



## MEMORANDUM

May 3, 2016

Mr. Tom Moore

Western States Air Resources (WESTAR) Council  
Cooperative Institute for Research in the Atmosphere  
Colorado State University  
Fort Collins, CO 80523-1375

Subject: Review and Analyses of the Kuparuk, Alaska Drill Rig 1-hour NO<sub>2</sub> Monitoring Study Data (Rev 01), Contract No. 15-11, Amendment 1

Dear Mr. Moore:

Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler) has performed a review and analyses of 1-minute and 1-hour continuous emissions, ambient pollutant, and meteorological data collected in Kuparuk, Alaska for the Drill Rig 1-hour NO<sub>2</sub> Collaborative Monitoring Study. In addition, the meteorological data have been processed and reformatted for input into AERMET, and the emissions and ozone data have been formatted for input to AERMOD. The Scope of Work (SOW) for the referenced contract with the Western States Air Resources (WESTAR) Council identified the following six tasks to prepare data for use in evaluating the AERMOD dispersion model:

**Task 1:** Calculate Hourly Mass Emission Rates and Emission Velocities;

**Task 2:** Perform Data Analyses;

**Task 3:** Format Hourly Kuparuk Data for AERMOD Evaluation;

**Task 4:** Research Upper Air Data, Surface Characteristics, and Building Downwash;

**Task 5:** Construct a Modeling Database

**Task 6:** Prepare a Report.

This memorandum serves as the final report defined in Task 6 and describes the work completed by Amec Foster Wheeler as applicable to Tasks 1 through 5, with a focus on Tasks 1, 3, and 4. Data quality issues with the continuous emissions data were encountered while performing

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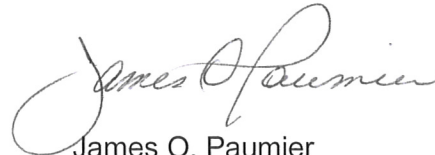
Task 1, and many of the contract resources were devoted to a detailed review of the emissions data and collaboration with the study management team (SMT), as well as staff at Nabors Alaska Drilling, Inc. (Nabors), SLR Consulting (SLR), and ConocoPhillips Alaska, Inc. (ConocoPhillips) to understand the source of the issues and attempts to resolve them. As a result, WESTAR prioritized the project tasks and subtasks which are reflected in the work reported in this memorandum. An end goal for the contract was to generate a preliminary 1-hour meteorological data file formatted for input to AERMET and preliminary 1-hour emissions and background ozone files formatted for input to AERMOD. These preliminary files will serve as a base set for the AERMOD evaluation workgroups that can be refined as needed based on additional analyses that will be performed by the workgroups.

All attachments referenced throughout this memorandum are provided as electronic files that should accompany this document. Appended to this memorandum is a file list that lists and describes the files included in each of the electronic attachments.

Sincerely,



Clint R. Tillerson  
Project Manager



James O. Paumier  
Technical Reviewer

## BACKGROUND

Emissions, ambient pollutant, and meteorological data were collected by ConocoPhillips Alaska during drill rig operations in Kuparuk on the North Slope of Alaska during the last four months of 2014 and provided to WESTAR for its Drill Rig 1-hour NO<sub>2</sub> Monitoring Study<sup>1</sup> (study). The dataset supplied to Amec Foster Wheeler contains 1-minute and 1-hour averages of emissions and ambient pollutant concentrations collected at well pad DS2N and hourly surface meteorology collected at well pad DSF1, located about 28 kilometers (km) northeast of DS2N. 1-minute and 1-hour wind data collected at DS2N were also included, but calibration and audit records were not provided with the data. We understand from the SMT that these data were collected to help understand short-term events and aid in the pollutant data QA process and should be used with extreme caution as they could have been influenced by nearby structures and activities. Figure 1 shows the locations of the DS2N and DSF1 well pads on the Alaska North Slope near the Kuparuk River.



Figure 1. Location of Well Pads DS2N and DFS1 on the Alaska North Slope

<sup>1</sup> Drill Rig 1-hour NO<sub>2</sub> Collaborative Monitoring Study, <http://www.wrapair2.org/DrillRig.aspx>

In addition to monitoring data, the Kuparuk dataset contains quality assurance and quality control (QA/QC) documentation including, but not limited to, audit reports and calibration records that coincide with the data collection period. The original data package provided to Amec Foster Wheeler by WESTAR is included with this memorandum as Attachment 01.

Amec Foster Wheeler previously performed a cursory review of the Kuparuk data for WESTAR as a task under a prior statement of work (SOW). The purpose of the cursory review was to identify any obvious errors and omissions in the Kuparuk data and the accompanying QA/QC documentation, but did not include a detailed review of individual data elements or QA/QC documents. Amec Foster Wheeler's findings of the cursory review are included with this memorandum as Attachment 02. The findings report also identifies the monitored parameters, units of measure, the period of data collection, and the QA/QC documents that are included in the Kuparuk dataset.

### Monitoring Configuration at the DS2N Well Pad

Drill rig operations were conducted at DS2N by ConocoPhillips at five different wells (at different distances from the monitors) during the months of September through December, 2014. The five wells at which drilling occurred during the study include: 303, 319, 336, 337, and 350. Drilling was performed with the Nabors 9ES drill rig which consists of six potential diesel emission sources including three engines two boilers, and an air heater. Table 1 lists the 9ES equipment inventory and the capacity of each source. The 3512B engines are used for electrical power generation when the rig was not operating from line power. The 3412 engine is a "move engine" that only operated when moving from one well to another. It did not operate during drilling. Consequently, emissions from the 3412 engine were not monitored. The two boilers provide steam heating throughout the rig, and the heater provides heated air for the rig pipe shed and cellar areas.

**Table 1. Nabors 9ES Drill Rig Equipment Inventory**

	<b>Equipment</b>	<b>Capacity*</b>
<b>Engines</b>	Caterpillar 3512B	1478 hp
	Caterpillar 3512B	1478 hp
	Caterpillar 3412	817 hp
<b>Boilers</b>	Superior 4x751-S150-JB3C-30UL	150 hp
	Superior 4x751-S150-JB3C-30UL	150 hp
<b>Heater</b>	Tioga IDF-11	2.42 MMBtu/hr

\* hp = horsepower; MMBtu/hr = one million British thermal units per hour

Emissions from the combustion of diesel fuel were monitored from the two 3512B engines (engine #1 and engine #2), the two boilers (boiler #1 and boiler #2), and the heater using two continuous emission monitoring systems (CEMSs). One CEMS was shared between the two 3512B engines, and the other CEMS was shared between the two boilers and the heater. Table 2 lists the stack parameters for the five sources that were monitored.

**Table 2. Drill Rig 9ES Stack Parameters**

<b>Source</b>	<b>Stack Height (feet)</b>	<b>Stack Diameter (inches)</b>	<b>Stack Temperature (Fahrenheit)</b>	<b>Notes:</b>
Boilers	46	16	350	Stack temperatures are estimated. All stacks are vertical, upward releases. The engine stacks have non-restrictive flappers. The heater stack has a non-restrictive rain diffuser.
Heater	38	16	450	
3512 B Engines	46	12	750	

Two fuel tanks supplied the sources with diesel fuel. One of the tanks supplied ultra-low sulfur diesel (ULSD) to the two engines while the second tank supplied the two boilers and heater with low sulfur diesel (LSD). ULSD fuel is limited to a maximum sulfur content of 15 parts per million (ppm). The sulfur content of LSD fuel is limited to no more than 500 ppm. Fuel use was metered independently for each of the five sources. A single data logger was used to process and store emissions data from each of the two CEMS, and a second data logger was used to process and store the fuel meter data. Data stored on each of the two data loggers were retrieved and merged daily via remote telemetry. The CEMS and fuel data include 1-minute and 1-hour averages of the following parameters for each of the five emission sources:

- Total Oxides of Nitrogen (NO<sub>x</sub>), ppm;
- Nitrogen Dioxide (NO<sub>2</sub>), ppm;
- Nitric Oxide (NO), ppm;
- In-stack Oxygen (O<sub>2</sub>), percent (%); and
- Fuel Rate (Fuel), gallons per minute and gallons per hour (GPM and GPH, respectively).

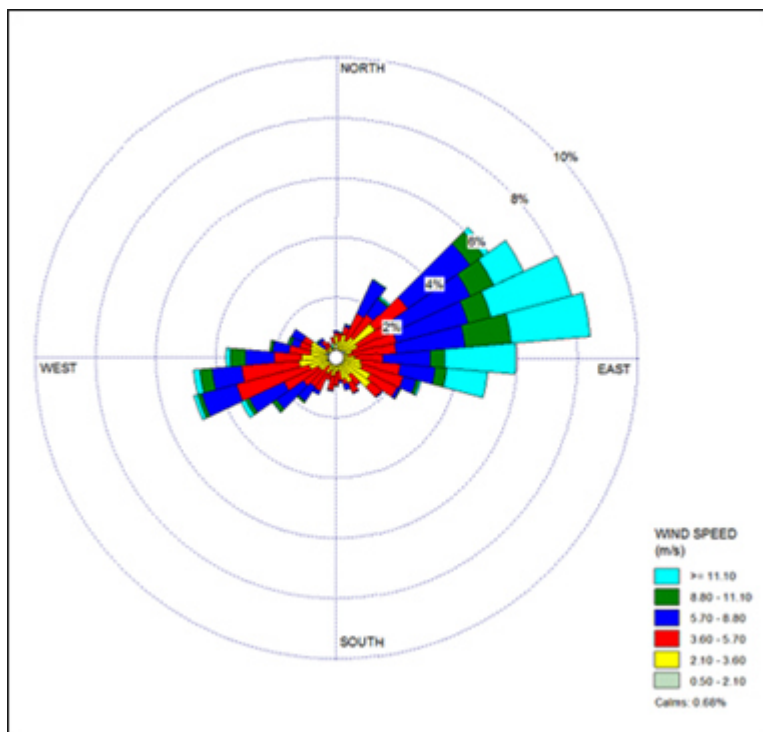
A monitoring equipment list is included in the ConocoPhillips Field Study Design Monitoring Plan which can be found in Attachment 01.

The DS2N well pad is generally oriented east-west, and a line of existing well heads spans much of the length of the pad. Ambient pollutant data were collected at two monitoring stations located at opposite ends of the pad from each other. The primary station at which most of the ambient pollutant data was collected was positioned at the west end of the pad and identified as the "downwind" station since the winds are predominantly from the east-northeast and the monitors are downwind of the well heads most of the time. A secondary "upwind" station, located at the east end of the pad, collected only ozone data. Figure 2 is an aerial view of the DS2N pad showing the locations of the five wells and the two ambient monitoring stations. Figure 3 is a wind rose generated from the meteorological data collected at DSF1 from September 1 through December 31, 2014.





**Figure 2. Well and Ambient Monitoring Station Locations at Well Pad DS2N**  
 (Note: This figure indicates well bore and not source locations.)



**Figure 3. Wind Rose at Well Pad DSF1, September 1 - December 31, 2014**  
 (Note: Wind rose illustrates the direction from which the wind was blowing.)

