Appendix J

Minimum Overwater Mixing Heights for Use in OCD and CALPUFF Modeling

J-1.0 Introduction

The Offshore and Coastal Dispersion (OCD) model requires the input of overwater mixing heights for use in the dispersion calculations for overwater emission sources. Input values for this parameter are usually not directly available because of the lack of on-site and continuous measurements of the temperature structure over the water. The OCD manual has a default value for the overwater mixing heights assigned at a value of 500 meters. As shown in the discussion below, this is a reasonable assumption.

In some cases, there may be routine twice-per-day balloon soundings taken at a coastal station, for which onshore flow is frequent. At these locations, the structure of the temperature sounding for onshore flow could be reasonably representative of the marine environment. However, use of land-based interpolation schemes (such as the Holzworth method[1] as implemented in the Industrial Source Complex model[2]) to derive hourly mixing heights can underestimate the hourly values in certain circumstances.

J-2.0 Application of the Land-Based Holzworth Mixing Height Method

With this method, the morning Holzworth mixing height is the height above ground at which the dry adiabat of the morning minimum surface temperature plus an arbitrary 5 °C intersects the vertical temperature profile observed at 1200 Greenwich Mean Time (GMT). This time is presumed to be near the time of sunrise and it is applicable for longitudes corresponding to the United States. The minimum temperature is determined from the regular hourly airways reports from 0200 through 0600 Local Standard Time (LST). The "plus 5 °C" is intended to allow for the effects of the nocturnal and early morning urban heat island since upper-air stations are generally located in rural or suburban surroundings. However, it can also be interpreted as a way to include the effects of some surface heating shortly after sunrise. In rural areas, however, only the afternoon Holzworth mixing height is used in the hourly interpolation method.

The afternoon Holzworth mixing height is calculated in a similar way, except that the maximum surface temperature observed from 1200 through 1600 LST is used and is applied to the 1200 GMT sounding. Urban-rural differences of maximum surface temperature are assumed negligible. If the surface temperature does not increase during the day (or even decreases) due to cold advection that could change the temperature structure of the entire sounding, then the assumption of no change to the 1200 GMT sounding will result in an underestimate of the afternoon mixing height. In occasional cases when the temperature actually decreases during the day (cold advection), the method recognizes this issue and flags the value for a possible data substitution.

Hourly mixing heights for use in regulatory dispersion modeling for rural areas are interpolated from these twice per day estimates, as shown in Figure J-1. The algorithm treats the mixing heights as convective, so that in rural areas, it is assumed that the value at the moment of sunrise is zero. Even though the interpolation in time to the afternoon maximum mixing height at hour 1400 may limit the period of low mixing heights, if the moment of sunrise is near the end of an hour, the hourly assignment of a mixing height for that hour near sunrise can occasionally be very low.

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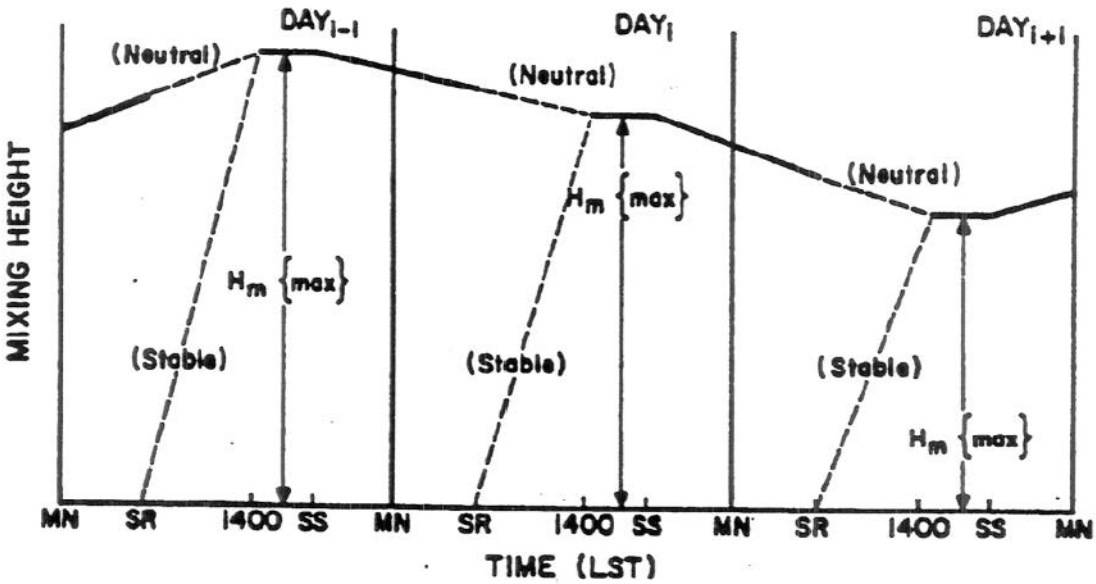
[1] G.C. Holzworth, 1972. "Mixing heights, wind speeds, and potential for urban air pollution throughout the contiguous United States", Environmental Protection Agency, Office of Air Programs, RTP, NC, PB-207103.

[2] EPA, 1985. User's Guide for the Industrial Source Complex (ISC3) Dispersion Models, Volume II Description of Model Algorithms. EPA-454/B-95-003b. U.S. Environmental Protection Agency, Research Triangle Park, NC.

As the OCD user manual[3] notes, however, the diurnal pattern of the mixed layer height over the ocean is much less than over land due to the moderating influence of the water and its high heat capacity. Therefore, the overwater mixing heights do not show the pronounced daily cycle characteristic that is seen over land because the heat flux over water depends mainly on the air-sea temperature difference, which does not exhibit a daily cycle[4]. Therefore, the occasional very low mixing height simulated by the interpolation procedure during stable conditions at sunrise shown in Figure J-1 are not realistic for an overwater environment. Their values, as well as the low mixing heights that are an artifact of the Holzworth scheme that are computed in the afternoon for cold advection cases, are conservatively low and will likely lead to overestimates in predicted pollutant concentrations if used in the OCD model. In these cases, it is advisable to either use a constant minimum value for the marine mixing height for all hours or to substitute a minimum marine mixing height for those hours for which the interpolated value is lower than the default minimum value.

Figure J-1: Illustration of Rural Mixing Height Interpolation Procedure



[3] DiCristofaro, D.C. and S.R. Hanna, 1989. *OCD: The Offshore and Coastal Dispersion Model.* Volume I: User's Guide. Sigma Research Corporation, Westford, MA.

J-3.0 Marine Mixing Height Observations

Gryning and others at the Danish Risø National Laboratory have conducted field experiments[4,5] to measure marine mixing heights. They have also devised an alternative mixing height algorithm[6,7,8] that is available for use in CALPUFF Version 6.

Sempreviva and Gryning report on the results of a study of the climatology of the mixed-layer height over inner Danish waters. For this study, a meteorological measuring station was operational from September 1990 to October 1992 on the island of Anholt in the Kattegat Sea, between Denmark and Sweden (see Figure J-2).

More than 400 radiosondes were launched as part of this study. The mixed-layer height was identified by visual inspection (and sudden increases with height) of temperature and humidity profiles.

The authors found that over the water, the temperature inversion does not show the pronounced daily cycle that is characteristic of that over land. Instead, the heat flux over water depends mainly on the air-sea temperature difference, which does not exhibit a diurnal behavior. Over the sea, the warming of the water surface caused by solar radiation is slower then over land because of the high heat capacity of the water.

Similar to overland, however, the mixed layer was found to be lower during the winter than during the summer. Figure J-3, reproduced from the Sempreviva and Gryning report, shows the nature of the diurnal pattern as a function of season, and also indicates that the minimum mixing height is about 250 meters, similar to the results found in the Kattegat Sea.

Gryning[5] (2005) described a 2-week field study conducted from small islands in the Baltic Sea, as shown in Figure J-4. The observed mixing heights shown in Figure J-5 show that there are no observations below about 250 meters.

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[4] Sempreviva, A. and S. Gryning, 2000. Mixing Height Over Water And Its Role On The Correlation Between Temperature And Humidity Fluctuations In The Unstable Surface Layer. *Boundary-Layer Meteorology*. Vol 97, No. 2, 273-291.

[5] Gryning, S. 2005. The height of the atmospheric boundary layer during unstable conditions. Risø-R-1536(EN).

[6] Batchvarova, E. and Gryning, S.E (1991). Applied Model for the Growth of the Daytime Mixed Layer. *Boundary-Layer Meteorol.,* **56**, 261-274.

[7] Batchvarova, E. and Gryning, S.E. (1994). An Applied Model for the Height of the Daytime Mixed Layer and the Entrainment Zone. *Boundary-Layer Meteorol.*, **71**, 311-323.

[8] Herkhof, D., 2007. CALPUFF Enhancements for Over Water Applications. Presentation available at www.cleanairinfo.com/regionalstatelocalmodelingworkshop/archive/2007/presentations/Wednesday%20-%20May%2016%202007/CALPUFF_MMS.pdf.

A Minerals Management Service presentation[8] (2007) describes the Batchvarova-Gryning mixing height algorithm developed largely from mixing-layer data collected in the aforementioned studies that has been installed into CALPUFF as well as the Mesoscale Model InterFace (MMIF) program that will replace CALMET. As shown in the presentation, this algorithm results in increased values of the overwater mixing height that lead to better model evaluation performance than the previous CALPUFF and OCD method that provided lower mixing heights using the Blackadar and Tennekes[9] (1968) mechanical mixing height approach. This result supports an approach that avoids very low mixing heights for use in overwater modeling using OCD or CALPUFF.

J-4.0 Conclusions

Two separate field studies, one lasting about two years, in northern latitudes near Denmark have found that minimum overwater mixing heights are on the order of 250 meters, and average much higher, more consistent with the OCD default value of 500 meters. Based upon these results, it would be acceptable to use a fixed overwater mixing height of 250 meters instead of 500 meters as a conservative approach, but the OCD average of 500 meters is consistent with the data shown above.

For OCD modeling with hourly mixing heights generated using the land-based Holzworth/ISC meteorological algorithms, it is advisable to use a minimum mixing height as applied to the hourly mixing heights (not the twice daily values before the hourly interpolation) due to the peculiarities of the interpolation scheme. The minimum hourly mixing height value could be as high as 250 meters, but even with some margin for uncertainty, it should probably be no lower than 100 meters.

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[9] **Blackadar, A. K., and H. Tennekes, Asymptotic similarity in neutral barotropic planetary boundary layers, J. *Atmos. Sci., 25*, 1015- 1020, 1968.**

Figure J-2: Location of 2-year Field Study between Denmark and Sweden

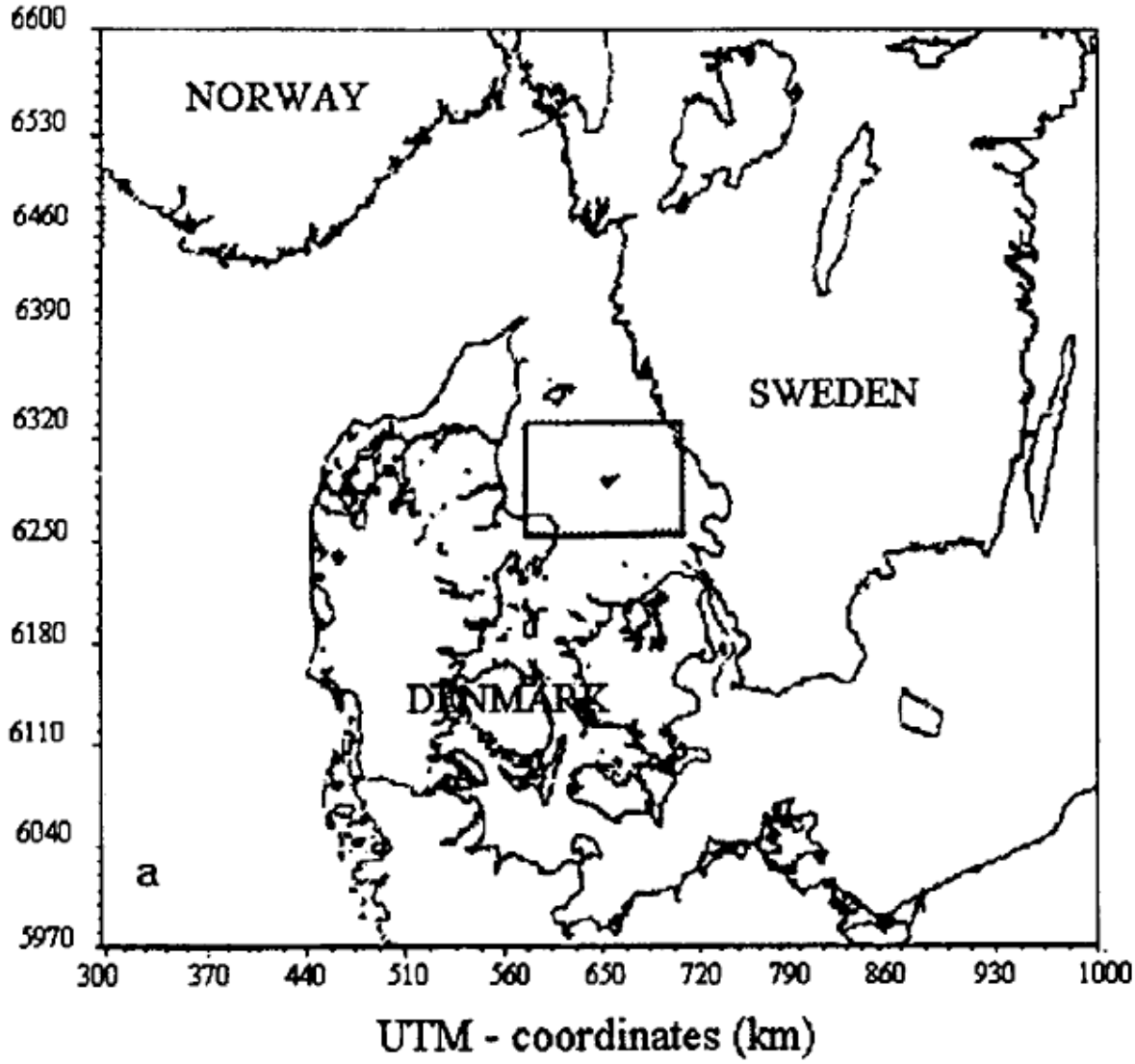


Figure J-3: Mean Seasonal Daily Evolution of the Inversion Height during (a) Winter, (b) Spring, (c) Summer, and (d) Autumn

