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AIR QUALITY
DISPERSION MODELLING AND RISK ASSESSMENT
FOR TRANSALTA CORPORATION
WATERCHARGER PROJECT

Prepared for:
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June 9, 2022

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June 9, 2022 J2022-110

TransAlta Corporation

SENT BY EMAIL: Chris_Teare@transalta.com

Attention: Mr. Chris Teare, P.Eng, MBA, Manager, Business Development

Subject: Air Quality Dispersion Modelling and Risk Assessment

As requested by TransAlta Corporation (TransAlta) on behalf of TA Alberta Hydro Inc., Calvin Consulting Group Ltd. (Calvin Consulting) has completed an Air Quality Dispersion Modelling and Risk Assessment (Assessment) for potential emissions emitted from a Battery Energy Storage System (BESS). The modelling pertains to the WaterCharger Project (Project), which is proposed to be located in the Southeast (SE) Quarter of Section 13, Township 026, Range 06, West of the 5th Meridian. The results of the Assessment are provided in this report.

If you require any additional information or have any comments or concerns pertaining to these results, please contact Ann Jamieson by email at ann.jamieson@calvinconsulting.ca or by phone at 403-560-7698. Thank you for the opportunity to work on this project.

Sincerely,
Calvin Consulting Group Ltd.

Ann Jamieson, EP, P.Chem.
President

DISCLAIMER

Calvin Consulting Group Ltd. (Calvin Consulting) has prepared this report to provide TransAlta Corporation (TransAlta) with predicted maximum concentrations of air contaminants that may occur in the vicinity of the WaterCharger Project (Project) in the unlikely event of a fire. These maximum concentrations are estimated based on, but not limited to, the following:

- Data provided by TransAlta, noting that in the absence of data for any emission source, estimated parameters were developed based on the professional experience of Calvin Consulting personnel and our Associate, Dr. Stephen Ramsay, as explained in Section 3.1 of this report.

- Digital terrain data that are publicly available from the Government of Canada

- Historical meteorology data provided by the Alberta Government

- Estimates of land use percentages for land classes (e.g., vegetation cover, urban development, agricultural land, forest, etc.) within the selected modelling domain

- A computer modelling system developed by the United States Environmental Protection Agency (U.S. EPA)

Information, data, facts and the computer model provided by others and used in preparation of this report are assumed to be accurate without any verification or confirmation by Calvin Consulting.

As a result of the uncertainty and inherent variability in the preceding data and/or estimates, Calvin Consulting makes no representation or warranty with respect to this report or the information contained herein other than that Calvin Consulting has exercised reasonable skill, care and diligence in accordance with accepted practice and usual standards of thoroughness and competence for the Environmental Profession with respect to the collection, assessment and evaluation of the information used in the preparation of this report. Liability for the acceptance and implementation of the information and/or recommendations made in this report is limited to the actual dollar value of professional fees charged to TransAlta by Calvin Consulting for the scope of work as indicated in this report.

EXECUTIVE SUMMARY

At the request of TransAlta Corporation (TransAlta) on behalf of TA Alberta Hydro Inc., Calvin Consulting Group Ltd. (Calvin Consulting) and our Associate, Dr. Stephen Ramsay, has completed a literature review and Dispersion Modelling and Risk Assessment (Assessment) pertaining to a potential fire event at a Battery Energy Storage System (BESS) that is proposed to be installed approximately 15 km west-northwest of Cochrane, Alberta. Literature pertaining to these types of fires was reviewed to assess the types of contaminants that are emitted during this type of fire and to obtain quantitative data related to estimated emission rates for each contaminant of concern, noting that Hydrogen Fluoride (HF) is stated in the literature as being the main contaminant of concern.

Source and emission data were derived based on the literature review, including reported laboratory test data. Air quality dispersion modelling was performed taking into account local wind data, groundcover, terrain influences, on-site building influences and the location of the closest residences. The modelling results were then compared to the Alberta Ambient Air Quality Objectives (AAAQOs), as well as the American Centers for Disease Control and Prevention (CDC) National Institute for Occupational Safety and Health (NIOSH) Immediately Dangerous to Life or Health (IDLH) values.

The following comments pertain to the conclusions from this Assessment:

- The winds in the area are predominantly from the west-southwest, along the river valley.
- All predicted air quality concentrations beyond the TransAlta property line and at the closest residences and recreational area comply with the AAAQOs.
- The IDLH will not be exceeded at or beyond the BESS site fenceline for the air contaminants of concern.
- The risk to the public and local residents from a fire, associated with the type of battery cells proposed for this BESS, is low.

GLOSSARY

AAAQO	Alberta Ambient Air Quality Objective
AEP	Alberta Environment and Parks
AQMG	Air Quality Model Guideline
BESS	Battery Energy Storage System
BPIP	Building Profile Input Program
CDC	Centers for Disease Control and Prevention
CO	Carbon Monoxide
CPR	Canadian Pacific Railway
FSS	Fire Suppression System
HCl	Hydrogen Chloride
HCN	Hydrogen Cyanide
HF	Hydrogen Fluoride
IDLH	Immediately Dangerous to Life or Health
LFP	Lithium Iron Phosphate
$LiFePO_4$	Lithium Iron Phosphate
Li-ion	Lithium-Ion
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
NMC	Nickel Manganese Cobalt
POF_3	Phosphoryl Fluoride
SE	Southeast
U.S. EPA	United States Environmental Protection Agency
WRF	Weather Research and Forecasting

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1.0 INTRODUCTION

TA Alberta Hydro Inc., a wholly-owned subsidiary of TransAlta Corporation (TransAlta), proposes to install a Battery Energy Storage System (BESS), WaterCharger Project (Project). The BESS will be installed in the Southeast (SE) Quarter of Section 13, Township 026, Range 06, West of the 5th Meridian. This Project is located approximately 15 km west-northwest of Cochrane, Alberta and 40 km west-northwest of Calgary, Alberta, as indicated in Figure 1.

1.1 Project Description

TransAlta has not yet selected a vendor for this Project, but has shortlisted two potential vendors. The emissions and proposed layout for both of these vendors have been considered in this Air Quality Dispersion Modelling and Risk Assessment (Assessment), noting the following:

- **Vendor A**. The proposed Vendor A BESS consists of 59 battery containers, each paired with an inverter and transformer skid. A container consists of ten racks, each containing eight modules with 52 Lithium Iron Phosphate (LFP or $LiFePO_4$) cells in each module.

- **Vendor B.** The Vendor B BESS consists of 104 battery containers, and each full-sized container consists of a maximum of four racks, each containing seven to eight modules, also with 52 LFP cells in each module.

1.2 Safety Features

Numerous safety standards have been developed to reduce the risk of BESS fires. A BESS installation must meet local building codes, utility regulations and industry standards. It is not the purpose of this study to review or apply the BESS safety standards. These standards are cited only to substantiate the fire modelling assumptions that rely on the fire spread limiting effect of these standards. The following industry safety standards were developed to minimize the hazards associated with BESSs:

- **National Fire Protection Association (NFPA) 855 - Standard for the Installation of Stationary Energy Storage.** This standard establishes the requirements for design, construction, installation, commissioning, operation, maintenance and decommissioning of stationary energy storage systems. This standard applies to battery installations greater than 70 kW-h.

- **UL 9540 - Standard for Safety Energy Storage Systems and Equipment.** This standard establishes that electrical, electro-chemical, mechanical and thermal energy storage systems operate at an optimal level of safety. It also establishes safety requirements for the integrated components of an energy storage system.

- **UL 9540A - Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems.** This standard establishes quantitative data to characterize potential battery storage fire events. The standard also establishes battery storage system fire testing on the cell level, module level, unit level and installation level.

Figure 1 Proposed Project location.

Additionally, the two vendor designs being considered for this Project also include numerous safety features to reduce the potential for fire and also to suppress fire in the unlikely event that a fire were to occur in electrical wiring, etc. Some of the safety features include the following:

- Fire-rated walls and doors in the containers
- Liquid cooling system for battery cells
- On-site control systems, including alarms, to continuously monitor and ensure operations remain within the design limits
- Gas and smoke detection and internal Fire Suppression System (FSS), noting that the vendor specifications indicate that an environmentally-friendly chemical agent would be released automatically to extinguish a fire in the container if one were detected by the internal monitoring system

Additionally, it is very important to note that there are several types of Lithium-Ion (Li-ion) batteries used worldwide. The materials in an LFP battery are less toxic than those in other types of Li-ion batteries, some of which contain cobalt and other hazardous substances. The sturdy iron phosphate crystal structure in LFP batteries will not break down during charging or discharging, and therefore, will not cause leakage. Additionally, since lithium iron phosphate is a thermally and structurally stable chemical compound, LFP batteries will not spontaneously combust and moreover, if LFP batteries do ignite, the fire will not spread easily from one module to another, even without the added safety feature of an FSS. While LFP batteries will burn if exposed to extreme heat, these batteries are very difficult to ignite and will burn much more slowly than other types of lithium-ion batteries, such as Lithium Nickel Manganese Cobalt (NMC) batteries that are used at other BESS projects and that have been widely reported in the media in relation to fires.

1.3 Site Description

As indicated in the plot plans presented in Figures 2 and 3, the BESS site fenceline is a polygon that is 350 m long on the north perimeter fenceline and 101 m long on the west perimeter fenceline. The site is rotated approximately 12° counterclockwise from True North and is roughly aligned with the Bow River, which flows eastward at a distance of about 250 m north of the site and the reservoir dam has a spillway passing near the southern portion of the Project fenceline and flowing into the main river 700 m east of the Project.

The east shore of the Ghost Reservoir lies 200 m west of the nearest point on the Project site fenceline. The site is also 800 m south of Highway 1A, also known as the Bow Valley Trail. This highway passes through two recreational communities in the vicinity of the Project. The Ghost Lake Provincial Recreational Area is 1000 m west of the proposed BESS site and the Cottage Club Ghost Lake community occupies the land that is between 350 and 800 m north and northwest of the BESS site.

The Canadian Pacific Railway (CPR) main line passes by, travelling east and west, at a distance approaching 700 m south of the BESS site. Figure 4, which was obtained from the TransAlta website, presents an aerial photograph indicating the location of the BESS site with respect to neighbouring developments within 1000 m.

Figure 2 Project plot plan indicating proposed preliminary Vendor A equipment site plan.

Figure 3 Project plot plan indicating proposed preliminary Vendor B equipment site plan.