The following data elements<sup>2</sup> were collected at the "downwind" station and were included in the Kuparuk dataset:

- NO<sub>x</sub>, parts per billion (ppb);
- NO<sub>2</sub>, ppb;
- NO, ppb;
- Ozone (O<sub>3</sub>), ppb;
- Carbon Monoxide (CO), ppm;
- Sulfur Dioxide (SO<sub>2</sub>), ppb;
- Particulate Matter < 2.5 micrometers in diameter (PM<sub>2.5</sub>), micrograms per cubic meter (µg/m<sup>3</sup>); and
- Particulate Matter < 10 micrometers in diameter (PM<sub>10</sub>), µg/m<sup>3</sup>.
- Horizontal Wind Speed (Ws) taken at 3 meters, m/s;
- Horizontal Wind Direction (Wd) taken at 3 meters, degrees; and
- Standard Deviation of the Horizontal Wind Direction (σ<sub>θ</sub>), degrees;

As stated prior, only ozone, in ppb, was collected at the "upwind" station. The dataset included both 1-minute and 1-hour averages of ozone concentrations. A monitoring equipment list is included in the ConocoPhillips Field Study Design Monitoring Plan which can be found in electronic Attachment 01 of this memorandum. All air quality monitoring data were conducted using EPA Reference or Equivalent methods with the exception of the "upwind" ozone monitor. The ozone monitors at the "upwind" and "downwind" stations are both Federal Equivalent Method (FEM) instruments. The "upwind" background ozone sampler is a 2B Technologies Model 202 sampler which received Federal Equivalent Method (FEM) designation by EPA making it suitable for Prevention of Significant Deterioration (PSD) monitoring. However, it was not deployed and operated under the conditions specified and linked to the EPA equivalency designation. During the Drill Rig 1-Hour NO<sub>2</sub> Collaborative Study it was operated using a small enclosure instead of a climate-controlled shelter with limited ability to control temperature fluctuations and was not collocated with a NIST-traceable calibration system enabling calibration verifications at the required PSD frequencies. These differences could potentially influence the applicability of the data collected by the instrument. As such, pre-study<sup>3</sup> and post-study<sup>4</sup> correlation assessments were performed to assess the correlation of the ozone data collected at the "upwind" and "downwind" monitors. The correlation assessments, performed by SLR, are included in the original Kuparuk dataset, Attachment 01 of this memorandum.

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<sup>2</sup> The Kuparuk dataset includes 1-minute and 1-hour averages of NO<sub>x</sub>, NO, NO<sub>2</sub>, and O<sub>3</sub> from the west "downwind" station. These are the pollutants of interest for the referenced SOW. Only 1-hour averages of all other pollutants listed were included in the Kuparuk dataset and were not utilized. The wind data from the "downwind" station were not utilized.

<sup>3</sup> ConocoPhillips Alaska, Inc. (CPAI) Alaska Field Study Design - Drill Rig 1-Hour NO<sub>2</sub> Collaborative Study, Pre-Study Ozone Sampler Correlation Comparison, SLR, August 2014.

<sup>4</sup> ConocoPhillips Alaska, Inc. (CPAI) Alaska Field Study Design - Drill Rig 1-Hour NO<sub>2</sub> Collaborative Study, Post-Study Ozone Sampler Correlation Comparison, SLR, January 2015.

## **Meteorological Data from DSF1**

The Kuparuk dataset includes 1-hour averages of the following meteorological parameters collected at DSF1 which is located about 28 km northeast of DS2N:

- Vertical Wind Speed ( $w$ ) taken at 10 meters, meters per second (m/s);
- Standard Deviation of the Vertical Wind Speed ( $\sigma_w$ ), m/s;
- Horizontal Wind Speed ( $W_s$ ) taken at 10 meters, m/s;
- Horizontal Wind Direction ( $W_d$ ) taken at 10 meters, degrees;
- Standard Deviation of the Horizontal Wind Direction ( $\sigma_\theta$ ) taken at 10 meters, degrees;
- Temperature at 2 meters ( $T_2$ ), degrees Celsius (°C);
- Temperature at 10 meters ( $T_{10}$ ), °C;
- Delta Temperature,  $T_{10}-T_2$  ( $\Delta T$ ), °C;
- Solar Radiation ( $R$ ), Watts per square meter ( $W/m^2$ );
- Relative Humidity ( $RH$ ), %; and
- Station Barometric Pressure ( $P$ ), millibars (mb).

A monitoring equipment list is included in the ConocoPhillips Field Study Design Monitoring Plan which can be found in electronic Attachment 01 of this memorandum.

## **Averaging Convention**

The data follow the "hour-ending" convention with regard to computing 1-hour averages. Using this convention, a 1-hour average is based on the instantaneous data collected from just after the beginning of the previous hour through the beginning of the current hour to which the average is assigned. With respect to the relationship between the 1-hour data and the 1-minute data, a 1-hour average corresponds to the instantaneous data that make up the 1-minute averages starting with minute 01 from the previous hour through minute 00 of the current hour (i.e., "ending" on the hour). For example, the 1-minute average for hour 02 is calculated from the instantaneous data from minute 01 of hour 01 through minute 00 of hour 02. This should be taken into account when comparing or correlating the 1-minute and 1-hour data.



## WORK COMPLETED

An end goal of the review and analyses of the Kuparuk data is the creation of an AERMOD-ready model evaluation dataset that includes: 1) hourly onsite meteorological data formatted for input to AERMET, the meteorological preprocessor for AERMOD; 2) an hourly NO<sub>x</sub> emissions file formatted for input to AERMOD; 3) an hourly background ozone file formatted for input to AERMOD; and 4) building downwash parameters formatted for input to AERMOD (i.e., generated with BPIPPRM). To this end, the work completed reflects the prioritization of tasks and direction given to Amec Foster Wheeler by the technical adviser, Dr. Chris Owen with the U.S. Environmental Protection Agency (EPA), and members of the SMT as the project progressed and data issues were encountered.

These data sets are considered preliminary and require additional technical review before they are incorporated into any model evaluations. Amec Foster Wheeler assumes the model evaluation workgroups will refine these data sets based on their findings during subsequent analyses and evaluations.

### Task 1: Calculate Hourly Mass Emission Rates and Emission Velocities

The purpose of Task 1 was to use the CEMS concentration data and fuel rate data to derive hourly mass emission rates for NO<sub>x</sub> and stack gas exit velocities for each of the monitored emission sources. These calculated values will be used as input to AERMOD in order to evaluate AERMOD's performance in the prediction of ground-level concentrations of NO<sub>2</sub>. Also included in this task is compiling stack temperature and physical dimensions of the stack.

#### EPA Method 19

NO<sub>x</sub> emissions are recorded in the dataset as a concentration in ppm by dry volume and had to be converted to a mass emission rate as required by AERMOD for point sources. In addition, an hourly stack gas exit velocity is required by AERMOD which is not reported in the data. The SMT specified the use of the EPA's Method 19<sup>5</sup> to derive the hourly mass emission rates and exit velocities. Method 19 is dependent, in part, on the amount of fuel burned and the measured amount of oxygen in the stack, both of which were monitored. The Method 19-based calculation steps include:

#### 1. Convert NO<sub>x</sub> concentration (ppm) to pounds per dry standard cubic foot (lb/dscf)

$$\text{NO}_x \text{ (lb/dscf)} = \text{NO}_x \text{ (ppm)} \times \text{MW} / 24.06 / 453,600 \times 0.028317 \quad (\text{Equation 1})$$

Where:

$$\begin{aligned} \text{NO}_x \text{ (lb/dscf)} &= \text{NO}_x \text{ concentration, pounds per dry standard cubic foot} \\ &\quad \text{at 68°F \& 29.92 inches mercury} \\ \text{NO}_x \text{ (ppm)} &= \text{NO}_x \text{ concentration, parts per million by volume, dry} \\ &\quad \text{basis} \end{aligned}$$

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<sup>5</sup> Method 19 - SO<sub>2</sub> Removal & PM, SO<sub>2</sub>, NO<sub>x</sub> Rates from Electric Utility Steam Generators  
(<http://www3.epa.gov/ttn/emc/methods/method19.html>)

MW = Molecular weight of NO<sub>2</sub>, 46.01 grams per gram mole (g/g-mole)  
24.06 = Constant, molar volume of dry air liters per gram mole (l/g-mole)  
453,600 = Constant, milligrams per pound (mg/lb)  
0.028317 = Constant, cubic meters per cubic foot (m<sup>3</sup>/ft<sup>3</sup>)

## 2. Calculate heat input, MMBtu/min

$$H = \text{Fuel} \times \text{HHV} \quad (\text{Equation 2})$$

Where:

H = Heat input, one million British Thermal Units per minute (MMBtu/min)  
Fuel = Fuel rate, gallons per minute (GPM)  
HHV = Diesel fuel higher heating value (assume 138,500 Btu/gallon)

## 3. Calculate stack volumetric flow rate, dry standard cubic feet per minute (dscfm)

$$Q_s = F_d \times H \times (20.9 / (20.9 - O_2)) \quad (\text{Equation 3})$$

Where:

Q<sub>s</sub> = Stack flow rate (dscfm)  
F<sub>d</sub> = Fuel-specific oxygen-based F factor, dry basis, from Method 19 (9,190 dscf/MMBtu)  
H = Fuel heat input rate (MMBtu/min)  
20.9 = Constant, percent of oxygen in ambient air (%)  
O<sub>2</sub> = Percent of in-stack oxygen, dry basis (%)

## 4. Calculate mass emission rate, lb/MMBtu

$$ER = C \times F_d \times 20.9 / (20.9 - O_2) \quad (\text{Equation 4})$$

Where:

ER = Mass emission rate (lb/MMBtu)  
C = NO<sub>x</sub> concentration, lb/dscf at 68°F & 29.92 inches mercury  
F<sub>d</sub> = Fuel-specific oxygen-based F factor, dry basis, from Method 19 (9,190 dscf/MMBtu)  
20.9 = Constant, percent of oxygen in ambient air (%)  
O<sub>2</sub> = Percent of in-stack oxygen, dry basis (%)

**5. Calculate mass emission rate, pounds per hour (lb/hr)**

$$E = ER \times H \quad (\text{Equation 5})$$

Where:

E = Mass emission rate (lb/hr)  
ER = Mass emission rate (lb/MMBtu)  
H = heat input (MMBtu/min) x 60 min/hr

**6. Calculate volumetric flow rate at stack pressure, temperature and moisture, actual cubic feet per minute (acfm)**

$$Q_a = Q_s \times (T_s + 460) / 17.64/P_s / (1 - Bws) \quad (\text{Equation 6})$$

Where:

Q<sub>a</sub> = Volumetric flow rate (acfm)  
Q<sub>s</sub> = Volumetric flow rate (dscfm)  
T<sub>s</sub> = Assumed stack gas temperature, degrees Fahrenheit (F),  
Boilers = 350 F, Heater = 450 F, Engines = 750 F  
460 = Constant to convert degrees Fahrenheit (F) to degrees Rankine (R)  
P<sub>s</sub> = Stack pressure, inches of mercury (in. Hg) (used ambient barometric pressure at DSF1)  
Bws = Constant, moisture fraction in stack gas (assume 0.10 based on professional experience in lieu of actual stack testing data)

**7. Calculate stack area, square feet (ft<sup>2</sup>)**

$$A_s = \pi \times r^2 / 144 \quad (\text{Equation 7})$$

Where:

A<sub>s</sub> = stack cross-sectional area (ft<sup>2</sup>)  
r = stack inner radius, inches (in),  
Boilers = 8 in., Heater = 8 in., Engines = 6 in.  
144 = Constant, conversion factor in<sup>2</sup> to ft<sup>2</sup>

## 8. Calculate stack gas velocity at actual stack conditions, feet per second (fps)

$$V_s = Q_a / A_s / 60 \quad (\text{Equation 8})$$

Where:

$V_s$  = Stack gas velocity, actual stack conditions (fps)

$Q_a$  = Stack gas volumetric flow rate at actual conditions (acfm)

$A_s$  = Cross-sectional area of stack, ft<sup>2</sup>

60 = Constant, seconds per minute

### **CEMS Data Issues**

As stated, Amec Foster Wheeler previously performed a cursory review of the emissions dataset to identify obvious errors and omissions in the data and accompanying documentation. The cursory review did not include a detailed review of individual data elements or QA/QC documents. Amec Foster Wheeler understands the CEMS data previously underwent a detailed quality assurance review prior to WESTAR's acquisition of the data. A subsequent review of the CEMS data was being performed by the Alaska Department of Environmental Conservation (ADEC) when Amec Foster Wheeler began this work. To avoid duplicating effort, Amec Foster Wheeler was instructed by the SMT to forego a detailed review of the individual data elements, other than what was necessary to complete the objectives of the SOW.