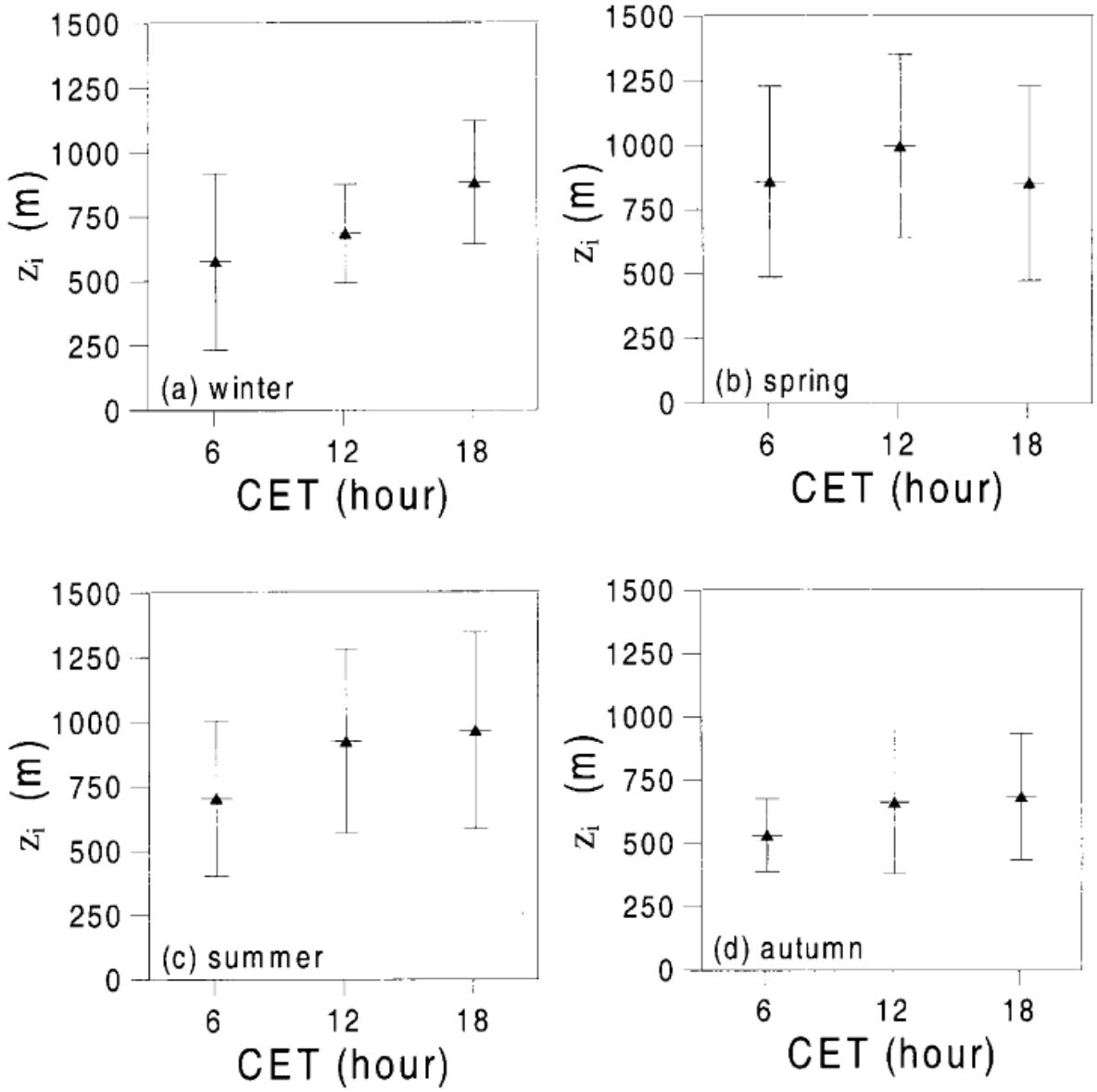


Figure J-4: Location of Temperature Profiling the Baltic Sea ("+" shows the Location of the Meteorological Monitoring)

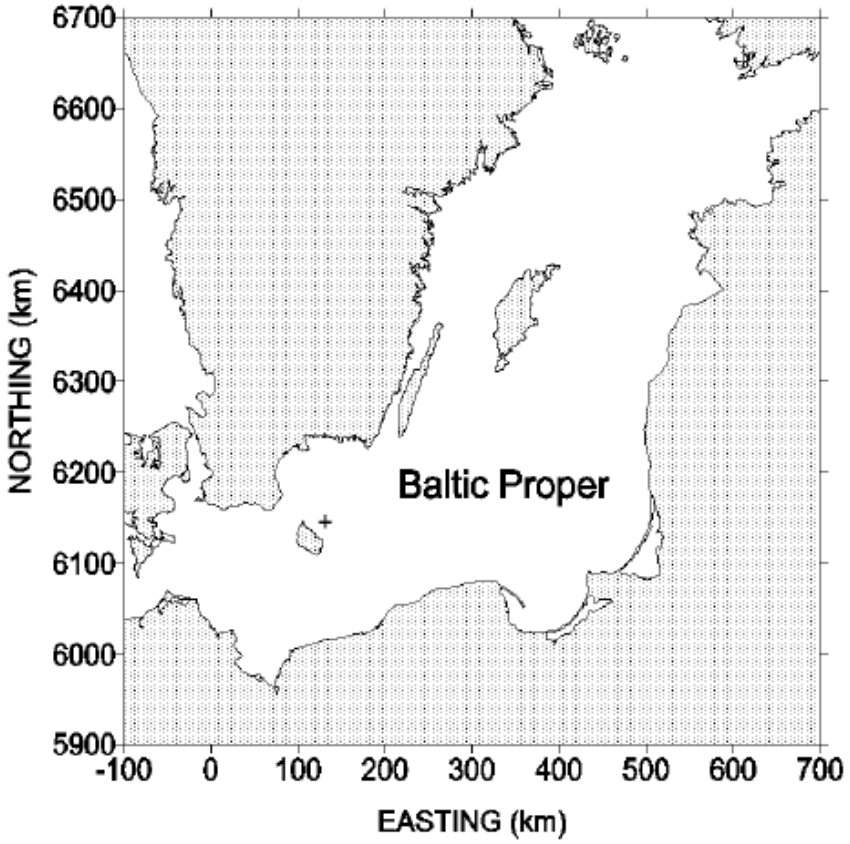
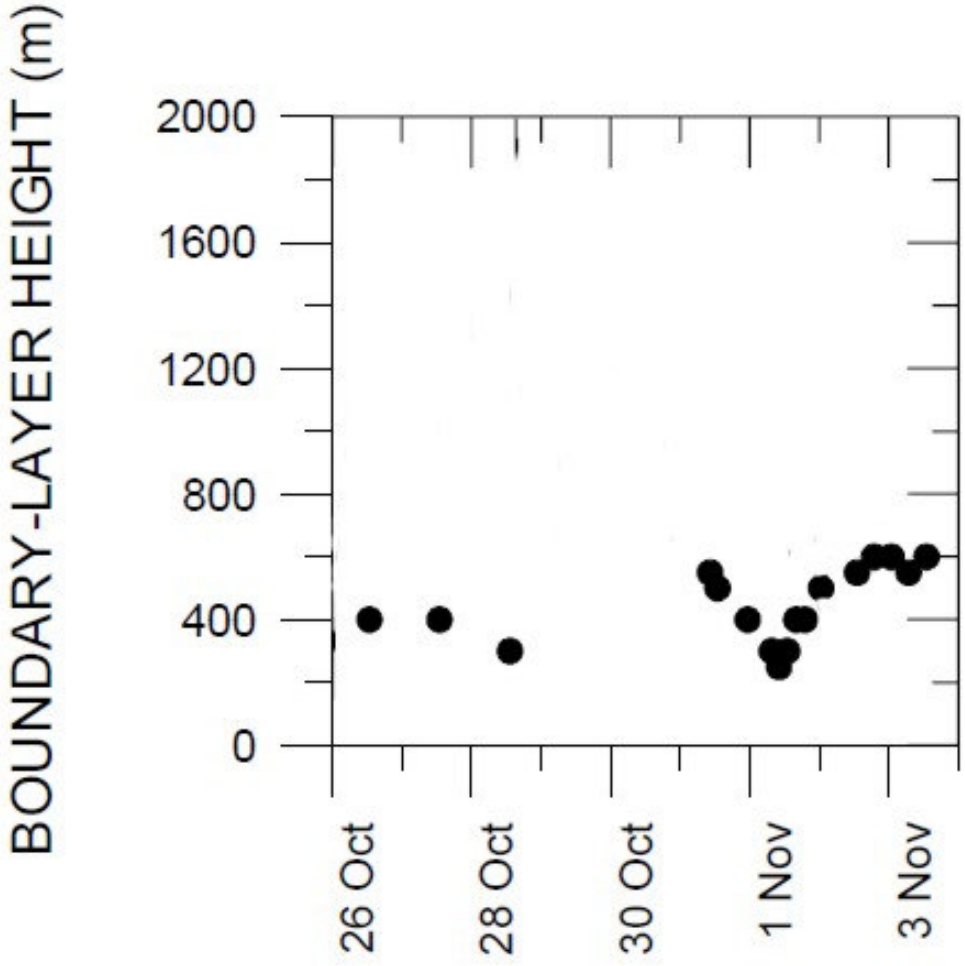


Figure J-5: Observed Mixing Heights over the Baltic Sea



Appendix K

Drill Rig Main Engine Partial Load Modeling Analysis

K-1 Vendor Data

Vendor provided emission factors for NO_X, CO and VOC at the 100%, 75% and 50% load conditions are presented in Table K-1. Vendor emission factors for particulate matter (PM) were not available for any load condition. These engines are equipped with selective catalytic reduction units (SCR) for NO_X control which are designed to achieve 1.83 g/kW-hr of NO_X across all load conditions. The emission factor for SO_2 is calculated to be 2.03E-04 lb/gal using a diesel fuel density of 6.75 lb/gal and a fuel sulfur content of 15 ppm (0.0015%) as presented in Equation K-1.

Equation K-1

$$SO_2\ Emission\ Factor\left(\frac{lb}{gal}\right) = \frac{Fuel\ Sulfur\ Content\ (\%)}{100} \times Fuel\ Density\left(\frac{lb}{gal}\right) \times \frac{MW_{SO_2}}{MW_S}$$
$$= 2.03E-04\frac{lb}{gal}$$

where,

- $MW_{SO2} = 64$
- $MW_S = 32$

Fuel density was obtained from the data provided by Tesoro Kenai Refinery, AK for the No.1 ultra-low sulfur diesel expected to be used on this project.

Table K- 1: Part Load Emission Factors for Criteria Pollutants

Vendor Supplied Emission Factors (g/kW-hr): Wartsila 8L26A2						
Engine Rating (kW)	**Percent Load (%)**	**SO_2[1] (lb/gal)**	**CO (g/kW-hr)**	**PM [2] (g/kW-hr)**	**Uncontrolled NO_X (g/kW-hr)**	**Controlled [3] NO_X (g/kW-hr)**
2480	100	2.03E-04	0.46	N/A	8.77	1.83
1862	75	2.03E-04	0.3	N/A	9.44	1.83
1249	50	2.03E-04	0.45	N/A	9.1	1.83

(1) Emission factor of SO_2 is calculated based on a fuel sulfur content of 15 ppm and a diesel density of 6.75 lb/gal (Equation K-1).
(2) PM emission factor information for part load conditions is not available from the manufacturer.
(3) NO_X emission factor given here is post SCR control.

K-2 Engine Emissions: Part Load

Short-term emissions of criteria pollutants at the three load conditions are summarized in Table K-2 (lb/hr) and Table K-3 (g/s).

A sample calculation is presented in Equation K-2 below for estimation of the controlled hourly NO_X emission rate at 75% load. Hourly emissions of the other criteria pollutants at the various load conditions were calculated in a similar manner. At the 75% load condition, vendor supplied emission factor of post-SCR NO_X is 1.83 g/kW-hr and the engine rating is 1862 kW.

Equation K-2

$$NOx\ Emissions\left(75\%\ Load, \frac{lb}{hr}\right) = 1.83\left(\frac{g}{kW-hr}\right) \times 1862\,kW \times \frac{lb}{453.6\,g}$$
$$= 7.51\frac{lb}{hr}$$

Since vendor provided emission factors were not available for PM at the various loads, it was conservatively assumed that the engines emit at the maximum possible rate as calculated using the emission factor given in AP-42 Table 3.4-2 (see Equation K-3).

- PM_{10} Emission Factor (AP-42, Table 3.4-2) = 0.0573 lb/MMBtu
- Brake Specific Fuel Consumption (AP-42, Table 3.4-1, footnote 'e') = 7000 Btu/hp-hr (HHV)
- Engine rating @ 100% load = 2480 kW

Equation K-3

$$PM\ Emissions\left(100\%\ Load, \frac{lb}{hr}\right) = 0.0573\left(\frac{lb}{MMBtu}\right) \times 7000\frac{Btu}{hp-hr} \times 1.34\frac{hp}{kW} \times 2480\,kW \times \frac{MMBtu}{10^6\,Btu}$$
$$= 1.33\frac{lb}{hr}$$

Throughout the application, CO emissions from engines at 100% load were estimated using the AP-42 emission factor and not the vendor provided emission factor which is lower. Therefore, the CO emissions at part load conditions were adjusted using the 100% load AP-42 emission factor to be consistent with the emissions presented in the rest of the application. Full load CO emission rate using the emission factor provided in AP-42 Table 3.4-1 is calculated to be 18.28 lb/hr (see Equation K-4) and CO hourly emissions at various load conditions were adjusted as shown in Equation K-5.

Equation K-4

$$CO\ Emissions\left(100\%\ Load; \frac{lb}{hr}\right) = 5.5E-03\left(\frac{lb}{hp-hr}\right) \div 0.746\left(\frac{kW}{hp}\right) \times 2480\,(kW)$$
$$= 18.28\frac{lb}{hr}$$

Equation K-5

$$Adj.CO\ Emiss.(X\%load, \frac{lb}{hr}) = \frac{AP-42\ Emiss.Rate\ @\ 100\%\ Load}{Vendor's\ Emiss.Rate\ @\ 100\%\ Load} \times Vendor's\ Emiss.Rate\ @\ X\%Load$$

Emissions of SO_2 (100% load case shown as an illustration) were calculated from diesel fuel properties using Equations K-6, K-7 and K-8 below.

- Engine rating @ 100% load = 2480 kW
- Brake Specific Fuel Consumption (AP-42, Table 3.4-1, footnote 'e') = 7000 Btu/hp-hr (HHV) or 9387 Btu/kW-hr
- Diesel HHV (fuel data from Tesoro Kenai Refinery, AK) = 132,096 Btu/gal
- Diesel LHV (fuel data from Tesoro Kenai Refinery, AK) = 124,500 Btu/gal
- Engine efficiency (Engineering judgment) = 95%

Equation K-6

$$Engine\ Heat\ Input\left(\frac{MMBtu_{LHV}}{hr}\right) = \frac{2480\,kW}{95\%} \times 9387\,\frac{Btu}{kW-hr} \times \frac{124{,}500\,\frac{Btu}{gal}}{132{,}096\,\frac{Btu}{gal}} \times \frac{1\,MMBtu}{10^6\,Btu}$$

$$= 23.10\,\frac{MMBtu_{LHV}}{hr}$$

Heat input in MMBtu/hr calculated in Equation K-6 was converted to the units of gal/hr as shown in Equation K-7.

