TECHNICAL MEMORANDUM

DATE April 9, 2015 **REFERENCE No.** 1416711-002-TM-Rev1

TO Nathan Gloag
Woodfibre LNG Limited

FROM Dennis Chang
Iain Jones

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WOODFIBRE LNG - RESPONSE TO INFORMATION REQUEST #53A & 53B

1.0 INTRODUCTION

This memorandum provides the information requested within Information Request #53A & 53B from the BC Ministry of Environment (MOE) during the working group review of Woodfibre LNG Ltd.'s Environmental Assessment Application under the BC Environmental Assessment Act. Information request 53A & 53B is reiterated as follows:

> *"If not provided already, submit the calculation and inputs used to generate the pseudo stack height for all flares. The prediction of wind (as shown by the wind rose graph) does not look reasonable at the project location given the topography of the area, which may result in unlikely air quality impact locations around the project location. To determine the validity of the predicted wind, the technical reviewer must review the following information: A small-scale map showing the grid point (or points) selected to determine the wind rose; and a wind speed frequency distribution graph and table for the location. The winter condition assumptions applied in the air dispersion modelling are not appropriate for Squamish, BC. Provide a report that shows the maximum hourly SO_2* [Sulphur dioxide] *isopleth map for the current run for the month of January and a run using autumn parameters for the month of January".*

The objectives of this technical memorandum are to:

- Provide the pseudo stack height calculations for the flares;
- Present the location where the CALMET model data were extracted;
- Provide wind speed frequency distribution for the CALMET model data at Project; and
- Present two-hourly SO_2 isopleths for the month of January, generated from the existing CALMET data set using winter values for geophysical parameters and the a CALMET data set using autumn values for geophysical parameters.

The four items listed above are illustrated in the following three sections.

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2.0 FLARE PSEUDO STACK HEIGHT

Pseudo parameters for the flares were calculated using the methods outlined in Chapter 11 of *Guidelines for Air Quality Dispersion Modelling in British Columbia* (MOE 2008) [BC Modelling Guideline]. As described in the BC Modelling Guideline, most air dispersion models are not explicitly capable of handling flares; therefore, pseudo-stack parameters need to be calculated to allow dispersion from flares to be simulated using conventional point source inputs. These pseudo-stack parameters allow for plume rise from the flares to be taken into account. Flares will only be used during upset conditions or maintenance activities. The physical stack parameters of each flare stack that were modelled in Section 5.2 (Atmospheric Environment [Air Quality] Assessment of the Environmental Assessment (EA) are summarised in Table 1.

Table 1: Physical Flare Parameters

Flare	Physical Stack Height [m]	Total Heat Release [BTU/hour]	Total Heat Release[1] [cal/s]	Effective Flare Height [m]
Flare WWGF (Depressuring Feed Gas)	100	11,849,164,800	829,441,536	183.6
Flare LPCF (Shut down Tank RG)	100	3,059,232,000	214,146,240	143.8
Flare CDGF (Major Maintenance of MR Compressor Unit)	100	31,933,528,000	2,235,346,960	234.3

Note: [1] - Total Heat Release in cal/s were calculated by assuming 1 BTU = 252 calories.

Equations for each of the pseudo stack parameters were taken from the BC Modelling Guideline and are provided in each of the following sections, with sample equations where appropriate.

Effective Flare Height

$$Effective\ flare\ height\ [m] = HSTK + 0.00456 \times THR^{0.478}$$

Where:

HSTK = Physical Stack Height in metres [m]

THR = Total Heat Release [cal/s]

Sample calculation for Flare WWGF:

$$Effective\ flare\ height\ [m] = 100 + 0.00456 \times 829441536^{0.478}$$

$$Effective\ flare\ height\ [m] = 183.6$$

Pseudo Flare Diameter

$$Pseudo\ Flare\ Diameter\ [m] = 0.000663\sqrt{THR}$$

Where:

THR = Total Heat Release [cal/s]

Sample calculation for Flare WWGF:

$$Pseudo\ Flare\ Diameter\ [m] = 0.000663\sqrt{829441536}$$

$$Pseudo\ Flare\ Diameter\ [m] = 19.09$$

Pseudo Flare Exit Velocity

As per the BC Modelling Guideline, the pseudo flare exit velocity is always set to 20 metres per second (m/s).

Pseudo Flare Exit Temperature

As per the BC Modelling Guideline, the pseudo flare exit temperature is always set to 1,000 degrees Celcius (°C), or 1,273 Kelvin (K).