While preparing to develop the hourly mass emission rates and exit velocities, Amec Foster Wheeler identified discrepancies and inconsistencies in the emissions data that bring into question the validity of some of the data. These issues result in calculated emission rates and exit velocities that are not representative of actual conditions for some hours, and in some cases, values that are not physically possible (e.g., negative emission rates and exit velocities). The following sections illustrate issues in the 1-minute data, their effects on the 1-hour data, and the uncertainty in the 1-hour data. As is shown in the sections that follow, the greatest uncertainty is associated with the data collected from Boiler #1. However, the emissions from Boiler #1 are small enough that their contribution of NO<sub>2</sub> at the ambient monitor is likely negligible. Also discussed are the methods explored for identifying and addressing the questionable data records.

### **Equipment Schedules**

The drill rig was powered by the diesel engines during different periods throughout the monitoring study, and the rig ran from line power when it was not powered by the engines. There were periods, however, when one or both engines were running while the rig was operating from line power. Table 3 lists the times, by well, when the drill rig was powered by one or more of the two diesel engines. As stated in the table footnotes, Table 3 is not an indication of the times when either of the engines was not operating since there were times when one or both engines was operating while the rig was on line power.

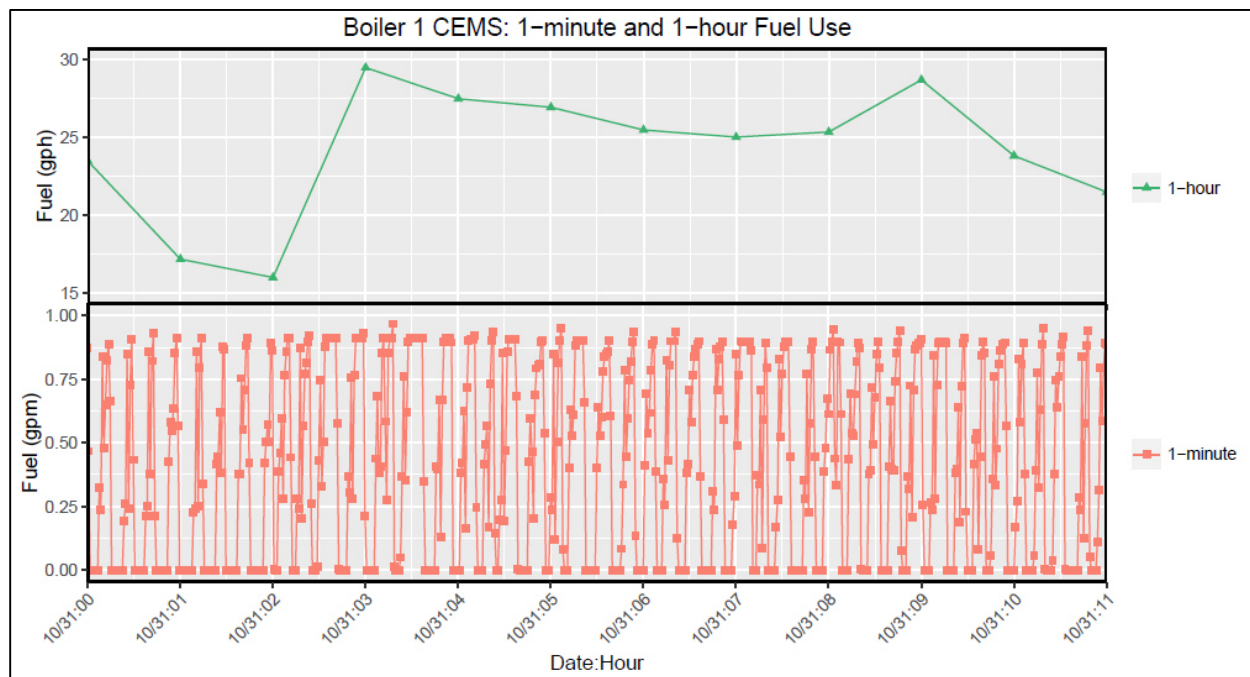
**Table 3. Schedule of Rig Engine Use (rig powered by diesel engines)**

Well	Engine #1*	Engine #2*
303	9/7/2014 11:00 - 9/14/2014 9:00	Engine Offline
350	10/23/2014 9:00 - 10/24/2014 15:00	10/24/2014 8:00 - 10/24/2014 15:00
319	10/24/2014 15:00 - 11/10/2014 17:00	10/24/2014 15:00 - 11/10/2014 17:00
337	11/28/2014 12:00- 12/29/2014 13:00	12/7/2014 12:00- 12/26/2014 9:00
336	N/A**	N/A**

\* Fuel data indicates one or both engines were often running simultaneously when the rig was on line power. This table only lists the hours that the rig was operating off of power from one or both engines.

\*\* Rig operated on line power for the duration at well 336 through the end of the study.

The boilers were used to generate steam to provide steam heating throughout the rig. The heater provided heated air for the rig pipe shed and cellar areas and ran nearly continuously during the monitoring study. Boiler #2, as it is identified in the data, was designated as the primary boiler and ran continuously during much of the study. Boiler #1 was not in operation during the first month of the study, but after it came online, it was used to supplement boiler #2 when there was more heat demand. Boiler #1 cycled on and off frequently until the outdoor temperature turned persistently colder during the latter part of the study when the weather turned persistently colder. The 1-minute data indicate boiler #1 cycled on and off as many as 3-5 times an hour during the middle of the study, roughly October and November. Boiler #1 did not operate at the beginning of the study. Figure 4 through Figure 8 are time-series plots of 1-minute and 1-hour fuel use for each of the five sources for a 12-hour period on October 31. Figure 4 illustrates frequent cycling on and off of boiler #1 to an extreme extent that is not observed with the other sources.



