Environmental Impact Assessment
Component Study

AIR QUALITY COMPONENT STUDY

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July 2007

Air Quality Component Study

FINAL REPORT

NEWFOUNDLAND AND LABRADOR REFINING CORPORATION (NLRC)

St.John's, Newfoundland

July 2007

O/Ref.: 722665

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1. INTRODUCTION

Air quality in a region is determined by the concentration of various pollutants in the atmosphere as well as the size and topography of the air shed basin, and its meteorological conditions. The Placentia Bay region has high turbulent winds, which are not conductive to local high accumulation of air pollutants for extended periods. Although there is the possibility for quick dispersal of air pollutants, NLRC has committed to the reduction of air emissions to as low as possible with the use of BATEA. NLRC has established an Air Quality Advisory Group consisting of local community leaders, local industry and government agencies to advise and provide feedback on NLRC's efforts to reduce air emissions.

The construction and operation of the refinery will result in atmospheric emissions. An inventory of all significant emissions has been prepared for the normal operation of the refinery and the detailed evaluation is presented in Appendix A.

The emission inventory includes:

- storage tanks;
- process unit emissions (stacks, vents, and fugitive emissions);
- waste water treatment and cooling water;
- ship loading/unloading
- vessel operations
- flares.

Upset and intermittent releases will be studied at the detailed engineering phase.

Emissions related to the construction phase are discussed in Appendix B but will need to be studied at the detailed engineering phase in order to minimize atmospheric emissions.

Air dispersion modeling was conducted for the normal operation of proposed refinery to evaluate the impacts of sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), suspended particulates (PM_{10} and $PM_{2.5}$) and benzene on ambient air quality. The predicted results were then compared with Newfoundland and Labrador ambient air quality standards.

The CALMET/CALPUFF version 6 (EarthTech, 2000a, 2000b) air dispersion modeling system was used to estimate ground level concentrations of contaminants in ambient air. CALPUFF is an advanced non-steady-state meteorological and air quality modeling system developed by the Atmospheric Science Group of TRC (formerly of EarthTech) in the USA. When provided with hourly three-dimensional meteorological fields, it can simulate the effects of time and space-varying meteorological conditions on pollution transport, transformation, and removal.

This model (CALMET/CALPUFF) was chosen over other regulatory models used worldwide for its ability to estimate changes in wind flow in complex terrain and its ability to consider changes in boundary layer parameters over the modeling domain, especially at the land-sea interface in a coastal region. The choice of the CALPUFF model was a requirement from the Department of Environment and Conservation (NL DEC) for this project.

2. METHODOLOGY

Several types of data and treatment are required to perform air dispersion modeling. This section presents the basic data sources and methodologies used for air dispersion modeling for this project. Land use, topography, meteorology, emissions and selected CALMET/CALPUFF models options are discussed and presented in the following subsections. From the start of the project, the Newfoundland Department of Environment and Conservation (NL DEC) was consulted regularly to discuss model options, data sources and specific issues related to air quality and modeling.

2.1 Meteorology and CALMET setup

CALMET is the meteorological processor for the CALPUFF air dispersion model. CALMET produces the 3D wind and temperature fields and calculates the 2D atmospheric boundary layer parameters needed by CALPUFF.

2.1.1 CALMET domain and meteorological grid

The study area is presented in Figure 1. The meteorological domain covers a 35 x 35 km area. The domain extends 15 km south and west and 20 km north and east from the proposed refinery. The grid resolution was set to 500 meters and 9 vertical levels (see Table 3 for height of each level) extending up to 2000 meters. CALMET estimates meteorological parameters for each node on the grid.

2.1.2 Topography, land use and surface parameters

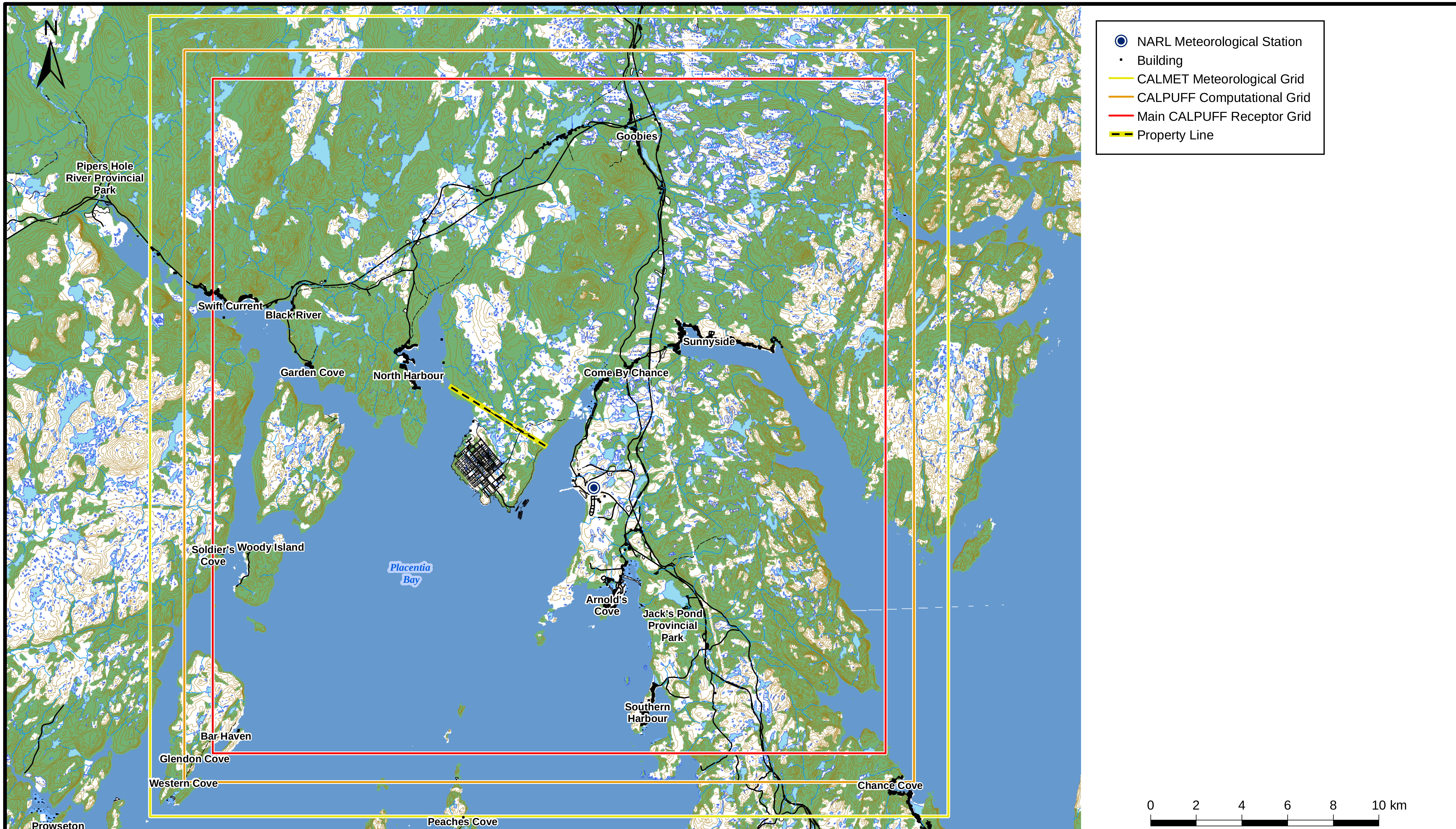
Topography and land use are important features that modified the state of the atmospheric boundary layer. An elevation, land use and various other surface parameters (surface roughness, albedo, etc.) must be estimated for each grid cell.

Topography was extracted from the Canadian Digital Elevation Data files the 1:50,000 scale using the TERREL tool included in the CALMET/CALPUFF system. Land use was obtained for the Natural Resource Canada 1:50,000 topographic maps for the study area. Using GIS software tools, the land use information was gridded (rasterized) at high resolution (50 m) for the following categories: water (large and small body), wetland, built-up areas, and wooden areas. Non-classified areas were designated as “barren-scrubland”. For each land use type, surface characteristics per season were estimated from literature (model user guides, modeling guidelines) and discussions with the Department of Environment and Conservation. These surface characteristics per land type and season are listed in Table 1.