The pseudo stack parameters calculated for each flare are provided in Table 2. These pseudo stack parameters were used to model emissions from the flares.

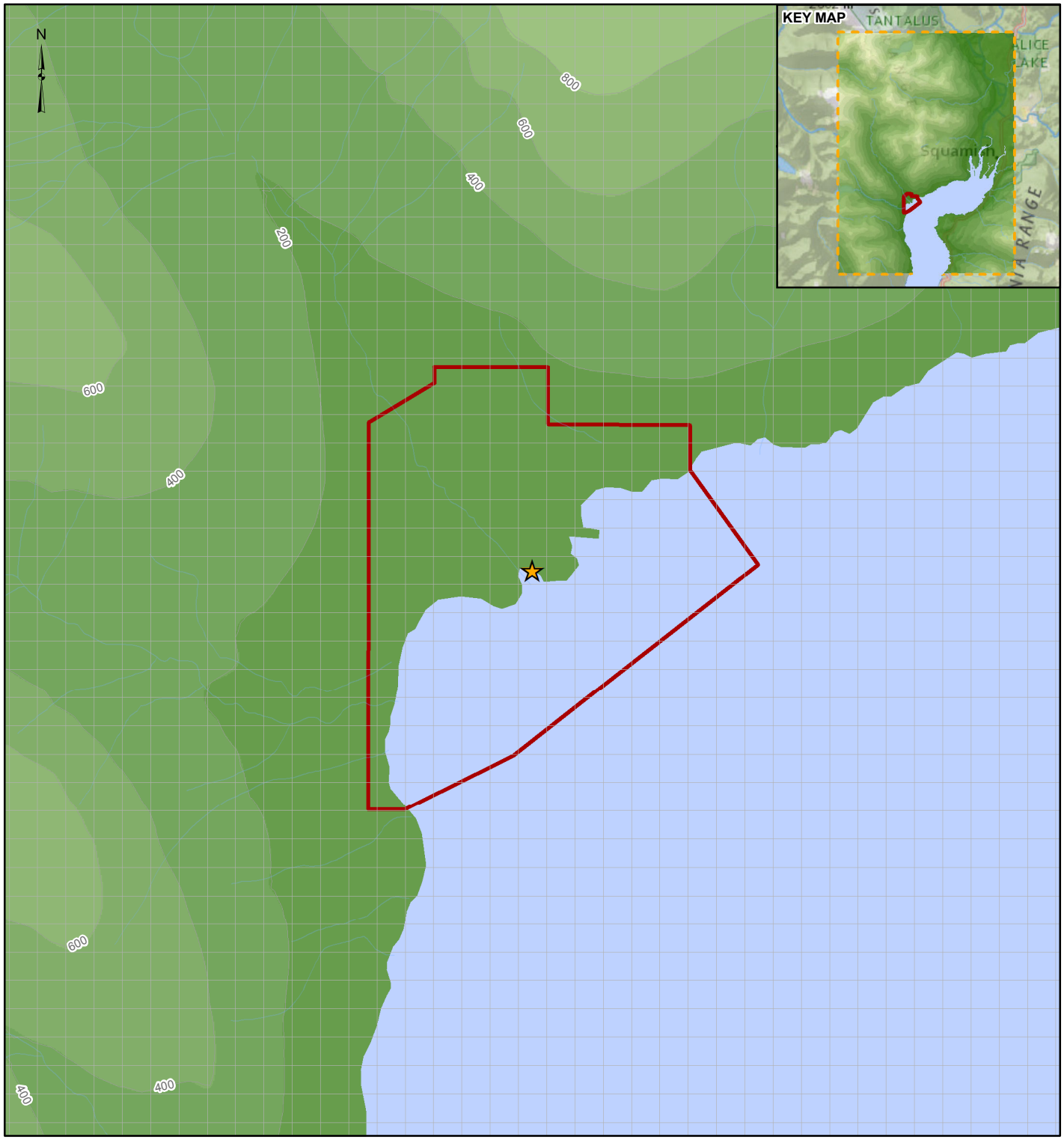
Table 2: Physical Stack Parameters

Flare	Effective Flare Height [m]	Pseudo Diameter [m]	Pseudo Exit Velocity [m/s]	Pseudo Exit Temperature [K]
Flare WWGF (Depressuring Feed Gas)	183.6	19.09	20.00	1,273
Flare LPCF (Shut down Tank RG)	143.8	9.70	20.00	1,273
Flare CDGF (Major Maintenance of MR Compressor Unit)	234.3	31.35	20.00	1,273

This summarises the pseudo stack parameters used in the assessment; this response does not change our assessment.