**Figure 4. 12-hour Sample of 1-minute and 1-hour Fuel Use: Boiler #1**



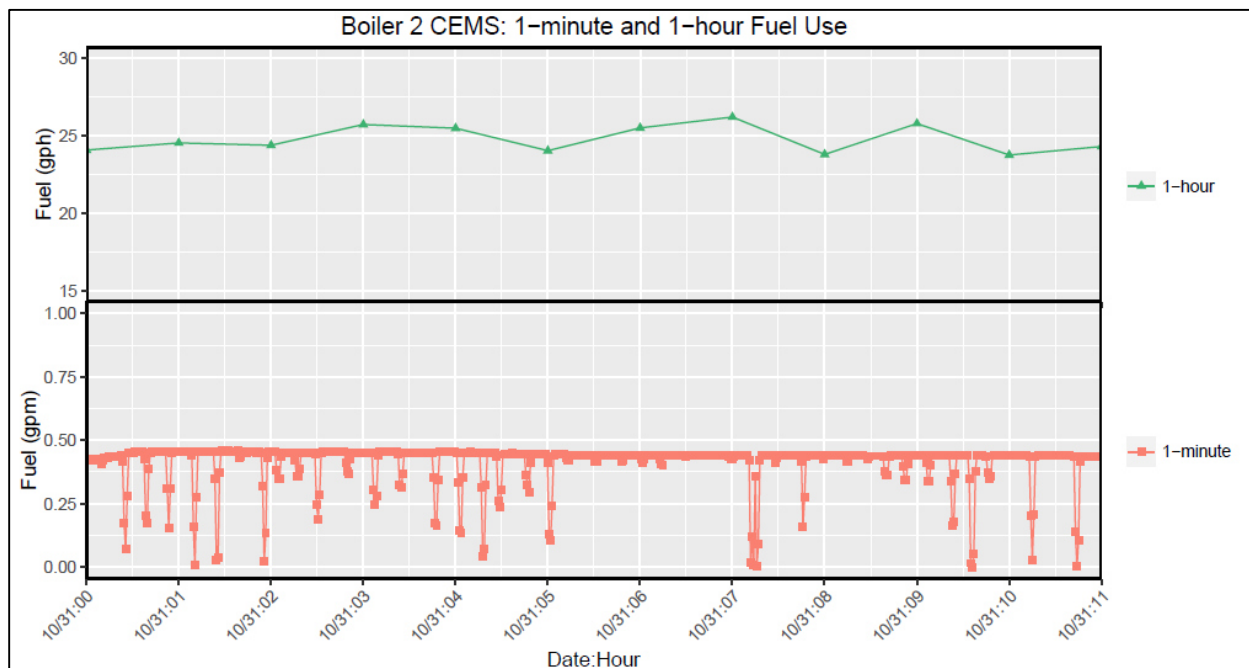


Figure 5. 12-hour Sample of 1-minute and 1-hour Fuel Use: Boiler #2

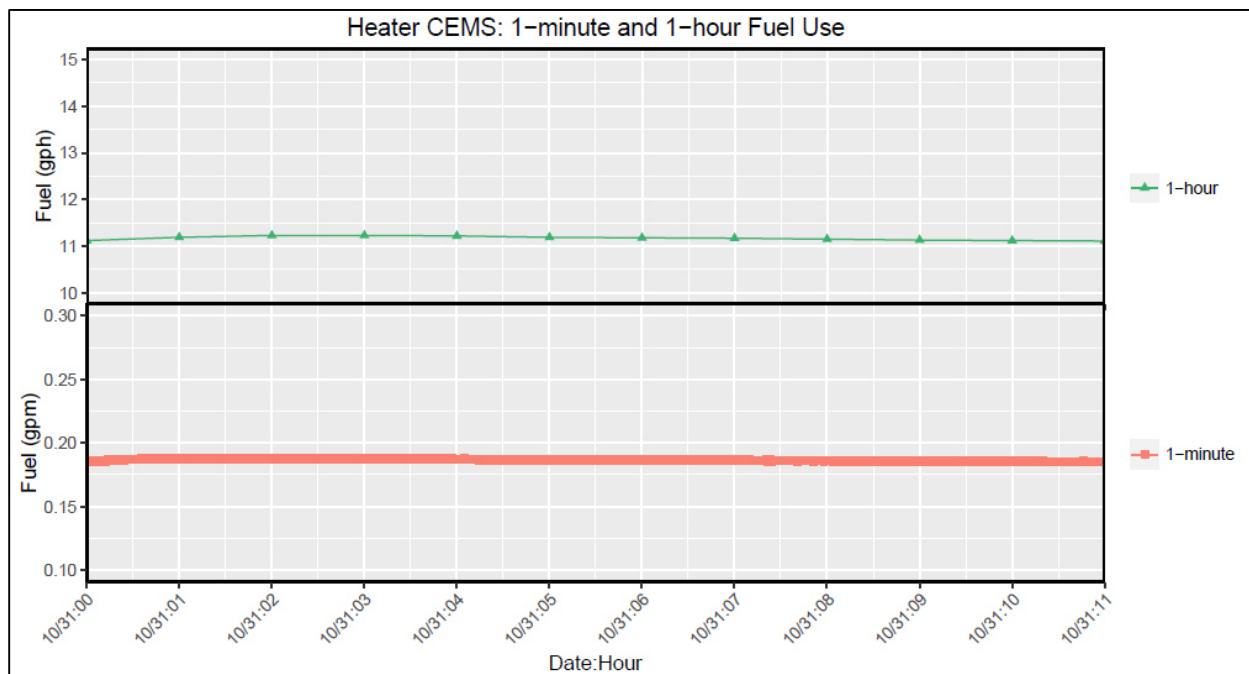


Figure 6. 12-hour Sample of 1-minute and 1-hour Fuel Use: Heater

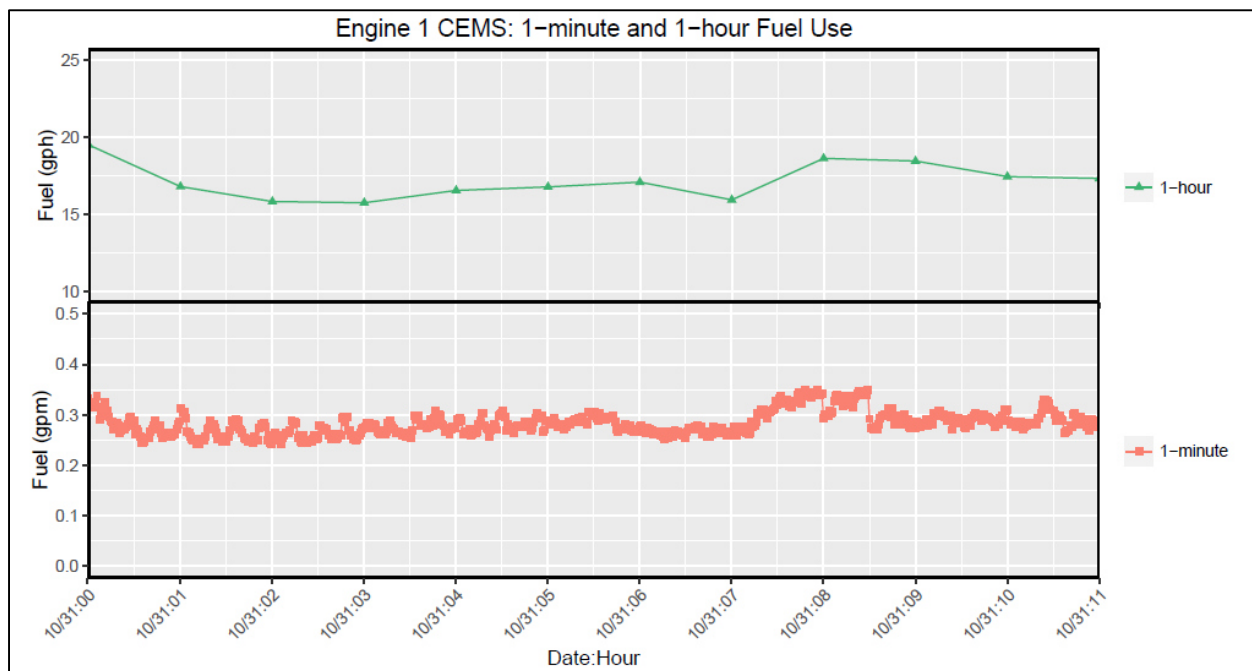


Figure 7. 12-hour Sample of 1-minute and 1-hour Fuel Use: Engine #1

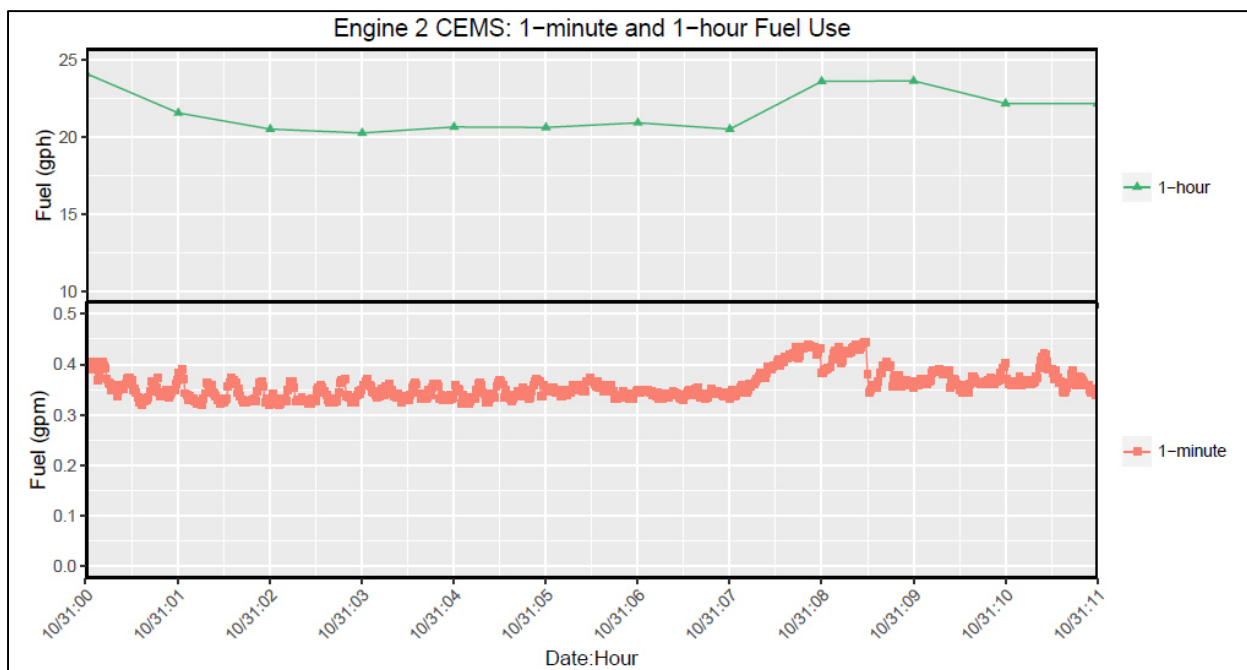


Figure 8. 12-hour Sample of 1-minute and 1-hour Fuel Use: Engine #2

### *CEMS Sharing*

As previously described, emissions from the five sources were monitored using two CEMS. One CEMS was shared between the two boilers and the heater. A second CEMS was shared between the two engines. A single data logger was used to record the monitored values from both of the CEMS.

Because the CEMS were shared between multiple sources and time was required to purge and stabilize the emission-stream between sampling periods when switching between sources, emissions data were collected for only a portion of each hour from each source. Each source was monitored for multiple 3-minute periods during each hour. The 1-minute data indicate that the minutes of the hour that were monitored each hour were constant for each source, and the 3-minute monitoring periods were spaced evenly across the hour for each source. Table 4 lists, by source, the minutes of the hour that were monitored for each source and the maximum number of minutes monitored each hour. There are more 1-minute NO<sub>x</sub> and O<sub>2</sub> values for the engines than for the boilers and heater since the engines shared one CEMS and the boilers and heater all shared the other CEMS. For the boilers and heater, a maximum of 12 minutes in each hourly period was monitored for each source due to CEMS sharing. The actual number of valid 1-minute averages for some hours is less due to equipment maintenance, calibration checks, or data that were invalidated for other reasons during the quality assurance process.

In contrast with the emissions data, source-specific fuel rates were monitored continuously by a dedicated meter installed on each source. Fuel rates are reported every minute of the hour for each source, except for periods when data are missing or were invalidated during the quality assurance process. Fuel rates for all sources were recorded by a single data logger, separate from the data logger used to record the emissions values from the two CEMS. Data stored on each of the two data loggers were retrieved and merged daily via remote telemetry.

**Table 4. Monitored Minutes O<sub>2</sub>, NO<sub>x</sub>, NO, and NO<sub>2</sub>, by Source**

<b>Emission Source</b>	<b>Monitoring Periods During Each Hour (Period: Minute of the Hour)</b>	<b>Maximum Number of Minutes Monitored During an Hour</b>
<b>Boiler 1</b>	1: 3, 4, 5 2: 18, 19, 20 3: 33, 34, 35 4: 48, 49, 50	12
<b>Boiler 2</b>	1: 8, 9, 10 2: 23, 24, 25 3: 38, 39, 40 4: 53, 54, 55	12
<b>Heater</b>	1: 13, 14, 15 2: 28, 29, 30 3: 43, 44, 45 4: 58, 59, 60*	12
<b>Engine 1</b>	1: 3, 4, 5 2: 13, 14, 15 3: 23, 24, 25 4: 33, 34, 35 5: 43, 44, 45 6: 53, 54, 55	18
<b>Engine 2</b>	1: 8, 9, 10 2: 18, 19, 20 3: 28, 29, 30 4: 38, 39, 40 5: 48, 49, 50 6: 58, 59, 60*	18
* Minute "60" is recorded as minute "0" of the next hour in the 1-minute data. 1-hour averages are based on the data collected during the previous hour to beginning of the current hour.		

### *Issues*

Amec Foster Wheeler observed two primary issues in the 1-minute emissions data: 1) NO<sub>x</sub> and O<sub>2</sub> values that are not consistent with the recorded fuel rates and 2) a discontinuity in emissions monitoring and fuel monitoring.

It is important to place the CEM issues into proper perspective. AERMOD and many other models have a minimum time step of 1 hour. This means that 1-hour average emissions and meteorological data are input into the model which computes 1-hour average predicted concentrations. Thus, the accuracy of average 1-hour emissions is important. The 1-minute emission data are the building block for the hourly average, but some of the uncertainty in the 1-minute data is averaged out through the calculation of a 1-hour average. An Earth System Sciences (ESS) memo included with this memorandum as Attachment 11 indicates for boiler 2

very good agreement between calculation of emissions using a derived emission factor based on all CEM data (lbs/gallon of fuel consumed) and fuel usage.<sup>6</sup>

#### *Issue #1: Inconsistent NO<sub>x</sub>, O<sub>2</sub>, and Fuel Rates*

The first issue involves records in the 1-minute data where the O<sub>2</sub> and NO<sub>x</sub> (NO<sub>x</sub> = NO + NO<sub>2</sub>) values are inconsistent with the fuel rate. In these cases, the fuel rate is greater than zero which indicates the source was operating (fuel was consumed). However, the O<sub>2</sub> value is equivalent to ambient air (20-21%) and NO<sub>x</sub> is close or equal to zero which implies no fuel was consumed.