Topographic information from TERREL and high resolution land use data were merged using the MAKEGEO tool included in the CALMET/CALPUFF system to produce the gridded geophysical data file needed by CALMET, at the same resolution as the meteorological grid (500 m).

Figure 2 presents the dominant land use for each cell in the modeling domain. It also shows the topography of the region, as seen by the model, i.e. at the resolution of the meteorological grid.

Since CALMET does not permit to vary surface characteristics during a model run, CALMET was run for each season using the appropriate geophysical gridded data set.



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0	2007/07/06	Preliminary	H. Dubois	É. Delisle
01	2007/07/17	Final	H. Dubois	É. Delisle

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Figure 1
Study Area, Meteorological and Air Dispersion Modeling Domains

PROJECT

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Table 1: Surface parameters per season and land use classification (CALMET)

Parameter [1]	Land classification					
	Build-up Area (plant site)	Large Water Body	Small Water Body	Scrub & Forest	Barren & Scrub	Wetland
Surface roughness (m)						
Winter	0.5	0.001	0.010	0.25	0.10	0.10
Spring	0.5	0.001	0.001	0.25	0.10	0.10
Summer	0.5	0.001	0.001	0.30	0.15	0.15
Fall	0.5	0.001	0.001	0.25	0.10	0.10
Albedo						
Winter	0.35	0.16	0.20	0.50	0.60	0.40
Spring	0.14	0.12	0.12	0.16	0.18	0.14
Summer	0.16	0.10	0.10	0.16	0.18	0.14
Fall	0.18	0.14	0.14	0.16	0.18	0.14
Bowen ratio						
Winter	0.5	0.1	0.8	0.8	0.8	0.8
Spring	1.0	0.1	0.1	0.5	0.5	0.1
Summer	1.0	0.1	0.1	0.5	0.5	0.1
Fall	0.5	0.1	0.1	0.8	0.8	0.1
Soil heat flux parameter						
Winter	0.15	1.0	0.1	0.10	0.10	0.10
Spring	0.25	1.0	1.0	0.15	0.15	0.25
Summer	0.25	1.0	1.0	0.15	0.15	0.25
Fall	0.25	1.0	1.0	0.15	0.15	0.25
Leaf area index[4]						
Winter	0.0	0.0	0.0	2.0	1.0	1.0
Spring	0.0	0.0	0.0	2.0	1.0	1.0
Summer	0.0	0.0	0.0	2.0	1.0	1.0
Fall	0.0	0.0	0.0	2.0	1.0	1.0
Notes	Process area and tank farm area	Placentia Bay Ice free all year	In-land small water bodies	NRC 1:50,000 maps “wooden areas”[3]	NRC 1:50,000 maps “no classification” areas	NRC 1:50,000 maps “wetland areas”

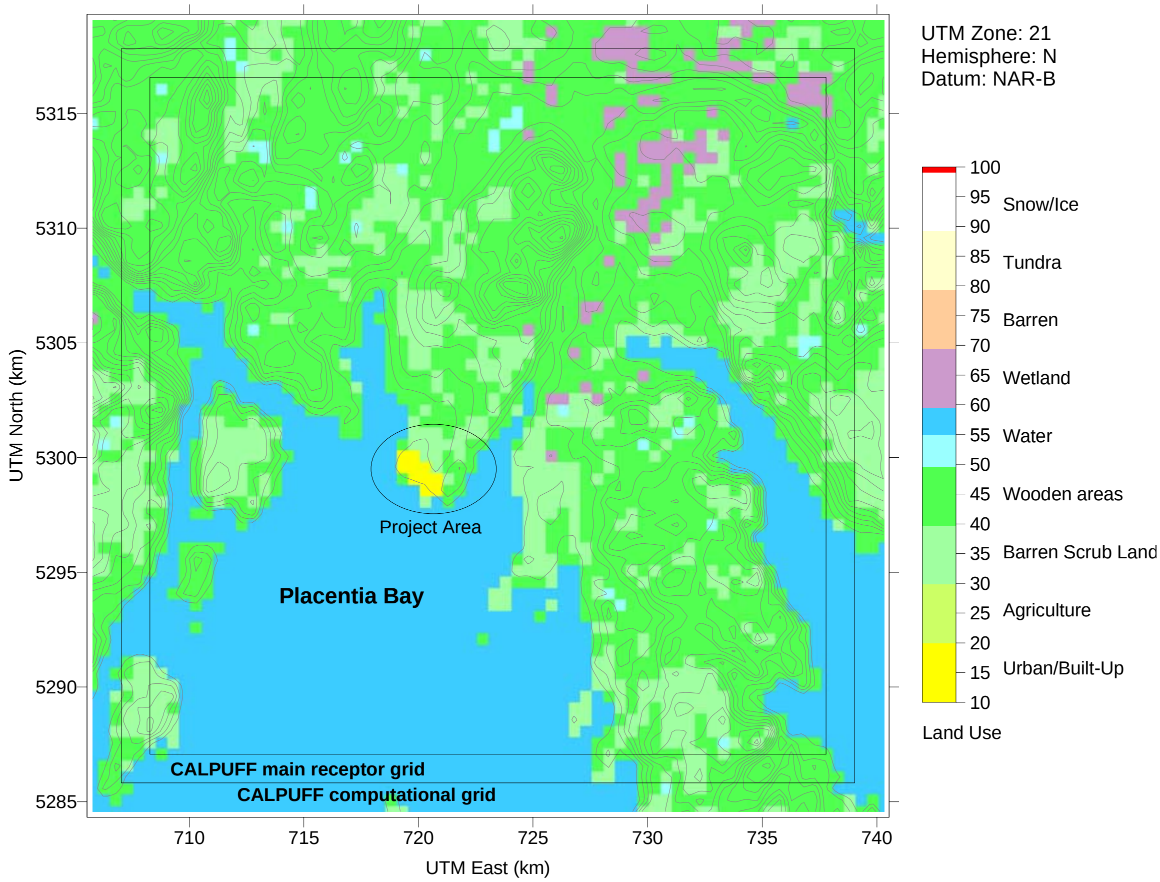
(1) For all land use categories, anthropogenic heat flux is set to “0”

(2) Winter: December to March
Spring: April to May
Summer: June to September
Fall: October to November

(3) Wooden area: at least 35 % of the surface with trees or shrubs with a minimum height of 2 meters.

(4) Not used since no deposition calculation in CALPUFF.

Figure 2: CALMET domain, dominant land use and topography (every 20 m)



2.1.3 Meteorological data

CALMET requires hourly surface observations of wind speed and direction, temperature, relative humidity, cloud cover and twice daily upper air sounding data. The North Atlantic Refinery Limited (NARL) in Come-by-Chance has been operating a surface station for many years. Hourly observations from 2002 to 2006 were obtained from NARL. To complete the meteorological database, hourly surface observations and twice daily upper air for the same period were obtained from Environment Canada for St.John's. Stephenville upper air station was also used to replace missing soundings in St.John's. Finally, CALMET requires air-sea temperature difference observations to drive its overwater boundary layer sub-model. The hourly observations for the Nickerson Bank Buoy were obtained for the same period.

Table 2 presents the sources of meteorological data and the approximate location of the stations. All these stations are the closest to the project site. Since the St.John's and Nickerson Bank stations are off-site and even outside of the modeling domain, most of the calculated meteorological fields will be dominated by observations at the NARL station, with the following exceptions:

- cloud cover for St.John's will be used over the entire domain, since this parameter is not available locally;

- overwater temperatures over Placentia Bay will come from the Nickerson Bank Buoy.

After analysing the NARL data, year 2002 was selected to perform air dispersion modeling mainly because data is more complete than other years.