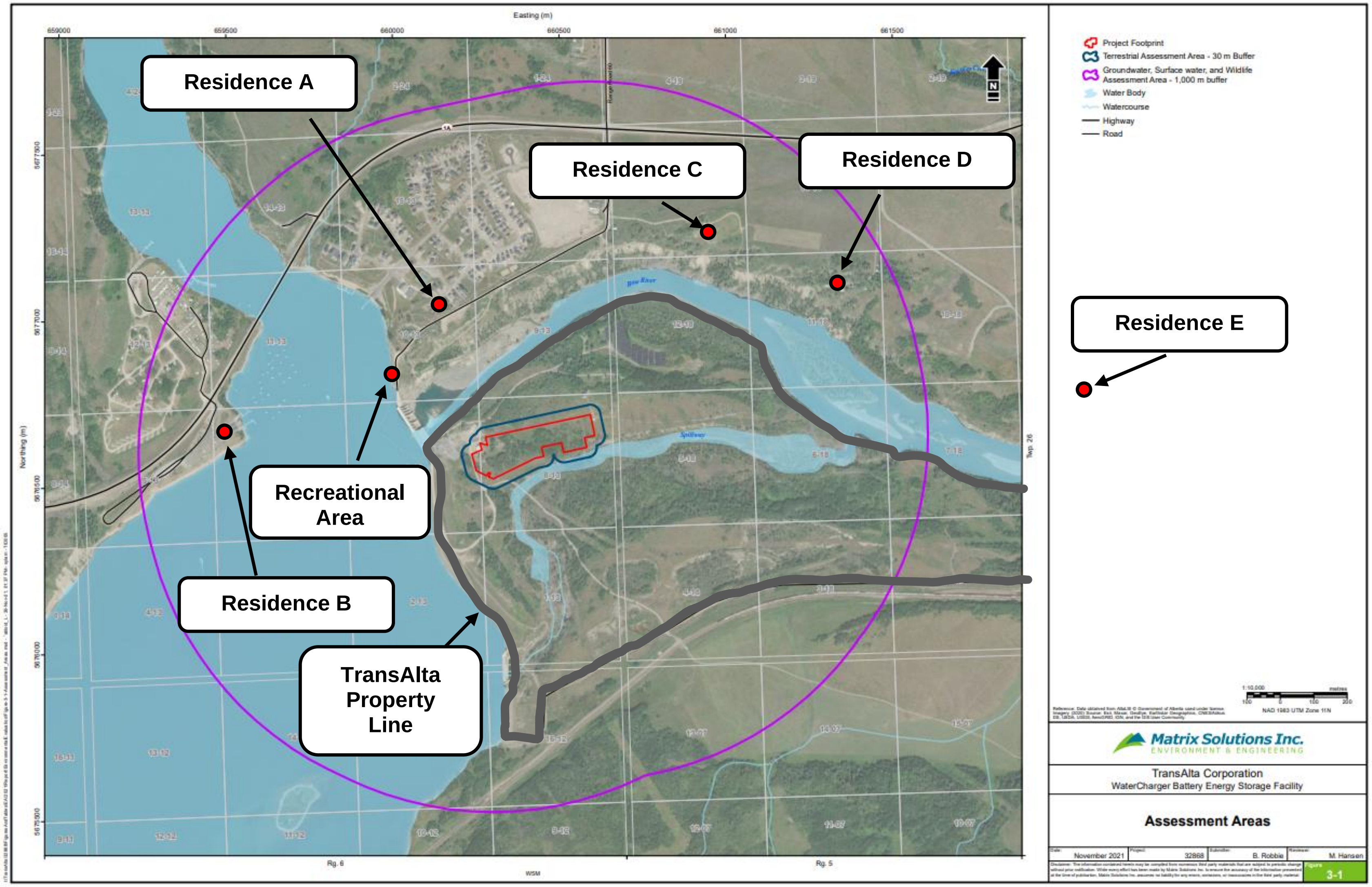

Figure 4 Project site with respect to neighbouring water, communities and roadways.

For modelling purposes, it was assumed that a fire occurred in the container that is located closest to the nearest residence (i.e., Residence A), which is located approximately 430 m north-northwest of the assumed emission source (see Figure 4).

2.0 LITERATURE REVIEW

Unless constantly kept within specific environmental conditions and electrical parameters, some types of Li-ion cells can fail. This can lead to spontaneous combustion and a process known as thermal runaway. Thermal runaway is an exothermic reaction that causes the internal temperature of the battery to rise and may eventually ignite the electrolyte. As such, thermal runaway events can escalate into fires and a single failing cell can quickly overheat the surrounding cells, causing them to go into thermal runaway in turn.

While a thermal runaway event can occur for LFP battery cells, which are the type of cells that will be installed at this Project, studies have shown that the internal temperature of an LFP battery must exceed 200°C before a runaway event could occur (e.g., in the presence of a forest fire or some other major ignition event). Research also indicates that since LFP batteries are not easily ignited, the fire would spread much more slowly than a runaway event might for other types of Li-ion batteries, such as NMC batteries.

It is not the purpose of this study to conduct an extensive independent review of Li-ion battery fires. Several authoritative studies detail the fire dynamics and resulting emissions from Li-ion battery cells. While extensive data are available for fires associated with NMC type batteries, which again are widely reported in the media in association with fires, less data are available for LFP batteries since these are not generally a concern from a fire perspective (i.e., LFP batteries do not easily ignite and if ignited, do not burn well). The studies reviewed for this Assessment are summarized in Table 1 and are studies that provide quantitative data that could be used as a basis for developing the source and emission parameters required for air quality dispersion modelling purposes.

Table 1 Studies on emissions from battery malfunctions.

Study	Description	Results
Anderson *et al.* 2013	Provides detailed assessment of fire emissions from LFP batteries. Exposure of battery to heat source, off gases tested.	Hydrogen Fluoride (HF): 30 to 50 ppm peak Phosphoryl Fluoride (POF_3): 1 to 2 ppm peak HF Rate: 0.01 g/s
Blum & Long, 2016	Detailed assessment of lithium-ion battery fire hazards, with specific reference to Tesla configurations. Modules tested with heat exposure until thermal runaway. 100 kW-h by Tesla.	HF: 100 ppm peak for NMC batteries
CATL	UL 9540A testing for NMC batteries (proprietary)	Composition of off gassing: primary gaseous contaminants only Up to 153.5 L off gas per cell
Larsson *et al.* 2017	External heat source used to heat batteries. Measured toxic gases. Focuses on HF emissions from lithium-ion battery fires.	For LFP batteries: HF: up to 148 ppm peak HF rate: 48 mg/s peak POF_3 rate: not detected
LG Chem	Proprietary data on LFP and NMC battery types.	
DNVGL, 2017	Measurement of a wide range of battery types and failures.	Release rates per kg battery weight: 1.7e-7 kg/s-kg
DNVGL, 2019	Measured characteristics of a Tesla powerpack thermal runaway scenario for NMC batteries (proprietary).	Hydrogen Chloride (HCl): 538 ppm HF: 183 ppm Hydrogen Cyanide (HCN): 67 ppm
MRS Environmental, 2019	Provides a detailed assessment of fire hazards focusing specifically on a Tesla 2XL-Megapacks.	
Quintiere *et al.* 2016	Provides detailed assessment of fire hazards focusing on NMC lithium-ion battery cells.	
Tesla	Proprietary studies for NMC batteries.	HF: 500 ppm HCl: 1000 ppm HCN: 1600 ppm Methanol: 32 ppm Styrene: 1 ppm Toluene: 3500 ppm

3.0 MODELLING ASSUMPTIONS

Under normal operating conditions, there will be no gaseous emissions from the Project. However, in the unlikely event of a fire that caused ignition of the LFP batteries, gases could be emitted to the atmosphere. For the purpose of this Assessment, the analysis is limited to a reasonable worst-case event, which is defined as ignition of a module, which could cause a runaway reaction in a group of LFP battery cells, noting that because of the safety features included in the BESS design, it is highly unlikely that an entire module or groups of modules would burn simultaneously. Research pertaining to NMC cells, which are more likely to burn than LFP cells, indicates that a maximum of only 10% of the cells in a single module would likely be involved in an event. As such, for the purpose of this Assessment, it has been conservatively assumed that 10% of the LFP batteries in any one module will burn simultaneously until such time as all modules in a container have burned.

In summary, for the purpose of modelling, fire emissions were assumed to be limited to the combustion of a single container. The fire was assumed to progress through the cells (i.e., 10% of which would burn simultaneously, igniting more batteries over time), until such time that all batteries in all modules within the container were consumed. The fire has been modelled as a continuous release with worst-case emission parameters and the modelling results are compared to the one-hour average Alberta Ambient Air Quality Objectives (AAAQOs).

3.1 Emission Parameters

The two compounds of potential concern associated with an LFP fire include the following:

- Hydrogen Fluoride (HF)
- Carbon Monoxide (CO)

Emission rates for these two air contaminants are indicated in Table 2 and are based on data compiled from the literature review. Both of these contaminants are regulated by the AAAQOs. Table 2 also presents a summary of the other source parameters that are required for modelling, noting the following:

- **Height.** The height of the containers, as stated in the vendor design specifications, was used as the height of the release.

- **Diameter.** The diameter of the release was assumed to be equivalent to the approximate diameter of the ventilation vent on the roof of the containers.

- **Exit Temperature and Exit Velocity.** The values used in the modelling were selected to represent worst-case emission conditions.

Table 2 Source parameters used for modelling a potential fire at the Project.

Parameter		Vendor A	Vendor B
Height	(m)	2.9	2.5
Pseudo Diameter	(m)	0.3	
Exit Temperature	(K)	323	
Exit Velocity	(m/s)	0.035	
HF Emission Rate		0.00093	
CO Emission Rate		10.88	

4.0 MODELLING APPROACH

The dispersion modelling was performed using the United States Environmental Protection Agency (U.S. EPA) AERMOD v.21112 dispersion model, meteorological data, terrain data and building downwash as required in Alberta for this type of assessment and as described in the following sections.

4.1 Meteorological Data

Meteorological data, including but not limited to wind data, were obtained from the Alberta Environment and Parks (AEP) Weather Research and Forecasting (WRF) Meteorological Data Repository as required by the Alberta Air Quality Model Guideline (AQMG). The data cover the period from 01-Jan-2015 to 31-Dec-2019 and are centred on the geographical point at 51.219°N and 114.703°W. Five years of the data were processed in AERMET v.21112 to produce meteorological files suitable for use in AERMOD.

Figure 5 provides a wind direction and wind speed frequency diagram (i.e., windrose) for the area based on the WRF data. As indicated in the windrose, the winds are dominated by west-southwest winds, along the river valley. However, as required in Alberta, the Assessment was completed using five years of wind data for all wind direction and wind speed combinations that occur in the area.

4.2 Terrain Data

Terrain data were obtained from the Government of Canada, Department of Natural Resources Geobase online portal, which provides public access to a base of quality geospatial data for all of Canada. The domain used for this Assessment incorporates topographic data from map tiles identified as 082O01, 082O02, 082O07 and 082O08.

4.3 Modelling Receptors

As indicated in Figure 6, the following receptor grids were used in the modelling for this Assessment:

- **Grid 1.** Every 20 m out to 500 m.
- **Grid 2.** Every 50 m out to 2000 m.
- **BESS Site Fenceline.** Modelling was completed at receptors placed every 20 m along the BESS fenceline.
- **TransAlta Property Line.** Modelling was completed at receptors placed every 20 m along the TransAlta property line.
- **Sensitive Receptors.** Modelling was completed at all residences in the nearest community and the five closest rural residences and the nearest recreational area in the vicinity for the BESS site.