Equation K-7

$$Engine\ Heat\ Input\left(\frac{gal_{LHV}}{hr}\right) = \frac{Engine\ Heat\ Input\left(\frac{MMBtu_{LHV}}{hr}\right) \times \frac{10^6\,Btu}{MMBtu}}{124{,}500\,\frac{Btu}{gal}}$$

$$= 185.51\,\frac{gal}{hr}$$

Using the SO_2 emission factor calculated from Equation K-1, hourly SO_2 emission rate for the 100% load case was calculated as shown in Equation K-8.

Equation K-8

$$SO_2\ Emissions\left(100\%\ Load; \frac{lb}{hr}\right) = 2.03E-04\,\frac{lb}{gal} \times 185.51\,\frac{gal}{hr}$$

$$= 0.04\,\frac{lb}{hr}$$

Table K-2 Part Load Hourly Emissions for Criteria Pollutants (lb/hr)

Part Load Engine Emission Rate (lb/hr): Wartsila 8L26A2							
Engine Rating (kW)	Percent Load (%)	SO_2 (lb/hr)	CO [1] (lb/hr)	PM [2] (lb/hr)	Uncontrolled NO_X (lb/hr)	Controlled [3] NO_X (lb/hr)	Adjusted [4] CO (lb/hr)
2480	100	0.04	2.51	1.33	47.91	10.00	18.28
1862	75	0.03	1.23	1.33	38.72	7.51	8.95
1249	50	0.02	1.24	1.33	25.04	5.03	9.01

(1) Vendor provided CO emission rate.
(2) PM emissions information for part load conditions is not available from the manufacturer. Therefore, emission rates are fixed at the maximum calculated using AP-42 emission factor (Table 3.4-2).
(3) NO_X emission rate given here is post SCR control.
(4) (4) Vendor supplied CO emission rate data was scaled to that determined using the AP-42 emission factor (used in the rest of the application) to maintain consistency (refer to Equation K-5).

Table K-3 Part Load Emissions for Criteria Pollutants (grams per second)

Part Load Engine Emission Rate (g/s) [1] : Wartsila 8L26A2						
Engine Rating (kW)	Percent Load (%)	SO_2 (g/s)	CO (g/s)	PM [2] (g/s)	Uncontrolled NO_X (g/s)	Controlled [3] NO_X (g/s)
2480	100	4.73E-03	2.304	0.168	6.036	1.260
1862	75	3.55E-03	1.128	0.168	4.878	0.946
1249	50	2.38E-03	1.135	0.168	3.154	0.634

(1) Grams per second (g/s) emission rate was calculated from the lb/hr emission rate as follows: Emission rate (g/s) = Emission rate (lb/hr) * 453.59 (g/lb) / 3600 (seconds/hour).
(2) PM emissions information for part load conditions is not available from the manufacturer. Therefore, emission rates are fixed at the maximum calculated using AP-42 emission factor (Table 3.3-1).
(3) NO_X emission rate given here is post SCR control.

K-3 Stack Parameters

Engine stack properties such as exhaust gas temperature, flow rate and velocity, as well as stack diameter for the three load cases modeled are presented in Table K-4. Exhaust gas flow rates at the three load cases were calculated using EPA's Method 19 calculation procedure. A sample calculation illustrating estimation of exhaust gas flow rates at the 100% load case is shown in Equation K-9.

- F_d, Volume of exhaust gases per unit heat content = 9628.76 dscf/MMBtu (LHV). F_d was calculated based on an analysis of fuel from the Tesoro Refinery for the No. 1 ultra-low sulfur diesel that will be used on this project.
- Heat input (calculated using Equation 6) = 23.10 MMBtu/hr
- Oxygen content of exhaust gas = 8%. This percent oxygen content is an assumed value for an internal combustion engine.
- Moisture Content of exhaust gas = 7.6%. Moisture content of the exhaust was calculated using a stoichiometric calculation specific to the fuel properties and oxygen content.
- Temperature of exhaust gas, T = 600°F. This is the lowest temperature required for the SCR to function.

Equation K-9

$$Exhaust\ Flow\,(acfm) = Heat\ Input\left(\frac{MMBtu}{hr}\right)\times F_{d\ LHV}\left(\frac{dscf}{MMBtu}\right)\times\left(\frac{20.9}{20.9-\%O_2}\right)\times\left(\frac{1}{1-\%H_2O}\right)$$
$$\times\left(\frac{T+460}{68+460}\right)\times\frac{hr}{60\sec}$$
$$Exhaust\ Flow\,(acfm) = 23.1\frac{MMBtu}{hr}\times 9629\frac{dscf}{MMBtu}\times\left(\frac{20.9}{20.9-8}\right)\times\left(\frac{1}{1-0.076}\right)$$
$$\times\left(\frac{600+460}{68+460}\right)\times\frac{hr}{60\sec}$$
$$Exhaust\ Flow\,(acfm) = 13{,}051\ acfm$$

The exhaust gas flow rate for the 100% load case was calculated to be 13,051 acfm or 6.16 m^3/s.

Table K-4 Stack Parameters at the 100%, 75% and 50% Load Cases

Stack Parameters: Wartsila 8L26A2										
Engine Load (%)	Capacity (kW)	Operational Data (LHV)	Stack Exit Properties							
			Temperature		Flow		Diameter		Velocity	
100%	2,480	23.10 MMBtu/hr	600	F [1]	13,051	ACFM	24.0	in	21	m/s
		186 gal/hr	589	K	6.16	m^3/s	0.61	m		
75%	1,862	17.34 MMBtu/hr	600	F [1]	9,799	ACFM	24.0	in	16	m/s
		139 gal/hr	589	K	4.62	m^3/s	0.61	m		
50%	1,249	11.63 MMBtu/hr	600	F [1]	6,573	ACFM	24.0	in	11	m/s
		93 gal/hr	589	K	3.10	m^3/s	0.61	m		

(1) 600 F is the minimum temperature required for the SCR. If exhaust gases drop below this temperature, they will be preheated to achieve this temperature. Therefore, this is the minimum exhaust gas temperature for an SCR controlled source. To be conservative, the stack exit temperature is assumed to be 600°F regardless of whether the SCR is operating or not.

Engine stack diameter is 24 inches or 0.61 m based on vendor drawings. Exhaust gas velocity (m/s) was calculated from the exhaust flow rate (m^3/s) and the cross-sectional area of the engine stack (m^2).

K-4 Predicted Impacts

The main drill rig engines dominate the air quality impacts, not only because they make up a large percentage of the total emissions, but also because these units exhaust horizontally and at the ambient boundary. Therefore, an initial worst case load analysis was conducted for the main drill rig engines only. Liquid-fired engine Wartsila 8L26A2 type was used to assess impacts at 100%, 75%, and 50% loads. This engine was modeled as a point source at a fixed location on the rig. Unlike other GAQM steady state dispersion models, OCD has the capability of simulating horizontal emission releases; therefore, no special techniques were required to simulate these types of releases. The meteorological data used in this modeling is discussed in Section 4.0 of the main body of the report whereas details of the receptor grid are presented in Section 5.4 of the report.

Predicted impacts from Wartsila 8L26A2 engines at the 100%, 75% and 50% load cases are summarized in Table K-5. The results indicate that 100% load is the worst case for SO_2 and CO for all averaging periods as well as for NO_2 (controlled and uncontrolled cases) for the annual averaging period. The 75% load case is the worst case for NO_2 (controlled and uncontrolled cases) for the 1-hour averaging period. The 50% load is the worst case for PM_{10} and $PM_{2.5}$ for all averaging periods. Therefore, all subsequent modeling of project sources included the main drill rig engines at these worst-case loads defined for each pollutant.

Table K-5 Rig Main Engine Load Analysis Modeling Results

Averaging Period	100% Load, Ts = 589 K, Vs = 21 m/s, D=0.61 m Max Predicted Impact ($\mu g/m^3$)				
	NO_x (SCR Controlled)	NO_x (Uncontrolled)	CO	SO_2	PM_{10} $PM_{2.5}$
1-hour	24.19	115.94	**44.25**	0.09	3.23
3-hours	19.20	92.03	35.12	**0.07**	2.56
8-hours	13.36	64.05	**24.45**	0.05	1.78
24-hours	9.85	47.21	18.02	**0.04**	1.31
Annual	**0.237**	**1.137**	0.4339	**0.0009**	0.0316
Short-Term Emission Rate (g/s)	1.26	6.04	2.304	4.73E-03	0.168
Annual Emission Rate (g/s)	0.216	1.034	0.3945	8.11E-04	0.0288
Hours of Operation	1500	1500	1500	1500	1500

Averaging Period	75% Load, Ts = 589 K, Vs = 16 m/s, D=0.61 m Max Predicted Impact ($\mu g/m^3$)				
	NO_x (SCR Controlled)	NO_x (Uncontrolled)	CO	SO_2	PM_{10} $PM_{2.5}$
1-hour	**25.92**	**133.73**	30.92	0.10	4.61
3-hours	19.11	98.60	22.80	0.07	3.40
8-hours	12.90	66.53	15.38	0.05	2.29
24-hours	8.71	44.95	10.40	0.03	1.55
Annual	0.214	1.102	0.2548	0.0008	0.0379
Short-Term Emission Rate (g/s)	0.95	4.88	1.128	3.55E-03	0.168
Annual Emission Rate (g/s)	0.162	0.835	0.1932	6.09E-04	0.0288
Hours of Operation	1500	1500	1500	1500	1500

Averaging Period	50% Load, Ts = 589 K, Vs = 11 m/s, D=0.61 m Max Predicted Impact ($\mu g/m^3$)				
	NO_x (SCR Controlled)	NO_x (Uncontrolled)	CO	SO_2	PM_{10} $PM_{2.5}$
1-hour	24.26	120.61	43.40	0.09	6.42
3-hours	15.27	75.91	27.31	0.06	4.04
8-hours	12.51	62.23	22.39	0.05	3.31
24-hours	7.99	39.72	14.29	0.03	**2.12**
Annual	0.1748	0.8691	0.3127	0.0007	**0.0463**
Short-Term Emission Rate (g/s)	0.63	3.15	1.135	2.38E-03	0.168
Annual Emission Rate (g/s)	0.109	0.540	0.1944	4.08E-04	0.0288
Hours of Operation	1500	1500	1500	1500	1500

Appendix L

Sensitivity Modeling Analyses

L-1.0 Comparison of Offshore Supply Vessel to Ware Vessel Model Predicted Impacts

The drill rig will be supplied by either an Offshore Supply Vessel (OSV) or ware vessel. Therefore, a sensitivity dispersion modeling analysis was performed to determine whether an OSV or a ware vessel would produce higher air quality impacts. The sections below detail the specific activities performed by each type of vessel and the procedures used to model each vessel for the sensitivity analysis. Based on the results of the sensitivity analysis presented below, all modeling analyses performed for the application were conducted with emissions from the OSV, not the ware vessel.

L-1.1 Ware Vessel Activities

A ware vessel will potentially be used to transport large amounts of supplies (i.e., fuel, drilling fluids, pipe, etc.) and manpower to the drill rig. This vessel will only operate within 25 miles of the drill rig while in transit to the drill rig, while transferring supplies, and for a short time afterwards while leaving the area. In the case of poor weather this vessel may idle within 25 miles of the drill rig waiting for proper conditions to transfer supplies.

A ware vessel will operate under its own power and will utilize dynamic positioning to sit stationary next to the drill rig without being tied to it (dynamic positioning mode). When transferring supplies at the drill rig, the ware vessel will be maintained adjacent to the rig by dynamic positioning and there will be no physical attachment between the ware vessel and the rig except for a fuel line during refueling activities.

A ware vessel will take up to 3 hours to travel one-way to the drill rig (cruising mode). A ware vessel will make an average of 4 resupply trips per week over approximately 14 weeks for a total of 50 trips between the edge of the 25-mile radius and the rig. Unloading the vessel to the rig will take up to 300 hours (in dynamic positioning mode) each season. The vessel will be dynamically positioned next to the rig for a maximum of 6 hours for each fuel transfer event, and less than 6 hours for transfer of other supplies. Open-water idling of the vessel due to poor weather may take place for up to 100 hours per season within a 25-mile radius of the drill rig.

L-1.2 Offshore Supply Vessel Activities

OSVs are smaller than ware vessels and are used to shuttle supplies and manpower to the drill rig from a supply barge located beyond 25 miles from the drill rig. Two OSVs will be used to support the proposed exploratory drilling activities; however, at one time only one vessel will operate within 25 miles of the drill rig while in transit to the drill rig, while transferring supplies, and for a short time afterwards while leaving the area. When transferring supplies, the OSV will be maintained adjacent to the rig by dynamic positioning (dynamic positioning mode) and there will be no physical attachment between the OSV and the drill rig except for a fuel line during refueling activities. In the case of poor weather this vessel may idle within 25 miles of the drill rig waiting for proper conditions to transfer supplies.

An OSV will take up to 3 hours to travel one-way to the drill rig (cruising mode). The OSV will make an average of 4 resupply trips per week over approximately 14 weeks for a total of 60 trips between the supply barge and the drill rig. Unloading the OSV to the rig will take up to 360 hours (in dynamic positioning mode) each season. The vessel will be dynamically positioned next to the rig for a maximum of 6 hours for each fuel transfer event and less than 6 hours for transfer of other supplies. Open-water idling of the vessel due to poor weather may take place for up to 100 hours per season within the 25-mile radius.

L-1.3 Dispersion Modeling Analysis

As noted above, each vessel has three primary activities: 1) transit, 2) fuel and supplies unloading, and 3) open water idling. It is assumed that unloading activities are the worse-case emissions scenario compared with vessel transiting to/from the rig because transiting emissions will be spread across a much larger area. Furthermore, open-water idling has similar emissions to unloading activities, but occur less frequently, and occur over a larger area and a large distance from the drill rig. Therefore, to determine whether use of an OSV or ware vessel would produce higher air quality impacts, emissions occurring while each vessel is transferring fuel to the rig were modeled separately with the OCD model for this sensitivity analysis.

For the 1-hour and 8-hour averaging period, CO emission rates were used for the evaluation. For the 24-hour averaging period, emission rates for $PM_{2.5}$, the controlling pollutant, was used. Annual emission rates for NO_2 and $PM_{2.5}$ were also modeled. Preliminary modeling indicated that SO_2 is not a controlling pollutant; therefore, SO_2 emissions were not included in the analysis. Source parameters and emission rates used in the analysis are listed in **Tables L1-1 and L1-2**. **Figure L1-1** shows sources located on each type of vessel.

Each vessel was modeled separately using a generic grid of receptors spaced 25-meters apart extending out to 50 km. Interaction with drill rig sources was not evaluated in this analysis.