3.0 WIND

The location of the CALMET grid cell used to represent the project location is shown in Figure 1. The wind speed frequencies from the CALMET model at the project site are provided in Table 3 and Figure 2.



LEGEND

- CALMET WIND DATA EXTRACTION POINT
- CALMET GRID - 100 m x 100 m
- PROJECT AREA
- CALMET NESTED DOMAIN
- WATERCOURSE
- WATERBODY

TERRAIN ELEVATION (masl)

- 0 - 200
- 201 - 400
- 401 - 600
- 601 - 800
- 801 - 1,000
- 1,001 - 1,200
- 1,201 - 1,400
- 1,401 - 1,600
- 1,601 - 1,800
- 1,801 - 2,000
- 2,001 - 2,200

0 400 800

1:20,000 METERS

REFERENCE(S)

1. ORIGINAL TERRAIN DATA FROM GEOBASE. ALL RIGHTS RESERVED

CLIENT
WOODFIBRE LNG LIMITED.

PROJECT
WOODFIBRE,
HOWE SOUND, B.C.

TITLE
CALMET WIND DATA EXTRACTION POINT AT PROJECT

CONSULTANT
Golder Associates

YYYY-MM-DD	2015-03-24
DESIGNED	TB
PREPARED	JW
REVIEWED	CB
APPROVED	GW

PROJECT NO.	PHASE	REV.	FIGURE
1416711	2000	A	01

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A

25mm

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Table 3: CALMET Wind Speed Frequencies at Project Site

calm	0.2 to 1 m/s	1 to 2 m/s	2 to 3 m/s	3 to 4 m/s	4 to 5 m/s	5 to 6 m/s	6 to 7 m/s	>7 m/s
0.81%	20.15%	34.51%	27.13%	10.66%	4.88%	1.68%	0.17%	0.01%