Because the fuel meter data were continuously recorded using a dedicated data logger, it is believed that when the meter indicated fuel was being consumed, that the emission source was operational.

Table 5 contains an example from the 1-minute emissions data for boiler #1. The 1-minute averages for a 3-minute sampling period are shown. In the two highlighted records, the fuel rate is positive, but O<sub>2</sub> is equivalent to ambient air, and NO<sub>x</sub> is equal to zero. It is not until the third minute of sampling in this example that O<sub>2</sub> and NO<sub>x</sub> indicate the source was operating even though the fuel data indicates the source was operating all three minutes.

**Table 5. Boiler 1: Three 1-minute Emissions Records**

Date	Minute	NO <sub>x</sub> (ppm)	NO <sub>2</sub> (ppm)	NO (ppm)	O <sub>2</sub> (%)	Fuel (GPM)
10/29/2014	21:48	0	-0.1	0.1	20.7	0.363
10/29/2014	21:49	0	-0.1	0.1	20.6	0.306
10/29/2014	21:50	4.7	2.3	2.3	12.4	0.799

The data that make up the first two minutes also figure into the 1-hour average. Therefore, when the 1-hour average is computed, the O<sub>2</sub> and NO<sub>x</sub> may be biased as a result of missing emission data. The magnitude of the bias will depend on the number of minutes missing during the hour.

This issue is more prevalent in the boiler #1 data when the boiler cycled on and off frequently, and there was a lot of variation in the fuel rate throughout an hour.

The CEMS data and fuel data were recorded using different data loggers. The data were retrieved and merged daily via remote telemetry, and it is possible that the time stamps on the two data loggers may have been offset by a small difference if the clock times were not identical. Another possibility is an error in the physical integration or pairing of the data from the two data loggers such that the timestamps were not aligned properly when the data were integrated together (i.e., the timestamps might not have been properly matched even though the data loggers might have been in perfect sync with each other). An offset in the data from the two data loggers would have a greater effect on the boiler #1 data during the middle portion of the study (October and November) when it cycled on and off frequently and less effect when it was running continuously and there was little variation in the fuel rate from minute-to-minute.

<sup>6</sup> Earth System Sciences, LLC, "Analysis and Comments of Kuparuk, AK Database, March 4, 2016.



It should be noted here, while exploring issues with the CEMS data, ADEC's review of the CEMS data was completed, and ADEC provided a copy of the final report to WESTAR. In the report, ADEC states the data were reviewed from a research perspective rather than a permit or New Source Review (NSR) compliance evaluation perspective. ADEC concluded that the sampling equipment and instrumentation generally met performance specifications. However, ADEC also concluded that the CEMS measurements met the quality control requirements roughly 65 percent of the time. There were periods in mid-September, the last week of October, and the first week of November that analyzer responses were outside quality control limits.<sup>7</sup> More specifically, the CEMS daily calibration drift check results were between 5-10% of the CEMS span value. (For NO<sub>2</sub> and O<sub>2</sub> CEMS, 40 CFR 60 Appendix F and Performance Spec 2 sets out of control periods as CEMS calibration drift of 5% or more for five consecutive days or any one day that exceeds 10%). Per information provided to ADEC by ConocoPhillips, during these periods the emission units were operating at relatively high loads (for the study) and fuel use was significantly variable. It is possible that this variability resulted in stack gas intrusion into the sampling system during the calibration drift check process, indicating drift in the 5-10% range. In contrast, calibration drift checks consistently met Appendix F limits during periods of non-variable loads. ConocoPhillips' analyses of the overall trend of calibration drift check results suggests values between 5-10% were caused by varying emission unit loads and were not indicative of measurement quality and accuracy. Of note, CEMS calibration drift was within allowable 40 CFR Appendix F limits before and after indicated out of control periods without any sort of intervening maintenance or adjustment.

It has not been determined whether a time offset between the emissions and fuel data exists or if ADEC's findings with regard to quality control limits are the source of the inconsistency between the NO<sub>x</sub>, O<sub>2</sub>, and fuel rates.

#### *Issue #2: Discontinuity in Emissions and Fuel Monitoring*

The second issue is related to the discontinuity in the emissions monitoring in which O<sub>2</sub>, NO<sub>x</sub>, NO, and NO<sub>2</sub> were monitored only certain minutes of the hour (see Table 4) while the fuel was monitored continuously and reported for each minute of the hour. Because of this discontinuity, the 1-hour averages of O<sub>2</sub>, NO<sub>x</sub>, NO, and NO<sub>2</sub> concentrations for a given hour may not be representative or consistent with the actual amount of fuel burned. When the fuel rate and emissions are near constant during an hour, this is not such an issue since the average emissions of any combination of minutes monitored are likely representative of the hour. However, when the fuel rate and emissions fluctuate significantly or for the more extreme case, where the source cycles on and off multiple times during an hour, the amount of fuel burned during the minutes that the emissions were monitored could be significantly different from the amount of fuel burned during one or more minutes when the emissions were not monitored. As demonstrated in

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<sup>7</sup> Alaska Department of Environmental Conservation, Air Quality Division. *Review of ConocoPhillips Alaska, Inc. Continuous Emissions Monitoring Data from a 2014 Drill Rig Study at Kuparuk Drill Site 2N*. October 28, 2015.

Table 4, the 1-hour average of NO<sub>x</sub> emissions and O<sub>2</sub> for the boilers and heater are based on measurements taken during 20% of the hour at most. While this discontinuity affects each of the sources to some degree, it is more prevalent in the data for boiler #1 which cycled on and off frequently during part of the study and there was greater variation in the fuel rate during an hour.

There are hours in the boiler #1 data that because of the frequent cycling on and off during the hour, many of the NO<sub>x</sub> and O<sub>2</sub> measurements were taken at times during the hour when the source was not operating. An example is provided in Table 6 and Table 7, below. Table 6 contains a complete hour of 1-minute NO<sub>x</sub>, O<sub>2</sub>, and fuel rates for boiler #1. Table 7 contains the corresponding 1-hour averages. The highlighted records in Table 6 are the 12 minutes during the hour that the in-stack O<sub>2</sub> and emissions were monitored. The 1-minute fuel rates in Table 6 indicate boiler #1 operated for 15-16 minutes during the hour. The corresponding fuel rate for the entire hour, shown in Table 7, is a little more than 11 GPH. However, the fuel rate recorded for 11 of the 12 minutes for which the emissions and O<sub>2</sub> were monitored is 0 GPM. For those same 11 minutes, O<sub>2</sub> is equivalent to ambient air and NO<sub>x</sub> is equal to or very close to 0 ppm, consistent with little or no fuel consumption. Likewise, the 1-hour average for NO<sub>x</sub> is near 0 (0.1) ppm and O<sub>2</sub> is equivalent to ambient air, but the fuel rate is more than 11 GPH.

While Table 6 and Table 7 demonstrate an extreme example, any hour during which there is significant fluctuation in the fuel use could be affected by this discontinuity in the emissions monitoring. Again, this issue is more prevalent in the boiler #1 data when the boiler cycled on and off frequently.

**Table 6. 60 Minutes of 1-minute Emissions Data for Boiler #1**

Date	Hour: Minute*	NO <sub>x</sub> (ppm)	NO <sub>2</sub> (ppm)	NO (ppm)	O <sub>2</sub> (%)	Fuel (GPM)
10/14/2014	20:01	No Data	No Data	No Data	No Data	0
10/14/2014	20:02	No Data	No Data	No Data	No Data	0
10/14/2014	20:03	0	-0.1	0.2	20.8	0
10/14/2014	20:04	0	-0.1	0.2	20.8	0
10/14/2014	20:05	0	-0.1	0.2	20.8	0
10/14/2014	20:06	No Data	No Data	No Data	No Data	0
10/14/2014	20:07	No Data	No Data	No Data	No Data	0
10/14/2014	20:08	No Data	No Data	No Data	No Data	0
10/14/2014	20:09	No Data	No Data	No Data	No Data	0
10/14/2014	20:10	No Data	No Data	No Data	No Data	0.488
10/14/2014	20:11	No Data	No Data	No Data	No Data	0.566
10/14/2014	20:12	No Data	No Data	No Data	No Data	1.021
10/14/2014	20:13	No Data	No Data	No Data	No Data	1.01
10/14/2014	20:14	No Data	No Data	No Data	No Data	1.011
10/14/2014	20:15	No Data	No Data	No Data	No Data	1.011
10/14/2014	20:16	No Data	No Data	No Data	No Data	0.377
10/14/2014	20:17	No Data	No Data	No Data	No Data	0
10/14/2014	20:18	0.5	0	0.7	20.8	0
10/14/2014	20:19	0	-0.1	0.1	20.8	0
10/14/2014	20:20	0	-0.2	0.2	20.8	0
10/14/2014	20:21	No Data	No Data	No Data	No Data	0

Date	Hour: Minute*	NO <sub>x</sub> (ppm)	NO <sub>2</sub> (ppm)	NO (ppm)	O <sub>2</sub> (%)	Fuel (GPM)
10/14/2014	20:22	No Data	No Data	No Data	No Data	0
10/14/2014	20:23	No Data	No Data	No Data	No Data	0
10/14/2014	20:24	No Data	No Data	No Data	No Data	0
10/14/2014	20:25	No Data	No Data	No Data	No Data	0
10/14/2014	20:26	No Data	No Data	No Data	No Data	0
10/14/2014	20:27	No Data	No Data	No Data	No Data	0
10/14/2014	20:28	No Data	No Data	No Data	No Data	0
10/14/2014	20:29	No Data	No Data	No Data	No Data	0
10/14/2014	20:30	No Data	No Data	No Data	No Data	0
10/14/2014	20:31	No Data	No Data	No Data	No Data	0
10/14/2014	20:32	No Data	No Data	No Data	No Data	0
10/14/2014	20:33	0	-0.2	0.2	20.8	0
10/14/2014	20:34	0	-0.1	0.2	20.8	0
10/14/2014	20:35	0	-0.2	0.2	20.8	0.1
10/14/2014	20:36	No Data	No Data	No Data	No Data	0.615
10/14/2014	20:37	No Data	No Data	No Data	No Data	0.982
10/14/2014	20:38	No Data	No Data	No Data	No Data	1.009
10/14/2014	20:39	No Data	No Data	No Data	No Data	1.011
10/14/2014	20:40	No Data	No Data	No Data	No Data	1.067
10/14/2014	20:41	No Data	No Data	No Data	No Data	0.003
10/14/2014	20:42	No Data	No Data	No Data	No Data	0
10/14/2014	20:43	No Data	No Data	No Data	No Data	0
10/14/2014	20:44	No Data	No Data	No Data	No Data	0
10/14/2014	20:45	No Data	No Data	No Data	No Data	0
10/14/2014	20:46	No Data	No Data	No Data	No Data	0
10/14/2014	20:47	No Data	No Data	No Data	No Data	0
10/14/2014	20:48	0	-0.1	0.2	20.8	0
10/14/2014	20:49	0	-0.1	0.2	20.8	0
10/14/2014	20:50	0	-0.1	0.2	20.8	0
10/14/2014	20:51	No Data	No Data	No Data	No Data	0
10/14/2014	20:52	No Data	No Data	No Data	No Data	0
10/14/2014	20:53	No Data	No Data	No Data	No Data	0
10/14/2014	20:54	No Data	No Data	No Data	No Data	0
10/14/2014	20:55	No Data	No Data	No Data	No Data	0
10/14/2014	20:56	No Data	No Data	No Data	No Data	0
10/14/2014	20:57	No Data	No Data	No Data	No Data	0
10/14/2014	20:58	No Data	No Data	No Data	No Data	0
10/14/2014	20:59	No Data	No Data	No Data	No Data	0.412
10/14/2014	21:00	No Data	No Data	No Data	No Data	0.534

\* Highlighted records identify the 12 minutes of the hour in-stack O<sub>2</sub> and emissions were monitored.

