 2006). For the PHRA, chronic inhalation exposures will be evaluated on an annual basis for non-carcinogens and over a 10 year exposure period for carcinogenic chemicals.

Because deposition was determined to be insignificant, only inhalation TRVs were sourced for the COPCs:

Benchmark concentration (Inhalation): Similar to reference concentrations, regulatory benchmarks are also health-based, but often policy derived exposure limits. For this assessment only health-based benchmarks were used. Benchmarks are acceptable levels of airborne chemicals and are generally expressed as a concentration of chemical in air (i.e., $\mu g/m^3$) and apply only to threshold chemicals.

Reference Concentration (RfC): an RfC can be defined as (i.e., inhalation NOAEL or LOAEL with uncertainty factors applied) the acceptable level of an airborne chemical for which the primary route of exposure is inhalation. It is expressed as a concentration of the chemical in air (i.e., $\mu g/m^3$) and applies only to threshold chemicals.

Inhalation Slope Factor/Unit Risk: For substances that are genotoxic (certain carcinogens and germ cell mutagens), the TRV represents an upper bound estimate of the slope between exposure and the occurrence of effect (cancer, in most cases). The slope of the dose-response relationship is referred to as the slope factor (relating to exposure dose) or unit risk (relating to exposure concentration in air).

Air quality inhalation assessments vary in large part from multi-pathway risk assessments in that the majority of TRVs are health based benchmarks developed by regulatory agencies for 1-hr, 24-hr and annual average exposures. For $PM_{2.5}$, NO_2 and SO_2, the Canadian Council of Ministers of the Environment Canadian Ambient Air Quality Standards (CAAQs) were used for evaluation. These are primarily health based benchmarks that were derived for protection of health and airshed management.

Where possible, RfCs from the United States Environmental Protection Agency (USEPA) or Health Canada were used over benchmarks for annual average concentrations. For other benchmarks, the credible agencies of Ontario Ministry of the Environment, Conservation and Parks (MECP), Alberta Environment (AENV) and Texas Commission on Environmental Quality (TCEQ) were given priority over other agencies as they have conducted the most comprehensive review of the toxicological literature for COPCs. Additional information on COPC toxicology was provided for those chemicals that exceed their applicable benchmark concentrations.

Table 8. Health-Based Inhalation Benchmarks and Reference Concentrations

Air Contaminant	Averaging Period	Health-Based Standard or RfC (ug/m3)	Critical Effect	Benchmark/RfC	Agency
$PM_{2.5}$	24-hour	27	Health Based	Benchmark	CAAQS (2020)
$PM_{2.5}$	Annual	8.8	Health Based	Benchmark	CAAQS (2020)
Carbon Monoxide (CO)	1-hour	15,000	carboxyhaemoglobin (COHb) blood level of less than 1%.	RFC	Health Canada
Carbon Monoxide (CO)	8-hour	15,700	Health Based	Benchmark	MOE AAQC
Hydrogen Chloride (HCl)	1-hour	75	Health Based	Benchmark	AENV AAQO
Hydrogen Chloride (HCl)	24-hour	20	Health Based	Benchmark	MOE AAQC
Hydrogen Chloride (HCl)	Annual	20	Hyperpasia of the nasal mucosa larynx and trachea	RfC	US EPA
Hydrogen Fluoride (HF)	1-hour	25	Redness of the skin and some burning and irritation of the nose and eyes	Benchmark	TCEQ ESL
Sulphur Dioxide (SO_2)	1-hour	183	effects-based level that is also reflective of technological, economic and societal information	Benchmark	CAAQS (2020)
Sulphur Dioxide (SO_2)	24-hour	275		Benchmark	Ontario AAQC
Sulphur Dioxide (SO_2)	Annual	13	effects-based level that is also reflective of technological, economic and societal information	Benchmark	CAAQS (2020)
Nitrogen Dioxide (NO_2) (Converted from NO_X)	1-hour	113	Respiratory Irritation	Benchmark	CAAQS (2020)
Nitrogen Dioxide (NO_2) (Converted from NO_X)	24-hour	200	Respiratory Irritation	Benchmark	Ontario AAQC
Nitrogen Dioxide (NO_2) (Converted from NO_X)	Annual	32	Respiratory Irritation	Benchmark	CAAQS (2020)
Total Dioxins and Furans (as PCDD/F TEQ)	24-hour	1.00E-07	Health Based	Benchmark	Ontario AAQC
Total Dioxins and Furans (as PCDD/F TEQ)	Annual	1.00E-06	Route-to-route extrapolation from RfD	RfC	Health Canada
Cadmium (Cd)	1-hour	0.1	Kidney Damage	benchmark	TCEQ ESL
Cadmium (Cd)	24-hour	0.025	Respiratory Irritation	benchmark	Ontario AAQC
Cadmium (Cd)	Annual	0.005	Kidney Effects	benchmark	Ontario AAQC
Mercury (Hg)	1-hour	0.6	CNS disturbances in rat offspring	benchmark	CalEPA REL
Mercury (Hg)	24-hour	2	Health Based	benchmark	Ontario AAQC
Mercury (Hg)	Annual	0.3	Neurotoxicity	RfC	US EPA
Sum of Lead (Pb), Arsenic (As), Chromium (Cr)	1-hour	1.5	Health-Based on Pb Exposure	Benchmark	AENV AAQO / TCEQ ESL
Lead (Pb)	1-hour	1.5	Impairment of hematopoietic system	Benchmark	AENV AAQO
Lead (Pb)	24-hour	0.5	Neurological effects in children	Benchmark	Ontario AAQC
Lead (Pb)	Annual	0.5	Blood lead levels	RfC	WHO
Arsenic (As)	1-hour	0.2	Decreased fetal weight in mice	Benchmark	CalEPA REL
Arsenic (As)	24-hour	0.3	Irritation, sensitization, immune suppression, teratogenesis, genotoxicity and carcinogenicity in exposed individuals	Benchmark	Ontario AAQC
Arsenic (As)	Annual	0.015	Decreased intellectual function in 10 year old children	Benchmark	CalEPA REL
Chromium (Cr)	1-hour	1	Health Based	Benchmark	TCEQ ESL
Chromium (Cr)	24-hour	0.5	Health Based	Benchmark	Ontario AAQC
Chromium (Cr)	Annual	60	Kidney effects in humans	RfC	RIVM
Chlorophenols	1-hour	5	Eye and upper respiratory tract irritation; CNS impairment; and cardiac system impairment	Benchmark	Surrogate TCEQ ESL
Pentachlorophenol	1-hour	5	Eye and upper respiratory tract irritation; CNS impairment; and cardiac system impairment	Benchmark	TCEQ ESL
Pentachlorophenol	24-hour	20	Health Based	Benchmark	Ontario AAQC
Pentachlorophenol	Annual	0.5	Cardiac system impairment	Benchmark	TCEQ ESL
Chlorobenzenes	1-hour	0.25	Health Based	Benchmark	TCEQ ESL
Pentachlorobenzene	1-hour	1000	Health Based	Benchmark	TCEQ ESL
Pentachlorobenzene	Annual	100	Health Based	Benchmark	TCEQ ESL
Hexachlorobenzene	1-hour	0.25	Health Based	Benchmark	TCEQ ESL
Hexachlorobenzene	Annual	0.025	Health Based	Benchmark	TCEQ ESL
Polycyclic Aromatic Hydrocarbons (PAHs)	24-hour	5.00E-04	Health Based Cancer Risk B(a)P	Benchmark	Ontario AAQC
Polycyclic Aromatic Hydrocarbons (PAHs)	Annual	1.00E-04	Health Based Cancer Risk B(a)P	Benchmark	Ontario AAQC
Polychlorinated Biphenyls (PCBs)	1-hour	0.1	Health Based	Benchmark	TCEQ ESL
Polychlorinated Biphenyls (PCBs)	24-hour	0.15	Health Based	Benchmark	Ontario AAQC
Polychlorinated Biphenyls (PCBs)	Annual	0.035	Health Based	Benchmark	Ontario AAQC