All original meteorological data files were reformatted to formats compatible with CALMET:

- Surface observations from NARL and St.John's were combined into a standard SURF.DAT file for CALMET;
- St.John's upper air data were translated from Environment Canada UAS format to US TD-6201 format. The READ62 utility included with the CALMET/CALPUFF system was used to produce the standard CALMET UP.DAT file;
- Nickerson Buoy data were reformatted into a standard CALMET SEA.DAT file, but wave data (period, amplitudes) were not included since the wave patterns are most probably different at Nickerson Bank and Placentia Bay.

Table 2 : List of meteorological sources and stations

Type of station	Station name	Station localisation	Parameters	Frequency	Notes
Surface	NARL Refinery	Near site 4 km east	Wind, air temperature, pressure	Hourly	Solar radiation not used
Surface	St.John's	Off site 100 km east	Wind, air temperature, pressure, cloud cover, humidity ceiling	Hourly	
Over Water	Nickerson Bank Buoy	Off site 150 km south	Wind, air and water temperature	Hourly	Wave data not used
Upper air	St-John's	Off site 100 km east	Wind, air temperature, humidity, pressure, height	Twice daily	
Upper air	Stephenville	Off site 350 km west north-west	Wind, air temperature, humidity, pressure, height	Twice daily	Used to replace missing sounding from St-John's

2.1.4 Meteorological modeling – CALMET options

As required by the Guideline for Plume Dispersion Modeling of the NL Department of Environment and Conservation, all default options of CALMET were selected.

For the wind field generation models in CALMET, several parameters must be selected to control the weight of surface (and vertically extrapolate surface observations) and upper air observations in the initial guess wind field. Table 3 presents the bias-weighting factor selected in this project for the initial guess wind field.

For every hour and for each grid node and elevation, the initial wind field is calculated for extrapolated surface observation and time interpolated upper air observations weighted using an inverse squared weighting procedure. Additionally, a user selected bias factor is introduced that allows to modify the default weighting procedure. The selected bias factors are presented in table. For the levels closer to the surface, the upper air data is completely discarded, as indicated by the bias factor of "-1". For the top layers, the surface extrapolated data is completely discarded (Bias factor of 1). For the middle layers, the bias factor is selected to provide a slow transition from both extremes. Since the upper air station is off-site, the wind observations will not have a strong influence on the initial guess field in the middle layers.

Table 4 presents the other user supplied parameters for the wind fields generated by CALMET.

Table 3: CALMET vertical levels and biases for initial wind field

CALMET Vertical Level	Level height (m) (Top of level)	Bias Initial wind field
1	20	-1
2	50	-1
3	100	-1
4	150	-1
5	200	-0.5
6	300	0
7	500	0.5
8	1000	1
9	2000	1

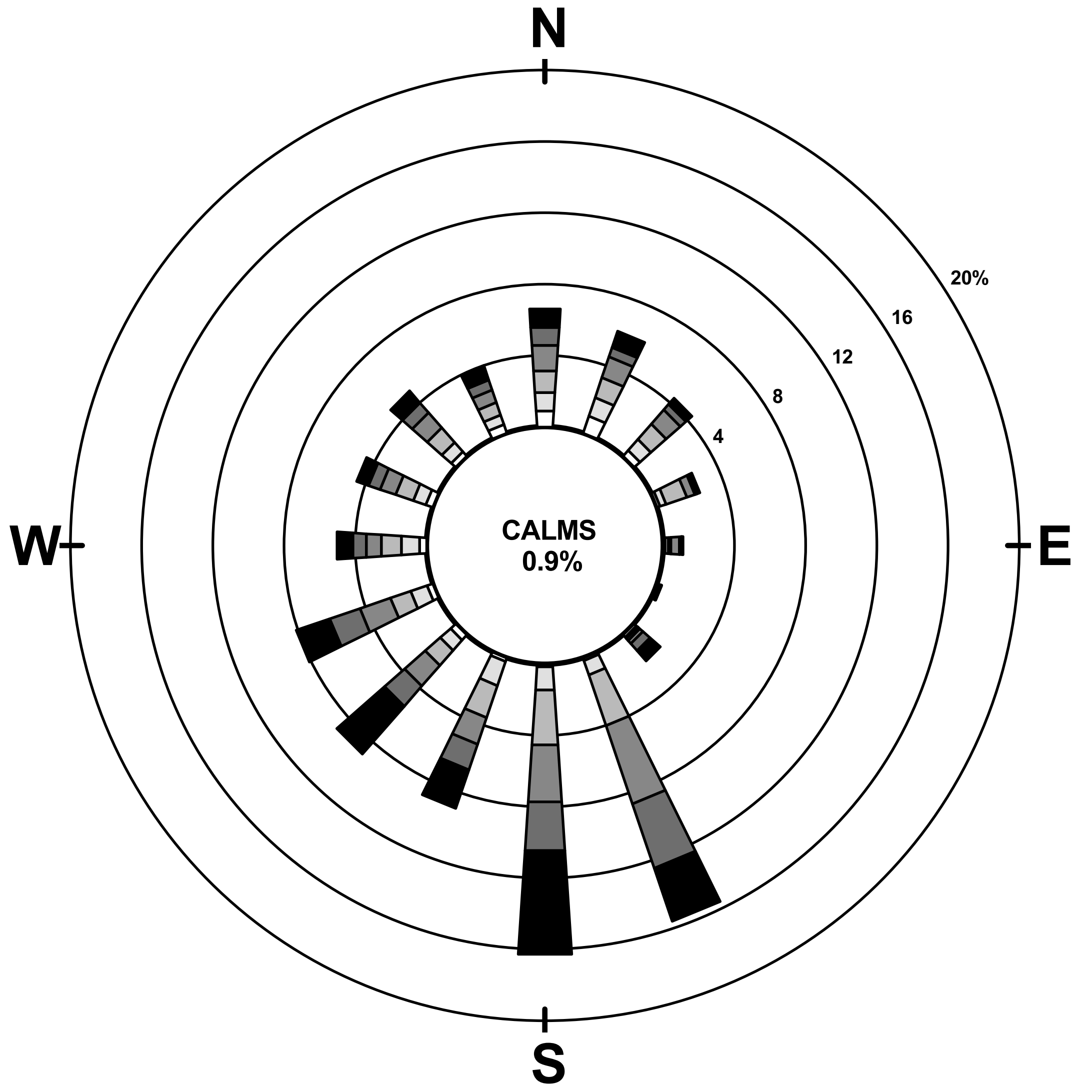
Table 4: CALMET user selected values for wind fields generation

CALMET option / user selected parameter	Selected value
Radius of influence – terrain (TERRAD)	3 km
Varying radius of influence (LVARY)	True
Radius of influence - land - surface (RMAX1)	5 km
Radius of influence - land - aloft (RMAX2)	10 km
Radius of influence - water (RMAX3)	5 km
Radius of influence - minimum (RMIN)	0.1 km
Weighting parameter - surface (R1)	2.5
Weighting parameter - aloft (R2)	5.0

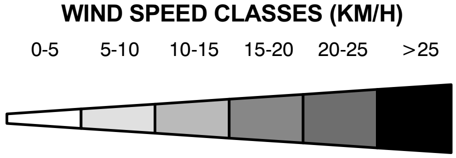
2.2 Wind roses

Figure 3 presents the 2002 annual wind rose for the observations at the NARL refinery. Figure 4 presents the wind rose for the proposed NLRC refinery derived from the CALMET generated wind fields. Finally, figure 5 presents a comparison of wind roses for the plant site, North Harbour, Sunny Side and Arnold's Cove. These wind roses were generated from the CALMET generated wind fields.

All wind roses are very similar, with dominant winds from the south and east-south-east. Very slight differences can be observed. This was expected since topographic features in the area are not significant.



WIND SPEED CLASSES (KM/H)



NOTE:
DIAGRAM OF THE FREQUENCY OF DIRECTION FROM WHICH THE WIND IS BLOWING. FOR EXAMPLE, WIND BLOWS FROM THE NORTH 6.6% OF THE TIME.