**Table 7. 1-hour Average Emissions Data for Boiler #1**

Date*	Hour*	NO <sub>x</sub> (ppm)	NO <sub>2</sub> (ppm)	NO (ppm)	O <sub>2</sub> (%)	Fuel (GPH)
10/14/2014	21:00	0.1	-0.1	0.2	20.8	11.22

\* 1-hour averages are based on the data collected during the previous hour to beginning of the current hour.

### *Affected Sources*

As stated previously, while both of these issues exist to some degree in the CEMS data for each of the boilers, engines, and the heater, it is more prevalent in the data for boiler #1 when the boiler was cycling on and off frequently during an hour and there was a lot of variation in the fuel rates from minute-to-minute as illustrated in Figure 4. The cases are more isolated for the other sources.

### *Effects on Calculated Mass Emission Rates and Exit Velocities*

For hours affected by either of the issues described above, the calculated mass emission rates and exit velocities may not be representative of actual conditions, which will affect model predicted concentrations. Less extreme cases are not easily identifiable, but in extreme cases, the calculated values can result in physically impossible conditions. Table 8 illustrates this with an example from boiler #1. Three consecutive 1-hour averages of NO<sub>x</sub> and O<sub>2</sub> are shown along with the hourly fuel rate and calculated mass emission rates and stack exit velocities, based on Method 19. The highlighted record, hour 7:00, has a low but positive NO<sub>x</sub> concentration and an O<sub>2</sub> value equivalent to ambient air, though the average fuel consumption was more than 16 GPH. This results in a negative emission rate and exit velocity. Method 19 assumes ambient air is 20.9% O<sub>2</sub> which is used in the calculation of the emission rate and exit velocity. In the Method 19 calculations, the measured in-stack O<sub>2</sub> value is subtracted from 20.9 resulting in a small negative difference which results in the negative emission rate and exit velocity in Table 8.

**Table 8. Hourly Mass Emission Rates and Exit Velocities  
Calculated from Original Boiler #1 CEMS Data**

Date	Hour	NO <sub>x</sub> (ppm)	O <sub>2</sub> (%)	Fuel (GPH)	Emission Rate (lb/hr)	Exit Velocity (ft/s)
11/11/2014	6:00	29.7	14.4	21.8	0.32	30.2
11/11/2014	7:00	4.8	21.0	16.8	-2.56	-1509.0
11/11/2014	8:00	16.6	17.1	19.8	0.28	46.8

### *Resolving CEMS Data Issues*

As previously stated, the effects of these issues appear to be more isolated for the two engines, heater, and boiler #2 since operations were continuous for longer durations than boiler #1. However, there needs to be some treatment applied to the CEMS data for these sources to either invalidate records or replace data for hours that are suspect. Two approaches for resolving the CEMS data issues were investigated as directed by the SMT: 1) regression analysis and 2) average values. The first approach replaced all hourly NO<sub>x</sub> and O<sub>2</sub> values in the 1-hour boiler #1 CEMS data with computed values based on regression equations developed from the correlation of NO<sub>x</sub> and O<sub>2</sub> with fuel usage. The second approach used an average emission factor and

average in-stack O<sub>2</sub> concentration to compute an hourly mass emission rate and exit velocity for suspect hours where the monitored NO<sub>x</sub>, O<sub>2</sub>, and fuel values are inconsistent. The two approaches are discussed in the next sections.

#### CEMS Data Treatment Approach 1 - Boiler #1 Regression Analysis

Regression equations based on the correlation of the 1-hour NO<sub>x</sub> and O<sub>2</sub> with fuel data for boiler #1 were developed and supplied by the SMT. Prior to deriving the regression equations, the SMT omitted hours where the monitored NO<sub>x</sub> concentration was less than 8 ppm. There is greater uncertainty in the data in this lower range, and applying this criteria also eliminated all hours where there was no fuel usage and the boiler was not operating. This accounted for about 10% of the boiler #1 CEMS data. Figure 9 and Figure 10 are scatter plots of the 1-hour boiler #1 fuel rate plotted against O<sub>2</sub> and NO<sub>x</sub>, respectively. The regression lines and the corresponding regression equation are included in the figures.

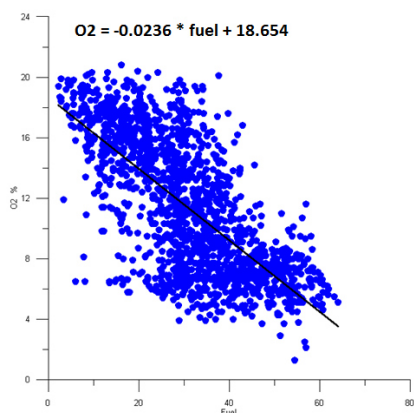


Figure 9. 1-hour Fuel vs O<sub>2</sub> Boiler #1

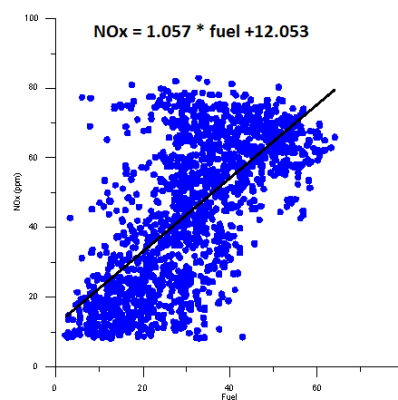


Figure 10. 1-hour Fuel vs NO<sub>x</sub> Boiler #1

Using the regression equations, NO<sub>x</sub> and O<sub>2</sub> were recalculated for every hour and the monitored values in the boiler #1 CEMS data were replaced with the calculated values. Hourly mass emission rates and exit velocities were then calculated using the Method 19 equations above using the calculated NO<sub>x</sub> and O<sub>2</sub> values. Table 9 shows an example of calculated values of 1-hour NO<sub>x</sub> and O<sub>2</sub> and the corresponding mass emission rates and exit velocities for the same hours shown in Table 8, after applying the regression equations. A time-series of the calculated hourly NO<sub>x</sub> emission rates in lb/hr for Boiler #1 are included in Figure 11, in the next section, which compares the emissions rates for Boiler #1 using the two approaches.

**Table 9. Recalculated NO<sub>x</sub>, O<sub>2</sub>, Mass Emission Rates, and Exit Velocities  
Based on Boiler #1 Regression Equations**

Date	Hour	NO <sub>x</sub> (ppm)	O <sub>2</sub> (%)	Fuel (GPH)	Emission Rate (lb/hr)	Exit Velocity (ft/s)
11/11/2014	6:00	35.1	13.5	21.8	0.32	26.5
11/11/2014	7:00	29.8	14.7	16.8	0.26	24.3
11/11/2014	8:00	33.0	14.0	19.8	0.30	25.7



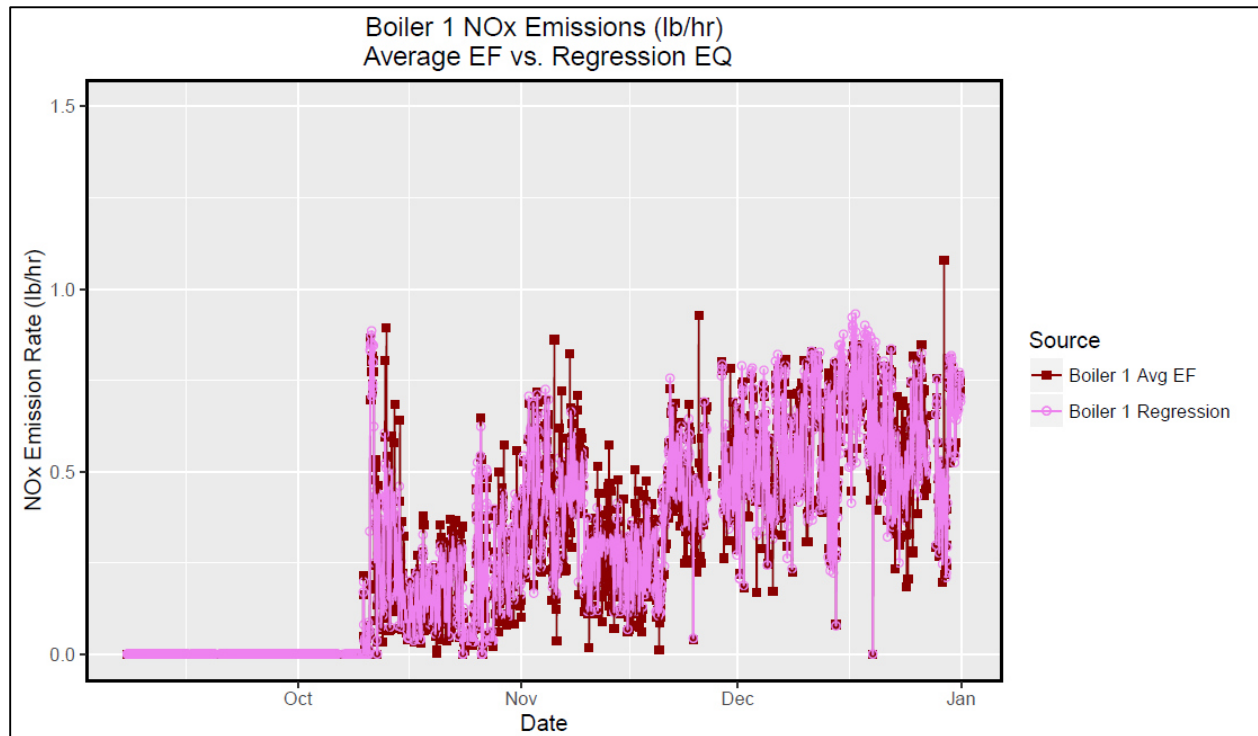
### CEMS Data Treatment Approach 2 - Apply Average Emission Factor and O<sub>2</sub> for Data Fill

A second data treatment approach was investigated for the 1-hour boiler #1 CEMS data and subsequently applied for all sources. This approach preserved the emission rates and velocities derived from the monitored data for the hours that are assumed to be "good" hours of data, i.e., those hours when there was not an obvious discrepancy in the data. Those hours were then used to compute a source-specific average emission factor (lbs/gal) and in-stack O<sub>2</sub> (%). To compute an average emission factor, an hourly emission factor was first computed for each "good" hour by dividing the emission rate (lb/hr) computed using Method 19 by the hourly fuel use to the amount of emissions per gallon of fuel for the hour (lb/gal). This is done for each hour for each source. A source-specific average emission rate is then computed from the hourly values. Similarly, a source-specific average in-stack O<sub>2</sub> (%) value is computed using the O<sub>2</sub> values for those same hours. For Boiler #1, this method yielded an average emission factor of 0.0148 lb/gal of NO<sub>x</sub> and an average in-stack O<sub>2</sub> value of 11.0%. These averages were, in turn, used to compute an hourly mass emission rate and exit velocity for those records in which the monitored NO<sub>x</sub>, O<sub>2</sub>, and fuel values are inconsistent with each other, as in the examples discussed previously.