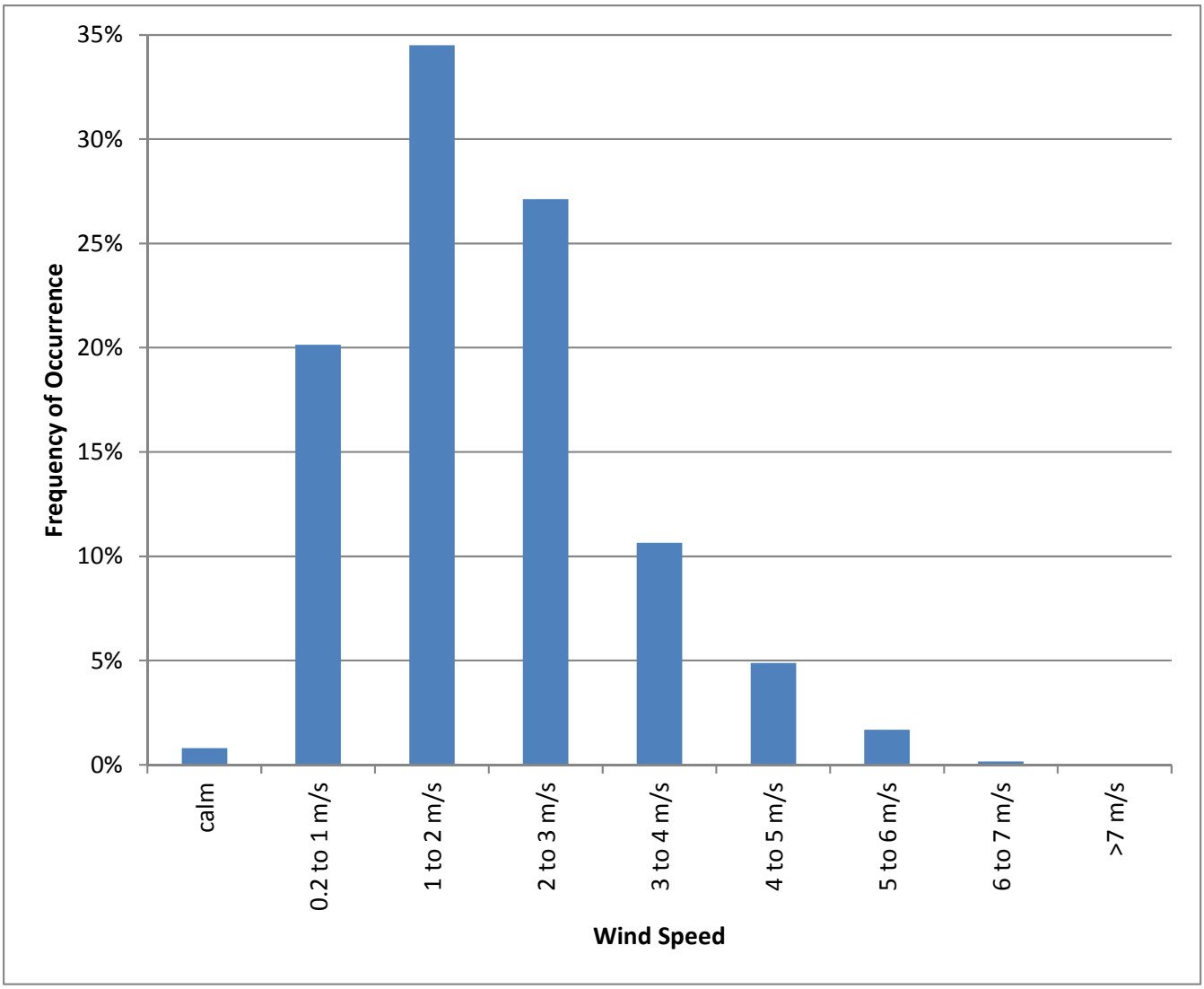


Figure 2: CALMET Wind Speed Frequencies at Project Site

Figure 1 shows where the CALMET data were extracted from for the Project location, and Table 1 and Figure 2 summarise the wind speed distribution frequency used in the assessment; this response does not change our assessment.

4.0 1-HOUR SO_2 PREDICTED CONCENTRATIONS WITH DIFFERENT GEOPHYSICAL PARAMETERS

As mentioned in Section 1.0, to generate maximum hourly SO2 isopleths, an updated set of geophysical parameters were used to run CALMET. BC Modelling Guidelines (MOE 2008) provides geophysical parameters for four seasons for surface roughness, albedo, and Bowen ratios. Table 4, and Table 5, present two sets of geophysical parameters, for roughness length and albedo, respectively. These geophysical parameters are the values used in: existing run, which was used in the EA; and autumn parameters used in the new run to address information request #53A & 53B. Table 6, Table 7, and Table 8 present the geophysical parameters for Bowen ratio, soil heat flux and leaf area index (LAI), respectively. However, these values did not change in the existing run and in the new run. Anthropogenic heat flux is used to estimate the heat flux at surface as a result of human activities. The CALMET default value of 0.0 Watts per square metre (W/m^2) was used for all land use. For the full description of the geophysical parameters, refer to EA, Appendix 5.2-C, Dispersion Meteorology, Section 4.5.

Table 4: Roughness Length Used in CALMET

Land Use Description	Roughness Length (m)	
	Existing run	New run
Urban or Built-up Land	1	1
Agricultural Land	0.01	0.05
Rangeland	0.001	0.01
Deciduous Forest Land	0.5	0.8
Evergreen Forest Land	1.3	1.3
Water	0.0001	0.0001
Wetland	0.05	0.2
Barren Land	0.05	0.05
Perennial Snow or Ice	0.2	0.2

Table 5: Albedo Used in CALMET

Land Use Description	Albedo (unitless)	
	Existing run	New run
Urban or Built-up Land	0.35	0.18
Agricultural Land	0.6	0.18
Rangeland	0.6	0.2
Deciduous Forest Land	0.5	0.12
Evergreen Forest Land	0.35	0.12
Water	0.14	0.14
Wetland	0.3	0.16
Barren Land	0.3	0.3
Perennial Snow or Ice	0.7	0.7

Table 6: Bowen Ratio Used in CALMET

Land Use Type	Bowen Ratio (existing and new run) (unitless)
Urban or Built-up Land	2
Agricultural Land	0.7
Rangeland	1
Deciduous Forest Land	1
Evergreen Forest Land	0.8
Water	0.1
Wetland	0.1
Barren Land	1
Perennial Snow or Ice	0.5