Seven of the COPCs were also determined to be carcinogenic (Table 9). Unit Risk (UR), otherwise known as cancer slope factors, were sourced from the USEPA and Health Canada. These URs were used to calculate the incremental lifetime cancer risks (ILCR) for COPCs.

Table 9. Inhalation Unit Risks / Cancer Slope Factors

Air Contaminant	Carcinogenic Unit Risk (ug/m3)-1	Agency
Cadmium (Cd)	9.8E-03	Health Canada
Arsenic (As)	4.3E-03	USEPA IRIS
Chromium (CR)	1.1E-02	Health Canada
Chlorophenols	3.1E-06	USEPA IRIS
Chlorobenzenes	4.6E-04	USEPA IRIS
Hexachlorobenzene	4.6E-04	USEPA IRIS
Total PAHs (as B(a)P	6.0E-04	USEPA IRIS

7 Risk Characterization

The inhalation risk characterization was conducted in a Tiered approach, as detailed below.

7.1 Tier 1 Risk Characterization

The Tier 1 risk characterization assumes that an exposed individual lives at the MPOI, 24 hours a day for an entire 80 year lifespan.

7.1.1 Tier 1 Non-Carcinogenic Risk Assessment at Maximum Point of Impingement

For non-carcinogenic COPCs the modeled ground level COPC concentrations were divided by the appropriate benchmark or RfC concentration.

$$\text{Hazard Quotient (HQ) / Concentration Ratio (CR)} = \frac{\text{Air Concentration } (ug/m^3)}{\text{RfC or Benchmark } (ug/m^3)}$$

This was done to evaluate both acute (1-hour and 24-hour) and chronic (annual) ground level air concentrations predicted at the MPOI. The resulting unitless Hazard Quotients (HQ), also referred to as Concentration Ratio (CR), was benchmarked against the acceptable value of 1.0 for criteria air contaminants (CACs), and 0.2 for all other COPCs. If the modeled air concentrations are less than the threshold "acceptable" health based benchmarks or RfCs, then no undue risk to exposure individuals would be predicted. Where available, the background ambient air concentrations for COPCs were added to predicated concentrations associated with WTEF emissions.

Table 10 provides the HQ/CR results for the inhalation assessment. The majority of COPCs had HQ/CR <1.0 for CACs and <0.2 for all other COPS at the MPOI, with the exception of:

- Permitted Scenario: 1-hr HCl and 24-hr total PAH (as B[a]P TEQ)
- All Scenarios + Background: 1-hr NO_2

Further evaluation of the spatial extent of the exceedances can be seen in the isopleth diagrams in the Air Dispersion Modeling Study (RWDI, 2018) and at Special Receptors (Table 12) for the Permitted Scenario.