Projet / Project

NLRC

Titre / Title

Figure 3
NARL Wind Rose
(Measurement in 2002)

Client

Consultant
Directeur de projet / Project Director
Jean-Luc Allard

Consultant
SNC·LAVALIN Environment

Échelle / Scale
No scale

No. projet / Project #
722665

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1	2007/07/06	Final	H. Dubois	E. Delisle

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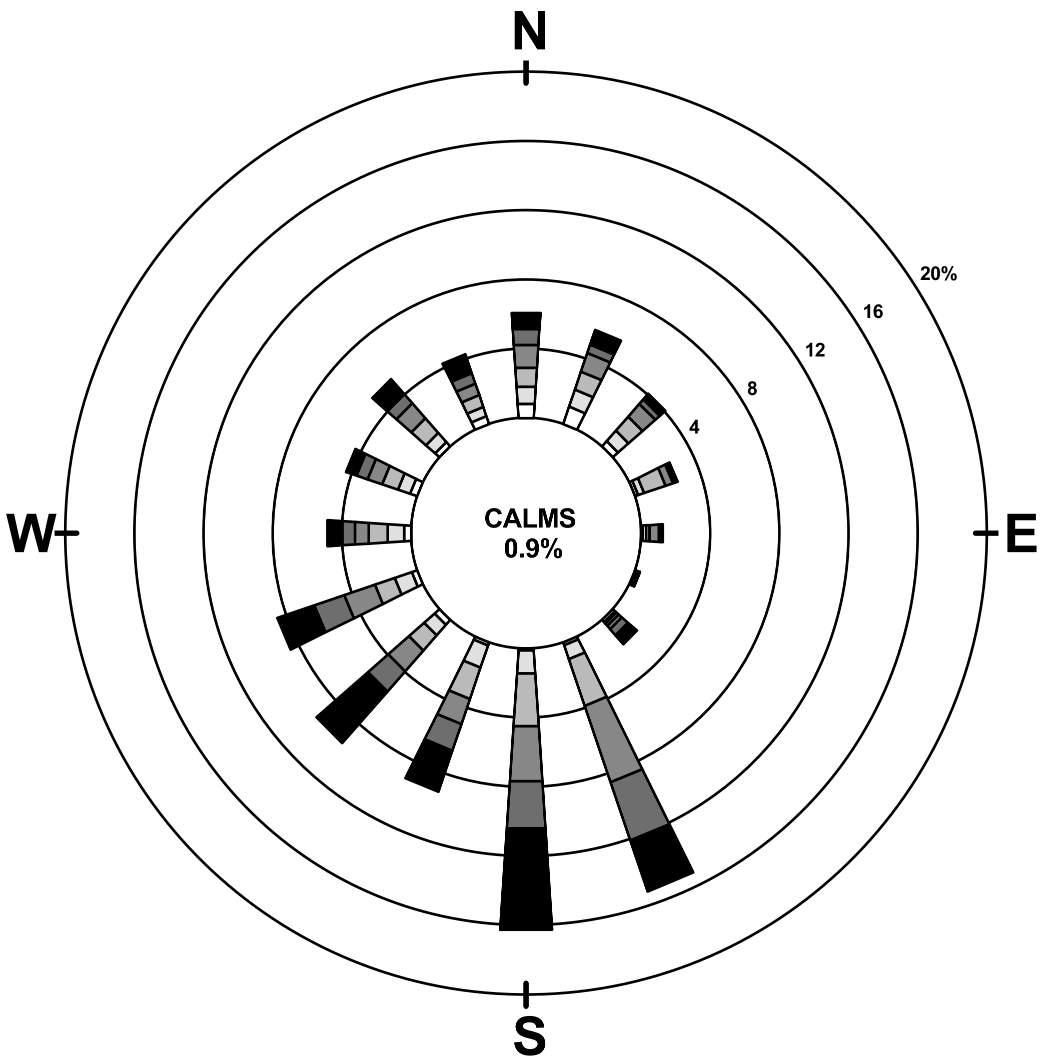

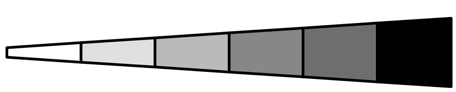

NOTE:
DIAGRAM OF THE FREQUENCY OF DIRECTION FROM WHICH THE WIND IS BLOWING. FOR EXAMPLE, WIND BLOWS FROM THE NORTH 6.6% OF THE TIME.

	Projet / Project **NLRC**	Titre / Title **Figure 4** **Plant Site Wind Rose** **(CALMET Modeling in 2002)**
	Client	Consultant Directeur de projet / Project Director **Jean-Luc Allard**
		Consultant SNC·LAVALIN Environment

Échelle / Scale	No. projet / Project #
No scale	**722665**

No.	aaaa/mm/jj yyyy/mm/dd	Description	Dessiné/Drawn	Vérifié/Verified
1	2007/07/06	Final	H. Dubois	E. Delisle

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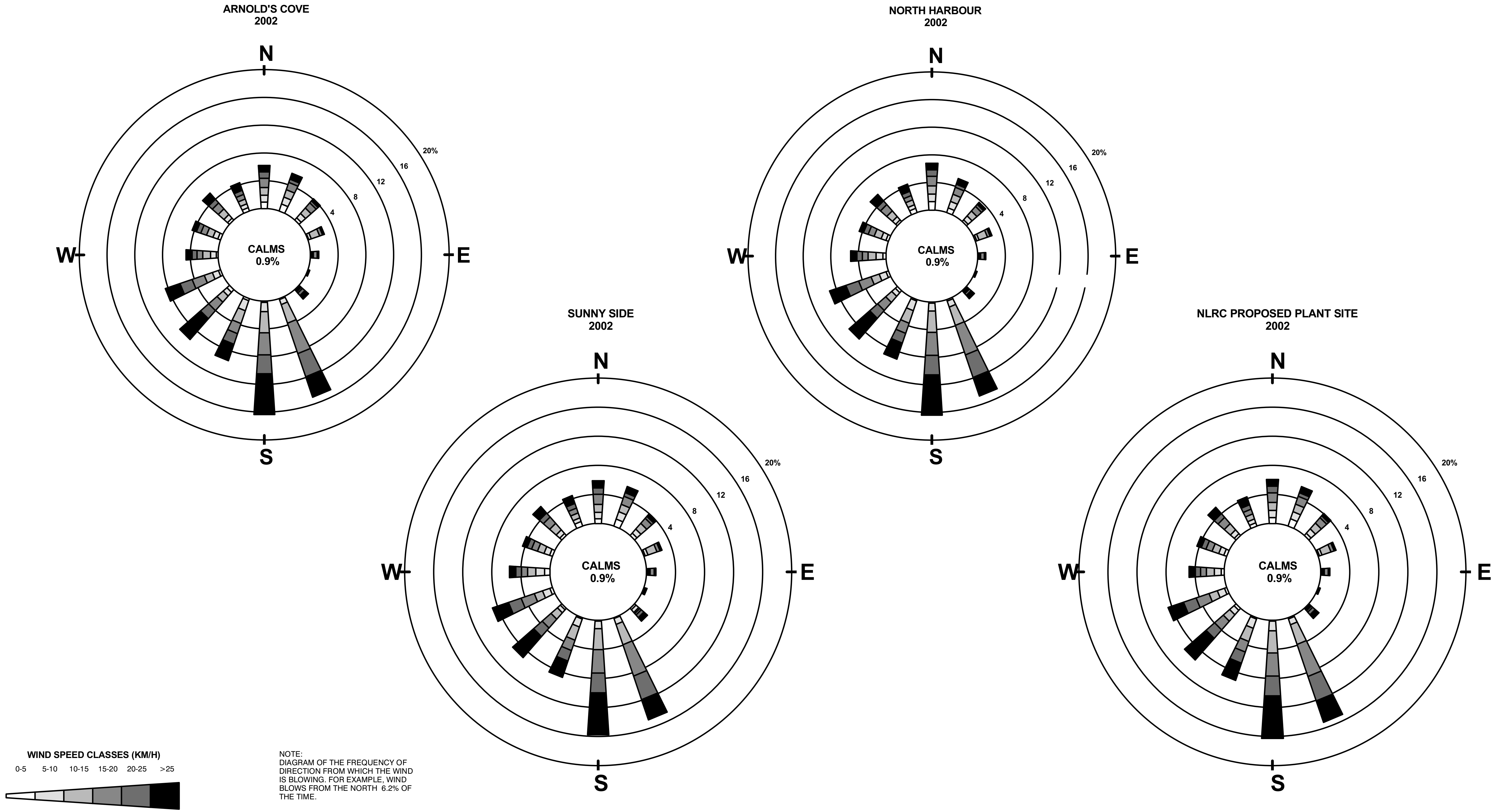

NOTE:
DIAGRAM OF THE FREQUENCY OF DIRECTION FROM WHICH THE WIND IS BLOWING. FOR EXAMPLE, WIND BLOWS FROM THE NORTH 6.2% OF THE TIME.