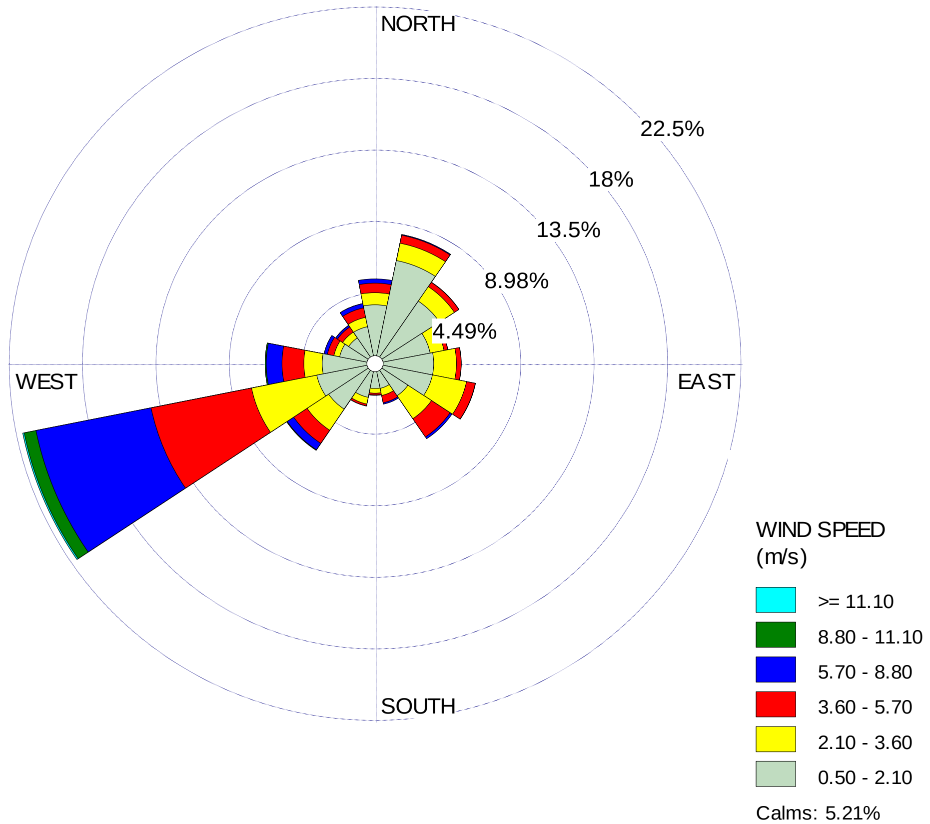

Figure 5 Windrose indicating the frequency of wind direction and wind speeds in the area.

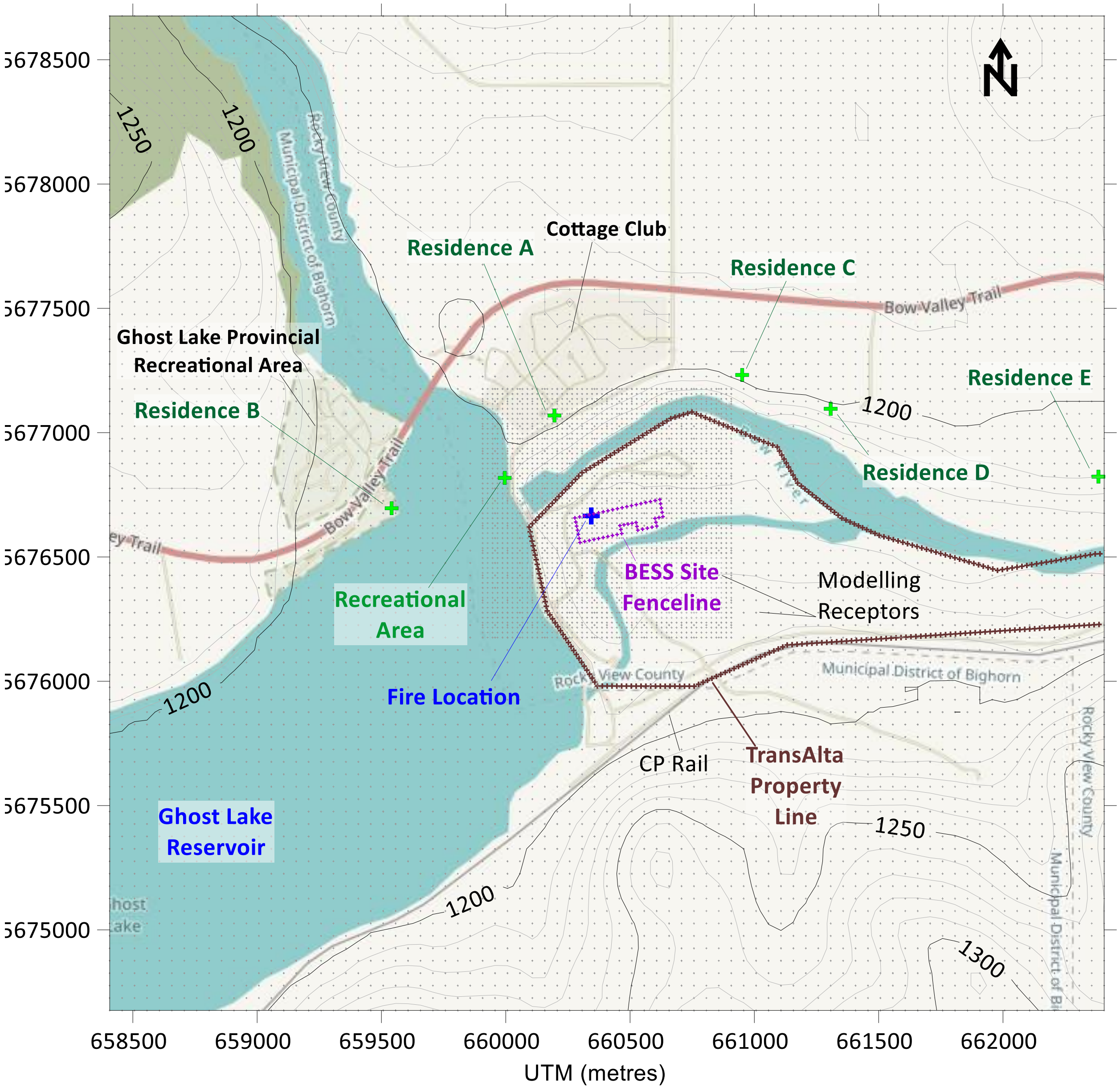

Figure 6 Location of dispersion modelling receptors, ground-level elevations (m) and sensitive receptors within 2 km of the Project.

- **Discrete Receptors.** The modelling was also completed at 100, 250, 400, 700 and 1000 m downwind distances from the assumed fire location.

4.4 Building Downwash

Building downwash effects were taken into account for this Assessment. The U.S. EPA Building Profile Input Program (BPIP) was used to determine the effects of building downwash on dispersion of emissions from the modelled fire.

5.0 MODELLING RESULTS

5.1 Modelling Cases

The following two cases were modelled for both of the vendors being considered for this project:

- **Ambient Air Quality Modelling.** The emissions from a potential fire were modelled for comparison to the hourly-average AAAQOs, which are designed to protect the most sensitive of species.

- **Health & Safety Modelling.** From a health and safety perspective, the overall maximum predicted hourly-average concentrations were modelled. These were then converted to 10-minute average concentrations using the methodology indicated in the AQMG. The resulting 10-minute average concentrations were compared to the United States Centers for Disease Control and Prevention (CDC) National Institute for Occupational Safety and Health (NIOSH) Immediately Dangerous to Life or Health (IDLH) values for HF and CO.

5.2 Ambient Air Quality Modelling Results

5.2.1 Regional Air Quality

The predicted one-hour average ground-level modelling results are summarized in Table 3. As indicated in Table 3, the predicted concentrations for HF and CO exceed their respective AAAQOs in close proximity to the BESS site for both design options. This is not unexpected during a fire. Specifically, the maximum off-site concentrations indicated in Table 3 are predicted to occur on the BESS site fenceline. Figures 7 and 8 present the maximum predicted concentrations for HF and CO, respectively, for the Vendor A design, while Figures 9 and 10 present the HF and CO results, respectively, for the Vendor B design.

5.2.2 Sensitive Receptors

Table 4 presents the maximum predicted concentrations at the six sensitive receptors. As indicated in Table 4, all predicted concentrations are well within their applicable AAAQOs at these locations.

Table 3 Predicted maximum hourly-average ground-level concentrations within the modelling domain.

Contaminant	Predicted Concentration (μg/m³)		AAAQO (μg/m³)
	BESS Site Fenceline	TransAlta Property Line	
Vendor A			
HF	30.5	2.2	**4.9**
CO	20758.0	1498.7	**15000**
Vendor B			
HF	34.9	2.0	**4.9**
CO	23747.4	1431.0	**15000**