Table 10. Hazard Quotients / Concentration Ratios for Chemicals of Potential Concern at the Maximum Point of Impingement

Air Contaminant	Averaging Period	*Background (Concentration Ratio)*	Permitted (Concentration Ratio)	Operational (Concentration Ratio)	Start-up (Concentration Ratio)	Shut-down (Concentration Ratio)
$PM_{2.5}$	24-hour	*0.61*	0.68	0.63	0.63	0.63
	Annual	*0.68*	0.70	0.68	0.68	0.68
Carbon Monoxide (CO)	1-hour	*0.040*	0.047	0.044	0.044	0.049
	8-hour	*0.036*	0.037	0.036	0.036	0.037
Hydrogen Chloride (HCl)	1-hour	*NV*	**1.5**	0.54	0.54	0.60
	24-hour	*NV*	0.48	0.19	0.19	0.21
	Annual	*NV*	0.054	0.021	0.021	0.022
Hydrogen Fluoride (HF)	1-hour	*NV*	0.084	0.0010	0.0020	0.0010
Sulphur Dioxide (SO_2)	1-hour	*0.029*	0.87	0.32	0.32	0.32
	24-hour	*0.013*	0.14	0.06	0.06	0.06
	Annual	*0.083*	0.38	0.18	0.18	0.18
Nitrogen Dioxide (NO_2) (Converted from NO_X)	1-hour	0.55	**1.2**	**1.1**	**1.1**	**1.1**
	24-hour	0.14	0.16	0.12	0.12	0.12
	Annual	0.79	0.90	0.87	0.87	0.87
Total Dioxins and Furans (as PCDD/F TEQ)	24-hour	*NV*	1.4E-01	1.4E-05	5.440E-03	9.3E-04
	Annual	*NV*	1.6E-03	1.6E-07	5.6E-06	1.1E-06
Cadmium (Cd)	1-hour	*9.2E-03*	1.6E-01	1.4E-02	1.366E-02	1.5E-02
	24-hour	*1.5E-02*	6.3E-02	1.6E-02	1.639E-02	1.7E-02
	Annual	*1.5E-02*	4.2E-02	1.5E-02	1.546E-02	1.6E-02
Mercury (Hg)	1-hour	*NV*	7.0E-02	4.9E-03	4.900E-03	4.9E-03
	24-hour	*NV*	1.7E-03	1.4E-04	1.353E-04	1.4E-04
	Annual	*NV*	1.3E-03	9.9E-05	9.921E-05	9.9E-05
Lead (Pb)	1-hour	*1.4E-02*	NV	1.6E-02	1.622E-02	1.6E-02
	24-hour	*1.7E-02*	NV	1.8E-02	1.784E-02	1.8E-02
	Annual	*3.9E-03*	NV	3.9E-03	3.915E-03	3.9E-03
Arsenic (As)	1-hour	*1.5E-02*	NV	1.9E-02	1.984E-02	1.9E-02
	24-hour	*4.0E-03*	NV	4.2E-03	4.286E-03	4.2E-03
	Annual	*2.6E-02*	NV	2.7E-02	2.696E-02	2.7E-02
Chromium (Cr)	1-hour	*5.4E-03*	NV	9.6E-03	9.607E-03	9.6E-03
	24-hour	*4.4E-03*	NV	5.1E-03	5.121E-03	5.1E-03
	Annual	*9.2E-06*	NV	9.9E-06	9.869E-06	9.9E-06
Chlorophenols	1-hour	*NV*	4.2E-04	3.5E-08	2.292E-05	1.2E-05
Pentachlorophenol	1-hour	*NV*	NV	7.6E-08	4.903E-07	2.9E-07
Pentachlorophenol	24-hour	*NV*	NV	1.8E-09	1.218E-08	7.1E-09
Pentachlorophenol	Annual	*NV*	NV	7.7E-09	1.214E-08	1.0E-08
Chlorobenzenes	1-hour	*NV*	8.4E-03	6.0E-05	3.561E-03	4.8E-03
Pentachlorobenzene	1-hour	*NV*	NV	4.2E-10	1.878E-09	2.1E-09
Pentachlorobenzene	Annual	*NV*	NV	4.3E-11	5.872E-11	6.1E-11
Hexachlorobenzene	1-hour	*NV*	NV	3.1E-07	1.641E-06	1.1E-06
Hexachlorobenzene	Annual	*NV*	NV	3.1E-08	4.534E-08	4.0E-08
Polycyclic Aromatic Hydrocarbons (PAHs)	24-hour	*NV*	**1.7**	5.1E-04	1.707E-02	1.0E-01
	Annual	*NV*	9.8E-01	2.8E-04	1.120E-03	5.3E-03
Polychlorinated Biphenyls (PCBs)	1-hour	*NV*	2.1E-02	4.4E-08	1.396E-07	2.6E-07
	24-hour	*NV*	1.2E-03	2.7E-09	9.167E-09	1.7E-08
	Annual	*NV*	5.6E-04	1.3E-09	1.576E-09	1.9E-09

7.1.2 Tier 1 Carcinogenic Risk Assessment at Maximum Point of Impingement

The modelled concentrations of carcinogenic COPCs in air at the MPOI were multiplied by their unit risk / inhalation slope factor to provide an estimate of the incremental lifetime cancer risk (ILCR).

Incremental lifetime Cancer risk = *Air Concentration (ug/m³) x* Unit Risk (ug/m³)⁻¹

The result is a unitless probability expressing the potential increase in cancer cases that could manifest due to exposure to the WTEF emissions. The ILCR was benchmarked against the acceptable level of 1 potential additional cancer case in an exposed population of 100,000 (i.e., 1E-05 or 0.00001). ILCRs at the MPOI under the Tier 1 assessment were not time activity pattern adjusted.

Risk estimates for all carcinogenic COPCs are provided in Table 11. ILCRs for all seven chemicals in all four scenarios were <1E-05, or 1 additional cancer case in 100,000 people exposed. Therefore, results in indicate that the WTEF does not pose an undue cancer risk to those in the vicinity of the facility.