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Figure 5
Wind Rose in Communities
(CALMET modeling for 2002)

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2.3 Computational grid, receptors, and CALPUFF setup

The computational grid or the CALPUFF modeling domain was set to a subset of the CALMET meteorological grid. The computational grid, in which CALPUFF tracks puffs until they exit the domain, covers a 32 x 32 km domain. The main receptor grid was set to a subset of the computational grid and covers a 30 x 30 km domain. Figures 1 and 3 present the extents of the meteorological, computational, and receptor grids. Each of these grids has a 500 m resolution. Discrete receptors were added to get high-resolution results at the property line (every 50 m).

All CALPUFF default options were selected with the following exceptions:

- No chemical transformation.
- No wet nor dry deposition: particulate matter emissions from the installations are mostly fine particulates that will not deposit (dry) significantly. Excluding deposition from modeling is a cautious approach since all emitted contaminants remain in the atmosphere.
- Use of PRIME algorithms for building wake effects.
- Dispersion coefficient based on micrometeorological parameters and use of Probability Distribution Function (PDF) under convective conditions. These options were selected to be consistent with the AERMOD US-EPA regulatory dispersion model.
- Puff slitting is allowed.
- Wind shear above stack top is considered.

2.4 Nitrogen oxides (conversion of NO to NO_2)

The NO_x emissions due to the combustion of fossil fuels usually consist of 90 % of NO and 10 % of NO_2. In the atmosphere, NO will react quicker with the ozone (O_3) in air than it will with the oxygen (O_2) and to form NO_2 in both cases. The presence of VOCs accelerates the process by which NO is transformed into NO_2. Furthermore, an inverse reaction occurs because NO_2 breaks up under the effect of sunrays to form NO and ozone. Several other reactions involving NO_x, free radicals and VOCs occur in the atmosphere, particularly in urban areas.

Air modeling for NO_2 was performed assuming a total conversion of NO into NO_2 at the top of the stack. This assumption implies an overestimation of predicted ground level concentrations of NO_2, especially close to the sources. However, the NL DEC air quality standard for NO_2 applies to both NO_x species (NO and NO_2) when expressed as NO_2. The total conversion assumption of NO to NO_2 is therefore a regulatory requirement for comparison of NO_x predicted concentrations with NL DEC air quality standards.

2.5 Background concentrations

Air quality modeling for this project does not include other sources in the area, the most important one being the North Atlantic Refinery in Come-by-Chance. In order to take into account these other sources, the NL DEC provided maximum background concentration values in communities for SO_2, NO_x, PM_{10} and $PM_{2.5}$. These values were determined from previous monitoring and air quality modeling studies in the region and are presented in Table 5. All background concentrations are below air quality standards.

For CO, no data is available in the region. Maximum observed concentrations of 2,200 µg/m³ and 1,400 µg/m³ respectively on an hourly and 8-hour basis observed at the closest National Air Pollution surveillance station in St.John's in 2004 (latest published report) were selected as background CO concentrations. Again, these values are much lower than air quality standard: 35,000 µg/m³ for a one-hour and 15,000 µg/m³ for an 8-hour period.

For the project site itself, the NL DEC estimates that hourly and 3-hour average concentrations of SO_2 may exceed the air quality standards a few times during a year, mainly because of the SO_2 emissions from the existing North Atlantic refinery in Come by Chance.

Table 5: Maximum background concentrations in communities

Pollutant	Time Frame	Ambient Standard	Communities				
			Arnold's Cove	Come-by-Chance	North Harbour	Southern Harbour	Sunnyside
SO_2	1-hour	900	348	279	200	175	235
	3-hour	600	220	169	125	125	149
	24-hour	300	79	74	20	30	70
	Annual	60	2	5	1	1	6
NOx	1-hour	400	100	75	60	30	45
	24-hour	200	12	10	6	5	10
	Annual	100	1	1	1	1	1
PM_{10}	24-hour	50	14	14	13	12	15
	Annual	N.A.	7	7	7	7	7
$PM_{2.5}$	24-hour	25	10	10	9	8	11
	Annual	N.A.	5	5	5	5	5

* Background concentrations estimated by the Department of Environment and Conservation.

2.5.1 Potential Cumulative effects

The NL DEC provided background concentration of pollutants in communities in order to take account for existing sources of pollutants and in particular the North Atlantic refinery.

Future projects were also analyzed on a qualitative basis.

Projects such as the future LNG Transhipment facility and the VBNC Long Harbor Commercial plant are either not a significant emitter of criteria air pollutant or too far away (> 10 km) to have a significant impact in the study zone.

2.6 Emissions scenarios and parameters

Air quality modeling was performed for process point sources at the refinery and for point source emissions from ships at the dock for SO_2, NO_x, CO, PM_{10} and $PM_{2.5}$. Fugitive benzene emission for storage tanks, processes leaks, cooling tower and ship cargo (loading/unloading) were also considered. Tables 6 and 7 present the emission parameters used as input to the CALPUFF air dispersion model.

Figure 6 shows the proposed plant layout, tank farm, jetty and source locations and major structure on the plant site.

2.6.1 Stack height and building wake effects

At this stage of the project, only the height of the tanks (14-18 m), boiler house (18 m) and coke silos (91 m) were identified as potential structures that may affect stack plumes at the refinery. For ships, the ship itself and especially “the taller part at the back of the ship near the stack” the bridge (20-30 m above water level) may also affect the ships stack plume.

All these structures and stack locations were analyzed with the building wake processor BPIP_PRIME to estimate building wake parameters for each stack. For the refinery, only the crude units (GRP1), the boiler house (GRP2) and coker units’ (GRP3) stacks may be affected mainly by surrounding structures, and in particular the coke silos (91 m).

Based on these results, all stack heights at the refinery were set to 45 m, except the ones affected by building wake effects. The 45 m height is the maximum height allowed by the NL *Air Pollution Control Regulations (2004)* for estimating ground level concentration*.* For the crude units, boiler units and coker units, several model runs were performed increasing stack heights until there was no more evidence of building wake effects. The selected heights for these stacks were set to 75 m, still much lower than the maximum Good Engineering Practice (GEP) stack height of over 200 m.

For ships (VLCC and Handymax), approximate dimensions and stack heights taken from typical layouts of those ships were used as input for the building wake program.

2.6.2 Estimation of emission parameters

Emissions from the refinery point sources are related to fuel combustion with the exception of the incinerator of the sulphur recovery units. From the estimated hourly fuel consumptions, flue gas flow rate were estimated assuming 3 % O_2 in flue gas. Temperature was set to 200 ºC. However, this is a relatively low temperature for these types of equipment, thus minimizing plume rise and maximizing the increase in predicted ground level concentrations. Typical exhaust velocities in similar installations are around 8 m/s and approximate stack diameters were calculated based on estimated flue gas volumetric flow rates and selected temperatures to maintain an 8 m/s exhaust velocity. This emission scenario considers that 61 % of the thermal energy needs of the plant come from refinery generated gas and 39 % from purchased heavy fuel oil containing a maximum sulphur content of 0.7 % by weight. Additionally, NOx emissions were set to the maximum permitted levels allowed in Schedule G of the Air Pollution Control Regulations, 2004, Newfoundland and Labrador Regulation 39/04. For other emissions, US-EPA AP-42 emission factors from heavy fuel oil and gas fuels were used. Therefore, the emissions considered in this analysis represent the maximum expected emissions from the refinery.