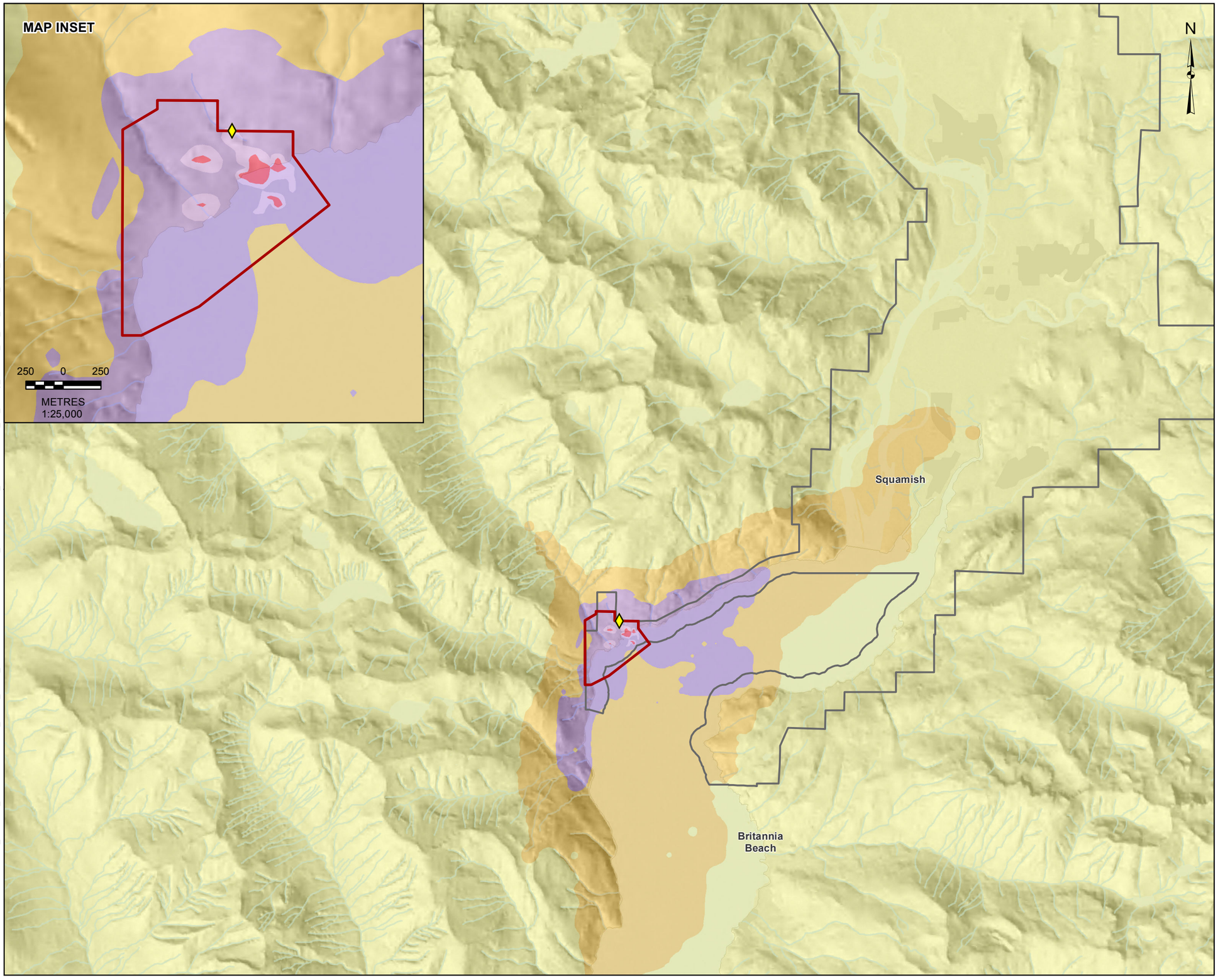
Table 7: Soil Heat Flux Used in CALMET

Land Use Type	Soil Heat Flux (existing and new run) (W/m^2)
Urban or Built-up Land	0.25
Agricultural Land	0.15
Rangeland	0.15
Deciduous Forest Land	0.15
Evergreen Forest Land	0.15
Water	1
Wetland	0.25
Barren Land	0.15
Perennial Snow or Ice	0.15

Table 8: LAI Used in CALMET

Land Use Type	LAI (existing and new run) (unitless)
Urban or Built-up Land	1.44
Agricultural Land	0.99
Rangeland	1.81
Deciduous Forest Land	1.48
Evergreen Forest Land	2.81
Water	0.00
Wetland	0.44
Barren Land	0.07
Perennial Snow or Ice	0.00

CALPUFF was executed for the month of January, using the CALMET model with the geophysical parameters shown above from Table 4 to Table 8. As described in Section 1.0, a comparison of two isopleths for predicted maximum 1-hour SO_2 concentration for January was requested. Figure 3 shows the predicted maximum 1-hour SO2 concentration isopleth using the winter (existing) geophysical parameters. Figure 4 shows the predicted maximum 1-hour SO_2 concentration isopleth using the autumn (new) geophysical parameters. The background 1-hour SO_2 concentration was assumed to be 7.9 microns per cubic metre ($\mu g/m^3$), which is the same value used in the EA. Please see EA, Appendix 5.2-D, Section 3.1.3 for the methods used to determine the 1-hour background concentration.