Table 11. Incremental Lifetime Cancer Risk of Chemicals of Potential Concern Exposure at the Maximum Point of Impingement

Air Contaminant	ILCR Permit	ILCR Operations	ILCR Start-up	ILCR Shutdown
Cadmium (Cd)	2.1E-06	7.6E-07	7.6E-07	7.6E-07
Arsenic (As)	NV	1.7E-06	1.7E-06	1.7E-06
Chromium (CR)	NV	6.5E-06	6.5E-06	6.5E-06
Chlorophenols	6.5E-09	5.4E-13	3.6E-10	1.8E-10
Chlorobenzenes	9.6E-07	6.9E-09	4.1E-07	5.5E-07
Hexachlorobenzene	NV	3.6E-13	5.2E-13	4.6E-13
Total PAHs (as B(a)P	5.9E-08	1.7E-11	6.7E-11	3.2E-10

7.2 Tier 2 Risk Characterization

A Tier 2 assessment is not required for the majority of COPCs in any of the evaluated scenarios. However, those chemicals that exceeded the conservative Tier 1 benchmarks require further assessment as to their potential impact on health. It was determined that for each of the three COPCs that were retained (HCl, NO_2 and total PAHs), evaluation of the frequency of exceedance events and further description of the toxicological basis of the benchmarks was warranted.

7.2.1 Spatial and Temporal Evaluation of Benchmark Exceedances

Table 12 provides the concentrations of the three COPCs at the Special Receptors for the Permitted Scenario.

The 1-hr HCl benchmark concentration is 75 ug/m^3 and the 24-hr PAH benchmark is 5E-04 ug/m^3. As the results in the table indicate, for both chemicals, the exceedances (highlighted in yellow) are located close to the WTEF and are not widespread over the study area.

For NO_2 the 2020 CAAQs 1-hr benchmark is 113 ug/m^3. In all PHRA scenarios, all predicted ground level concentrations due to the facility emissions alone are below this benchmark. However, the existing background ambient NO_2 concentration at the Metro Vancouver Burnaby South monitoring station is 62 ug/m^3. Therefore, subtracting the background concentration from the CAAQS benchmark results in an allowance of an additional 51 ug/m^3 from the facility alone.

The majority of the Special Receptors had modeled 1-hr concentrations in excess of the 51 ug/m^3 buffer, as indicated in Table 12.

Table 12. Hazard Quotients / Concentration Ratios for Chemicals of Potential Concern Exceedances at Special Receptor Locations for the Permitted Scenario, Including Background Levels for 1-hour NO_2.

Receptor	1-hour NO2 (ug/m3)	1-hour HCl (ug/m3)	24-hour PAHs (ug/m3)
Benchmark	113	75	5.00E-04
MPOI	145	115	8.7E-04
Tippet-Richardson	134	89	5.3E-04
BC Roofing Products	132	46	5.1E-04
Strip Mall	127	24	2.8E-04
Vanguard Steel	122	27	2.7E-04
River Rd	122	33	2.3E-04
Queensborough	128	34	3.6E-04
New Westminster	102	20	2.2E-04
Hamilton Elementary	127	31	3.0E-04
Glenwood Elementary	99	23	2.4E-04
Taylor Park Elementary	113	23	1.8E-04
Queen Elizabeth Elementary	87	11	1.3E-04
Burnaby South	127	29	2.5E-04
Connaught Heights Elementary	123	27	3.0E-04
Cranberry Childrenâ€™s Centre	114	28	2.7E-04
Betheny Child Care Centre	128	30	3.0E-04
Happy Learning Child Centre	91	23	1.6E-04
Burnaby Childrenâ€™s Centres Society	91	22	1.6E-04
Seniors Services Society	117	24	2.1E-04
Seniors Services Society	117	24	2.1E-04
Kennedy Senior Recreation Center	98	13	1.4E-04
RYT Medical Centre	102	18	1.9E-04
Royal Columbian	72	6.7	5.1E-05
Surrey Memorial Hospital	82	10	1.2E-04
Burnaby Hospital	93	12	1.2E-04
Womens and Childrens	71	4.8	4.5E-05
Burnaby Youth Custody Centre	126	36	3.2E-04
RichBerry Cranberry Farm	127	41	3.6E-04
Farm	128	40	4.0E-04
Riverway Golf Course	97	17	2.4E-04

The next step was to evaluate the number of hours (NO_2 and HCl) or days (in the case of PAHs) that that benchmark concentrations are predicted to be exceeded in a given year. Predicated concentrations for the COPCs are provided by percentile in Table 13. The shaded cells indicate the percentiles that exceed the relevant benchmarks. For both 1-hr NO_2 and HCl, predicated concentrations fall below the relevant benchmarks by the 99.98th. This means that for both of these COPCs, benchmark concentrations would be exceeded for 2 hours or less in a year. For the 24-hr total PAHs, predicated concentrations fall below the relevant benchmarks by the 99.9th percentile, representing an exceedance of the benchmark for less than 1 day a year.