Emissions from the process vents and flares will be treated later on, at the detailed engineering phase of the project. At this stage, it is not possible to set realistic emission parameters for these sources. Flaring will not be a major source of SO_2 with an estimated total of about 6 t/y.

For ships, the scenario considers the unloading of a Very Large Crude Carrier (VLCC) and the presence of a smaller ship loading at the dock. During unloading, the VLCC must produce energy (steam, electricity) for its internal systems and the unloading pumps. The emission scenario presented in Table 6 considers the concurrent use of a 4 MW diesel auxiliary generator and a 42 MW (heat input) steam generator (boiler) during unloading of a VLCC. Approximately one third of the flue gases generated by the boiler(s) will be used as an inert blanket gas for the unloading cargo compartments. For the other ship present at the dock, emissions from a 1 MW diesel generator were considered.

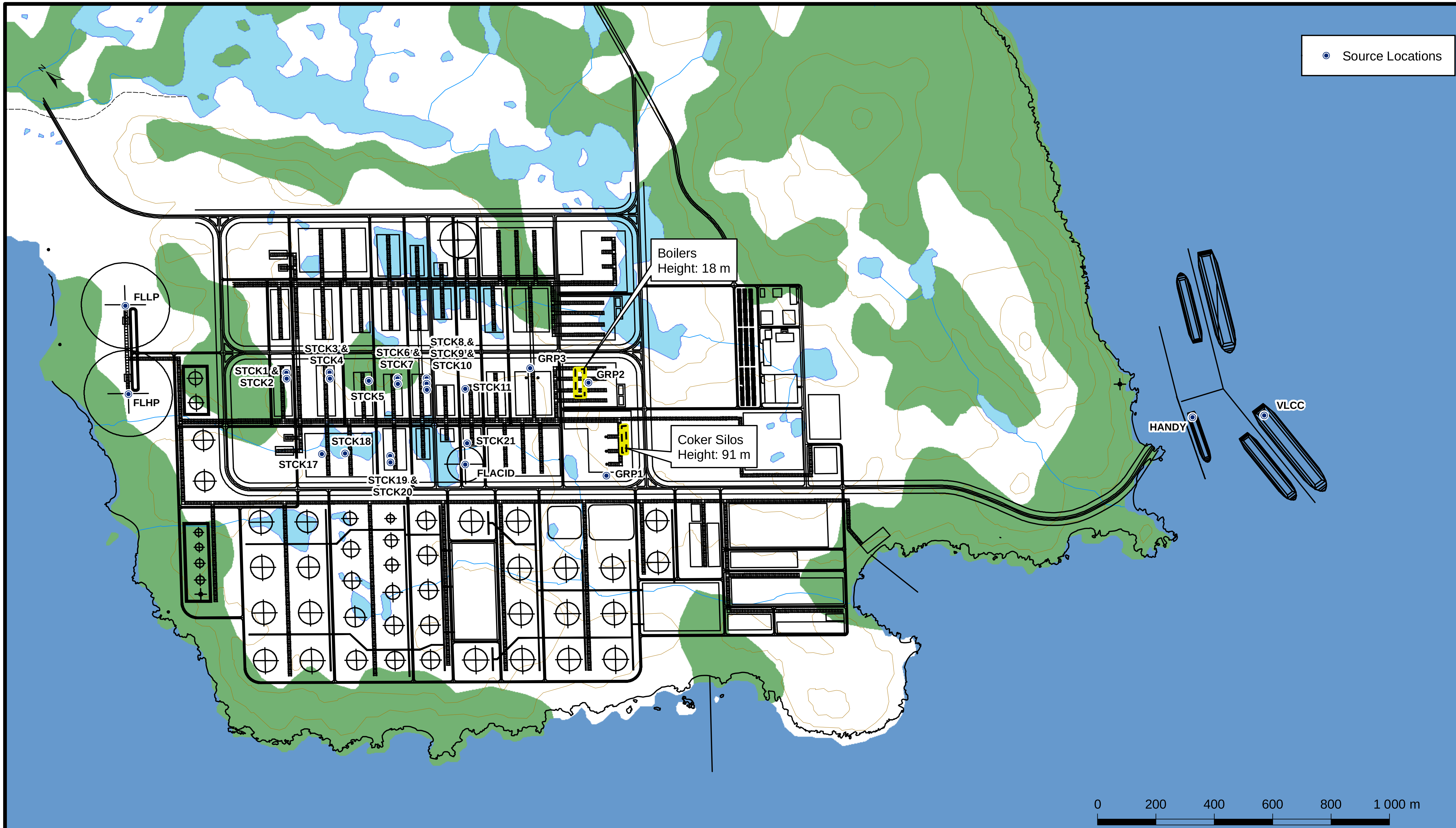
As for the refinery stacks, flue gas flowrates from ships were estimated based on fuel consumption and considering 3 % O_2 in the flue gas for the boilers and 15 % O_2 for the auxiliary diesel generator. Temperature was fixed at 200°C, and stack diameter set to a reasonable exhaust velocity. The fuel considered in the scenario is Marine Diesel Oil with a 1.5 % sulphur content for all ships.

The CALPUFF model was ran in several sub-runs:

1. Refinery stacks from units firing refinery gas, excluding the coker units;
2. Refinery stacks from units firing fuel oil, excluding the crude oil units and boiler house;
3. Crude units (GRP1: which includes items 12 and 13 in table 6)
4. Boiler house (GRP2, which includes items 14 and 15 in table 6)
5. Coker units (GRP3, which includes items 20, 21, and 22 in table 6)
6. VLCC ship unloading;
7. HANDYMAX hotelling ship at the jetty.

The POSTUTIL tool included with CALMET/CALPUFF system was then used to sum results from individual runs prior to running the CALPOST utility for results analysis (graphical output, statistics). This method saves a lot of computer running time when performing stack height analysis or analysis of results from the refinery itself, the ships themselves or all sources together.

VLCC tankers take about 20 hours to unload and smaller Suzemax tankers take about 16 hours to unload. A total of 66 crude oil deliveries per year (39 for VLCCs and 27 for Suzemax tankers) is expected. When estimating maximum daily and annual concentrations, the hourly emissions for the VLCC tankers in table 6 were scaled by 0.85 on a daily basis (20 hours per day) and by 0.15 on an annual basis (66 days per year and 20 hours per day). These scaling factors neglect that Suzemax tankers would only take 16 hours instead of 20 hours for VLCC tankers.