Modeling results shown in **Table L1-3** indicate that operation of an OSV yields higher impacts than operation of a ware vessel. Therefore, the significance and cumulative modeling analyses presented in the Modeling Report incorporated emissions from OSV activities, while ware vessel activities were not given further consideration in the ambient air quality analysis.

Table L1-1: Stack Parameters and Emission Rates for Offshore Supply Vessel Used in Modeling[1]

Emission Sources	Model ID	Emissions (g/sec)				Base Elev.	Stack Height Above Base Elev.	Exhaust Temp.	Exit Vel.	Diam.	Exhaust Orient.	OCD Bldg Ht.	OCD Bldg Width
		Avg. Period	NOx[4]	CO[4]	$PM_{2.5}$	(m)	(m)	(K)	(m/sec)	(m)		(m)	(m)
Thruster Engine 1	OSV_THR1	Short-Term	3.09E+00	8.21E-01	1.38E-02	0.00	3.3	589	32	0.254	Vert.	25.91	56
		Annual	1.27E-01	--	2.27E-03								
Thruster Engine 2	OSV_THR2	Short-Term	3.09E+00	8.21E-01	1.38E-02	0.00	3.2	589	38	0.254	Horiz.	25.91	56
		Annual	1.27E-01	--	2.27E-03								
Thruster Engine 3	OSV_THR3	Short-Term	3.09E+00	8.21E-01	1.38E-02	0.00	3.2	589	38	0.254	Horiz.	25.91	56
		Annual	1.27E-01	--	2.27E-03								
Generator 1	OSV_GEN1	Short-Term	1.47E+00	1.16E-01	7.91E-03	0.00	3.3	589	49	0.152	Vert.	25.91	56
		Annual	6.03E-02	--	1.30E-03								
Generator 2	OSV_GEN2	Short-Term	1.47E+00	1.16E-01	7.91E-03	0.00	3.3	589	49	0.152	Vert.	25.91	56
		Annual	2.01E-02	--	4.34E-04								
Emergency Generator	OSV_EGEN	Short-Term	4.34E-01	3.44E-02	2.34E-03	0.00	3.6	589	21	0.127	Horiz.	25.91	56
		Annual	1.49E-03	--	3.21E-05								

[1] Emissions calculations are detailed in Appendix E. Details regarding the stack parameters can be found in Appendix G.

Table L1-2: Stack Parameters and Emission Rates for Ware Vessel Used in Modeling[1]

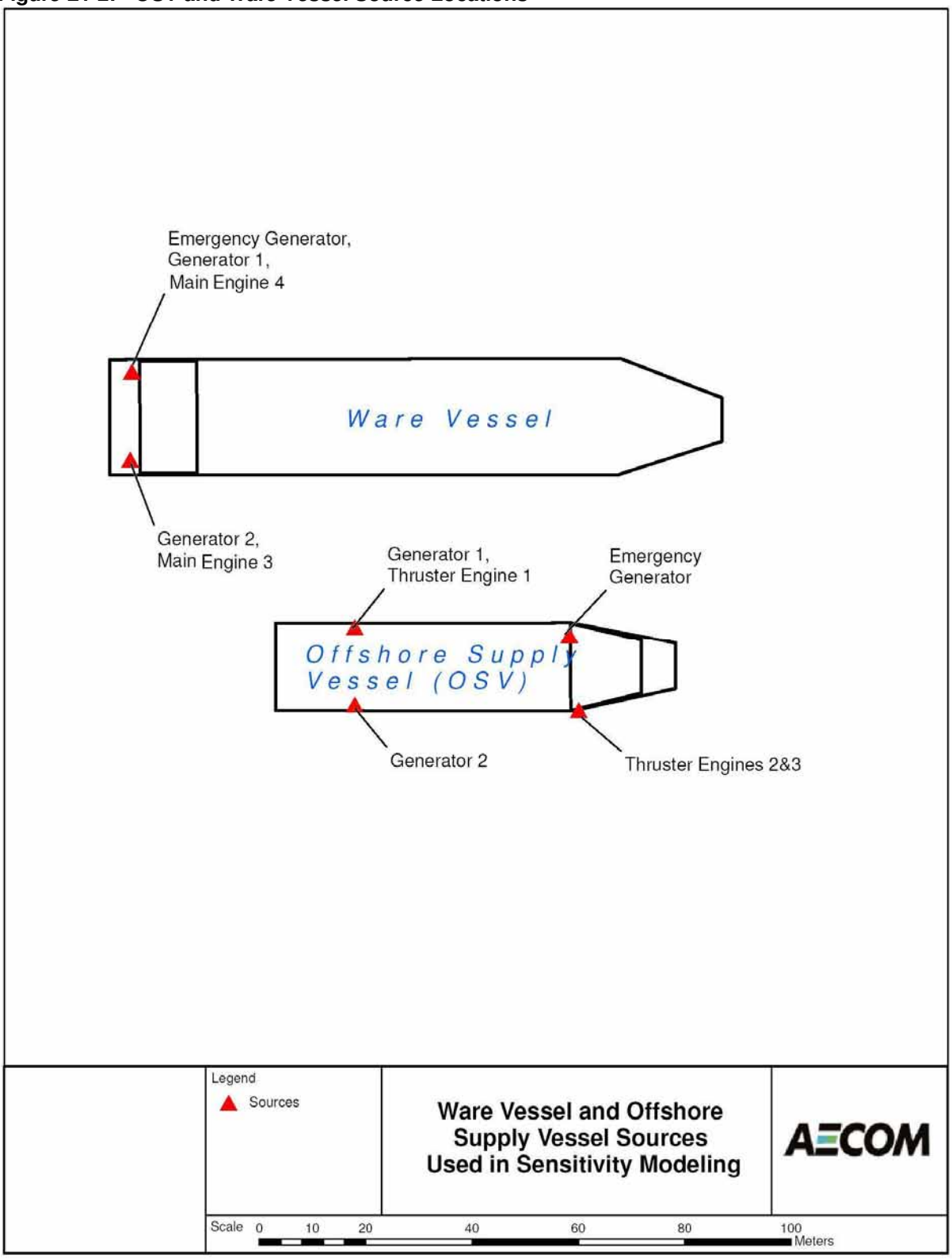
Emission Sources	Model ID	Emissions (g/sec)				Base Elev.	Stack Height Above Base Elev.	Exhaust Temp	Exit Vel.	Diam.	Exhaust Orient.	OCD Bldg Ht.	OCD Bldg Width
		Avg. Period	NOx[4]	CO[4]	$PM_{2.5}$	(m)	(m)	(K)	(m/sec)	(m)		(m)	(m)
Main Engine 3	WAR_ENG3	Short-Term	4.31E+00	1.15E+00	1.93E-02	0.00	15.25	589	21	0.406	30 deg from N	25.91	56
		Annual	1.48E-01	--	2.65E-03								
Main Engine 4	WAR_ENG4	Short-Term	4.31E+00	1.15E+00	1.93E-02	0.00	15.25	589	21	0.406	30 deg from N	25.91	56
		Annual	1.48E-01	--	2.65E-03								
Generator 1	WAR_GEN1	Short-Term	1.74E+00	1.38E-01	9.38E-03	0.00	15.25	589	38	0.203	30 deg from N	25.91	56
		Annual	5.95E-02	--	1.28E-03								
Generator 2	WAR_GEN2	Short-Term	1.74E+00	1.38E-01	9.38E-03	0.00	15.25	589	38	0.203	30 deg from N	25.91	56
		Annual	1.98E-02	--	4.28E-04								
Emergency Generator	WAR_EGEN	Short-Term	6.52E-01	5.16E-02	3.52E-03	0.00	15.25	589	31	0.127	30 deg from N	25.91	56
		Annual	2.23E-03	--	4.82E-05								

[1] **Emissions calculations are detailed in Appendix E. Details regarding the stack parameters can be found in Appendix G.**

Table L1-3: OSV and Ware Vessel Modeling Results

Pollutant	Ave Period	Rank	Wainwright NWS Met Data					Vessel Met Data	Overall Maximum Impact
			1999	2002	2004	2005	2006	2008	
Offshore Supply Vessel Predicted Impacts (μg/m^3)									
CO	1-hr	MAX	1,089.76	1,364.39	1,252.77	1,143.11	1,088.39	1,267.61	1,364.4
CO	8-hr	MAX	611.45	503.63	554.54	575.77	553.65	454.51	611.5
NO_x	Annual	MAX	11.18	8.02	9.32	11.90	10.81	7.56	11.9
$PM_{2.5}$	24-hr	MAX	9.50	7.14	7.89	11.00	6.68	7.02	11.0
$PM_{2.5}$	Annual	MAX	0.21	0.15	0.18	0.22	0.20	0.14	0.2
Ware Vessel Predicted Impacts (μg/m^3)									
CO	1-hr	MAX	362.54	416.63	351.87	369.66	400.65	374.14	416.6
CO	8-hr	MAX	216.09	201.94	212.20	203.67	213.83	168.72	216.1
NO_x	Annual	MAX	3.83	2.71	3.21	4.16	3.48	2.45	4.2
$PM_{2.5}$	24-hr	MAX	3.77	3.54	3.50	4.31	2.86	2.19	4.3
$PM_{2.5}$	Annual	MAX	0.07	0.05	0.06	0.08	0.06	0.05	0.1

Figure L1-2: OSV and Ware Vessel Source Locations



L-2.0 OSV Position Relative to the Rig Analysis

Once it was determined that drill rig resupply by an OSV yields higher air quality impacts than resupply by a ware vessel, an analysis evaluating the worst-case position of the OSV during unloading was conducted. The drill rig, shown in Figure L1-1, has two unloading/loading stations, one on the north side and the other on the south side of the drill rig as it was positioned for the modeling analysis. Therefore, sensitivity modeling was conducted to determine if the worst-case position of the OSV is on the north or south side of the rig.

For the 1-hour and 8-hour averaging period, CO emission rates were used in the analysis. For the 24-hour averaging period, emission rates for $PM_{2.5}$, the controlling pollutant, was used. Annual emission rates for NO_2 and $PM_{2.5}$ were also modeled. Preliminary modeling indicated that SO_2 is not a controlling pollutant; therefore, SO_2 emissions were not included in the analysis. OSV stack parameters and emission rates used in the analysis are listed in **Table L1-1**. **Figure L2-2** shows the modeled locations.

Modeling results, shown in **Table L2-1,** indicate that the OSV positioned south of the rig yields slightly higher or equivalent impacts for all pollutants and averaging periods as compared to when the OSV is positioned on the north side of the rig. Therefore, the significance and cumulative modeling analyses presented in the Modeling Report included the OSV vessel located on the south side of the drill rig.

Table L2-1: OSV Position Relative to the Rig Analysis Modeling Results

Pollutant	Averaging Period	Rank	Wainwright NWS Met Data					Vessel Met Data	Overall Maximum Impact
			1999	2002	2004	2005	2006	2008	
Offshore Supply Vessel Positioned NORTH of the Rig Predicted Impacts (µg/m^3)									
CO	1-hr	MAX	1,136.4	1,331.7	1,331.7	1,331.7	1,074.8	1,212.2	1,331.7
CO	8-hr	MAX	571.6	523.0	523.0	523.0	602.6	489.1	602.6
NO_x	Annual	MAX	12.1	8.6	10.1	13.0	10.3	7.6	13.0
$PM_{2.5}$	24-hr	MAX	14.2	14.4	11.8	16.7	10.5	8.1	16.7
$PM_{2.5}$	Annual	MAX	0.2	0.2	0.2	0.3	0.2	0.2	0.28
Offshore Supply Vessel Positioned SOUTH of the Rig Predicted Impacts (µg/m^3)									
CO	1-hr	MAX	1,099.5	1,442.8	1,254.0	1,143.3	1,098.8	1,270.6	1,442.8
CO	8-hr	MAX	613.7	507.7	567.7	625.7	619.6	455.0	625.7
NO_x	Annual	MAX	11.3	8.5	9.4	14.4	10.9	7.7	14.4
$PM_{2.5}$	24-hr	MAX	14.3	14.3	11.9	16.7	10.8	8.1	16.7
$PM_{2.5}$	Annual	MAX	0.2	0.2	0.2	0.3	0.2	0.2	0.28

Figure L2-1: Jack-up Drill Rig Layout (Top View, Cantilever Centered)