Table 13. Percentile Concentration Evaluation for Chemicals of Potential Concern That Exceed the Concentration Ratio at the Maximum Point of Impingement for the Permitted Scenario

Pecentile	1-hour NO2 (ug/m3)	1-hour HCl (ug/m3)	24-hour PAHs (ug/m3)
Standard	51	75	5.0E-04
50	1.7E-05	0.00	1.2E-05
75	0.014	0.01	8.2E-05
90	0.14	0.11	1.6E-04
95	0.45	0.43	2.2E-04
98	2.3	2.4	3.0E-04
99	5.9	6.6	3.6E-04
99.9	22	24	5.0E-04
99.98	47	37	7.9E-04
100	66	115	8.7E-04

7.2.2 Tier 2: 1-hr Hydrogen Chloride Evaluation for Permitted Scenario

The exceedance of the HCl benchmark concentration was predicted only in the Permitted emissions scenario, and not in Operational, Start-up or Shut-down scenarios. As such, it does not indicate a health risk under current operating conditions at the facility. Instead, it highlights the potential for a very time-limited exceedance of benchmark levels (less than 2 hours per year) if the facility where to continuously emit HCl from all three boilers at its OC permitted levels, which is very unlikely to occur.

For additional context on the predicted exceedance, it is useful to look to the USEPA acute exposure guideline (AEGL) values for the protection of very short-term acute exposure.

> *AEGL-1 is the airborne concentration (expressed as parts per million or milligrams per cubic meter [ppm or mg/m3]) of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic, nonsensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.*

For HCl:

> *The lowest acute exposure guideline level (AEGL) values are based on a 45-minute (min) no-observed-adverse- effect level (NOAEL) of 1.8 parts per million (ppm) in exercising adult asthma patients (Stevens et al. 1992). No uncertainty factors (UFs) were applied for inter- or intraspecies variability because the study population consisted of sensitive humans. The same 1.8-ppm value was applied across the 10- and 30-min and 1-, 4-, and 8-hour (h) exposure times, because mild irritance generally does not vary greatly over time, and because it is not expected that prolonged exposure will result in an enhanced effect.*

This results in an AEGL 1 of 2700 ug/m^3 for 1-hr exposure to HCl, much higher than predicted level of 115 ug/m^3 for the Permitted emissions scenario.

In summary, based on the fact the predicted benchmark exceedance occurs only under the Permitted emissions scenario and is very limited in temporal and spatial extent, it can be reasonably concluded that maximum short term HCl concentrations at the MPOI under actual operating conditions do not pose an undue public health risk.

7.2.3 Tier 2: 24-hr Total PAH Evaluation for Permitted Scenario

The exceedance of the Total PAH (as B[a]P) benchmark concentration was predicted only in the Permitted emissions scenario, and not in Operational, Start-up or Shut-down scenarios. As such, it does not indicate a health risk under current operating conditions at the facility. Instead, it highlights the potential for a very time-limited exceedance of benchmark levels (less than 1 day per year) if the facility where to continuously emit Total PAH from all three boilers at its OC permitted levels, which is very unlikely to occur.

In addition, the ILCR for total PAHs as B(a)P TEQ was 5.9E-08 for the Permitted Scenario, was three orders of magnitude below the acceptable BC benchmark (Table 13). Based on the fact the predicted benchmark exceedance occurs only under the Permitted emissions scenario, is very limited in temporal and spatial extent, and calculated cancer risk even for the Permitted Scenario is well below BC benchmark levels, it can be reasonably concluded that maximum short term Total PAH concentrations at the MPOI under actual operating conditions do not pose an undue public health risk.

7.2.4 Tier 2: 1-hr NO_2 Evaluation for all Scenarios

Maximum predicted 1-hr NO_2 concentrations due to WTEF emissions alone were below the CAAQS 2020 guideline of 113 ug/m^3 at the MPOI for all emissions scenarios. However, when ambient background NO_2 levels are added, the maximum NO_2 concentrations at the MPOI (and other Special Receptors) exceed of the CAAQS for all emissions scenarios.

From the CAAQS on NO_2:

> *Short-term exposure to NO_2 can elicit a range of adverse respiratory effects including decreased lung function, increased respiratory symptoms, and airway inflammation, and cause aggravation of respiratory diseases, particularly asthma and chronic obstructive pulmonary disease. Long-term exposure to NO_2 may contribute to allergic responses, asthma development and may increase susceptibility to respiratory infections. Inhalation of NO_2 has also been linked to effects on the cardiovascular system, and some reproductive effects.*

The Human Health Risk Assessment for Nitrogen Dioxide (Health Canada, 2016) states:

> *Thus several lines of evidence indicate that ambient NO_2 is associated with asthma exacerbations. The epidemiological associations with short-term asthma-related endpoints exhibit strength of association, consistency, robustness, and coherence. In conjunction with the experimental findings in animals and humans, the overall evidence indicates that there is a causal relationship between short-term exposure to ambient NO_2 at current levels and increased asthma-related morbidity (including airway inflammation and AHR, respiratory symptoms, and asthma hospitalizations and ERVs).*

However, per Table 13, the 98th percentile modelled 1-hr NO_2 levels at the MPOI was only 2.3 ug/m^3. This represents only a 3.5% increase in expected ground level NO_2 concentrations at the MPOI, remaining well below the CAAQS 2020 guideline for 98% of the year. In fact, predicted levels for all emissions scenarios remain below the CAAQS for all but 2 hours, or 99.98% of the year. Further, it is important to note that background concentrations used in this assessment where taken from Metro Vancouver's

Burnaby South monitoring station, which was cited in the late 1980s specifically to monitor for ambient air quality impacts of the WTEF. As such, it is likely that measured background NO_2 levels at this monitoring station already incorporate NO_2 emitted from the facility in the ambient background. In this way, additional Burnaby South background adds a further level of conservatism, and may result in some "double counting" of NO_2 emissions impacts from the facility.