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0	2007/07/06	Preliminary	H. Dubois	É. Delisle
1	2007/07/16	Final	H. Dubois	É. Delisle

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Figure 6
Plant Layout and Source Locations

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Table 6: Point sources emission parameters used for air dispersion modeling for the proposed petroleum refinery

Item N°	Unit	Service	Stack number	Base elev.	Stack Height	Temp.	Velocity	Stack Diameter	Building wake	Contaminant emission rates (g/s)				
				(m)	(m)	(°C)	(m/s)	(m)	(Yes/No)	SO_2	NOx	CO	PM_{10}	$PM_{2.5}$
1	Hydro cracker	Recycle Gas Htr 1	STCK1	30	45	200	8	1.60	No	0.038	1.320	0.942	0.085	0.085
2	**Hydro cracker**	**Product Frac Fd Htr 1**	**STCK2**	**30**	**45**	**200**	**8**	**1.96**	**No**	**15.147**	**4.226**	**0.689**	**1.351**	**0.952**
3	Hydro cracker	Recycle Gas Htr 2	STCK3	30	45	200	8	1.60	No	0.038	1.320	0.942	0.085	0.085
4	**Hydro cracker**	**Product Frac Fd Htr 2**	**STCK4**	**30**	**45**	**200**	**8**	**1.96**	**No**	**15.147**	**4.226**	**0.689**	**1.351**	**0.952**
5	Diesel HTU	Combined Feed Htr	STCK5	30	45	200	8	1.16	No	0.020	0.448	0.496	0.045	0.045
6	Kero HTU	Rx Charge Htr	STCK6	30	45	200	8	0.78	No	0.009	0.203	0.225	0.020	0.020
7	Kero HTU	Stripper Reboiler	STCK7	30	45	200	8	1.47	No	0.032	0.714	0.790	0.071	0.071
8	Naphtha HTU	Charge Htr	STCK8	30	45	200	8	1.14	No	0.019	0.430	0.475	0.043	0.043
9	Naphtha HTU	Stripper Reboiler	STCK9	30	45	200	8	1.53	No	0.035	1.208	0.862	0.078	0.078
10	Naphtha HTU	Splitter Reboiler	STCK10	30	45	200	8	2.12	No	0.067	2.298	1.641	0.148	0.148
11	Coker Naphtha HTU	Rx 2 Charge Htr	STCK11	30	45	200	8	0.89	No	0.012	0.262	0.290	0.026	0.026
12	**Crude**	**Crude Heater**	**GRP3**	**30**	**75**	**200**	**8**	**3.44**	**Yes**	**51.180**	**17.639**	**4.743**	**4.775**	**3.429**
13	**Crude**	**Vac Heater**												
14	**Utility**	**Steam Boiler 1**	**GRP2**	**30**	**75**	**200**	**8**	**4.52**	**Yes**	**80.906**	**22.571**	**3.681**	**7.216**	**5.084**
15	**Utility**	**Steam Boiler 2**												
16	**Utility**	**Steam Boiler 3**												
17	H2 Plant	Reformer	STCK17	30	45	200	8	2.47	No	0.091	3.135	2.238	0.202	0.202
18	H2 Plant	Reformer	STCK18	30	45	200	8	2.47	No	0.091	3.135	2.238	0.202	0.202
19	CCR	Charge Htrs 3	STCK19	30	45	200	8	3.62	No	0.196	6.730	4.805	0.435	0.435
20	CCR	Vent Stack	STCK20	30	45			0.00	No					
21	TGT/TO	Incinerator	STCK21	30	45	650	8	4.01	No	2.992				
22	Delayed Coker	Coker Htr 1	GRP1	30	75	200	8	4.42	Yes	0.177	6.080	4.341	0.393	0.393
23	Delayed Coker	Coker Htr 2												
24	Delayed Coker	Coker Htr 3												
25	Acid Gas Flare	Acid Gas Flare	FLACID	30	80									
26	High Pressure Flare	High Pressure Flare	FLHP	30	80									
27	Low Pressure Flare	Low Pressure Flare	FLLP	30	80									
28	**VLCC unloading**	**Ship**	**VLCC**	**0**	**45**	**200**	**15**	**1.49**	**Yes**	**26.992**	**17.586**	**4.102**	**1.185**	**0.941**
29	**Handymax loading**	**Ship**	**HANDY**	**0**	**30**	**200**	**10**	**0.54**	**Yes**	**1.509**	**2.500**	**0.697**	**0.076**	**0.074**

Sources in bold use heavy fuel oil, others use refinery gas.

Table 7: Area source emission parameters for fugitive benzene emissions

Source	Surface Area (m^2)	Base Elevation (m)	Height (m)	Benzene Emissions (t/y)	Benzene Emissions ($g/s/m^2$)
Storage Tanks	704,000	25	15	0.71	3.20×10^{-8}
Process Area	617,500	30	5	3.73	1.92×10^{-7}
Ship (loading)	7,264	0	10	0.34	1.48×10^{-6}

3. RESULTS

Results of maximum and average predicted concentrations are presented on figures 7 to 16 over a map of the modeling domain. These results are produced from predicted concentrations on the main receptor grid used in the CALPUFF air dispersion model. For criteria air contaminants, results are presented for each regulated time frame in the NL regulations. For benzene, only the long-term concentration is presented, since potential health effects related with this contaminant are for a very long-term exposure.

As shown on Figures 7 to 16, all maximum predicted concentrations occur on the plant site. Secondary maxima also occur over water near the jetty and on elevated terrain several kilometers from the proposed refinery.

3.1 Criteria air contaminants

3.1.1 Results in communities

Tables 8 to 12 present maximum predicted concentrations in the communities of Arnold's Cove, Come-by-Chance, North Harbour, Southern Harbour and Sunnyside. Maximum background concentrations are also added to maximum predicted concentration to give the so called total result concentration, even if maximum predicted and maximum background concentrations are unlikely to occur at the same moment and at the same receptor. All results are also expressed in term of percentage of the NL DEC air quality standards. All results for all contaminants and time frames remain well below the NL DEC air quality standards.

Table 8: Summary of results for criteria air contaminants in Arnold's Cove

Pollutant	Time Frame	Standard	Background	NLRC (Maximum)		Total	
		(µg/m³)	(µg/m³)	(µg/m³)	(%Standard)	(µg/m³)	(%Standard)
SO_2	1-hour	900	348	136	15 %	484	54 %
	3-hour	600	220	76	13 %	296	49 %
	24-hour	300	79	32	11 %	111	37 %
	Annual	60	2	1.5	3 %	3.5	6 %
NO_2	1-hour	400	100	58	15 %	158	40 %
	24-hour	200	12	15	8 %	27	14 %
	Annual	100	1	0.9	1 %	1.9	2 %
CO	1-hour	35,000	2,200	23	0.1 %	2,223	6 %
	8-hour	15,000	1,400	9	0.1 %	1,409	9 %
PM_{10}	24-hour	50	14	3.1	6 %	17	34 %
	Annual	N.A.	7	0.12	N.A.	7.1	N.A.
$PM_{2.5}$	24-hour	25	10	2.3	9 %	12	49 %
	Annual	N.A.	5	0.08	N.A.	5.1	N.A.

Notes: NO_2 results consider a total conversion of NO to NO_2.
Maximum results for NLRC are added to maximum background concentrations without considering that maximums would most probably not occur simultaneously.

Table 9: Summary of results for criteria air contaminants in Come-by-Chance

Pollutant	Time Frame	Standard	Background	NLRC (Maximum)		Total	
		(µg/m³)	(µg/m³)	(µg/m³)	(%Standard)	(µg/m³)	(%Standard)
SO_2	1-hour	900	279	120	13 %	399	44 %
	3-hour	600	169	75	13 %	244	41 %
	24-hour	300	74	40	13 %	114	38 %
	Annual	60	5	2.3	4 %	7.3	12 %
NO_2	1-hour	400	75	60	15 %	135	34 %
	24-hour	200	40	20	10 %	60	30 %
	Annual	100	1	1.4	1 %	2.4	2 %
CO	1-hour	35,000	2,200	25	0.1 %	2,225	6 %
	8-hour	15,000	1,400	11	0.1 %	1,411	9 %
PM_{10}	24-hour	50	14	4.1	8 %	18	36 %
	Annual	N.A.	7	0.21	N.A.	7.2	N.A.
$PM_{2.5}$	24-hour	25	10	3	12 %	13	52 %
	Annual	N.A.	5	0.16	N.A.	5.2	N.A.

Notes: NO_2 results consider a total conversion of NO to NO_2.
Maximum results for NLRC are added to maximum background concentrations without considering that maximums would most probably not occur simultaneously.