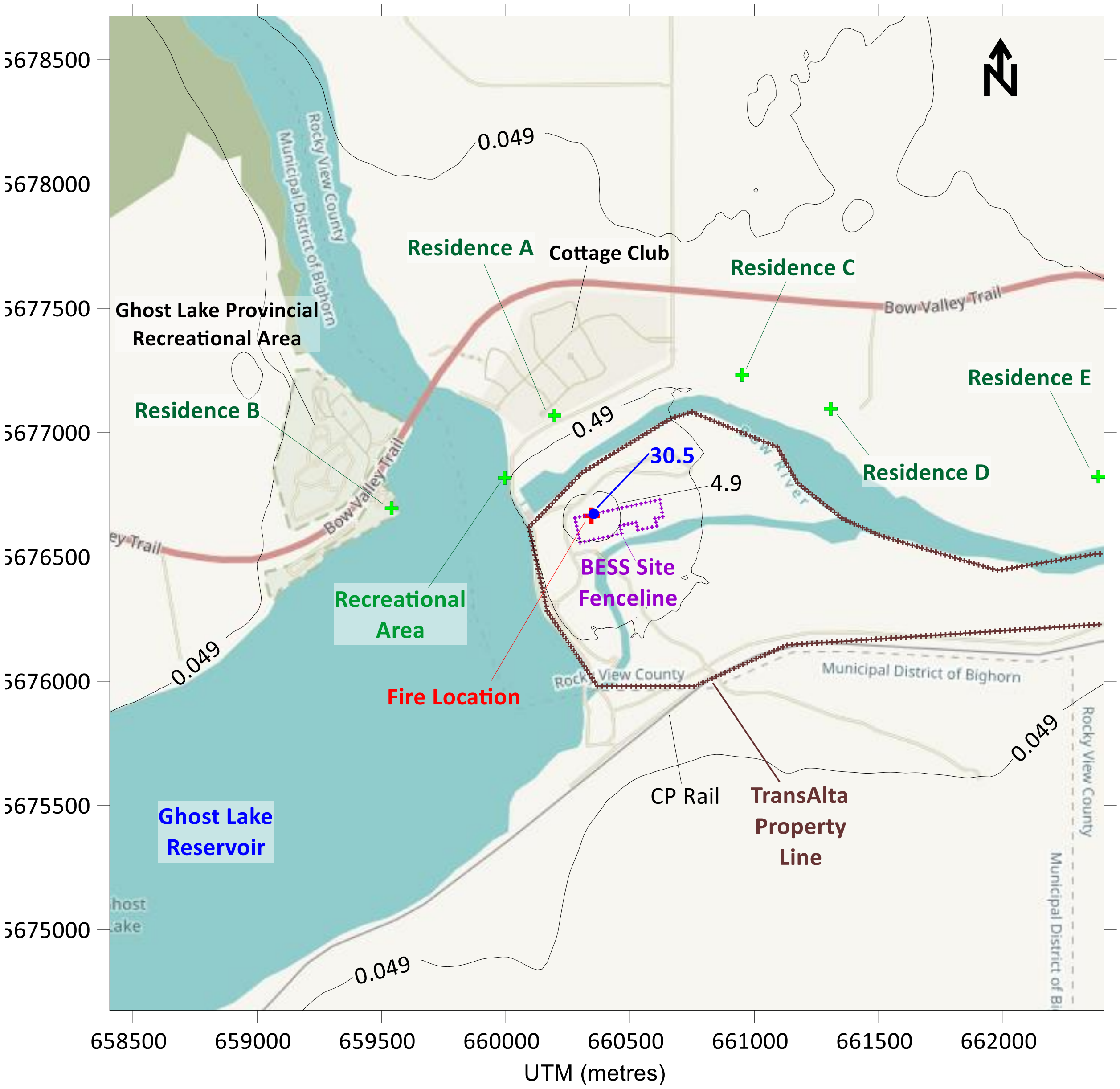

Figure 7 The maximum predicted hourly-average ground-level HF concentrations associated with a potential fire, including sensitive receptors, assuming the Vendor A option. Isopleths shown include 0.049, 0.49 and 4.9 µg/m^3.

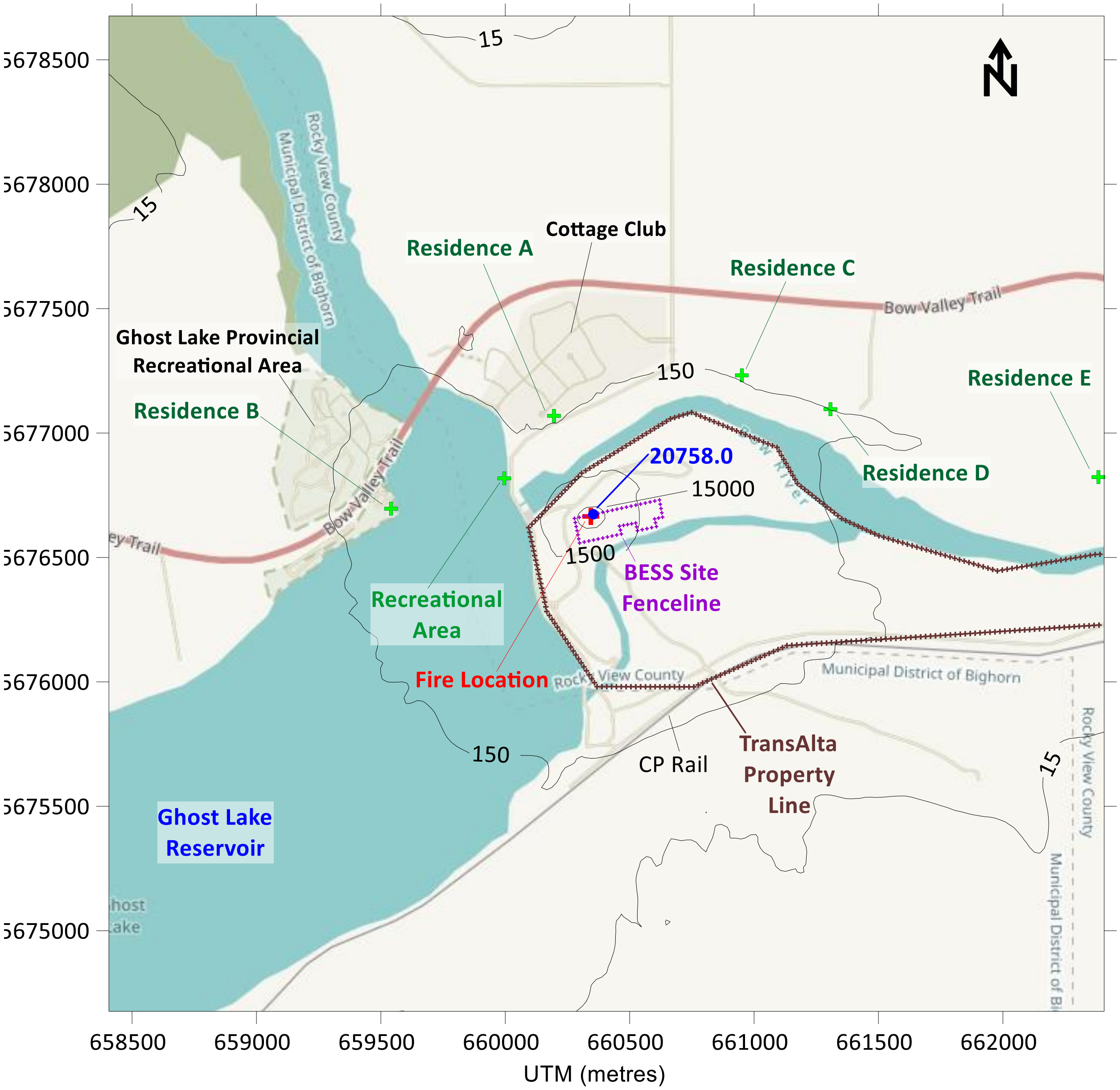

Figure 8 The maximum predicted hourly-average ground-level CO concentrations associated with a potential fire, including sensitive receptors, assuming the Vendor A option. Isopleths shown include 15, 150, 1500 and 15000 µg/m^3.

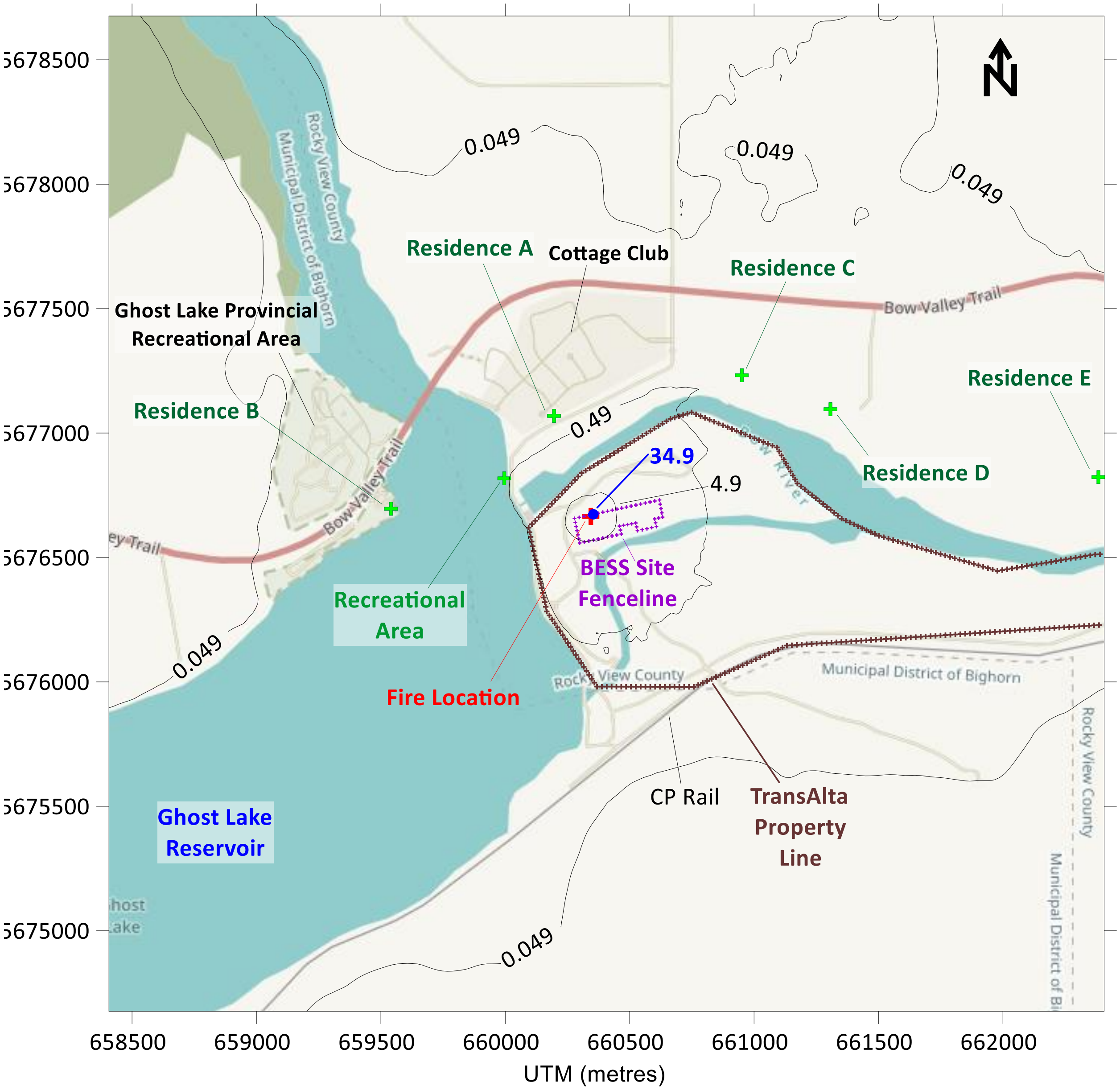

Figure 9 The maximum predicted hourly-average ground-level HF concentrations associated with a potential fire, including sensitive receptors, assuming the Vendor B option. Isopleths shown include 0.049, 0.49 and 4.9 µg/m^3.