Finally, the USEPA AEGL-1 is 0.5 ppm [940 ug/m^3] for 1-hr maximum exposure to NO_2. This value was derived as the no-adverse-effect level (NOAEL) for the asthmatic population and since asthmatics are potentially the most susceptible population, no uncertainty factor was applied. The maximum predicted 1-hr NO_2 concentration at the MPOI in the Permitted Scenario was 135 ug/m^3, well below the AEGL-1.

Based on the fact that the predicted benchmark exceedance is very limited in temporal extent, and may include "double counting" of NO_2 emissions from the facility due to addition of background levels measured near the facility, it can be reasonably concluded that maximum short term NO_2 concentrations at the MPOI under actual operating conditions do not pose an undue public health risk.

8 Results and Recommendations for Potential Future Monitoring

The OC includes specific requirements related to the efficacy of the current air quality monitoring network and emissions monitoring program at the WTEF. These requirements are detailed below, along with discussion of the results of the PHRA.

1. An assessment of the existing regional air quality monitoring network and program to confirm its appropriateness and effectiveness in assessing potential impacts from facility emissions.

The results of the PHRA indicate that all concentrations of COPCs in the Operations, Start-up and Shutdown Scenarios were below their respective health-based benchmarks, with the exception of 1-hr NO_2. Due to the very short duration of exceedance, and the potential conservatism of background values used in the assessment, it was determined that this exceedance does not constitute an undue public health risk.

Metro Vancouver has an extensive regional air quality monitoring network, including Burnaby South and North Delta in relatively close proximity to the WTEF. These stations were originally sited in the late 1980s specifically to monitor for air quality impacts from the WTEF. Spatial air quality modelling results shown in the Air Dispersion Modelling Study (RWDI, 2018) indicate that these stations are sited in areas that may experience higher ground levels impacts due to facility emission relative to other areas around the facility. However, given that modelling results indicate that ground-level concentrations of COPCs even at the MPOI immediately beside the facility do not pose an undue public health risk, it can reasonably be concluded that the existing monitoring network is appropriate and effective in capturing and assessing potential impacts from facility emissions. Therefore, additional ground level monitoring is not required to ensure the protection of public health.

2. *An assessment of the effectiveness of the monitoring requirements made in this Operational Certificate, and recommendations for sampling or evaluation of receptors such as soil, vegetation, or other media.*

The results of the PHRA indicate that under Operations, Start-up and Shutdown Scenarios there is no undue risk to public health from ground level inhalation exposure to COPC emitted from the WTEF. The results of the deposition assessment indicate that there would be no analytically significant accumulation of COPCs in soil, even at the MPOI, over a 10-year period. This is consistent with the findings of the literature review. Therefore, there would be no added benefit to monitoring COPCs in soil, vegetation or other environmental media. The Continuous Emissions Monitoring (CEMS) and quarterly stack testing program required under the current OC provides an appropriate means of monitoring facility air quality impacts to ensure the protection of public health.

9 Conclusions

This PHRA, and the associated Air Dispersion Modeling Study and Startup and Shutdown testing were conducted to satisfy reporting requires in the BC MOECC Operational Certificate (OC) for the WTEF. As expected, the highest ground level concentrations of COPCs were predicted for the Permitted Scenario. This is the maximum concentration of contaminants that can be emitted from the WTEF. There was a considerable decrease of maximum ground level contaminant concentrations for the Operations Scenario, or the actual emissions that come from the facility. This is because the WTEF routinely emits considerably less of each contaminant than limited by the permit. For the first time, COPCs were directly monitored at the facility's stack during Start-up and Shutdown conditions. There was a slight increase in concentrations of some COPCs at the MPOI over the day-to-day Operational Scenario; however, these events did not materially impact the ground level concentrations of most contaminants.

The results of the deposition analysis for the WTEF were consistent with those found in the scientific peer-reviewed literature. No analytically significant increase in soil COPC concentrations was predicted. As a result, no multi-media PHRA was performed, per the PHRA Framework methodology. The only operable exposure pathway was determined to be through ground level inhalation of COPCs.

The Tier 1 inhalation assessment determined that COPCs were below their respective health-based benchmarks for the Operations, Start-up and Shutdown Scenarios and required no further evaluation. The only exceedances of the health-based benchmarks of COPCs were for the Permitted Scenario maximum concentrations of 1-hr HCl and 24-hr total PAHs of and 1-hr NO_2 for all scenarios when added to the existing background level.

A Tier 2 assessment was conducted for the COPC health-based benchmark exceedances. This was completed through additional spatial, temporal and toxicological evaluation for each of the three chemicals and time periods. The following was found:

1-hr NO_2

- The maximum 1-hr concentration of NO_2 from WTEF emission only was below the CAAQS for all scenarios. However, when added to the background ambient conditions there was an exceedance of the CAAQS at several of the Special Receptor locations for each of the scenarios.
- Further assessment of modelling data indicated CAAQS exceedance occurred during very limited time periods, amounting to less than 2 hours per year.
- Ambient background data for NO_2 was taken the Metro Vancouver Burnaby South monitoring station, which already includes existing emissions from the WTEF its background measurements. As such, addition of the ambient background to model results may result in some "double counting" of facility emissions.
- Additionally, review of the toxicological information indicates that even the maximum concentration of 1-hr NO_2 from the WTEF plus background was below the health-based USEPA

NAAQS and more than four times lower than the USEPA Acute AEGL-1 value for the protection of health.

1-hr HCl

- The exceedance of the HCl benchmark concentration was predicted only for the Permitted emissions scenario, and not in Operations, Start-up or Shut-down scenarios.
- Further assessment of modelling data indicated HCl benchmark exceedance for the Permitted emissions scenario occurred during very limited time periods, amounting to less than 2 hours per year.
- Modeled HCl levels do not exceed USEPA AEGL-1 for 1-hr HCl.