Table 10: Summary of results for criteria air contaminants in North Harbour

Pollutant	Time Frame	Standard	Background	NLRC (Maximum)		Total	
		(µg/m³)	(µg/m³)	(µg/m³)	(%Standard)	(µg/m³)	(%Standard)
SO_2	1-hour	900	200	169	19 %	369	41 %
	3-hour	600	125	121	20 %	246	41 %
	24-hour	300	20	54	18 %	74	25 %
	Annual	60	1	4	7 %	5.0	8 %
NO_2	1-hour	400	60	69	17 %	129	32 %
	24-hour	200	6	23	12 %	29	15 %
	Annual	100	1	2.2	2 %	3.2	3 %
CO	1-hour	35,000	2,200	28	0.1 %	2228	6 %
	8-hour	15,000	1,400	15	0.1 %	1415	9 %
PM_{10}	24-hour	50	13	4.1	8 %	17	34 %
	Annual	N.A.	7	0..35	N.A.	N.A.	N.A.
$PM_{2.5}$	24-hour	25	9	3.0	12 %	12	48 %
	Annual	N.A.	5	0.26	N.A.	5.3	N.A.

Notes: NO_2 results consider a total conversion of NO to NO_2.
Maximum results for NLRC are added to maximum background concentrations without considering that maximums would most probably not occur simultaneously.

Table 11: Summary of results for criteria air contaminants in Little Southern Harbour

Pollutant	Time Frame	Standard (µg/m³)	Background (µg/m³)	NLRC (Maximum) (µg/m³)	NLRC (Maximum) (%Standard)	Total (µg/m³)	Total (%Standard)
SO_2	1-hour	900	175	78	9 %	253	28 %
	3-hour	600	125	58	10 %	183	31 %
	24-hour	300	30	21	7.0 %	51	17 %
	Annual	60	1	0.7	1.2 %	1.7	3 %
NO_2	1-hour	400	30	41	10 %	71	18 %
	24-hour	200	5	11	6 %	16	8 %
	Annual	100	1	0.36	0.4 %	1.4	1 %
CO	1-hour	35,000	2,200	20	0.1 %	2,220	6 %
	8-hour	15,000	1,400	6	0.0 %	1,406	9 %
PM_{10}	24-hour	50	12	2	4.0 %	14	28 %
	Annual	N.A.	7	0.05	N.A.	7.1	N.A.
$PM_{2.5}$	24-hour	25	8	1.5	6 %	10	38 %
	Annual	N.A.	5	0.04	N.A.	5.0	N.A.

Notes: NO_2 results consider a total conversion of NO to NO_2.
Maximum results for NLRC are added to maximum background concentrations without considering that maximums would most probably not occur simultaneously.

Table 12: Summary of results for criteria air contaminants in Sunny Side

Pollutant	Time Frame	Standard (µg/m³)	Background (µg/m³)	NLRC (Maximum) (µg/m³)	NLRC (Maximum) (%Standard)	Total (µg/m³)	Total (%Standard)
SO_2	1-hour	900	235	122	14 %	357	40 %
	3-hour	600	149	91	15 %	240	40 %
	24-hour	300	70	27	9.0 %	97	32 %
	Annual	60	6	1.4	2.3 %	7.4	12 %
NO_2	1-hour	400	45	43	11 %	88	22 %
	24-hour	200	10	14	7 %	24	12 %
	Annual	100	1	0.8	0.8 %	1.8	2 %
CO	1-hour	35,000	2,200	14	0.0 %	2,214	6 %
	8-hour	15,000	1,400	10	0.1 %	1,410	9 %
PM_{10}	24-hour	50	15	2.8	5.6 %	18	36 %
	Annual	N.A.	7	0.13	N.A.	7.1	N.A.
$PM_{2.5}$	24-hour	25	11	2.1	8 %	13	52 %
	Annual	N.A.	5	0.1	N.A.	5.1	N.A.

Notes: NO_2 results consider a total conversion of NO to NO_2.
Maximum results for NLRC are added to maximum background concentrations without considering that maximums would most probably not occur simultaneously.

3.1.2 Maximum results near the property line

Table 13 presents the maximum predicted concentrations at the property line. With the exception of the property line to the north of the refinery, the property line coincides with the coastline in this evaluation. All these maxima occur at the property line, or more precisely at the coastline, to the south and south-east of the refinery. Maximum hourly (734 µg/m³) and daily (251 µg/m³) SO_2 concentrations predicted at the most impacted receptor can reach over 82 % of the value of the standards, 900 µg/m³ and 300 µg/m³ respectively on an hourly and daily basis. For NO_x (expressed as NO_2), the maximum hourly-predicted concentration (297 µg/m³) reaches 74% of the air quality standard (400 µg/m³) and the maximum daily average predicted NO_2 concentration (163 µg/m³) reaches 82% of the air quality standard (200 µg/m³). For hourly and daily SO_2 and NO_2 concentrations, the second highest maximum over all property line receptors are also presented.

Table 14 presents the maximum contribution of the refinery source and the unloading ship at the property line. These results show that the refinery emissions produce the hourly maximum predicted concentrations of SO_2 and NO_2 at the property line and that the unloading VLCC produced the maximum daily average concentrations of SO_2 and NO_2 at the property line. From the refinery, the boilers stack (GRP2) and the crude units (GRP3) are the major contributors to the predicted maxima from the refinery. Since the property line is in between both sources (ship and refinery), it is unlikely that both sources contribute significantly to the same short maximum concentration, as shown in table 14.

Table 13: Summary of results for criteria air contaminants at the property line

Pollutant	Time Frame	Standard	NLRC - Highest First (Second) Maximum	
		(µg/m³)	(µg/m³)	(%Standard)
SO_2	1-hour	900	734 (539)	82 % (60 %)
	3-hour	600	335	56 %
	24-hour	300	251 (207)	84 % (69 %)
	Annual	60	21	35 %
NO_2	1-hour	400	297 (267)	74 % (67 %)
	24-hour	200	163 (135)	82 % (68 %)
	Annual	100	16	16 %
CO	1-hour	35,000	123	0.4 %
	8-hour	15,000	38	0.3 %
PM_{10}	24-hour	50	11	22 %
	Annual	N.A.	1.1	N.A.
$PM_{2.5}$	24-hour	25	8.7	35 %
	Annual	N.A.	0.9	N.A.

Notes: NO_2 results consider a total conversion of NO to NO_2.

Table 14: Maximum short-term predicted concentration outside the property line from the refinery and the unloading ships

Pollutant	Time Frame	Standard (μg/m³)	NLRC Refinery (μg/m³)	Ships (μg/m³)	Both (μg/m³)
SO_2	1-hour	900	734 Coast line South of refinery	414 Coast line West of jetty	734 Coast line South of refinery
	24-hour	300	64 Local summit 10 km north north-west of refinery	251 Coast line South of refinery	251 Coast line South of refinery
NO_2	1-hour	400	297 Coast line South of refinery	270 Coast line West of jetty	297 Coast line South of refinery
	24-hour	200	31 Local summit 10 km north north-west of refinery	163 Coast line West of jetty	163 Coast line West of jetty

Notes: NO_2 results consider a total conversion of NO to NO_2.
Ships: one VLCC unloading and one Handymax in standby

Background concentrations are not included in these results. Even if the existing NARL refinery in Come-by-Chance can contribute to relatively high concentrations on the proposed refinery site, with possible exceedences of hourly SO_2 standards a few times a year according to NL DEC, maximum contribution from both refineries simultaneously is unlikely since the maximum contribution from the proposed refinery at the property line would occur with winds from the North (refinery contribution) or the South-East (ships' contribution) and that for these conditions emissions from the NARL refinery, located to the East of the proposed refinery, could not impact at the same receptors.

3.2 Benzene

Annual average predicted concentrations of benzene in ambient air are presented in Figure 16 and are summarized for communities and at the property line in Table 15. There is no local air quality standard for benzene in ambient air. These results will be used in the health impact assessment since benzene is a known cancerogenic substance. The highest concentrations are predicted at the property line. In communities, the highest concentrations are predicted in Come-by-Chance and North Harbour.

Table 15: Summary of results for benzene

Receptor area	Maximum annual average concentration in the area (µg/m³)
Arnold's Cove	0.0086
Come-by-Chance	0.0126
North Harbour	0.0173
Little Southern Harbour	0.0026
Sunny Side	0.0062
Property line	0.42 (on the coastline, near the jetty)