LEGEND

- PROJECT AREA
- URBAN AREA
- DISTRICT OF SQUAMISH MUNICIPALITY
- WATERCOURSE
- MAXIMUM OFFSITE LOCATION

1-HOUR SO_2 CONCENTRATION ($\mu g/m^3$)

- < 7.9
- 7.9 - 10.0
- 10.1 - 15.0
- 15.1 - 30.0
- 30.1 - 40.0
- 40.1 - 199.9
- > 200

DRAFT

NOTES

BACKGROUND 1-HOUR SO_2 CONCENTRATION TAKEN AS 7.9 $\mu g/m^3$

REFERENCE

MODELLED CONCENTRATIONS FROM CALPUFF VERSION 6.42. MUNICIPALITIES FROM GEOBC. BASE DATA FROM CANVEC © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED. HILLSHADE PROVIDED BY GOVERNMENT OF BRITISH COLUMBIA.
PROJECTION: UTM ZONE 10 DATUM: NAD 83

SCALE

2 0 2
KILOMETRES

PROJECT
WOODFIBRE LNG LIMITED.
WOODFIBRE, HOWE SOUND, B.C.

TITLE
1-HOUR SULPHUR DIOXIDE (SO_2) PREDICTIONS, NORMAL OPERATIONS, WINTER GEOPHYSICAL PARAMETERS

Golder Associates

PROJECT NO. 1416711			PHASE 2000
DESIGN	TB	01 Apr. 2015	SCALE 1:80,000
GIS	DL	07 Apr. 2015	**FIGURE 3**
CHECK			
REVIEW			

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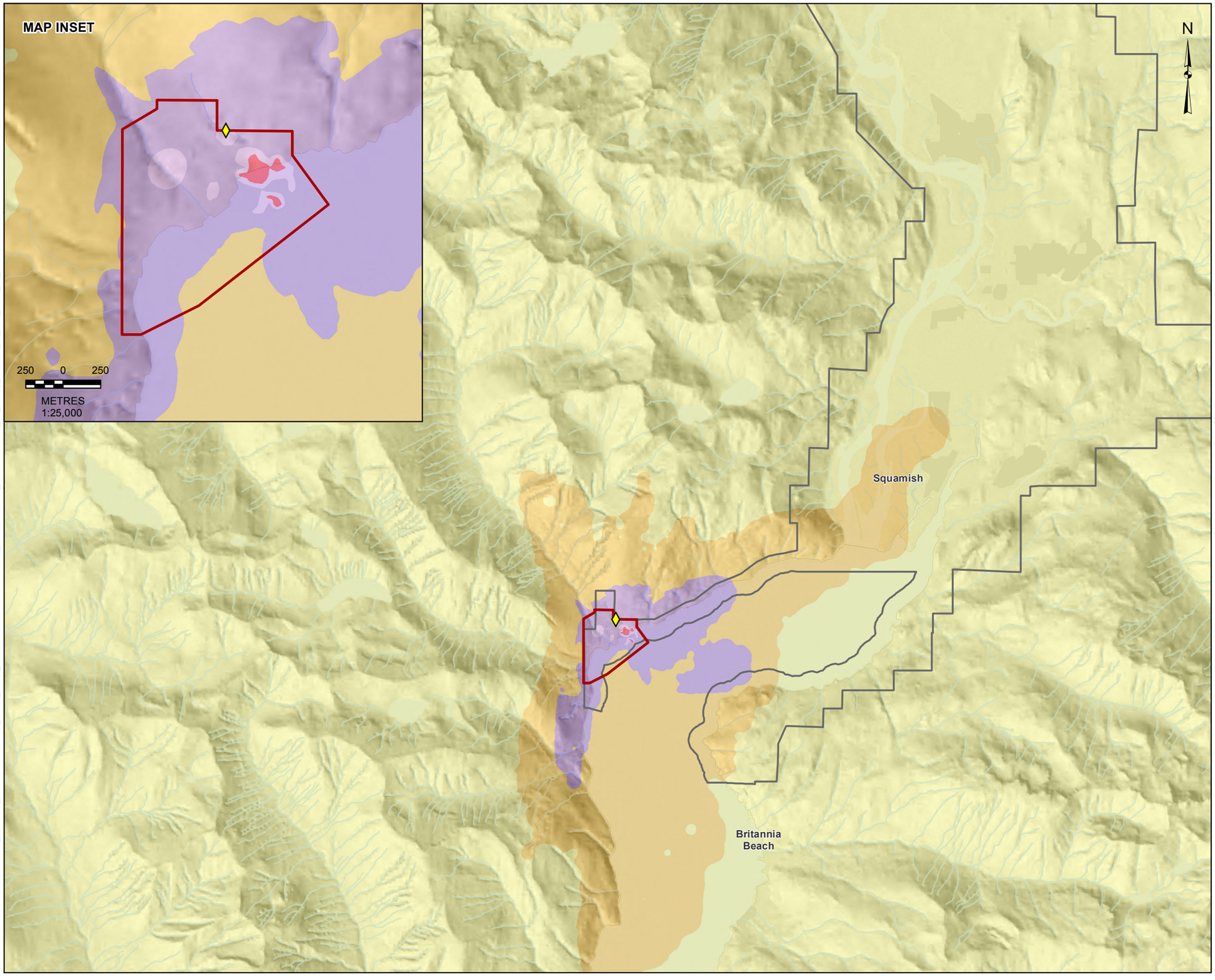