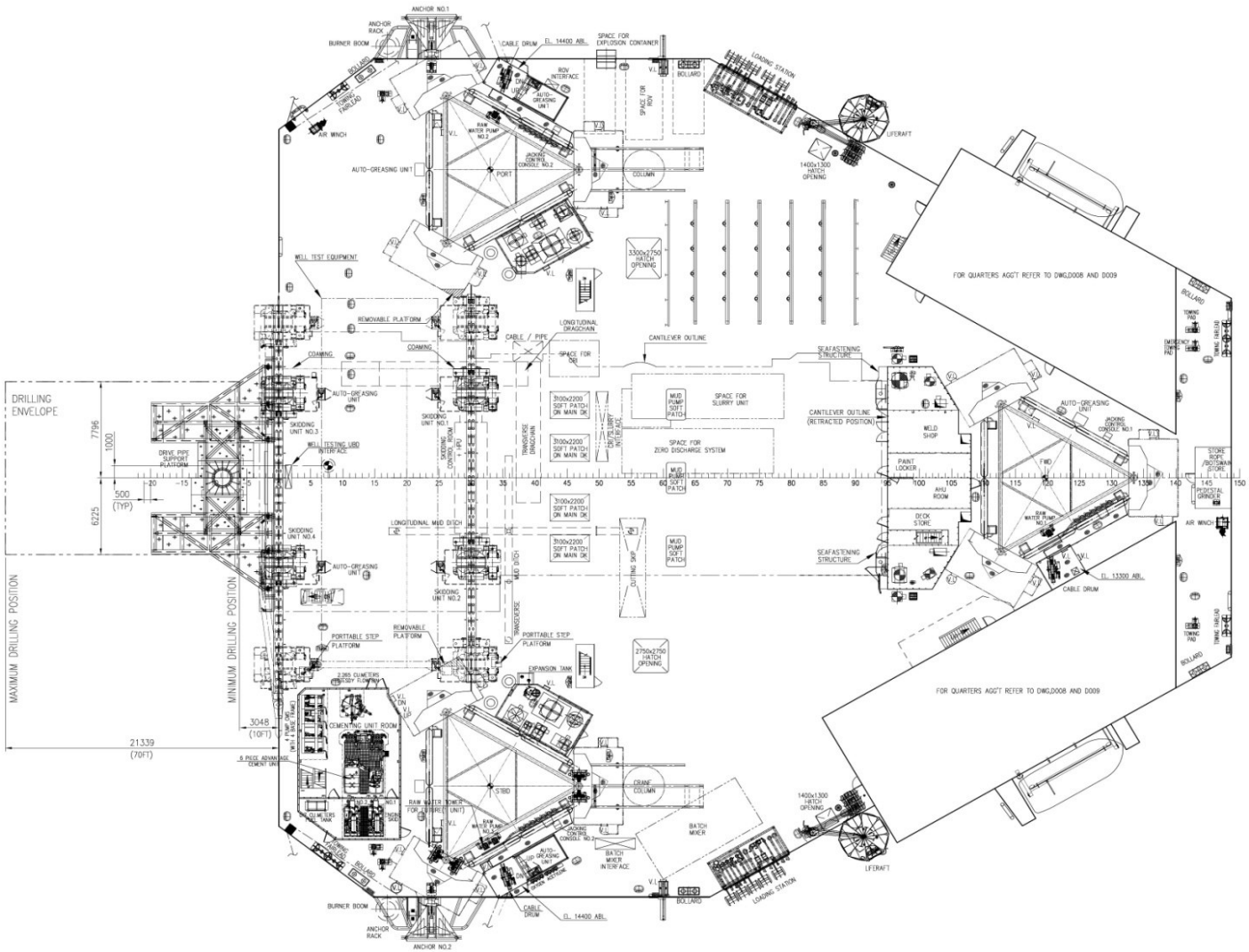
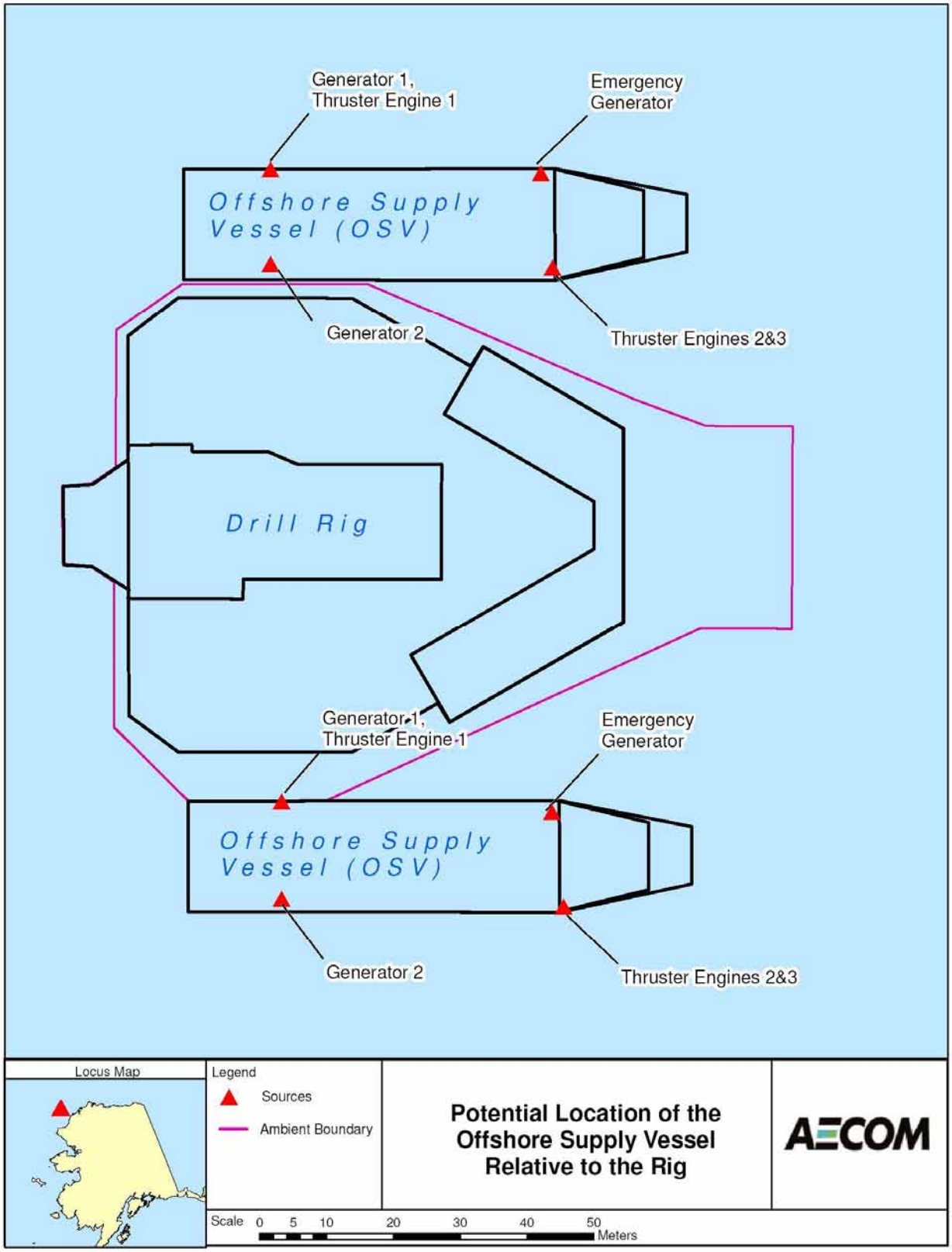


Figure L2-2: Modeled Location of the OSV Sources Relative to the Rig



L-3.0 Alignment of Support Vessels Relative to the Drill Rig

Due to the nature of mobile equipment, the position of the project support vessels varies in relation to the drill rig, and will not be fixed. Therefore, a sensitivity modeling analysis was conducted to determine the alignment of these sources relative to the drill rig that would maximize short-term project air quality impacts. For dispersion modeling of the annual averaging period in the significance and cumulative modeling documented in the Modeling Report, it was assumed that the worst-case direction is upwind (east) of the rig according to the modeled meteorological dataset. Placing activities upwind when conducting annual modeling will maximize plume overlap and model predicted impacts. Therefore, it was not necessary for this sensitivity analysis to evaluate annual impacts. **Table L3-1** lists the sources that were included in this analysis.

Table L3-1: Sources Included in the Alignment Sensitivity Analysis

Source Description	Source Type	Distance From Rig
OSRV Anchored During Fuel Transfer	4 Point Sources	1/4 mile (0.4 km)
OSRV Regular Operations	Circular Area Source, 1-km diam.	10 miles (16 km)
OSRV Spill Exercises[1]	Circular Area Source, 1-km diam.	1 mile (1.6 km)
Workboats assoc. w/ Spill Exercises	Circular Area Source, 1-km diam.	1 mile (1.6 km)
Spill Storage Tanker[1]	Circular Area Source, 1-km diam.	1 mile (1.6 km)
Anchor Handling Supply Tug[1]	Circular Area Source, 1-km diam.	1 mile (1.6 km)
Research Vessel Activity[1]	Circular Area Source, 1-km diam.	1 mile (1.6 km)
Icebreaker Activity	Circular Area Source, 2-km diam.	5 miles (8 km)
OSV in Transit	3 Point Sources	1 mile (1.6 km)
OSV idling in open water when delayed by poor weather (annual emissions only)[1]	Circular Area Source, 1-km diam.	1 mile (1.6 km)

[1] These five area sources were collocated into a single area source due to the OCD model's limitation that it can only model 5 area sources at one time.

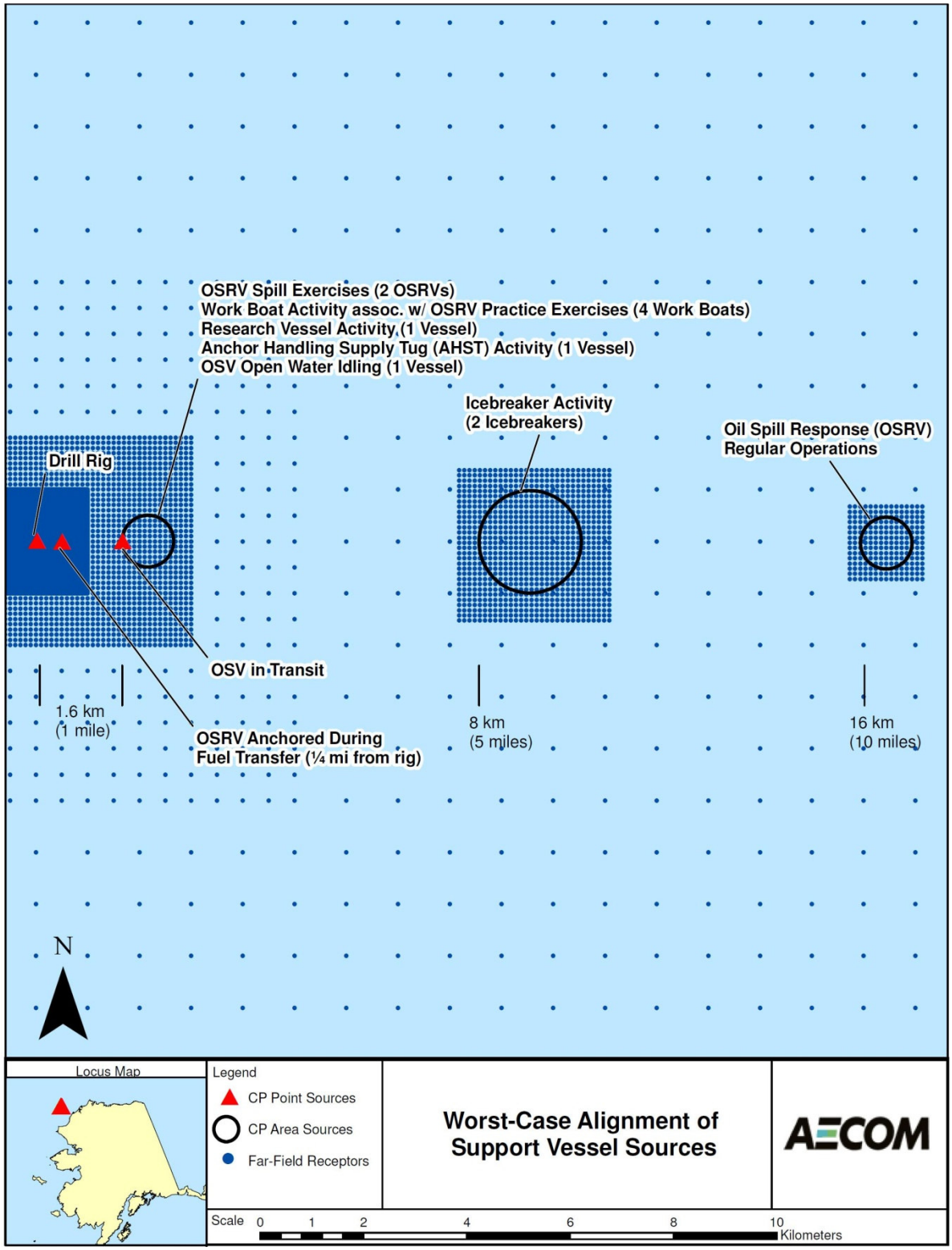
The modeled source parameters and emission rates are listed in **Appendix G**. For the 1-hour and 8-hour averaging period, CO emission rates were used for the evaluation. For the 24-hour averaging period, emission rates for $PM_{2.5}$, the controlling pollutant, was used. Preliminary modeling indicated that SO_2 is not a controlling pollutant; therefore, SO_2 emissions were not included in the analysis. When conducting the sensitivity modeling, the sources were positioned in a line at the noted distance from the rig, aligned at 45 degree increments relative to the rig for a total of 8 separate alignment model evaluations.

The modeling results are summarized in **Table L3-2** below. The results demonstrate that the worst-case alignment of these sources is east of the drill rig as shown in **Figure L3-1**, and consistent with the easterly predominant wind direction present in the modeled meteorological data set.

Table L3-2: Modeling Results for each Alignment of Support Vessel Sources

Pollutant	Averaging Period	Rank	Wainwright NWS Met Data					Vessel Met Data	Overall Maximum Impact
			1999	2002	2004	2005	2006	2008	
Source Position Relative to the Rig: 0 degrees (North) - Predicted Impacts (µg/m^3)									
CO	1-hr	MAX	438.1	1,174.9	549.9	802.5	1,393.0	1,101.1	1,393.0
CO	8-hr	MAX	187.3	246.9	127.9	156.4	174.1	227.3	246.9
$PM_{2.5/10}$	24-hr	MAX	3.4	5.1	5.1	3.1	4.6	5.5	5.5
Source Position Relative to the Rig: 45 degrees - Predicted Impacts (µg/m^3)									
CO	1-hr	MAX	979.3	782.2	496.4	907.4	928.9	649.9	979.3
CO	8-hr	MAX	216.1	309.5	117.7	129.2	235.4	152.6	309.5
$PM_{2.5/10}$	24-hr	MAX	3.6	7.1	2.4	3.4	4.7	2.5	7.1
Source Position Relative to the Rig: 90 degrees (East) - Predicted Impacts (µg/m^3)									
CO	1-hr	MAX	1,803.5	1,084.1	1,035.3	1,477.0	1,834.2	795.7	1,834.2
CO	8-hr	MAX	345.6	369.8	309.7	293.6	269.1	286.5	369.8
$PM_{2.5/10}$	24-hr	MAX	8.8	7.0	5.7	6.1	7.2	4.6	8.8
Source Position Relative to the Rig: 135 degrees - Predicted Impacts (µg/m^3)									
CO	1-hr	MAX	934.7	1,705.0	527.4	1,287.3	1,255.6	328.5	1,705.0
CO	8-hr	MAX	134.9	272.4	132.5	168.4	264.1	99.2	272.4
$PM_{2.5/10}$	24-hr	MAX	3.5	8.3	2.4	4.2	4.5	1.6	8.3
Source Position Relative to the Rig: 180 degrees (South) - Predicted Impacts (µg/m^3)									
CO	1-hr	MAX	621.7	1,488.8	471.8	764.0	556.7	468.2	1,488.8
CO	8-hr	MAX	152.7	282.5	176.2	245.9	296.5	109.5	296.5
$PM_{2.5/10}$	24-hr	MAX	3.9	5.3	2.8	5.7	3.8	2.0	5.7
Source Position Relative to the Rig: 225 degrees - Predicted Impacts (µg/m^3)									
CO	1-hr	MAX	398.6	891.2	373.7	328.2	429.6	764.0	891.2
CO	8-hr	MAX	109.3	121.6	103.9	109.5	129.5	140.3	140.3
$PM_{2.5/10}$	24-hr	MAX	2.0	2.5	2.0	2.0	2.2	2.8	2.8
Source Position Relative to the Rig: 270 degrees (West) - Predicted Impacts (µg/m^3)									
CO	1-hr	MAX	381.5	651.1	824.9	480.1	433.0	1,318.2	1,318.2
CO	8-hr	MAX	206.0	171.8	145.0	154.6	160.3	248.9	248.9
$PM_{2.5/10}$	24-hr	MAX	2.8	4.2	3.4	3.6	3.2	4.3	4.3
Source Position Relative to the Rig: 315 degrees - Predicted Impacts (µg/m^3)									
CO	1-hr	MAX	905.1	1,187.4	318.8	1,073.6	439.9	700.1	1,187.4
CO	8-hr	MAX	236.7	252.5	140.9	257.9	98.3	112.6	257.9
$PM_{2.5/10}$	24-hr	MAX	5.0	7.2	1.7	5.2	1.7	1.8	7.2

Figure L3-1: Worst-Case Alignment of Support Vessel Sources



L-4.0 Determination of the Worst-Case Location for Shell's OCS Source with Respect to CP Project Sources

ConocoPhillips' (CP) OCS Source may be located in any of their lease holdings within the Devil's Paw Prospect. Shell's exploration plan for the next year indicates that their operation could be potentially located northeast of the Devil's Paw Prospect in the Burger Prospect, due north of the Cracker Jack Prospect, or west of the project area in the SW Shoebill Prospect. **Figure L4-1** shows the different prospects and their relationship to one another. None of the potential locations for Shell clearly produce maximum impacts in CP's project area. Therefore, a sensitivity modeling analysis was conducted to determine the worst-case location for Shell's OCS Source with respect to CP project sources.