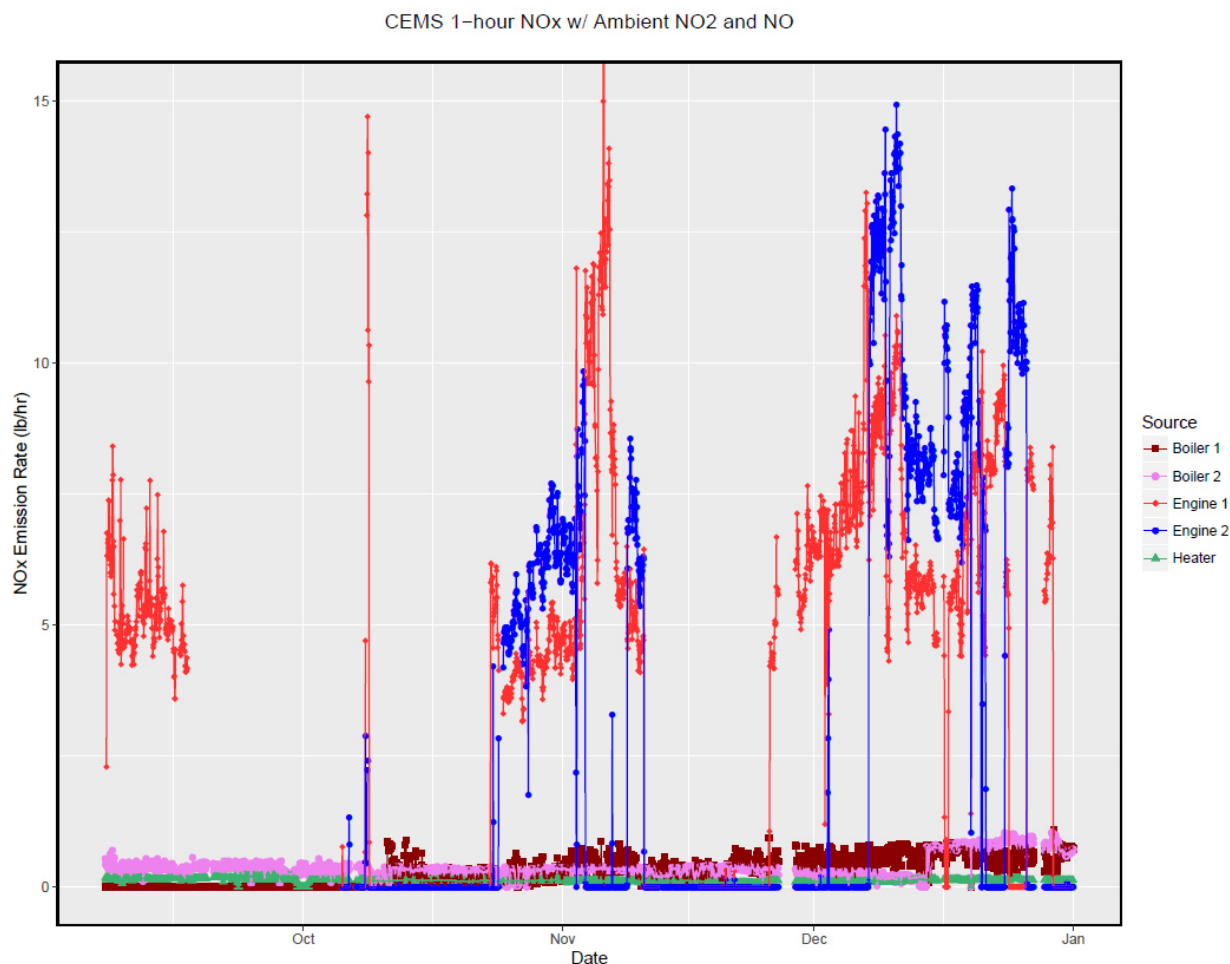
For those hours that have a discrepancy in the data, the hourly mass emission rate was calculated as the product of the average emission factor and the monitored hourly fuel rate. The hourly exit velocity was calculated by substituting the average in-stack O<sub>2</sub> value for the monitored value in Equation 3 to calculate the hourly stack volumetric flow rate for dry conditions (dscfm). The flow rate for actual conditions was then calculated using Equation 6 and the exit velocity using Equation 8. The highlighted row in Table 10, below, shows the mass emission rate and exit velocity calculated using the average emission factor and O<sub>2</sub> for the same suspect hour shown in Table 8 and Table 9, above. Figure 11, is a time-series plot that compares the hourly NO<sub>x</sub> emissions rates in lb/hr for Boiler #1 using the approach described in this section with the first approach described in the previous section. Figure 12 is a time-series plot showing the hourly NO<sub>x</sub> emission rates for all five sources.

**Table 10. Boiler #1 Mass Emission Rates and Exit Velocities  
Based on Average Emission Factor and Average O<sub>2</sub>**

Date	Hour	NO <sub>x</sub> (ppm)	O <sub>2</sub> (%)	Fuel (GPH)	Emission Rate (lb/hr)	Exit Velocity (ft/s)
11/11/2014	6:00	29.7	14.4	21.8	0.32	30.2
11/11/2014	7:00	4.8	21.0	16.8	0.25	16.0
11/11/2014	8:00	16.6	17.7	19.8	0.28	46.8



**Figure 11. Boiler 1 Hourly NO<sub>x</sub> Emissions Rates  
Regression Analysis Vs. Average Emission Factor Approaches**



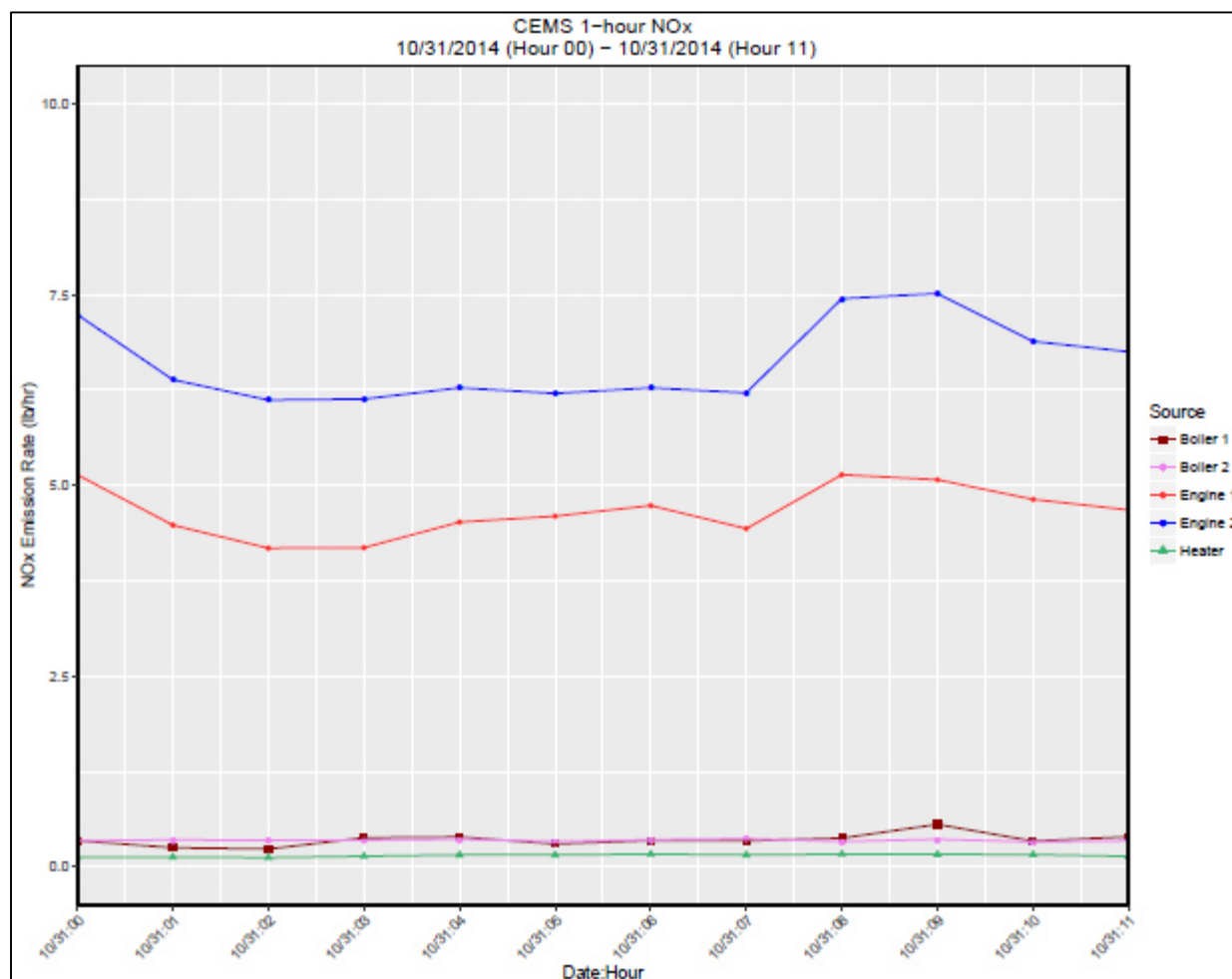
**Figure 12. Hourly NO<sub>x</sub> Emission Rates for All Sources Using an Average Emission Factor to Fill Data Records**

Since using an average emission factor to calculate a mass emission rate to fill those hours where there is a discrepancy between the NO<sub>x</sub>, O<sub>2</sub>, and fuel data preserves much of the original data (the "good" hours), it was chosen as the preferred method and is the method applied when the emission data were processed and formatted for input to AERMOD in Task 3.

#### *Uncertainty in the CEMS Data*

Figure 13 is a plot of NO<sub>x</sub> emissions by source. The data are for the same 12-hour period for which the fuel rates are plotted in Figure 4 through Figure 8, a time when all five sources were operating. The plot illustrates the relative magnitude of the stack emissions for each of the sources after hourly mass emissions were computed using the second approach discussed above. While the data issues that were discussed are known to affect each of the sources to some extent, they are more prevalent in the boiler #1 which has been pointed out numerous times in the previous discussions. The cases are more isolated for the other sources that operated continuously for longer durations and fuel consumption and emissions show less variability during an hour. Therefore, the greatest uncertainty is in the boiler #1 data. As Figure 13 illustrates, the

highest emissions are from the two engines which are an order of magnitude larger than the boilers and heater. For this reason, the effect of the boiler #1 data on measured concentrations at the "downwind" monitor are expected to be minimal on the overall evaluation.



**Figure 13. 12-Hour Sample of 1-hour NO<sub>x</sub> Emissions by Source**

In spite of the identified issues associated with the stack measurements, the overall data provide an accurate emission database for model evaluation. It is recommended that careful review of the emission data be conducted for periods when there are elevated ambient NO<sub>x</sub> and NO<sub>2</sub> concentrations. Also, no further evaluation of the 1-minute data should be performed.