LEGEND

- PROJECT AREA
- URBAN AREA
- DISTRICT OF SQUAMISH MUNICIPALITY
- WATERCOURSE
- MAXIMUM OFFSITE LOCATION

1-HOUR SO_2 CONCENTRATION ($\mu g/m^3$)

- < 7.9
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- 30.1 - 40.0
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- > 200

DRAFT

NOTES

BACKGROUND 1-HOUR SO_2 CONCENTRATION TAKEN AS 7.9 $\mu g/m^3$

REFERENCE

MODELLED CONCENTRATIONS FROM CALPUFF VERSION 6.42. MUNICIPALITIES FROM GEOBC. BASE DATA FROM CANVEC © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED. HILLSHADE PROVIDED BY GOVERNMENT OF BRITISH COLUMBIA.
PROJECTION: UTM ZONE 10 DATUM: NAD 83

SCALE

2 0 2
KILOMETRES

PROJECT
WOODFIBRE LNG LIMITED.
WOODFIBRE, HOWE SOUND, B.C.

TITLE
1-HOUR SULPHUR DIOXIDE (SO_2) PREDICTIONS, NORMAL OPERATIONS, AUTUMN GEOPHYSICAL PARAMETERS

Golder Associates

PROJECT NO. 1416711			PHASE 2000
DESIGN	TB	01 Apr. 2015	SCALE 1:80,000
GIS	DL	07 Apr. 2015	**FIGURE 4**
CHECK			
REVIEW			

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Based on the existing run and the new run results, maximum offsite location of each run for January was identified. The maximum offsite locations between the two runs are found at two separate receptors, both along the northern boundary of the Project at 40m apart. Table 9 compares the maximum 1-hour SO_2 predictions at maximum offsite location and the receptors evaluated in the Human Health Risk Assessment (Section 9.2.2) in the EA. Overall, the SO_2 isopleths in Figures 3 and 4 are very similar. The difference between the maximum offsite 1-hour SO_2 predictions in the existing run (32.47µg/m³) and new run (32.61µg/m³) is +0.14µg/m³ or +0.4%. At the other receptors that were evaluated in the Human Health Risk Assessment, the differences in the maximum 1-hour SO_2 predictions are also very small, in the range of -0.33 to +0.04µg/m³ or -3.7% to +0.5%. It can be concluded that applying the winter or autumn geophysical parameter values for winter season in the dispersion modelling will not make any sensible differences in the model predictions or the assessment conclusions.