Several different locations were evaluated with respect to Shell's impacts within CP's project area. Five scenarios were developed by considering all of the Shell lease holdings, not just the specific prospects noted above and that are detailed in Shells Exploration Plan for the first year of drilling. The Shell OCS Source was located on the Shell lease blocks that are closest to CP lease blocks. Likewise, CP's project was located on the CP lease blocks closest to Shell lease blocks. As a result, five separate scenarios were modeled to determine which location produced the maximum impacts. **Figure L4-2** shows the five location scenarios and the relationship of each OCS source to one another. **Table L4-1** lists the lease blocks that correspond to the five modeling scenarios.

Each modeling scenario featured Shell's project emission sources centered in the Shell lease block using a receptor grid (as described in Section 5.4 of the Modeling Report) centered in the CP lease block. For simplicity, CP's project sources were not included in the modeling as the analysis focused on which scenario would produce the highest impacts due to the Shell OCS on CP's receptor grid.

The emissions and stack parameter data found in Shell's revised Chukchi Sea air permit application submitted on December 22, 2009 were used for this analysis. The data are duplicated in **Tables L4-2** and **L4-3**. Because preliminary modeling indicated that $PM_{2.5}$ was the controlling pollutant, it was the main focus of the analyses. Annual emission rates for NO_2 were also evaluated. The preliminary modeling indicated that CO and SO_2 are not controlling pollutants; therefore, these pollutants were not included in the analysis.

For Shell's stationary sources, the discrete locations found in Shell's permit application were used. The center of the Shell lease block was set to the well center corresponding to Shell's OCS source. Mobile sources emissions were combined into a single point source, located in the center of the lease block. The combined mobile sources were assigned the stack parameters of the Vladimir Ignatjuk Icebreaker, which are the worst-case parameters considering each of the mobile vessel types.

OCD modeling results for the five modeling scenarios are presented in **Table L4-4**. The results show that Modeling Scenario 2 (where Shell is located northwest of CP) results in the highest $PM_{2.5}$ 24-hour concentration. NO_x annual concentrations between the five scenarios have a small variance. Therefore, the locations of the Shell OCS Source in Scenario 2 were used in the cumulative analysis. Furthermore, for both the significance and cumulative analyses, CP project sources used UTM coordinates corresponding to CP's assumed location in Scenario 2 (setting the well center in the center of lease block 6069). This location corresponds to a latitude and longitude of approximately 70° 56'N, 165° 43'W.

Table L4-1: CP and Shell Lease Blocks Used in the Five Modeling Scenarios

Modeling Scenario	CP Lease Block	Shell Lease Block
1	7101	6905
2	6069	7014
3	6317	6561
4	6372	6722
5	7101	6962

Table L4-2: Emissions Rates Used to Model Shell Sources[1]

Stack #	Source ID	Source Name	$PM_{2.5}$ (g/sec)	NOx (g/sec)	$PM_{2.5}$ (g/sec)	NOx (g/sec)
			Short-term Emissions		Annual Emissions	
Stationary Sources						
1	FD1-8	Generator Engines	1.57E-01	6.24E-01	6.91E-02	2.70E-01
2	FD9-11	MLC Compressors	7.00E-02	1.34E+00	7.48E-03	1.55E-01
3	FD12-13	HPU Engines	3.00E-02	1.36E+00	4.60E-03	2.35E-01
5a	FD14	Port Deck Crane	2.00E-02	7.40E-01	8.63E-04	1.37E-01
5b	FD15	Starboard Deck Crane	5.00E-03	7.80E-01	8.63E-04	1.37E-01
4	FD16-18	Cementing Units	5.00E-03	7.80E-01	9.21E-03	3.68E-01
6	FD21-22	Heat Boilers	5.00E-02	4.00E-01	2.19E-02	1.86E-01
7	FD19-20	Logging Winches	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	FD23	Incinerator	1.00E-02	0.00E+00	1.29E-02	9.21E-03
9	FD-31	Resupply Ship - Docked	4.00E-02	5.70E-01	8.63E-04	1.24E-02
Mobile Sources *(all Shell mobile sources modeled through Vladimir Ignatjuk icebreaker stack)*						
-	VLADIGN2	Vladimir Ignatjuk	7.26	170.06	3.19	32.71

[1] Data from Shell's revised Chukchi Sea air permit application submitted on December 22, 2009

Table L4-3: Stack Parameters Used to Model Shell Sources[1]

Stack #	Source ID	Source Name	Height (m)	Diam. (m)	Temp. (deg K)	Vel. (m/sec)	Bldg. Ht. (m)	Bldg. Width. (m)	Platform Ht. (m)
1	FD1-8	Generator Engines	12.83	0.32	710	32.90	19.80	44.00	4.6
2	FD9-11	MLC Compressors	8.53	0.21	700	40.00	19.80	44.00	4.6
3	FD12-13	HPU Engines	6.10	0.18	700	40.00	19.80	44.00	4.6
5a	FD14	Port Deck Crane	13.72	0.25	672	20.10	19.80	44.00	4.6
5b	FD15	Starboard Deck Crane	13.72	0.25	672	20.10	19.80	44.00	4.6
4	FD16-18	Cementing Units	6.10	0.18	800	46.60	19.80	44.00	4.6
6	FD21-22	Heat Boilers	12.83	0.46	478	7.30	19.80	44.00	4.6
7	FD19-20	Logging Winches	8.53	0.10	711	53.00	19.80	44.00	4.6
8	FD23	Incinerator	2.44	0.46	623	10.00	19.80	44.00	4.6
9	FD-31	Resupply Ship - Docked	15.24	0.18	700	40.00	19.80	44.00	4.6
-	VLADIGN2	Vladimir Ignatjuk	24.38	0.79	668	33.20	19.81	17.51	0.0

[1] Data from Shell's revised Chukchi Sea air permit application submitted on December 22, 2009

Table L4-4: Modeling Results for the Five Simulated Location Combinations for the CP and Shell OCS Sources

Pollutant	Ave Period	Rank	Wainwright NWS Met Data					Vessel Met Data	Overall Maximum Impact
			1999	2002	2004	2005	2006	2008	
Modeling Scenario 1 Predicted Impacts (µg/m^3)									
NO_x	Annual	MAX	12.6	9.3	14.5	10.2	8.8	12.3	14.5
$PM_{2.5}$	24-hr	MAX	17.2	21.3	29.2	19.8	17.0	21.4	29.2
$PM_{2.5}$	Annual	MAX	1.2	0.9	1.4	1.0	0.8	1.1	1.4
Modeling Scenario 2 Predicted Impacts (µg/m^3)									
NO_x	Annual	MAX	11.3	7.8	13.8	8.6	10.1	8.5	13.8
$PM_{2.5}$	24-hr	MAX	17.6	19.2	35.5	16.8	26.0	27.5	35.5
$PM_{2.5}$	Annual	MAX	1.0	0.7	1.3	0.8	0.9	0.8	1.3
Modeling Scenario 3 Predicted Impacts (µg/m^3)									
NO_x	Annual	MAX	10.8	11.1	11.5	16.4	7.9	6.4	16.37
$PM_{2.5}$	24-hr	MAX	18.2	34.2	23.3	20.7	18.0	15.5	34.2
$PM_{2.5}$	Annual	MAX	1.0	1.0	1.1	1.5	0.7	0.6	1.54
Modeling Scenario 4 Predicted Impacts (µg/m^3)									
NO_x	Annual	MAX	10.9	7.5	10.9	7.5	7.9	5.3	10.9
$PM_{2.5}$	24-hr	MAX	16.1	14.5	20.8	18.5	15.5	10.5	20.8
$PM_{2.5}$	Annual	MAX	1.0	0.7	1.0	0.7	0.8	0.5	1.0
Modeling Scenario 5 Predicted Impacts (µg/m^3)									
NO_x	Annual	MAX	9.2	6.5	8.7	7.0	6.1	5.4	9.22
$PM_{2.5}$	24-hr	MAX	13.9	12.0	13.1	12.9	11.2	11.2	13.9
$PM_{2.5}$	Annual	MAX	0.9	0.6	0.8	0.7	0.6	0.5	0.89

Figure L4-1: Chukchi Sea Sales 193 Lease Areas Prospects and Ownership

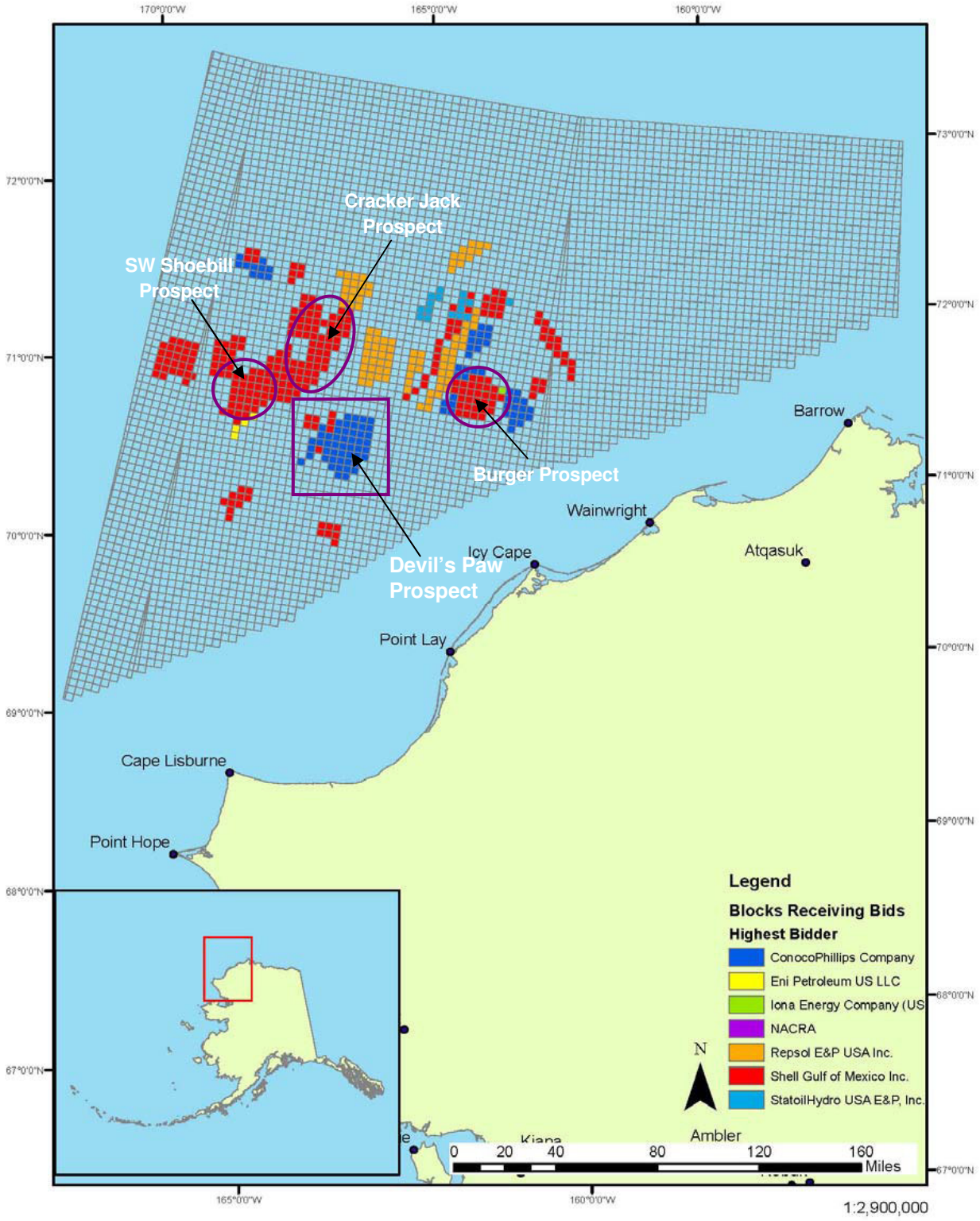
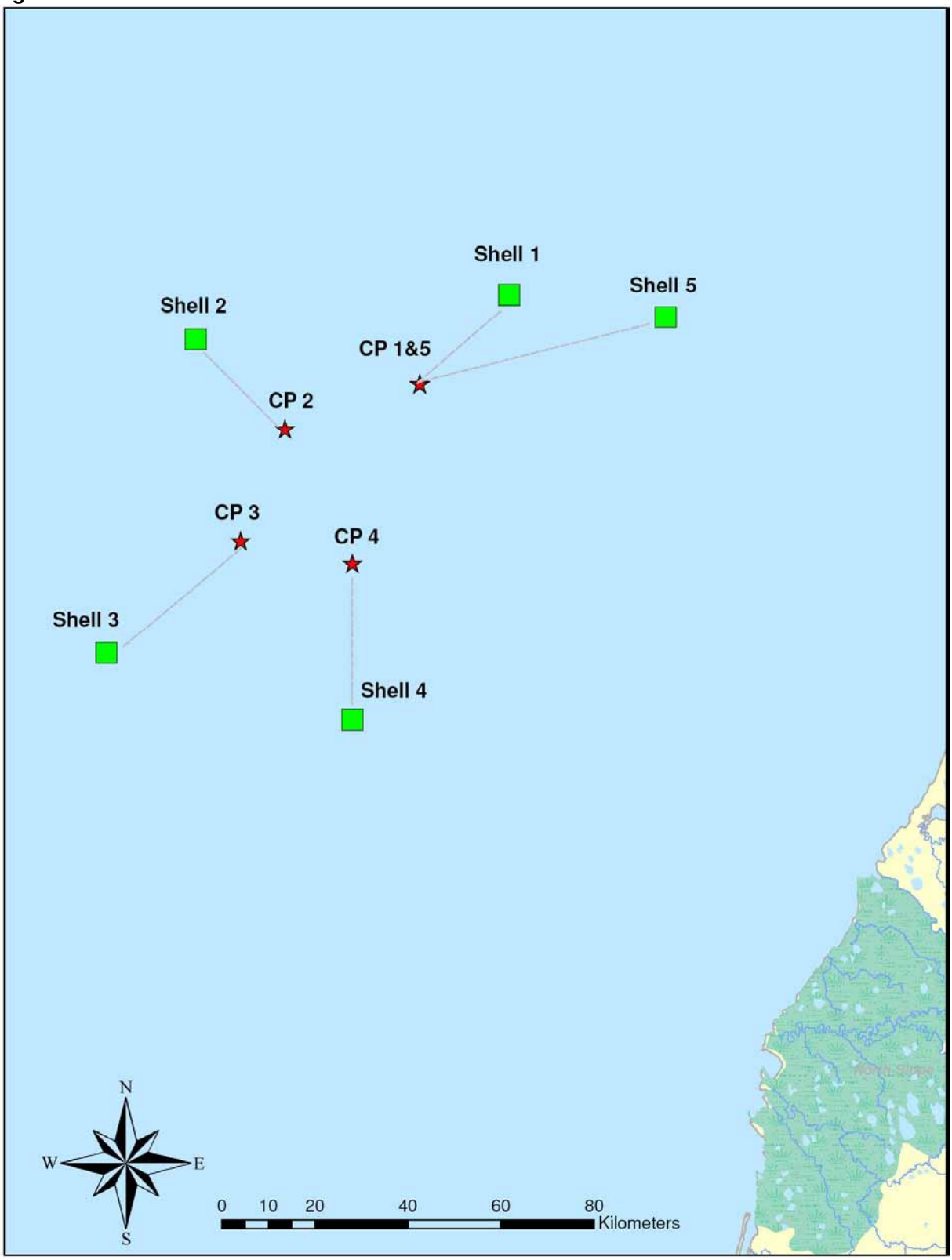


Figure L4-2: Five CP-Shell OCS Source Location Scenarios



Appendix M

Development of Representative Short-Term Particulate Background Concentrations

M-1 Introduction

This appendix documents the development of the representative 24-hour background concentration that was used in conjunction with modeled impacts from the cumulative air quality analysis to demonstrate compliance with the NAAQS.