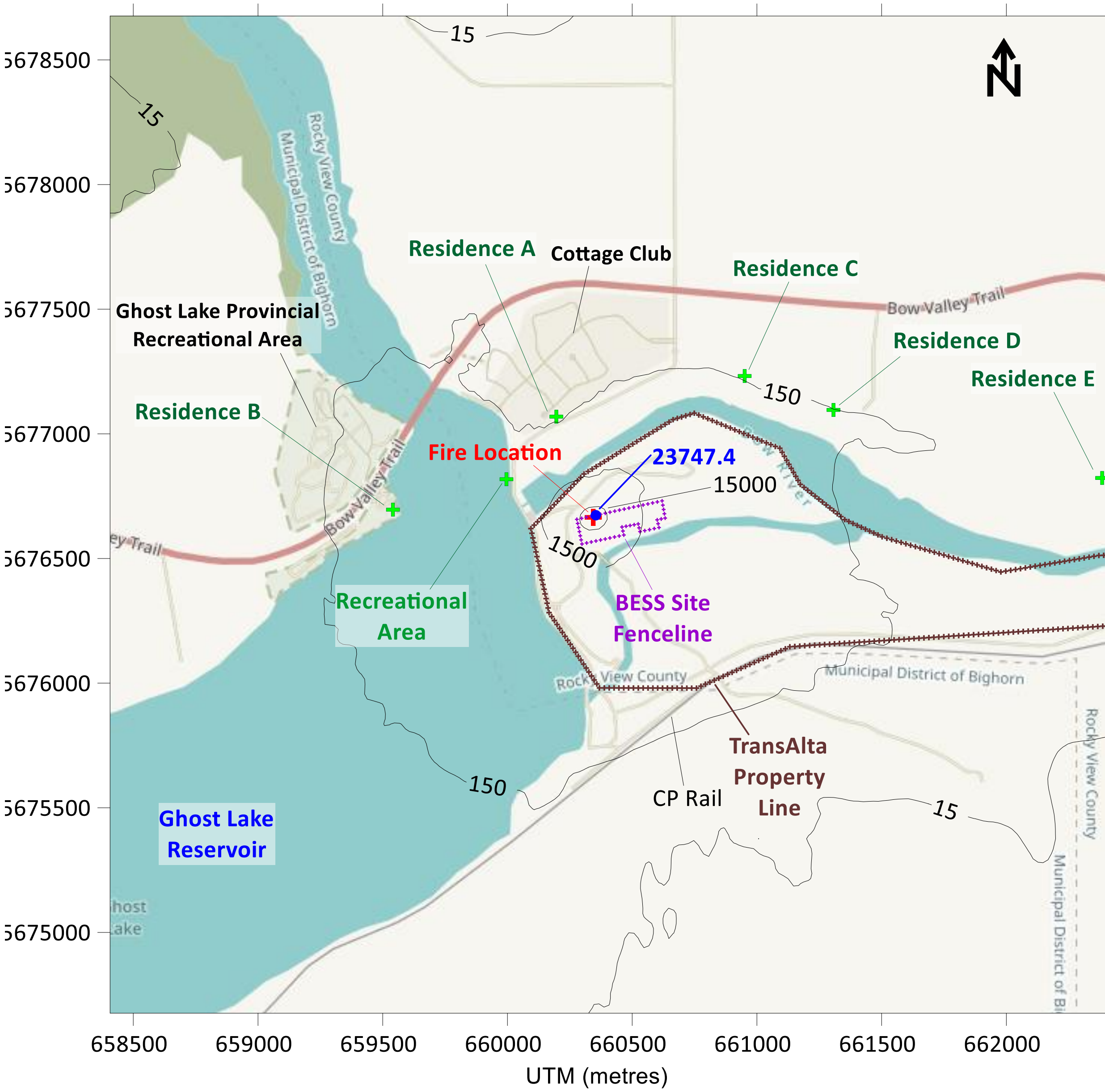

Figure 10 The maximum predicted hourly-average ground-level CO concentrations associated with a potential fire, including sensitive receptors, assuming the Vendor B option. Isopleths shown include 15, 150, 1500 and 15000 µg/m^3.

Table 4 Predicted maximum hourly-average ground-level concentrations at closest residences.

Residence	Predicted Concentration ($\mu g/m^3$)			
	Vendor A		Vendor B	
	HF	CO	HF	CO
AAAQO ($\mu g/m^3$)	**4.9**	**15000**	**4.9**	**15000**
Residence A	0.12	112.3	0.13	121.0
Residence B	0.19	184.2	0.21	195.2
Residence C	0.12	112.4	0.13	119.1
Residence D	0.15	103.2	0.16	152.9
Residence E	0.09	90.1	0.10	90.5
Recreational Area	0.33	312.3	0.35	333.7

5.2.3 Discrete Receptors

Modelling was completed at varying distances (i.e., 100, 250, 400, 700 and 1000 m) downwind from the assumed fire location. The results from this modelling indicate the following, noting that the peaks shown in the diagrams in the east and the west-southwest direction are a result of the prevailing winds and the battery enclosures resulting in building downwash effects, which pull the plume closer to the ground in the immediate vicinity of the Project (i.e., within 100 m), but beyond 100 m from the modelled fire the downwash effects are resolved and do not cause a peak:

- **HF.** As indicated in Figures 11 and 12, concentrations at 100 m downwind of the modelled fire are predicted to exceed the HF hourly-average AAAQO. However, all concentrations at or beyond 250 m downwind of the assumed fire location are predicted to comply with the HF hourly-average AAAQO of 4.9 µg/m^3 for both of the vendor designs.

- **CO.** As indicated in Figure 13 and 14, all concentrations at or beyond 100 m downwind of the assumed fire location are predicted to comply with the hourly-average AAAQO of 15000 µg/m^3 for CO for both design options.

5.3 Health and Safety Modelling Results

5.3.1 Regional Modelling

Table 5 presents a summary of the maximum predicted 10-minute average concentrations within the modelling domain. These values are compared to the IDLH values. As indicated in Table 5, all maximum predicted 10-minute average concentrations are well within the IDLH limits at all locations beyond the BESS site fenceline.

5.3.2 Discrete Receptors

The modelling results for the discrete receptors are presented in Table 6. As indicated in Table 6, at distances beyond the BESS site fenceline, all predicted contaminant concentrations are well within their corresponding IDLH limits.

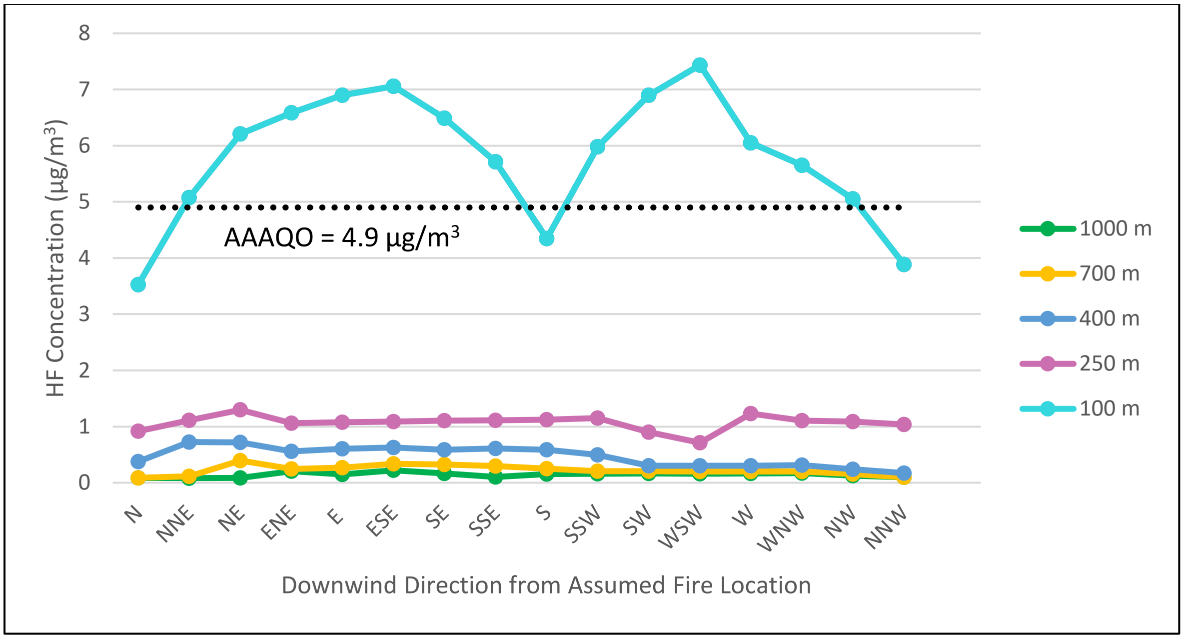

Figure 11 The predicted one-hour average HF concentrations (µg/m^3) associated with the Vendor A design at 100, 250, 400, 700 and 1000 m downwind of the assumed fire location.

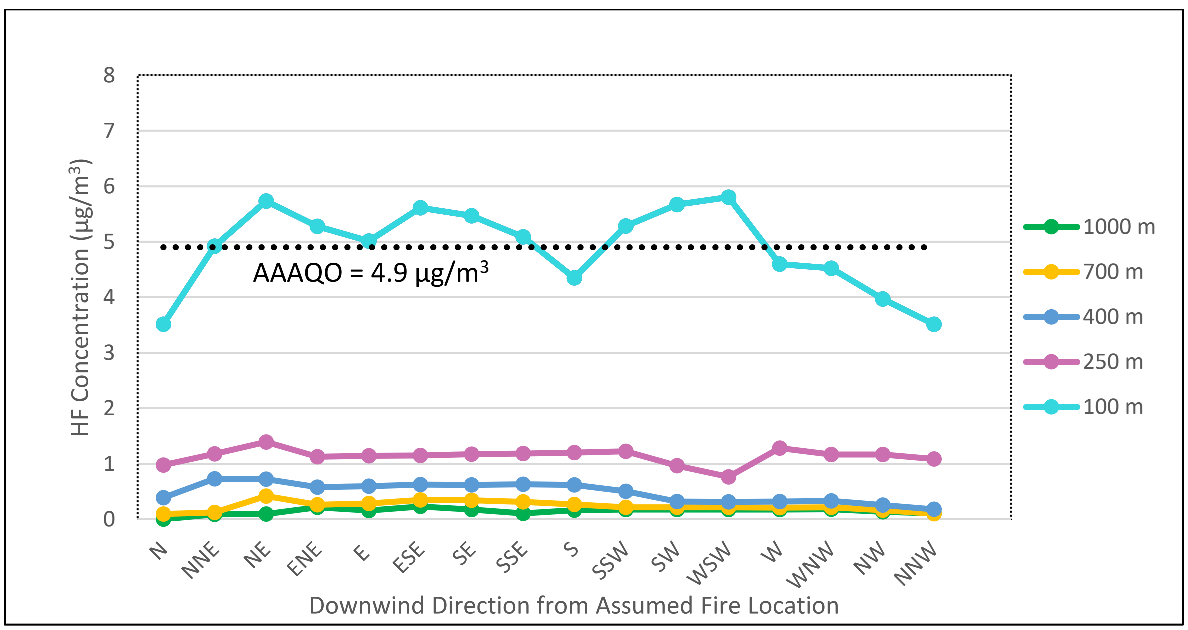

Figure 12 The predicted one-hour average HF concentrations (µg/m^3) associated with the Vendor B design at 100, 250, 400, 700 and 1000 m downwind of the assumed fire location.