24-hr Total PAHs

- The exceedance of the total PAH benchmark concentration was predicted only for the Permitted emissions scenario, and not in Operations, Start-up or Shut-down scenarios.
- Further assessment of modelling data indicated total PAH benchmark exceedance for the Permitted emissions scenario occurred during very limited time periods, amounting to less than 1 day per year.
- The incremental lifetime cancer risk for total PAHs as B(a)P TEQ was 5.9E-08 for the Permitted Scenario three orders of magnitude below the acceptable BC benchmark for cancer risk.

Based on the Tier 2 spatial, temporal and toxicological evaluation, exposure to the maximum concentrations of all three COPCs at the MPOI are short lived, in close proximity to the WTEF and below toxicologically relevant benchmarks. Therefore, it was concluded that no undue public health risk exists for those living, working or engaged in recreational activity surrounding the WTEF.

Based on these results additional monitoring of COPCs in air, soil, water, vegetation or other environmental media are not recommended. Although there were minor temporal exceedances of the Permitted Scenario these OC limits are reasonable, do not result in a public health risk and therefore no changes to the OC limits are recommended. The findings of the PHRA are consistent with the past two decades of peer-reviewed scientific literature and government reports.

Appendix A
Deposition Calculations

Methodology

The following sections present the equations used to calculate the concentrations used in the PHRA. Generally, the equations and the terms explained. Unless otherwise stated, the equations presented are found in US EPA (2005). In cases where values used were based on site specific quantities, rationale for use of these values is provided below. Where known standards or default values (as presented in US EPA, 2005) were adopted, these values are given in brackets.

Soil Concentration

Chemical concentrations in soil are calculated by summing the various wet and dry as well as vapour and particle phase deposition of chemicals to the soil. The US EPA (2005) guideline includes three different deposition equations, one for standard (non-carcinogenic) chemicals, and two for carcinogenic chemicals. The equation used for each parameter depends on the type of chemical and duration of exposure. For this study, the long term exposure results in the requirement for only one of the carcinogenic equations to be used in the model. The non-carcinogenic equation is a variation of the first carcinogenic equation, calculating the highest 1-year annual average soil concentration; which typically occurs at the end of the operating life of the emission source (US EPA, 2005).

Carcinogen – soil concentration averaged over exposure duration

$$C_s = \frac{\left(\frac{D_S \times tD - C_{stD}}{ks}\right) + \left(\frac{C_{stD}}{ks}\right) \times (1 - \exp[-ks \times (T_2 - tD)])}{(T_2 - T_1)} + C_{sBackground}$$

For T1<tD<T2 – (exposure duration greater than operating lifetime of the emission source):

$$C_s = \frac{D_s \times [1 - \exp(-ks \times tD)]}{ks}$$

Non-Carcinogens – maximum annual average soil concentration

Where:			Units
Cs	=	average chemical soil concentration over exposure duration	mg/kg soil
Ds	=	deposition term; discussed below	mg chemical/kg soil/yr
T_1	=	time period at the beginning of combustion	0 years
ks	=	chemical soil loss constant due to all processes; discussed below	yr^{-1}
tD	=	time period over which deposition occurs	10 yr
C_{stD}	=	soil concentration at time tD (equivalent to C_s for non-carcinogens)	mg/kg
T_2	=	length of exposure duration (applicable for carcinogens only)	80 yr

The deposition term (Ds) is calculated as follows:

$$D_s = \left[\frac{100 \times Hg_{factor} \times Q}{Z_s \times BD}\right] \times D_{loading}$$

Where: Units

Ds	=	deposition term	mg CoPC/kg soil/yr
100	=	units conversion factor	$mg\text{-}m^2/kg\text{-}cm^2$
$Hg_{factorDS}$	=	mercury factor for deposition; discussed below	unitless
Q	=	CoPC emission rate; discussed previously	g/s
Zs	=	soil mixing zone depth	cm
BD	=	soil bulk density (1.5 g/cm^3)	g soil/cm^3 soil
$D_{loading}$	=	loading of deposition based on modelling output, CoPC-specific	($g/m^2/yr$)

The $Hg_{factorDS}$ for deposition is 1.0 for all CoPCs, with the following exceptions:
0.0 for Hg^0 (i.e., 0.482 * 0.0)
0.47236 for Hg^{2+} (i.e., 0.482 * 0.98)
0.00964 for MHg (i.e., 0.482 * 0.02)

A soil mixing zone depth (Zs) of 10 cm has been selected for this assessment, based on contaminant distribution in soils and root uptake zones. The deposition loading terms $D_{loading}$ are determined by air modelling of the site of a reference particulate and vapour, and are applied to the other CoPC's based on chemical classification as determined during the air modelling. US EPA (2005) outlines several mechanisms which result in the removal of chemicals from the soil. These methods may or may not occur simultaneously, and have varying amounts of significance depending on the type of chemical. The total rate at which a chemical is lost from the soil is referred to as the soil loss constant (ks). I

$$ks = ks_g + ks_e + ks_r + ks_l + ks_v$$

Where:			Units
ks	=	CoPC soil loss constant due to all processes	yr^{-1}
ksg	=	CoPC loss constant due to biotic and abiotic degradation; discussed below	yr^{-1}
kse	=	CoPC loss constant due to soil erosion (=0)	yr^{-1}
ksr	=	CoPC loss constant due to surface runoff; discussed below	yr^{-1}
ksl	=	CoPC loss constant due to leaching; discussed below	yr^{-1}
ksv	=	CoPC loss constant due to volatilization (=0)	yr^{-1}