For those pollutants where the maximum modeled project impacts were greater than the SILs, the cumulative modeled impacts of the proposed project sources and significant off-site sources were added to a background concentration which represents sources not explicitly modeled. Concentrations recorded as part the Wainwright Near-Term Ambient Air Quality Monitoring Program (Wainwright Monitoring Program) were used as background data to demonstrate compliance with the NAAQS for 1-hour and 8-hour CO, annual NO_2, and annual PM_{10}.

Section 8.2 in USEPA's Guideline on Air Quality Models (GAQM) (USEPA 2005) indicates that all regional emission sources should be included in air quality modeling analyses either through the use of an appropriate background concentration or explicitly modeled unless a source can be shown not to cause a significant concentration gradient in the project impact area. Short-term particulate concentrations (PM_{10} and $PM_{2.5}$) measured as part of the Wainwright Monitoring Program include, and are dominated by, the contribution from local fugitive dust sources that are not representative of the offshore project area which is located more than 100 km from the nearest fugitive dust source. Therefore, simply adding 24-hour particulate concentrations measured at Wainwright to model predicted concentrations would not be representative of over water locations. However, for annual average particulate concentrations and for other monitored pollutants, the traditional approach of using the monitored data directly to characterize a conservatively high estimate of the regional background concentrations was followed.

Following the guidance outlined in Section 8.2 of the GAQM, representative 24-hour $PM_{2.5}$ and PM_{10} background concentrations over water were determined by summing the following two components:

- A regional background concentration (minus impacts from dominant local particulate sources by looking at wind sectors with onshore trajectories), and
- A concentration determined through modeling which represented the effect of the dominant Wainwright particulate sources in the project area.

As of late 2009, 12 months of PM_{10} data and 8 months of $PM_{2.5}$ data (March 2009 through October 2009) were available from the Wainwright Near-Term Ambient Air Quality Monitoring Program (Wainwright Monitoring Program). While this is less than the 1 year of $PM_{2.5}$ data typically desired, the 8 months of data that was available spanned the drilling season and represents the highest concentrations measured during a 12-month period. This is because the data is collected in an area where particulate emissions are dominated by fugitive dust, and the 8-month timeframe encompasses the warmest and driest portion of the year, when local fugitive dust sources are exposed (i.e., no longer frozen and/or snow covered) and will be the most active.

M-2 Regional Background Concentration

Analysis of the data measured by the Wainwright Monitoring Program indicated that measured particulate concentrations were dominated by fugitive dust from disturbed areas associated with the Wainwright Airport, located approximately a tenth to one mile from the Wainwright Monitoring Program station location. Because there is no similar source type in the over water project area, the regional background concentration was developed by determining the highest 24-hour measured particulate concentration that excluded the influence of the disturbed areas associated with the Wainwright Airport. Excluding the

Wainwright Airport fugitive dust sources, the measured particulate concentrations were attributed to the following sources:

- Local combustion sources in the community of Wainwright (cars, diesel generators, etc);
- Fugitive dust sources in the village (dirt roads, dirt piles, and other exposed areas); and, most importantly,
- Sea salt particles from Chukchi Sea.

The measured particulate concentrations due to these sources were determined by calculating the highest daily average concentration on days with at least 18 hours featuring winds that blow from these sources towards the Wainwright monitor. The pertinent wind directions were determined to be within the sector from 260 through 20 degrees. The resulting 24-hour $PM_{2.5}$ and PM_{10} concentrations of 9.6 µg/m^3 and 45.0 µg/m^3, respectively, were determined to be the regional background concentration. Spreadsheets showing the derivation of the regional background concentrations, including the measured particulate concentrations from the Wainwright monitor coupled with concurrent wind directions, are provided on DVD as part of the Digital Record.

Figure M-1 shows the sector of pertinent wind directions, as well as an aerial view of the local sources that it encompasses.

M-3 Maximum Modeled Impact Due to Wainwright Airport Fugitive Dust in Project Area

Because concentrations due to fugitive dust from the Wainwright Airport were excluded from the regional background concentration, dispersion modeling was used to account for potential air quality impacts from this fugitive source in the project area even though it is reasonable to assume that this source will not create a significant concentration gradient in the project area and could be eliminated from consideration, according to Section 8.2 of the GAQM.

The AERMOD model was chosen to conduct this analysis because the fugitive emissions have their initial dispersion over land, and the appropriate guideline model for that aspect of the dispersion is AERMOD.

Use of the AERMOD model required processing 5 years of surface meteorological data from Wainwright NWS and concurrent upper air sounding data from Barrow with the AERMET meteorological processor. AERMET requires specification of site characteristics including surface roughness, Albedo, and Bowen ratio. **Table M-1** shows the seasonal values that were selected. These values are approved by the Alaska Department of Environmental Conservation for Alaskan North Slope Coastal Plain modeling applications.

Table M-1: Fugitive Area Source (Airport Runway) Strength Calculations

Surface Parameter	Winter Value (Oct-May)	Summer Value (June - Sept)
Albedo	0.8	0.18
Bowen Ratio	1.5	0.8
Surface Roughness Length	0.004	0.02

It is assumed that most fugitive dust from Wainwright Airport originates from the airport's runway. Therefore, modeling was conducted for a polygonal area source equal to the outline of the runway. The airport runway source characteristics and source strength were based on modeling the particular day that produced the highest measured particulate concentration at the Wainwright monitoring station. Modeling of the runway area source used actual meteorology on that day, i.e., actual wind directions and all wind speeds were used.

Both the release height and initial vertical dimension height (σ_z) of the area source were set to zero because the fugitive source is a ground-level source that has no initial depth. The area source emission rate was adjusted so that the model predicted concentration at a receptor located at the Wainwright monitoring station was equal to the maximum 24-hour measured concentration at the monitoring station. **Figure M-1** shows the location of the runway and the outline of the area source used in the modeling. **Table M-2** shows the area source emission rate determined by modeling.

Table M-2: Fugitive Area Source (Airport Runway) Emission Calculations

Date	Pollutant	Maximum Measured 24-hr Concentration at the Wainwright Monitor ($\mu g/m^3$)	Maximum Predicted 24-hr Concentration at the Monitor ($\mu g/m^3$ per g/sec)	Calculated Source Emission Rate (g/sec)	Calculated Area Source* Emission Rate ($g/sec/m^2$)
10/8/2009	$PM_{2.5}$	23	7.3	3.2	2.609E-05
7/3/2009	PM_{10}	114	5.1	22.2	1.832E-04

**Area Source =121,293 m^2*

Impacts from the simulated PM_{10} and $PM_{2.5}$ airport runway area source were predicted on an arc of 65 discrete receptors placed 50 kilometers from the area source in the direction of the project (see **Figure M-2**). Receptors were placed at a distance of 50 kilometers instead of the distance of the actual project location (>150 km from the area source) because 50 kilometers is the EPA-specified limit of the AERMOD model. The maximum concentration at 50 kilometers was assumed to be a conservative representation of the maximum impact at the project location, even though the project is located much farther away, where modeled impacts would be smaller.

To determine the maximum concentration at 50 kilometers, it was assumed that the fugitive dust area source was active only when winds were above 4 m/sec. This threshold is documented in AP-42 Sections 13.2 and 13.2.5 (USEPA 2006), as well as a Desert Research Institute publication (Desert Research Institute 2000). The documents suggest that fugitive dust sources become active at wind speeds of 4-5 m/sec. Moreover, the 4 m/sec threshold is supported by analysis of Wainwright particulate measurements.

Table M-3 summarizes the maximum predicted $PM_{2.5}$ and PM_{10} 24-hour concentrations, at 50 kilometers from the area source, for each modeled year. The impacts from this regional source clearly do not create a significant concentration gradient in the project impact area; therefore, this source could be eliminated from the cumulative analysis based on Section 8.2 of GAQM. However, it was included in the analysis for conservatism.

Table M-3: Maximum Modeled Impact Due to Wainwright Airport Fugitive Dust in the Project Area

Year	Maximum Predicted $PM_{2.5}$ 24-hr Concentration at 50 km (µg/m^3)	Maximum Predicted PM_{10} 24-hr Concentration at 50 km (µg/m^3)
1999	0.4	3.3
2002	0.3	2.4
2004	0.6	4.1
2005	0.4	2.6
2006	0.3	2.4
Overall Maximum	**0.6**	**4.1**

M-4 Calculation of Representative Background Concentration

As stated above, to determine the representative 24-hour $PM_{2.5}$ and PM_{10} background concentrations over water, the previously defined regional background concentration was summed with the maximum modeled impact due to Wainwright Airport fugitive dust source in the project area. As shown in **Table M-4**, the representative background concentration is equal to 10.2 µg/m^3 for $PM_{2.5}$ and 49.2 µg/m^3 for PM_{10}.

Table M-4: Summary of Representative Background Concentrations Over Water

Component	$PM_{2.5}$ 24-hr Concentration (µg/m^3)	PM_{10} 24-hr Concentration (µg/m^3)
Regional Background (minus fugitive dust from Wainwright Airport)	9.6	45.0
Maximum Modeled Impact of Wainwright Airport Fugitive Dust in the Project Area	0.6	4.1
Representative Background Over Water	10.2	49.1