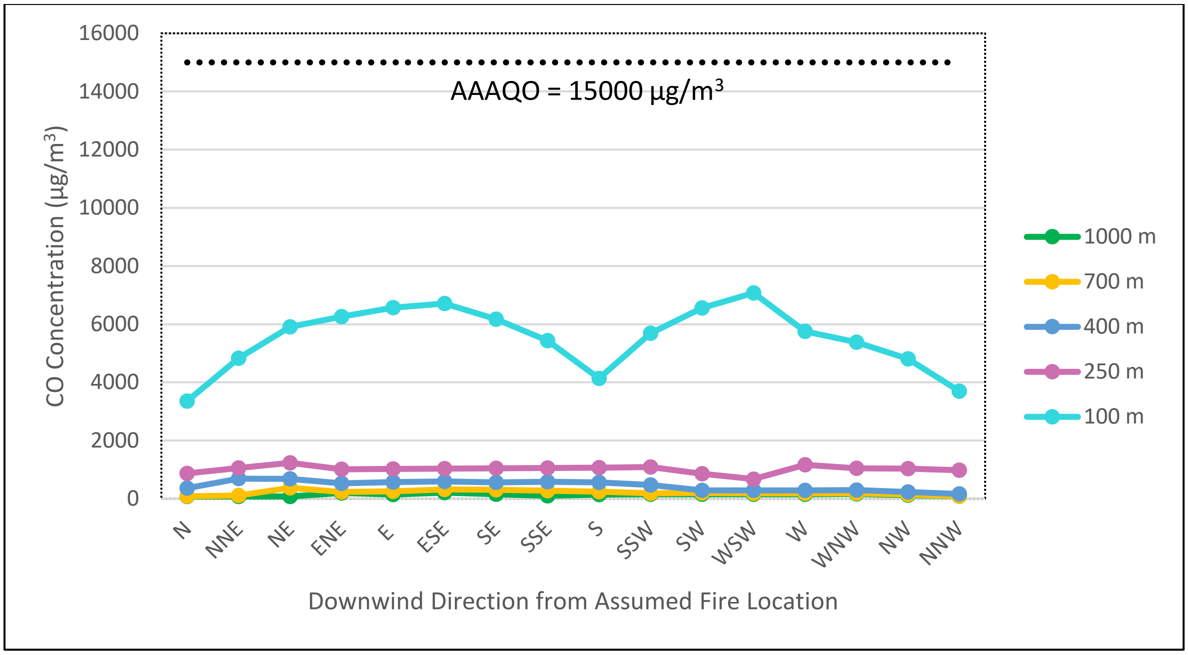

Figure 13 The predicted one-hour average CO concentrations (µg/m³) associated with the Vendor A design at 100, 250, 400, 700 and 1000 m downwind of the assumed fire location.

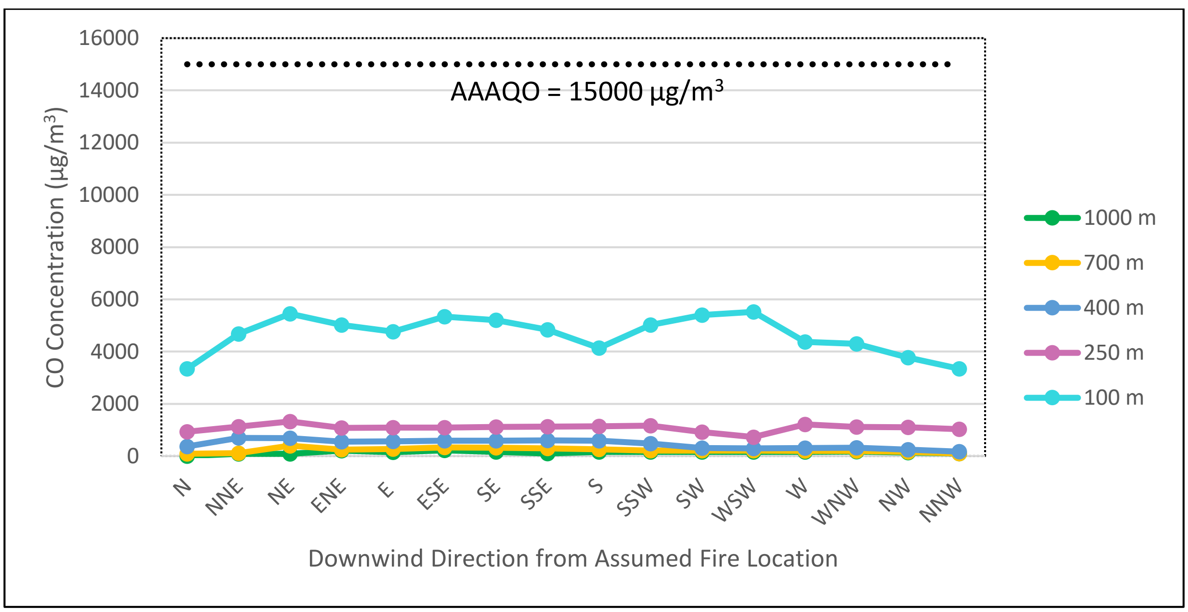

Figure 14 The predicted one-hour average CO concentrations (µg/m³) associated with the Vendor B design at 100, 250, 400, 700 and 1000 m downwind of the assumed fire location.

Table 5 Maximum predicted 10-minute average concentrations within the modelling domain.

Contaminant	10-Minute Average Maximum Predicted Concentration (ppm)		IDLH (ppm)
	Vendor A	Vendor B	
HF	0.0748	0.0848	**30**
CO	50.9	57.6	**1200**

Table 6 Maximum predicted 10-minute average concentrations at varying downwind distances from the assumed fire location.

Contaminant	Concentration (ppm)					IDLH
	Downwind Distance					
	100 m	250 m	400 m	700 m	1000 m	
Vendor A						
HF	0.0160	0.0031	0.0018	0.0010	0.0005	**30**
CO	10.9	2.1	1.2	0.7	0.4	**1200**
Vendor B						
HF	0.0136	0.0034	0.0019	0.0010	0.0005	**30**
CO	9.2	2.3	1.3	0.7	0.4	**1200**

6.0 CONCLUSIONS

6.1 Ambient Air Quality

In the event of a BESS fire, maximum concentrations for HF and CO are predicted to exceed their respective AAAQOs in close proximity to the BESS site, as would be expected during a fire. However, all concentrations are predicted to comply with their applicable AAAQOs beyond the TransAlta property line.

6.2 Health and Safety

From a health or safety perspective, all maximum 10-minute average concentrations beyond the TransAlta property line are predicted to be well within applicable IDLH limits within the modelling domain. As such, the modelling performed in this Assessment does not predict any significant off-site health or safety impact associated with BESS emissions in the event of a fire.

6.3 Risk Assessment

Fire risks, including emissions, from various types of Li-ion batteries, including LFP, have been studied extensively. LFP batteries are generally accepted as having lower risk of fire and lower emissions than for other commonly used battery types. To ensure conservative estimates of emissions from an LFP battery fire, this Assessment considered worst-case conditions.

Risk is estimated according to the following:

$$\text{Risk} = \text{Probability of Occurrence} \times \text{Consequences}$$

Given the safety features of the BESS systems being considered for this project and the low probability of a BESS fire from LFP batteries, coupled with the acceptable off-site maximum predicted air quality and IDLH concentrations, the risk to the public and area residents in association with this project is deemed to be low.

7.0 REFERENCES

Anderson *et al.* 2013. *Investigation of Fire Emissions from Li-ion Batteries.* SP Technical Research Institute of Sweden.

Blum & Long. 2018. *Hazard Assessment of Lithium Ion Battery Energy Storage Systems.*

CATL. 2018. *271Ah BEV LFP Cell Specification and Performance Summary.* EVC_BET and UL9540 Testing.

DNVGL. 2017. *Considerations for ESS Fire Safety.*

DNVGL. 2019. *Live Fire Test of Tesla Powerpacks.* Tesla, Inc. DNV GL Doc. No.: 10118434-HOU-R-02-D Issue: D; Status: Release Issue Date: April 17th, 2019.

Larsson *et al.* 2017. *Toxic-Fluoride Gas Emissions from Lithium-Ion Battery Fires.* Nature.

LG Chem. Proprietary Testing discussed in Rincon 2017 NRG Ellwood Battery Storage Project Final Initial Study - Mitigated Negative Declaration Case #15-145-CUP.

MRS Environmental. 2019. *Hazard Assessment Field Report.* ORNI 34 LLO Battery Energy Storage Systems.

Quintiere *et al.* 2016. *Fire Hazards of Lithium Batteries.* Federal Aviation Administration – Fire Safety.

ATTACHMENT A

RESUMES
FOR
ASSESSMENT PROJECT TEAM

STEPHEN RAMSAY, PH.D., P.ENG.
BARRY J. LOUGH, EP, P.PHYS., P.MET.
ANN L. JAMIESON, EP, P.CHEM.

Dr. Stephen Ramsay P.Eng.

Senior Consultant

SYNOPSIS

Dr. Stephen Ramsay is a professional engineer with over 35 years of experience in teaching, research and consulting related to environmental issues the oil & gas, pipeline, mining, chemical processing, energy, transportation and related industries.

Dr. Ramsay's expertise includes environmental engineering, process design, pipeline engineering, dispersion modelling, risk assessment, process design, simulation and project management. Dr. Ramsay is an internationally recognized expert in matters related to environmental risk assessment.

Dr. Ramsay obtained a BASc and MASc degrees in Civil and Mechanical Engineering from the University of British Columbia and a PhD in Engineering and Applied Mathematics & Theoretical Physics (Fluid Mechanics) from the University of Cambridge. Dr. Ramsay was Professor of Engineering Science at the University of Western Ontario and Research Director of the prestigious Boundary Layer Wind Tunnel Laboratory.

Dr. Ramsay has provided expert testimony in numerous hearings and trials in many jurisdictions in Canada and internationally.

WORK RELATED EXPERIENCE OR SKILLS

- Engineering, design, and project management of oil and gas facilities, pipelines, chemical process and mining projects.
- Strong understanding of processes involved in the realization of projects from drawing board to construction and commissioning.
- Technical support through design and drafting coordination, review, and approval.
- Facility and pipeline system optimization, recommendations, planning, and construction coordination.
- Preparation of applications (AER,AUC, AENV, NEB, FERC, DFO, Coast Guard) and audit documentation.
- Support to production operations.

PROCESS ENGINEERING

Dr. Ramsay is familiar with all upstream oil and gas processes. Dr. Ramsay has an expert knowledge of relevant thermodynamics, fluid mechanics, transport processes and chemistry of all oil and gas processes.

ENVIORNMENTAL MODELLING

Dr. Ramsay has extensive experience with environmental modelling of air and water quality including dispersion modelling.

TRAINING

Dr. Ramsay has extensive experience with professional training. Dr. Ramsay is Senior Instructor with the Schlumberger Networks of Excellence in Training (NExT) and provides short course to industry and government internationally. Dr. Ramsay was a Professor of Engineering Science at the University of Western Ontario and brings formal university teaching skills and expertise to the industrial training setting. In addition, Dr. Ramsay has training contracts with many major international oil & gas companies including CNPC, Enbridge, Petrobras and many others.