Table 9: Change in Concentration at Health Receptors

Receptor	UTM Coordinates[1]		Maximum 1-hour SO_2 Concentration (µg/m³)		
	Easting (m)	Northing (m)	Existing run	New run	Difference
Maximum offsite	481,945 (existing run) 481,905 (new run)	5,501,993 (existing run) 5,501,993 (new run)	32.47	32.61	+0.14
Squamish	488,444	5,504,644	9.25	9.24	-0.01
Porteau Cove	482,956	5,489,680	8.56	8.41	-0.15
Bowen Island	477,166	5,474,096	8.10	8.09	-0.01
Lions Bay	482,966	5,479,801	8.14	8.10	-0.04
Langdale	465,863	5,477,734	8.04	8.04	-0.01
Horseshoe Bay	479,592	5,469,590	8.04	8.03	-0.01
New Brighton	468,316	5,479,272	8.07	8.06	-0.01
Britannia Beach	484,988	5,496,856	8.87	8.85	-0.01
Furry Creek	483,657	5,491,970	8.50	8.32	-0.18
Gibsons	463,278	5,472,093	8.02	8.01	-0.01
Ch'iyakmesh	486,428	5,515,378	8.23	8.23	0.00
First Nations Cultural Site	484,578	5,498,086	9.21	9.19	-0.01
Residence	468,030	5,491,634	8.01	7.99	-0.02
Potlach Creek	476,990	5,492,115	8.31	8.25	-0.06
KWUM KWUM	479,216	5,491,787	8.80	8.69	-0.11
Tetrahedron Park	464,210	5,497,848	7.96	7.95	-0.01
Anvil Island	477,803	5,484,737	8.53	8.53	0.01
Ekin's Point	472,337	5,486,959	8.13	8.10	-0.03
Kaikalahun	464,231	5,485,289	8.02	8.02	0.00
McNab Creek Strata	472,492	5,490,163	8.10	8.07	-0.03
Camp Artaban	474,374	5,480,622	8.28	8.27	-0.02
Camp Latona	471,321	5,486,657	8.10	8.07	-0.02
Residence on Gambier Island	475,689	5,482,589	8.41	8.40	-0.01
Brackendale Provincial Park	488,227	5,511,539	8.65	8.63	-0.02
Alice Lake Campground	491,693	5,514,662	8.16	8.18	0.02
Evans Lake Forest Education Centre/Paradise Valley Campground	489,213	5,520,153	8.08	8.02	-0.05

Receptor	UTM Coordinates[1]		Maximum 1-hour SO_2 Concentration (µg/m³)		
	Easting (m)	Northing (m)	Existing run	New run	Difference
Garibaldi Lake Campsite Area	495,918	5,532,148	7.95	7.94	-0.01
Klahanie Campground/Stawamus Chief	488,239	5,502,227	9.37	9.38	0.01
Eagle Vista RV Resort & Campground	490,054	5,508,293	8.89	8.89	0.00
Elfin Lakes Shelter	500,864	5,515,123	7.99	7.98	-0.01
Wonderland Valley Resort	490,134	5,512,858	8.42	8.46	0.04
Squamish Valley Campground	482,612	5,524,920	8.06	8.06	0.00
Schaltuuch	465,209	5,472,541	8.02	8.01	-0.01
Chekwelp	463,833	5,473,149	8.02	8.01	-0.01
Defence Island	480,163	5,491,569	9.22	9.20	-0.02
Stawamus	489,410	5,504,316	8.88	8.55	-0.33
Yekwaupsum	488,329	5,508,189	9.31	9.30	-0.01
Kowtain	489,939	5,510,090	8.55	8.52	-0.03
Seaichem	489,787	5,511,430	8.63	8.58	-0.05
Waiwakum	488,464	5,513,143	8.41	8.40	0.00
Poquiosin & Skamain	487,383	5,514,494	8.30	8.28	-0.01
Cheakamus	486,116	5,516,903	8.17	8.17	0.00
Skowishin	478,512	5,531,112	7.99	7.96	-0.03
Skowishin Graveyard	478,939	5,528,555	8.01	7.99	-0.02
Port Mellon Station	464,087	5,486,080	8.00	8.00	0.00
Pam Rocks Station	478,313	5,481,725	8.48	8.43	-0.05
Squamish Airport Station	488,422	5,514,523	8.31	8.29	-0.01

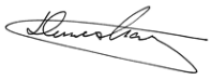
Note: [1] - UTM NAD83 Zone 10.

This response summarises the predicted concentrations derived from the existing assessment's meteorological dataset and a new meteorological dataset using autumn geophysical parameters. For the winter season, as Figure 3, Figure 4 and Table 9 suggest, there are no significant changes between the two sets of model results. Therefore, this response does not change the conclusion of the original assessment.

5.0 CLOSURE

We trust the above information provides that requested from the MOE in Information Request 53A & 53B and that no further action is required at this time.

GOLDER ASSOCIATES LTD.



Dennis Chang, B.A.Sc.
Senior Air Quality Scientist

Iain Jones, R.P.Bio., M.Sc., Dip. Tech.
Associate, Senior Project Manager, Ecologist

DC/SC/lih

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6.0 REFERENCES

British Columbia Ministry of Environment (MOE). 2008. Guidelines for Air Dispersion Modelling in British Columbia.