The CoPC loss constant (ks_g) represents the rate of chemical degradation in the soils based on biotic and abiotic degradation. This represents the loss of a given chemical by processes which do not include leaching. Abiotic degradation can include photolysis, hydrolysis, and redox reactions as well as metabolic pathways under biologic conditions. Lyman et al. (1982) states that degradation rates can be assumed to follow first order kinetics in a homogeneous media

The loss constant due to surface runoff can be estimated using the following equation, US EPA (2005):

$$ks_r = \frac{RO}{\theta_{sw} \times Z_s} \times \left(\frac{1}{1 + \left(Kd_s \times {}^{BD}/_{\theta_{sw}} \right)} \right)$$

Where: Units

Where:			Units
ks_r	=	CoPC loss constant due to surface runoff; discussed below	yr^{-1}
RO	=	average annual surface runoff from pervious areas; discussed below	cm/yr
θ_{sw}	=	soil volumetric water content (0.2)	mL/cm
Z_s	=	soil mixing zone depth (discussed previously) (10cm)	cm
Kd_s	=	soil/water partition coefficient; CoPC-specific	mL water/g soil

BD	=	soil bulk density (1.5 g/cm3)	g soil/cm^3 soil

The average annual surface runoff from pervious areas (RO) was 150 cm/yr, based on precipitation and evapotranspiration rates and a 2013 Agricultural Canada Report. Losses of soil CoPCs due to leaching (ksl) depend on the amount of water available to generate leachate and soil properties. The recommended equation for calculating ksl (US EPA, 2005) is as follows:

$$ks_l = \frac{P + I - RO - E_V}{\theta_{sw} \times Z_s \times \left[1 + \left(BD \times {}^{Kd_s}/_{\theta_{sw}}\right)\right]}$$

Where:			Units
ks_l	=	CoPC loss constant due to leaching	yr^{-1}
P	=	average annual precipitation	cm/yr
I	=	average annual irrigation	cm/yr
RO	=	average annual surface runoff from pervious areas	cm/yr
E_v	=	average annual evapotranspiration	cm/yr
θ_{sw}	=	soil volumetric water content (0.2 mL/cm^3)	mL/cm^3
Z_s	=	soil mixing zone depth; discussed previously	Cm
BD	=	soil bulk density (1.5 g/cm^3)	g soil/cm^3 soil
Kd_s	=	soil/water partition; CoPC-specific	cm^3 water/g soil

The following climatological data was used in the assessment:

Variable	Site Value (cm)	Reference
P	195.2	City of Burnaby Average Monthly Precipitation Data, Environment Canada
I	0	No irrigation
RO	150	Agriculture and Agri-Food Canada, “Annual Unit Runoff in Canada, January 2013
E_v	34.0	Annual evapotranspiration, NASA’s Moderate Resolution Imaging Spectroradiometer (MODIS), University of Montana Numerical Terradynamic Simulation Group

Chemical of Potential Concern	ks_g (yr^{-1})	k_{Ds} mL water/g soil	k_{ow}	$C_{S\ background}$ (µg/g)	
Total Dioxins and Furans (as PCDD/F TEQ)					
2,3,7,8-TCDD Equivalent	3.00E-02	3.89E+04	6.31E+06	7.00E-06	Ontario MECP Rationale For The Development Of Soil And Ground Water Standards For Use At Contaminated Sites In Ontario 2011
Metals					
Cadmium (Cd)	0	75	1.00E+01	0.8	Metro Vancouver 1992 Soil and Vegetation Report
Mercury (Hg) (inorganic) - divalent MH2+	0	1.00E+03	6.10E-01	0.33	Metro Vancouver 1992 Soil and Vegetation Report
Lead (Pb)	0	900	5.37E+00	80.74	Metro Vancouver 1992 Soil and Vegetation Report
Arsenic (As)	0	29	4.79E+00	5.7	Metro Vancouver 1992 Soil and Vegetation Report
Chromium (Cr)	0	19	1.70E+00		BC SALM data (average Burnaby north and Burnaby Lake, 0-10 cm)
Chlorophenols					
2,4,6-Trichlorophenol	3.61E+00	7.60E-01	5.01E+03	0.1	Ontario MECP Rationale For The Development Of Soil And Ground Water Standards For Use At Contaminated Sites In Ontario 2011
Pentachlorophenol	1.42E+00	1.20E+00	1.26E+05	0.1	Ontario MECP Rationale For The Development Of Soil And Ground Water Standards For Use At Contaminated Sites In Ontario 2011
Chlorobenzenes					
Pentachlorobenzene	7.30E-01	1.21E+03	1.48E+05	0.05	Ontario MECP Rationale For The Development Of Soil And Ground Water Standards For Use At Contaminated Sites In Ontario 2011
Hexachlorobenzene	1.20E-01	1.10E+02	2.00E+05		
Polycyclic Aromatic Hydrocarbons (PAHs)					
Benzo(a)pyrene TEQ for carcinogenic PAHs	5.50E-01	1.60E+05	1.00E+06	0.062875	Supplemental Data received from BCMOE (average of all locations provided)
Polychlorinated Biphenyls (PCBs)					
Total PCB (AROCLOR 1254)	3.00E-02	2.45E+04	3.16E+06	0.3	Ontario MECP Rationale For The Development Of Soil And Ground Water Standards For Use At Contaminated Sites In Ontario 2011

1 All k values obtained from the 2005 HHRAP Database (USEPA)