PIPELINE ENGINEERING

Dr. Ramsay is familiar with all aspects of the design, construction and operation of oil and gas pipelines. Dr. Ramsay is the developer of several oil and gas pipeline models including non-isothermal transient gas pipeline models, risk assessment models, pipeline pigging models and two phase models.

OPTIMIZATION

Dr. Ramsay is experienced in optimization of oil and gas processes and transportation including linear and nonlinear programming, dynamic programming, stochastic programming, convex optimization, mixed integer nonlinear programming and related optimization techniques.

RISK ASSESSMENT

Dr. Ramsay is an international recognized expert in risk assessment of hazardous industrial operations and transportation. Dr. Ramsay has completed approximately 1,500 risk assessments. Dr. Ramsay is the author of the textbook "Dense Gas Dispersion and Risk Assessment" and is an internationally recognized expert in dense gas dispersion. Dr. Ramsay has worked extensively in safety case regimes for risk management.

SIMULATION

Dr. Ramsay is experienced in many aspects of simulation of industrial processes including chemical process simulation, atmospheric dispersion, quantitative risk assessment (QRA) and simulation of oil and gas processes and transportation. The methods employed include discrete event simulation (DES) and Monte Carlo simulation.

INTERNATIONAL WORK

Dr. Ramsay has worked extensively on international projects in over 25 countries.

EXPERT TESTIMONY

Dr. Ramsay has appeared as an expert witness in numerous tribunals, hearings and trials in Canada and internationally.

EDUCATION

2012-	LLB	Law (In progress) University of London
1979	BASc	Civil Engineering University of British Columbia
1982	MASc	Mechanical Engineering University of British Columbia
1988	PhD	Engineering/Applied Mathematics & Theoretical Physics University of Cambridge

INDUSTRIAL EXPERIENCE

2009-present **Senior Consultant & Co-Owner**
Grey Owl Engineering
Calgary, AB

- Responsible for all aspects of international oil and gas projects including facility design, commissioning, pipeline design and analysis, storage and transportation systems. Responsible for supervision, mentoring and training of engineering and technical staff of approximately 45 employees.

2015-present **President**
Inform Pipeline Solutions Inc.
Vancouver, B.C.

2008-present **President**
Arctic Simulation Consultants Inc.
Vancouver, B.C.

1995-present **Senior Consultant**
Calvin Consulting
Calgary, AB

- Responsible for risk assessment aspects of business focusing on oil & gas facilities, mining, pipelines and other process facilities. Involved in numerous risk assessment and air quality assessments for flares, compressor stations, gas plants, mines and transportation systems.

2004-2007 **Senior Consultant**
Sandwell Engineering
Vancouver, B.C.

- Responsible for process engineering and risk assessment related to oil & gas industry coastal projects especially LNG terminals.

2000-2004 **Principal Consultant**

biome Technologies Limited
Vancouver, B.C.

- Independent consulting to oil & gas, offshore, mining and forest industries on various matters relating to pipeline and process simulation, air quality, water quality, modeling and risk assessment.

- Expert testimony for trials and hearings in several Canadian jurisdictions.

1999-2000 **Principal Consultant**
Conor Asset Management Decisions
Vancouver, B.C.

- Risk assessment for clients in oil & gas and offshore industries. Conducted comprehensive assessments of offshore safety cases for North Sea and Newfoundland regulatory agencies. Provided expert testimony in hearings in Canada, Europe and Africa.

1998-1999 **Senior Consultant, Risk Assessment**
Jacques Whitford Environmental Limited
Vancouver, B.C.

- Responsible for risk assessment related to major pipeline and process project developments in B.C. and internationally. Numerical modeling and simulation of environmental impacts and risk of proposed developments.

1996-1997 **Director, Technology Development**
US Filter Corporation
Vancouver, B.C.

- Senior management responsibility for water treatment technology development , intellectual property management, pilot plant development and testing. Development of applications and markets for innovative water treatment in U.S., Mexico, Asia, Australia and Europe.

1988-1996 **President**
EnviroTech Research Limited
London, Ontario

- Developed simulations and numerical models for risk assessment and environmental assessment of chemical process, oil & gas, mining and pipeline projects.
- Provided expert testimony for trials and hearings in Ontario and Alberta.

1984-1988 **Associate Consultant**
Cambridge Environmental Research Consultants
Cambridge, U.K.

- Developed numerical models of highly stratified environmental flows in industrial processes, atmosphere and ocean. Developed risk assessment models for dense gas dispersion. Analyzed meteorological and oceanographic data for design. Developed models for dispersion of chemical and biological weapons (CBW).

1984 **Project Engineer**
Reid Crowther & Partners Limited
Vancouver, B.C.

- Responsible for Special Projects division of Vancouver Skytrain project concerned with numerical modeling of complex structural systems.

1984-1988 **Research Engineer**
BC Hydro Research & Development
Surrey, B.C.

- Responsible for research on environmental loading of transmission structures including development of wind and ice loading climatology. Developed Bayesian statistical methodology for analysis of short term meteorological records and determination of extreme value distributions for wind and ice loading of transmission line conductors.

ACADEMIC EXPERIENCE

1996-1999 **Adjunct Professor**
Faculty of Engineering Science
University of Western Ontario
London, ON

1989-1996 **Assistant Professor**
Faculty of Engineering Science
University of Western Ontario
London, ON

1989-1997 **Research Director**
Boundary Layer Wind Tunnel Laboratory
University of Western Ontario
London, ON

1989-1998 **Research Associate**
Boundary Layer Wind Tunnel Laboratory
University of Western Ontario
London, ON

1989-1999 **Research Fellow**
Boundary Layer Wind Tunnel Laboratory
University of Western Ontario
London, ON

PUBLICATIONS

Numerous refereed journal and conference papers and several books.

PATENTS

Several patents on processes related to industrial water treatment.

PROFESSIONAL MEMBERSHIPS

P.Eng. Association of Professional Engineers and Geoscientists of Alberta

P.Eng. Association of Professional Engineers and Geoscientists of British Columbia

P.Eng. Professional Engineers Ontario

Member American Society of Mechanical Engineers

Mr. Barry J. Lough, P.Phys., EP

PRINCIPAL DISPERSION METEOROLOGIST

Mr. Barry Lough is a dispersion meteorologist with over 20 years of experience performing air quality dispersion modelling assessments, designing air monitoring programs, interpreting air quality monitoring data, compiling emissions inventories and interpreting atmospheric influences. He has also developed programs and analytical techniques for evaluating air quality monitoring and meteorological data. Barry has contributed to problem solving in industry and government, specializing in air quality modelling, data validation and operational meteorology.

CAREER HIGHLIGHTS

Calvin Consulting Group Ltd. — 2005 to Present

Principal Meteorologist: Air Quality & Regulatory Compliance Services

Responsible for preparing air quality compliance information for regulatory applications. This includes compilation of complex emissions inventories, air dispersion modelling, providing recommendations for modifications to plant design to meet air quality guidelines, assessing culpability in issues resolution, determining statistical calculation methodologies, designing procedural documents and handbooks and participating in meetings and liaisons.

- Completed air quality dispersion modelling using various U.S. EPA dispersion models for hundreds of oil and gas facilities and power plants.
- Recommended alternate plant and stack design, based on predicted and actual ambient air quality effects and evaluating solutions scientifically.
- Communicated technical information with clients and stakeholders efficiently and in non-technical language. Explained the modelling process to clients and prospects on an as-needed basis. Instructed non-experts in the techniques of air quality modelling. Published related user-friendly exposition on the internet.
- Emissions modelling for a petroleum company power generating station located off of the shore of Nigeria. This project involved determination of emission parameters and obtaining model specifications and meteorological data.
- Completed numerous renewal and amendment applications for industry in Alberta.
- Compiled and interpreted information from a variety of sources using principles leading to consensus amongst multiple parties.
- Dispersion modelling of NO_x emissions from an airstrip, located on an island off the cost of Nigeria. Barry extracted and parameterized source data for the airplanes, after determining that no background sources of NO_2 were affecting the area. He also evaluated and encoded meteorological data for the model input.
- Prepared monthly and annual air quality, GHG and emission regulatory reports.
- Modelling in support of an approval application for a site situated in a large industrial complex, for which neighbouring sources and background concentrations contribute heavily to the regional ambient NO_x, SO_2, Ethylene, CO and PM.

Duke Energy Field Services Canada 2004 to 2005
Senior Environmental Scientist (contract position)

Responsible for regulatory and compliance issues for numerous gas plants.
- Obtained operational emissions data and prepared monthly and annual production and compliance reports.
- Completed annual emissions inventory reports (National Pollutant Release Inventory and Greenhouse Gas) for company facilities.
- Prepared regulatory approval applications for facility expansions and licence renewals, including air quality dispersion modelling.
- Completed on-site air quality empirical surveys and analyzed results.
- Represented member company at regular government and industry airshed meetings.

SEACOR Environmental Inc. 2002 to 2004
Project Scientist: Regulatory Compliance & Air Quality Management Services

Responsible for regulatory compliance, data acquisition and validation and air quality modelling.
- Conducted surveys, obtained NO_x, PM and SO_2 data, observed and compiled hypothetical information from servers, clients and other sources for use in preparing reports for clients and regulatory bodies.
- Applied theoretical principles to atmospheric inventory data in order to evaluate the validity of individual entries. Developed data verification procedure. Suggested data collection improvements based on instrument performance data.
- Combined input data from diverse sources to adapt the modelling approach to the plant in question.

Environment Canada 2001 to 2002
Operational/Research Meteorologist: Meteorological Services of Canada

Responsible for providing daily weather forecasts and validating empirical inventory data.
- Interpreted meteorological data and organized it into recognizable patterns. Explained the occurrence of weather phenomena, applying knowledge of atmospheric physical and dynamic systems while recognizing the strengths and limitations of the model output.
- Produced short-term predictions, keeping the clients' purposes in mind, and conforming to user-specified formats. Publicly presented weather and climate information using both computer and hand-drawn graphics, while fitting the presentation to meet the needs and expertise of the audience.

Jacques Whitford Environment Ltd. 1996 to 2001
Air Quality Scientist: Air Quality and Risk Assessment Group

Responsible for dispersion modelling, graphical output and presentations.
- Completed modelling for existing and proposed industrial facilities
- Determined refined dispersion modelling techniques, tested various solution prototypes, advised client of techniques to most efficiently diminish problem situations.

DESIGNATIONS

Canadian Environmental Certification Approvals Board Professional Meteorologist 2011
Canadian Environmental Certification Approvals Board Environmental Practitioner 2008

EDUCATION

Diploma in Science (Meteorology), University of Alberta	1994
Bachelor of Science (Physics), University of Alberta	1989

PROFESSIONAL MEMBERSHIPS

Canadian Environmental Certification Approvals Board	2007
H_2S Alive, ENFORM, Alberta, Canada	2006
Canadian Air & Waste Management Association	1996 to Present

Ms. Ann L. Jamieson, EP, P.Chem.