Figure M-1: Location of the Wainwright Monitor and Local Particulate Sources

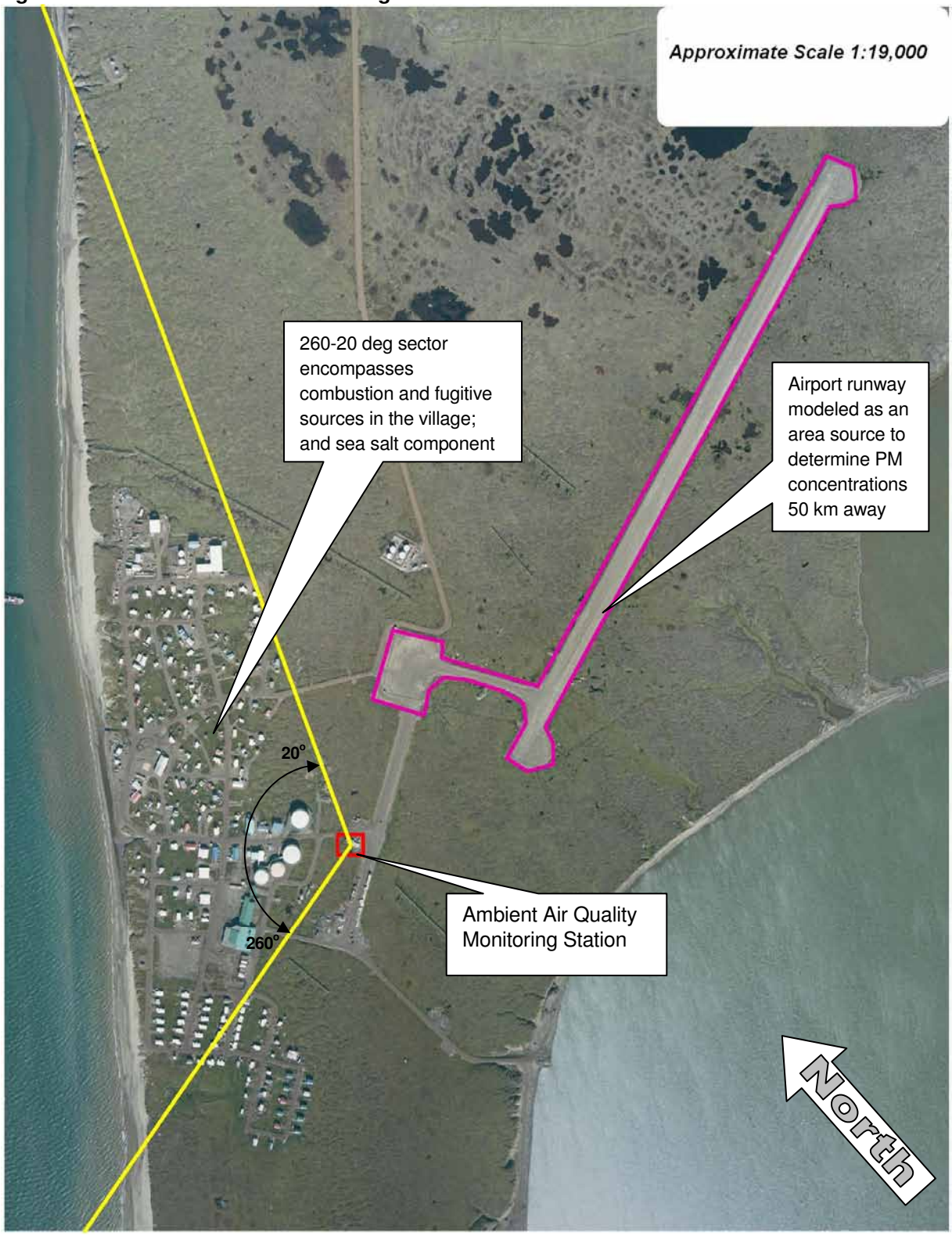
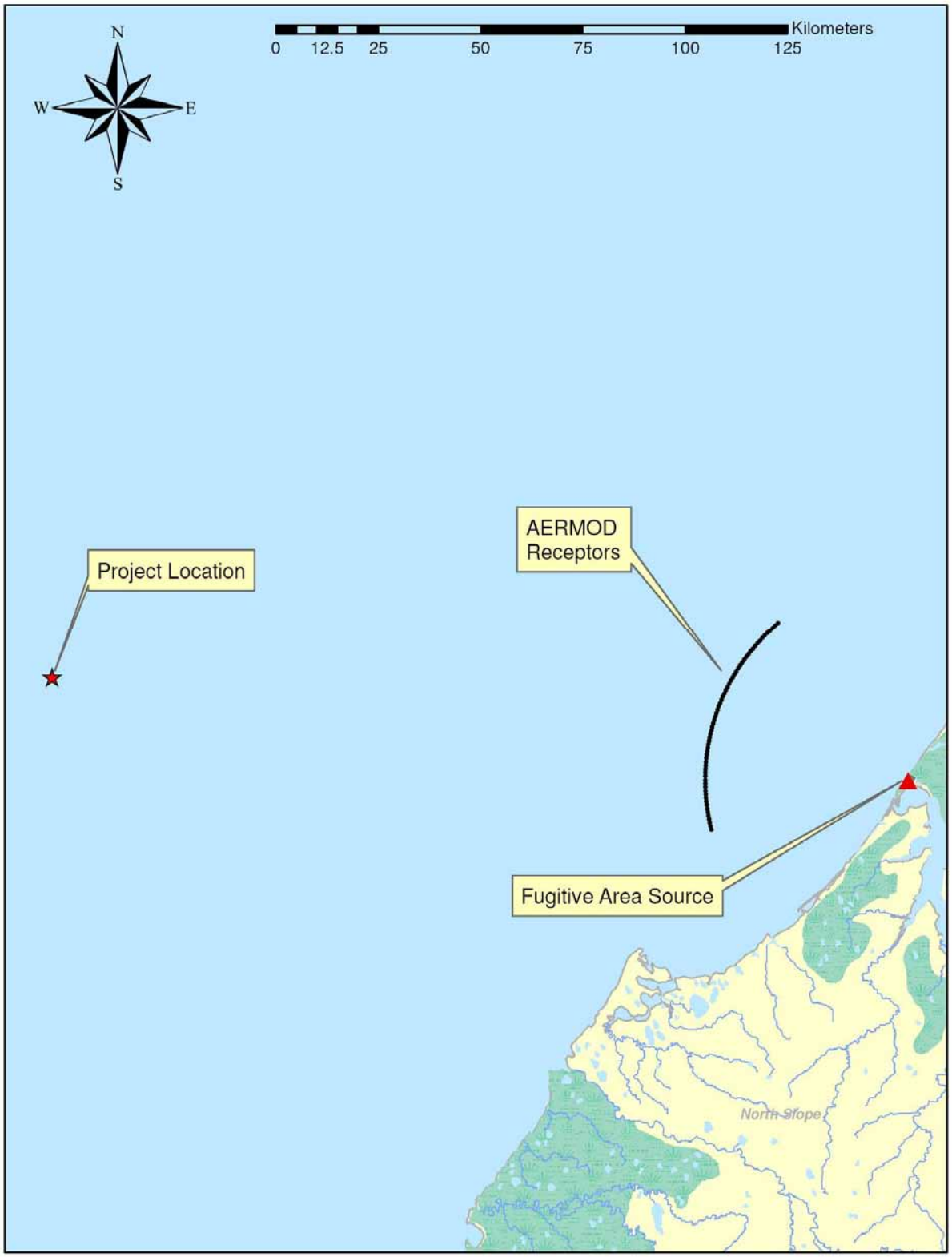


Figure M-2: Location of the Wainwright Airport Fugitive Area Source and Receptors



References

United States Environmental Protection Agency (USEPA). AP 42 Fifth Edition, Volume I Chapter 13. (Section 13.2 Introduction to the Fugitive Dust Sources (January 1995) and Section 13.2.5.1 Industrial Wind Erosion (November 2006).

_____. 2005. Guideline on Air Quality Models (GAQM) (Revised). Codified in the Appendix W to 40 CFR Part 51. Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. November 2005.

Desert Research Institute. 2000. Reconciling Urban Fugitive Dust Emissions Inventory and Ambient Source Contribution Estimates: Summary of Current Knowledge and Needed Research. (Section 3.2.4 Wind Speeds). DRI Document No. 6110.4F. May 2000.

Appendix N

Model Simulation of a Large Vessel Transiting the CP Project Area

Vessel Transiting Emissions

In order to assess impacts from a transiting vessel in the proposed project area, ConocoPhillips elected to model a transiting ice breaker vessel because ice breakers are the biggest and dirtiest of vessels expected to transit the project area.

OCD modeling of the ice breaker transiting CP project area was conducted to determine its impacts. The maximum 24-hour emission rates of $PM_{2.5}$ and NO_X, as well as the ice breaker exhaust parameters and ship dimensions, were obtained from the September 17, 2009 revision of the Shell Chukchi OCS Air Permit (EPA Permit R10OCS/PSD-AK-2009-01).

The Vladimir Ignatjuk ice breaker was chosen to be modeled because according to the Shell application, it produces the highest impacts among all vessels in Shell's ice management fleet. Hourly emissions of $PM_{2.5}$ and NO_X from the Vladimir Ignatjuk are presented in Table N-1 below.

Table N-1 Maximum 24-hour Emission Rates for the Primary Ice Management Fleet

Maximum 24-hour Emission Rates[1]: Primary Ice Management Fleet		
Type	**$PM_{2.5}$ (lb/hr)**	**NO_X (lb/hr)**
Vladimir Ignatjuk Ice Breaker (Primary Vessel)	42.2	1,108.7
(1) Emission rates obtained from the September 17, 2009 revision to the EPA Permit R10OCS/PSD-AK-2009-01, Attachment A, Page 3.		

For modeling purposes, it was assumed that the Vladimir Ignatjuk travels at a speed of 25 km/hr (13.5 knots) and covers a distance of 4 kilometers. Hence, it will take the vessel 0.16 hours to cover the 4 kilometers at a speed of 25 km/hr. Note that the vessel transits the CP project area only once during a given 24-hour period. Therefore, the icebreaker's $PM_{2.5}$ and NO_X emission rates (lb/hr) during a 24-hour period were calculated using Equations N-1 and N-2, respectively.

Equation N-1

$$PM_{2.5}\,Emission\,Rate\,(icebrkr, \frac{lb}{24\,hr}) = 42.2\frac{lb}{hr} \times 0.16\,hr = 6.75\frac{lb}{24\,hrs}$$

Equation N-2

$$NO_x\,Emission\,Rate\,(icebrkr, \frac{lb}{24\,hr}) = 1108.7\frac{lb}{hr} \times 0.16\,hr = 177.39\frac{lb}{24\,hrs}$$

The icebreaker's $PM_{2.5}$ and NO_X emission rates (g/s) during a 24-hour period were calculated using Equations N-3 and N-4, respectively.

Equation N-3

$$PM_{2.5}\,Emission\,Rate\,(icebrkr, \frac{g}{s}) = 6.75\frac{lb}{24\,hrs} \times 453.6\frac{g}{lb} \times \frac{hr}{3600\,s} = 0.0354\frac{g}{s}$$

Equation N-4

$$NO_x\,Emission\,Rate\,(icebrkr, \frac{g}{s}) = 177.39\frac{lb}{24\,hrs} \times 453.6\frac{g}{lb} \times \frac{hr}{3600\,s} = 0.93\frac{g}{s}$$

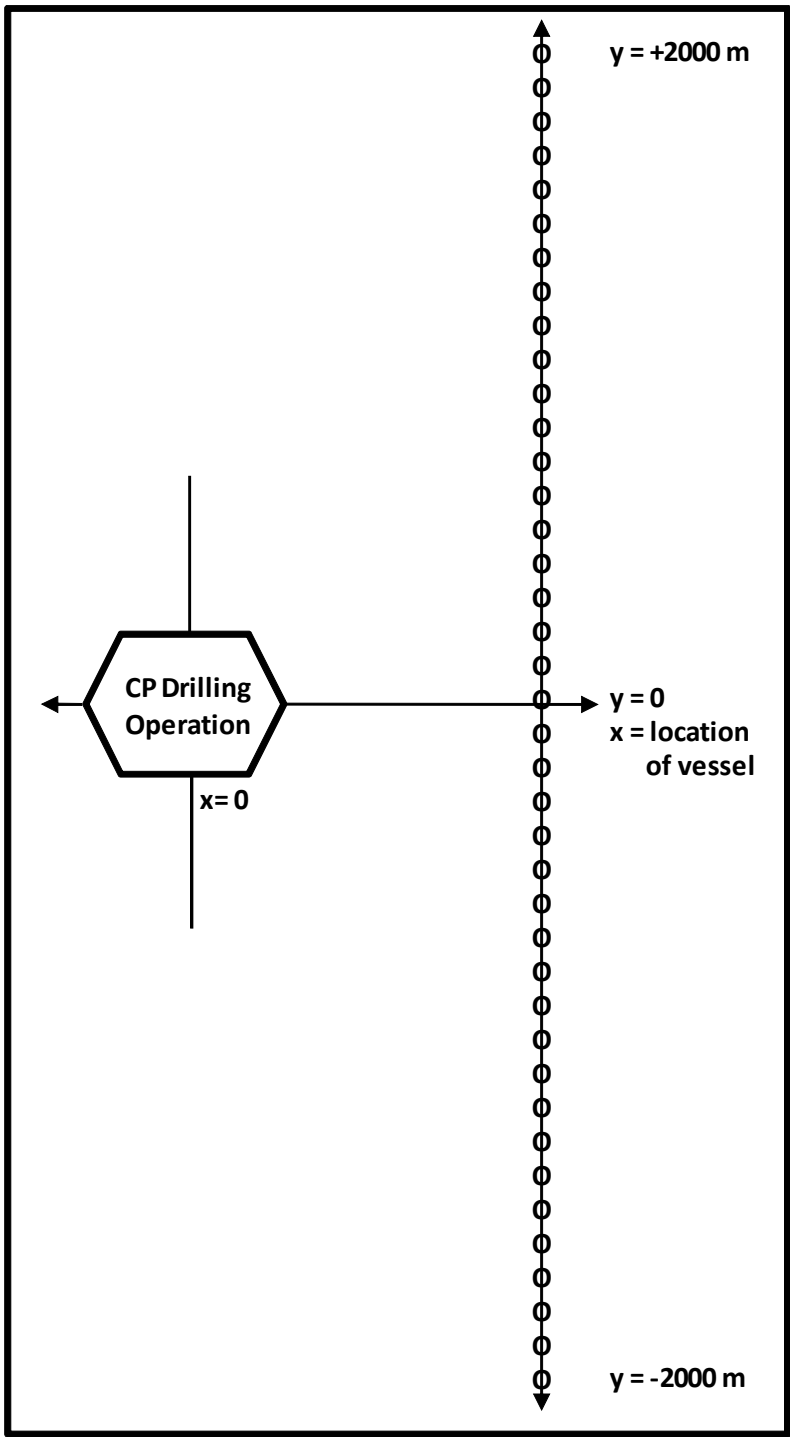
The transit distance of 4 kilometers was divided into 40 segments with a source placed every 100 meters. The vessel's transit simulation was modeled with OCD as a series of equidistant point sources as shown in Figure N-1. Therefore, the emission rates given in Equations N-3 and N-4 represent those for the 40 point sources combined.

Emission rates of $PM_{2.5}$ and NO_X per source were calculated as shown in Equations N-5 and N-6, respectively.

Equation N-5

$$PM_{2.5}\,Emission\,Rate\,(icebrkr, \frac{\frac{g}{s}}{source}) = \frac{0.0354\frac{g}{s}}{40\,sources} = 8.86E-04\frac{\frac{g}{s}}{source}$$

Figure N-1 Ice Breaker Transit Model Schematic



Equation N-6

$$NO_x\,Emission\,Rate\,(icebrkr, \frac{\frac{g}{s}}{source}) = \frac{0.93\frac{g}{s}}{40\,sources} = 2.33E-02\frac{\frac{g}{s}}{source}$$

Table N-2 summarizes the modeled $PM_{2.5}$ and NO_X emission rates as well as the source parameters for the Vladimir Ignatjuk primary ice breaker vessel.

Table N-2 Emission Rates and Source Parameters for the Vladimir Ignatjuk Vessel

OCD Modeling Inputs: Vladimir Ignatjuk Vessel[1]		
Parameter	**Value**	**Units**
$PM_{2.5}$ Emissions	8.86E-04	g/s
NO_X Emissions	2.33E-02	g/s
Stack Height [2]	24.38	Meters (above ocean)
Platform Height [2]	0	Meters
Stack Temperature [2]	668	Kelvin
Stack Velocity [2]	33.2	m/s
Building Height [2]	19.81	Meters
Stack Diameter [2]	0.79	Meters

(1) These source parameters are on a per source basis. There are 40 such sources.
(2) Source parameters obtained from the September 17, 2009 revision to the EPA Permit R10OCS/PSD-AK-2009-01, Attachment A, Page 5.

Shell Ice Breaker Modeling Results

The transiting vessel was modeled with OCD using the same meteorological data and receptor grid as that used to model the stationary sources at the rig. According to procedures in the OCD manual, a segmented line source (such as the transiting vessel) can be simulated as a series of virtual point sources to represent a moving ship with the typical travel time of 24 hours and, as such, line sources can only be modeled for a maximum of 24 hours using OCD. Therefore, the vessel's transit simulation was modeled with OCD as a series of 40 equidistant point sources placed every 100 m for a total distance of 4 km.

The OCD modeling results of the Vladimir Ignatjuk transiting CP project area are summarized in Table N-3 below. The results demonstrate that the impacts from a transiting vessel are insignificant and would have little impact on the CP project area. Therefore, emissions resulting from vessel transit will not cause a significant concentration gradient in the CP project area and therefore they do not need to be included in the cumulative analysis.

Table N-3 Transiting Vessel OCD Modeling Results

Pollutant	Ave Period	Rank	Wainwright NWS Met Data					Vessel Met Data	Overall Maximum Impact	SIL
			1999	2002	2004	2005	2006	2008	($\mu g/m^3$)	($\mu g/m^3$)
NO_2 [1]	Annual	MAX	0.113	0.083	0.114	0.122	0.113	0.116	0.122	1.0
$PM_{2.5}$	24-hr	MAX	0.033	0.065	0.047	0.051	0.046	0.032	0.065	1.2 [2]

(1) NO_2 impacts are calculated as 75% of NO_X impacts.
(2) The SIL for $PM_{2.5}$ is being proposed at 1.2 $\mu g/m^3$.