EMISSIONS, AIR QUALITY & REGULATORY COMPLIANCE CONSULTANT

Ann is a proven environmental consultant with 40 years of experience specializing emissions reporting, air quality dispersion modelling, air quality assessments and environmental auditing. Ann has worked in industry, as a consultant to industry and as a government regulator. She has successfully completed projects in more than 30 countries and has extensive experience providing liaison services between engineering design firms in Canada and International Environmental Assessment Teams, ensuring that whenever technically possible and economically feasible, identified potential environmental impacts are incorporated directly into the design phase of a project prior to the completion of the detailed engineering. Ann has excellent communication skills, coupled with a strong technical background and solid understanding of process engineering. Ann also has extensive major project management, regulatory liaison and boardroom experience. She is a Professional Chemist (P.Chem.) and a Canadian Certified Environmental Practitioner (EP).

CAREER HIGHLIGHTS

Calvin Consulting Group Ltd. 2000 to Present
President/CEO

Calvin Consulting Group Ltd. is a privately-owned environmental consulting company that specializes in emissions management, air quality dispersion modelling assessment, development and implementation of environmental management systems, environmental auditing and preparation of regulatory approval applications for obtaining operating permits.

- Completed more than 1000 emissions inventory, air quality dispersion modelling, air quality monitoring and air quality assessment projects in Canada, U.S. and abroad. Provides consulting services at various environmental regulatory hearings and community meetings.
- Completed several hundred major due diligence, air management system, Air Monitoring Directive (AMD) and Continuous Emission Monitoring System (CEMS) audits for various oil & gas corporations and power generation facilities.
- Prepared regulatory applications and obtained regulatory approvals for more than 500 industrial projects since incorporating the company in 2000. Managed EIAs and/or Air Components of EIAs in Barbados, Argentina, Pakistan and Nigeria.
- Responsible for National Pollutant Release Inventory (NPRI) and Greenhouse Gas (GHG) Reporting in Canada for several major Canadian companies since 2002.
- Responsible for monthly and annual emissions and air quality reporting for several major industrial facilities in Western Canada.
- Developed and implemented more than 30 Environmental, Health and Safety Management Systems (EHSMS) and Quality Assurance Plans (QAPs) to ISO 14001 Standards for numerous Canadian and international clients. Performs Annual Quality System Audits for these clients. Wrote Safe Work Standards Manuals for numerous clients.
- Provides on-going liaison services between various industry corporations and environmental regulators in Alberta and British Columbia. Provided liaison services between engineering design team and EIA team for two major oilsands development projects in Fort McMurray, Alberta.

- Provided Air Quality Assessment and/or Dispersion Modelling Training to Nigerian, Canadian, Barbadian, Brazilian and Trinidadian environmental regulators and petroleum industry personnel.
- Has participated on various federal and international air quality and emissions inventory committees representing the natural gas industry in Canada.

Spectra (Duke) Energy Field Services Ltd. — 2002 to 2005

Director: Environment, Health & Safety (contract position)

Responsible for executive management of Environment, Health and Safety (EHS) issues resulting from operation of all Canadian assets, which include gas plants, compressor stations and pipelines. Responsible for management of full-time EHS personnel, including six direct reports, and for controlling budgets and scheduling. Major projects included:

- Developed and implemented EHSMS to ISO 14001 standards, including development of new document and records management systems as well as system-wide programs for solid waste management, wastewater management and air quality management.
- Developed system-wide NO_x and SO_2 emissions inventory databases.
- Successful completed gas plant expansion and pipeline looping EIA and obtained required regulatory approvals for construction.
- Performed various due diligence audits for Duke Energy acquisitions and divestitures.
- Developed and implemented corrective action plans to address findings from various regulatory audits.

SEACOR Environmental Inc. — 2000 to 2002

National Vice-President: Regulatory Compliance & Air Quality Management Services

Responsible for management of regulatory compliance and air quality management services in 12 SEACOR offices across Canada. Member of executive management team responsible for marketing, contracts, management of sub-consultants, hiring, budget tracking and project management. Project highlights include:

- Senior project management and quality assurance of air quality assessments, dispersion modelling projects, environmental audits, due diligence audits and preparation of regulatory applications related to the oil and gas industry.
- Wrote and implemented numerous CEMS QAPs for Alberta clients.
- Responsible for training of air quality technical personnel in Canadian offices.
- Responsible for interaction with executive management team of former parent company, SECOR Engineering, in the United States.
- Managed multi-million dollar EIA projects for various pipeline companies in Canada and the U.S.

MacDonald Engineering Group Ltd. 1996 to 2000

Manager: Environmental Engineering

Responsible for on-site project management of three major EIAs including the Shell (SPDC) Bonny Terminal Upgrade Project in Nigeria, the Mudi Oil Field Development Project in Indonesia and the Bridgetown Port Expansion Project in Barbados. Responsible for technical liaison between the local multi-disciplinary EIA Teams based overseas and the Conceptual Engineering Design Teams based in Canada. Provided environmental testimony at public forums and regulatory hearings that were held overseas. Resident of Nigeria from July 1997 to December 2000. Details of job responsibilities in Nigeria included:

- Hired and managed multi-disciplinary team of Nigerian environmental personnel responsible for preparation of EIA and all aspects of CASHES (Community Affairs, Security, Health, Environment and Safety) associated with design and construction phases of oil terminal upgrade project in Nigeria.
- Prepared emissions inventory for the SPDC Bonny Terminal, the Mobil Bonny Terminal and the Bonny LNG Plant, as well as for other emission sources on Bonny Island (e.g., vehicles, power generators, fuelling stations, etc). Performed air quality dispersion modelling for various contaminants. Worked closely with process design engineers to incorporate various emission reduction initiatives into design of Bonny Terminal. Made recommendations for emission reductions.
- Provided liaison between SPDC and environmental regulators and between SPDC and Traditional Tribal Leaders.
- Conducted air quality and dispersion modelling training courses in Canada and in Nigeria for Nigerian Environmental Regulators from the Federal Environmental Protection Agency (FEPA) and Department of Petroleum Resources (DPR).
- Developed, documented and implemented EHSMS for SPDC in Nigeria.
- Other duties in Nigeria included marketing, preparation of proposal, contract negotiations, budget management, payroll for Nigerian personnel, organization of logistics for field personnel, development of community and regulatory contacts, orientation of new contractors from Canada, filing of Nigerian regulatory license applications and general day-to-day trouble-shooting (e.g., associated with power shortages, phone outages, immigration requirements, etc.).

BOVAR Environmental 1994 to 1996

Assistant Manager: Air Quality and Risk Assessment Group

Responsible for management of consultants specializing in EIAs and air quality assessments. Project highlights included:

- Senior Report Editor for several major Canadian EIAs.
- Co-author and presenter of courses pertaining to air quality assessment and air quality dispersion modelling for various domestic and international clients (e.g., Government of China, Ecopetrol in Colombia, PetroCanada in Canada).
- Managed Air Quality Monitoring & Emissions Inventory Project for Athabasca Oilsands Area of Alberta, Canada. Project included documentation of monitoring network, analysis of data, compilation of emission sources in area, dispersion modelling of emission sources and comparison of monitoring data with dispersion modelling results.
- Dispersion modelling for various pulp and paper mills and power generating plants in New Brunswick and Nova Scotia.
- Provided critical review of Barbados Landfill EIA for Government of Barbados.
- Designed monitoring network and prepared emissions inventory for Government of Barbados.
- Completed numerous air quality assessments, dispersion modelling and regulatory permitting projects.

- Responsible for monthly and annual air quality reporting for approximately 20 industrial facilities in Alberta.
- Participated in the air components of various multi-disciplinary environmental audits.

TransCanada Pipelines **1992 to 1994**
Assistant Manager: Environmental Affairs

Responsible for management of projects related to EIAs, air quality management and solid waste management. Highlights of projects included:

- EIA Project Manager for Tuscarora Pipeline in California and Nevada. Provided liaison between TransCanada Pipelines and U.S. Regulators. Provided expert witness services at Federal Energy Regulatory Commission (FERC) Environmental Hearing in the United States.
- Developed system-wide NO_x emissions inventory database for all TransCanada compressor stations nationwide and performed NO_x dispersion modelling for all airsheds along more than 5000 km of natural gas pipeline.
- EIA Project Manager for various compressor station expansions, co-generation projects and pipeline expansions in Canada and the United States. Responsible for supervision of environmental inspectors at various construction sites across Canada. Provided expert witness services at National Energy Board hearings in Canada.
- Developed and implemented system-side Methane Reduction Program addressing fugitive emissions for compressor and metering stations across Canada.
- Responsible for development of system-wide Waste Tracking & Waste Reduction Program and PCB Waste Management Program for compressor stations across Canada.
- Developed and implemented corrective action plans to address National Energy Board (NEB) audit findings.
- Represented Canadian Gas Industry on Urban Airshed Super Modelling Committee formed by the U.S. Gas Research Institute in Washington, D.C. Participated on various technical sub-committees reporting to New England environmental regulators on issues related to dispersion modelling of NO_x and ground-level ozone.

Concord Environmental **1987 to 1992**
Supervisor: Environmental Assessment Group

- Supervised personnel and provided training on air quality dispersion modelling techniques.
- Designed air quality monitoring programs and prepared air quality monitoring reports for numerous oil and gas clients on a monthly and annual basis.
- Participated in air quality and noise components of numerous EIAs.
- Completed several hundred regulatory compliance and permitting applications.

Western Research & Development **1980 to 1987**
Air Pollution Scientist: Air Quality Assessment Group

Specialized in air quality dispersion modelling, air quality and climate assessments. Specific projects included:

- Received specialized training in air quality dispersion modelling and regulatory permitting, successfully completing more than 500 projects.
- Prepared emissions inventory of SO_2 emissions for major emission sources in Western Canada and Washington State for use in Environment Canada long-range pollutant modelling (SERTAD, RCDM and OME).
- Participated in flaring research project for Government of Alberta.
- Evaluated visibility from time-lapse photography for various potential airstrips on Melville Island in the Arctic.

- Participated in Alberta Energy & Utilities Board (EUB) GASCON Model Field Verification Project.

Education

Chemical Engineering Courses (3rd Year Level), University of Calgary	1984
Graduate Studies (Chemistry), University of Alberta	1978 to 1980
Bachelor of Science (Chemistry/Mathematics), Dalhousie University	1978

Professional Training

Expert Witness Training, Calgary	2015
Professional Ethics Training for Chemists.	2014
Behavioural Safety Technology Training, BST Institute, Texas, USA	2005
Total Quality Management Certification, Alberta, Canada	1996
Expert Witness Training, MJ Solutions, New Jersey, USA	1994
Environmental Inspector Training for Pipeline Construction, FERC, USA	1992
Noise Assessment Training, Ontario Ministry of Environment, Canada	1986
Dispersion Meteorology Certification, CMOS & American Meteorology Association	1983
Technical Editing Training	1978

Professional Affiliations

Canadian Environmental Certification Approvals Board (CECAB)
Certified Canadian Environmental Practitioner (EP) - Air Quality Assessment
Professional Chemist - Atmospheric (P.Chem.)