## Task 2: Perform Data Analyses

Because of the resources required to address the issues encountered in the CEMS data, the SMT reprioritized tasks defined in the SOW, and many of the data analyses subtasks were put on hold until higher priority tasks were completed. Tasks 3 (Format Hourly Kuparuk Data for AERMOD Model Evaluation) and part of Task 4 (Research Upper Air Data, Surface Characteristics, and Building Downwash) were identified as the priority objectives. As several of the subtasks under Task 2 were prerequisites to completing Task 3, Amec Foster Wheeler completed several of the primary Task 2 objectives which are discussed below.

### ***Correlate Monitoring Periods with Drill Rig Locations by Drill Schedule***

There were times during the monitoring study when the rig was in transit between wells. For the purpose of model evaluation, it was necessary to correlate the data with the time period the rig was at each well and omit those hours from the final evaluation dataset when the rig was in transit and the exact location was not known. The schedule for the five wells where drilling was performed during the study was provided by ConocoPhillips and is shown in Table 11. When clarification on the schedule was requested, Nabors noted that the "Rig Release" and "Rig Accept" times do not take into account the time the rig was in transit from one well to the next. Nabors stated the rig was in transit between two wells for approximately 12 hours. To ensure the monitoring data are properly matched to a particular well location and hours when the rig was in transit are omitted, Nabors recommended assuming the rig was in transit 6 hours prior to the "release" time through 6 hours after the "accept" time. Table 12 presents a modified schedule used by Amec Foster Wheeler. The "Rig On" and "Rig Off" times represent about a six hour offset to the "Rig Accept" and "Rig Release" times in Table 11. Data collected after the "Rig Off" and prior to the "Rig On" times were omitted from the final evaluation dataset.

**Table 11. ConocoPhillips Drilling Schedule at DS2N**

Well Name	Rig Accept	Rig Release
303	08/20/2014, 23:59	09/15/2014, 23:59
350	09/16/2014, 00:00	10/24/2014, 15:00
319	10/24/2014, 15:00	11/27/2014, 00:00
337	11/28/2014, 12:00	12/27/2014, 12:00
336	12/28/2014, 06:00	12/31/2014, 24:00



**Table 12. Amec Foster Wheeler Modified Drilling Schedule**

Well Name	Rig On	Rig Off
303	08/21/2014, 06:00	9/15/2014, 18:00
350	09/16/2014, 06:00	10/24/2014, 09:00
319	10/24/2014, 21:00	11/26/2014, 18:00
337	11/28/2014, 18:00	12/27/2014, 06:00
336	12/28/2014, 12:00	01/01/2015, 00:00*

\* Marks the end of the monitoring study. The rig was assumed to be at well 336 through the end of the study, and time was not adjusted.

### ***Correlate Emissions and Ambient Data to Identify Hours Rig Powered by Engines***

At each well location there are one or more periods when the drill rig was powered by the diesel engines. When not powered by the engines, the rig operated on line power. Even though the rig engines were assumed to be idle when the rig was on line power, the emission monitoring data show that during any given hour, one or both of the boilers and the heater may have been operating (boiler #2 and the heater operated nearly continuously during the study), and one or more of the engines often operated during times when the rig was on line power. For these reasons, Amec Foster Wheeler was directed by the SMT to include the hours of data when at least one of the five sources was operating, except for those hours where other criteria were applied, such as the drilling schedule discussed above. Hours during which one or more emission sources were operating were identified based on the 1-hour fuel data, when the fuel use for a source is greater than zero.

### ***Evaluate Distance of Each Emission Source to Each Monitoring Site at Each Well***

Amec Foster Wheeler confirmed the coordinates of each of the monitoring stations with SLR and obtained coordinates for the five wells from ConocoPhillips. Nabors provided scaled drawings of the 9ES rig which are provided as Attachment 03. Using the well coordinates and scale drawings of the rig, Amec Foster Wheeler derived coordinates of each of the five emission sources (two boilers, two engines, and the heater) and calculated the distance of each source to the two monitoring stations at each well. The coordinates of each of the monitoring stations are listed in Table 13. Table 14 lists the coordinates of each wells, the coordinates of each emission source at each well, and the distance from each source to each monitoring station. Table 15 lists the azimuth between each source and each monitoring station.

**Table 13. Monitoring Station Coordinates**

Monitor	UTM-E (m)	UTM-N (m)	UTM Zone
West "Downwind"	601317.3	7787065.6	5
East "Upwind"	601588.1	7787127.7	5

**Table 14. Distance from Emission Sources to Monitors by Well**

Well	Source	UTM-E (m)	UTM-N (m)	UTM Zone	Distance to "Downwind" Monitor (m)	Distance to "Upwind" Monitor (m)
303	Boiler #1	601574.0	7787119.3	5	262.3	16.4
	Boiler #2	601573.4	7787122.4	5	262.3	15.6
	Heater	601576.4	7787114.5	5	263.7	17.7
	Engine #1	601563.3	7787112.6	5	250.5	29.0
	Engine #2	601562.4	7787116.0	5	250.2	28.2
319	Boiler #1	601508.4	7787100.3	5	194.2	84.3
	Boiler #2	601507.8	7787103.3	5	194.2	83.9
	Heater	601510.8	7787095.4	5	195.8	83.7
	Engine #1	601497.7	7787093.5	5	182.6	96.6
	Engine #2	601496.8	7787096.9	5	182.2	96.3
336	Boiler #1	601433.5	7787079.4	5	117.0	161.9
	Boiler #2	601432.9	7787082.5	5	116.8	161.6
	Heater	601435.9	7787074.5	5	119.0	161.2
	Engine #1	601422.8	7787072.7	5	105.8	174.2
	Engine #2	601421.9	7787076.1	5	105.1	174.0
337	Boiler #1	601429.2	7787078.2	5	112.7	166.4
	Boiler #2	601428.6	7787081.3	5	112.4	166.1
	Heater	601431.7	7787073.4	5	114.6	165.6
	Engine #1	601418.6	7787071.5	5	101.4	178.6
	Engine #2	601417.7	7787074.9	5	100.8	178.4
350	Boiler #1	601372.2	7787061.8	5	55.0	225.7
	Boiler #2	601371.6	7787064.8	5	54.3	225.4
	Heater	601374.6	7787056.9	5	58.0	224.9
	Engine #1	601361.5	7787055.1	5	45.5	237.9
	Engine #2	601360.6	7787058.4	5	43.9	237.8

**Table 15. Azimuth between Sources and Monitors**

Well	Source	Azimuth	Azimuth
		"Downwind" Monitor (degrees from North)	"Upwind" Monitor (degrees from North)
303	Boiler #1	-101.8	59.2
	Boiler #2	-102.5	70.0
	Heater	-100.7	41.3
	Engine #1	-100.8	58.6
	Engine #2	-101.6	65.4
319	Boiler #1	-100.3	71.0
	Boiler #2	-101.2	73.1
	Heater	-98.7	67.3
	Engine #1	-98.8	69.3
	Engine #2	-99.9	71.3
336	Boiler #1	-96.8	72.6
	Boiler #2	-98.3	73.7
	Heater	-94.3	70.7
	Engine #1	-93.8	71.6
	Engine #2	-95.7	72.7
337	Boiler #1	-96.4	72.7
	Boiler #2	-98.0	73.8
	Heater	-93.9	70.8
	Engine #1	-93.3	71.7
	Engine #2	-95.3	72.8
350	Boiler #1	-86.0	73.0
	Boiler #2	-89.1	73.8
	Heater	-81.3	71.6
	Engine #1	-76.6	72.2
	Engine #2	-80.5	73.1

### ***Time-series Plots of Ambient Data***

Amec Foster Wheeler generated various time-series plots of the raw 1-minute and 1-hour ambient pollutant data for review by the SMT. Separate plots were generated for consecutive 7-day periods for readability, through the end of the study period. The following time-series plots were created:

- 1-hour CO plotted with 1-minute CO,
- 1-hour NO<sub>x</sub> plotted with 1-minute NO<sub>x</sub>,
- 1-hour NO plotted with 1-minute NO,
- 1-hour NO<sub>2</sub> plotted with 1-minute NO<sub>2</sub>,

- 1-hour SO<sub>2</sub> plotted with 1-minute SO<sub>2</sub>,
- 1-hour upwind O<sub>3</sub> plotted with 1-minute upwind O<sub>3</sub>,
- 1-hour downwind O<sub>3</sub> plotted with 1-minute downwind O<sub>3</sub>,
- 1-hour NO<sub>x</sub>-NO-NO<sub>2</sub>,
- 1-minute NO<sub>x</sub>-NO-NO<sub>2</sub>,
- 1-hour NO<sub>x</sub>-NO-NO<sub>2</sub> plotted with 1-hour wind direction, and
- 1-hour upwind and downwind O<sub>3</sub> plotted with wind direction.

The time-series plots were generated using R for Statistical Computing (R).<sup>8</sup> The R scripts used to generate the plots are included in Attachment 04. The time-series plots in Portable Document Format (PDF) are included in Attachment 05. No further evaluation was performed with the exception of the ozone data to determine hourly background ozone concentrations for input to AERMOD, which is discussed in further detail in the next section.

### ***Quantify Hourly Background Ozone for Input to AERMOD***

Several of the more refined AERMOD options for predicting NO<sub>2</sub> concentrations require information on the concentration of ambient background ozone. While there is an array of options in AERMOD for specifying background ozone temporally, it is preferable to provide an hourly concentration file formatted for AERMOD. Amec Foster Wheeler generated a time-series plot of the 1-hour O<sub>3</sub> from the "upwind" monitor plotted along with ambient "downwind" 1-hour NO<sub>2</sub>, O<sub>3</sub>, and NO<sub>2</sub> + O<sub>3</sub> and wind direction from DSF1 for the SMT to review. (NO<sub>2</sub> + O<sub>3</sub> is an indication of the maximum amount of O<sub>3</sub> available to interact with NO<sub>x</sub> prior to ozone scavenging.) As with the previous time-series plots, each consecutive 7-day period was plotted separately for readability. The R script used to generate the plot is included in Attachment 04. A PDF file of the time-series is included in Attachment 06. A sample of the complete time-series is shown in Figure 14 at the end of this section.

The time-series shows a strong correlation between the wind direction and the impact of the NO<sub>2</sub> on the "downwind" monitor. For most of the hours when there is an NO<sub>2</sub> impact on the "downwind" monitor, the O<sub>3</sub> at the "downwind" monitor is lower than the O<sub>3</sub> at the "upwind" monitor due to ozone scavenging. During discussions with the technical director and members of the SMT, two potential methods were identified for quantifying hourly background O<sub>3</sub> for evaluating AERMOD:

**Method 1:** Limit the dataset to only those hours for which there is an NO<sub>2</sub> impact on the "downwind" monitor and use the O<sub>3</sub> value from the "upwind" monitor as the background O<sub>3</sub> value for each hour.

**Method 2:** Compare the O<sub>3</sub> value from both monitors each hour, and take the higher of the two values as the background value for the hour. This assumes the lower value always resulted from background ozone scavenging and preserves hours when the plume did not impact the monitor for model evaluation.

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<sup>8</sup> R Core Team (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <http://www.R-project.org/>.

Amec Foster Wheeler implemented both methods under Task 3 and generated separate datasets based on each method. The implementation for each of these methods is discussed under the Task 3.

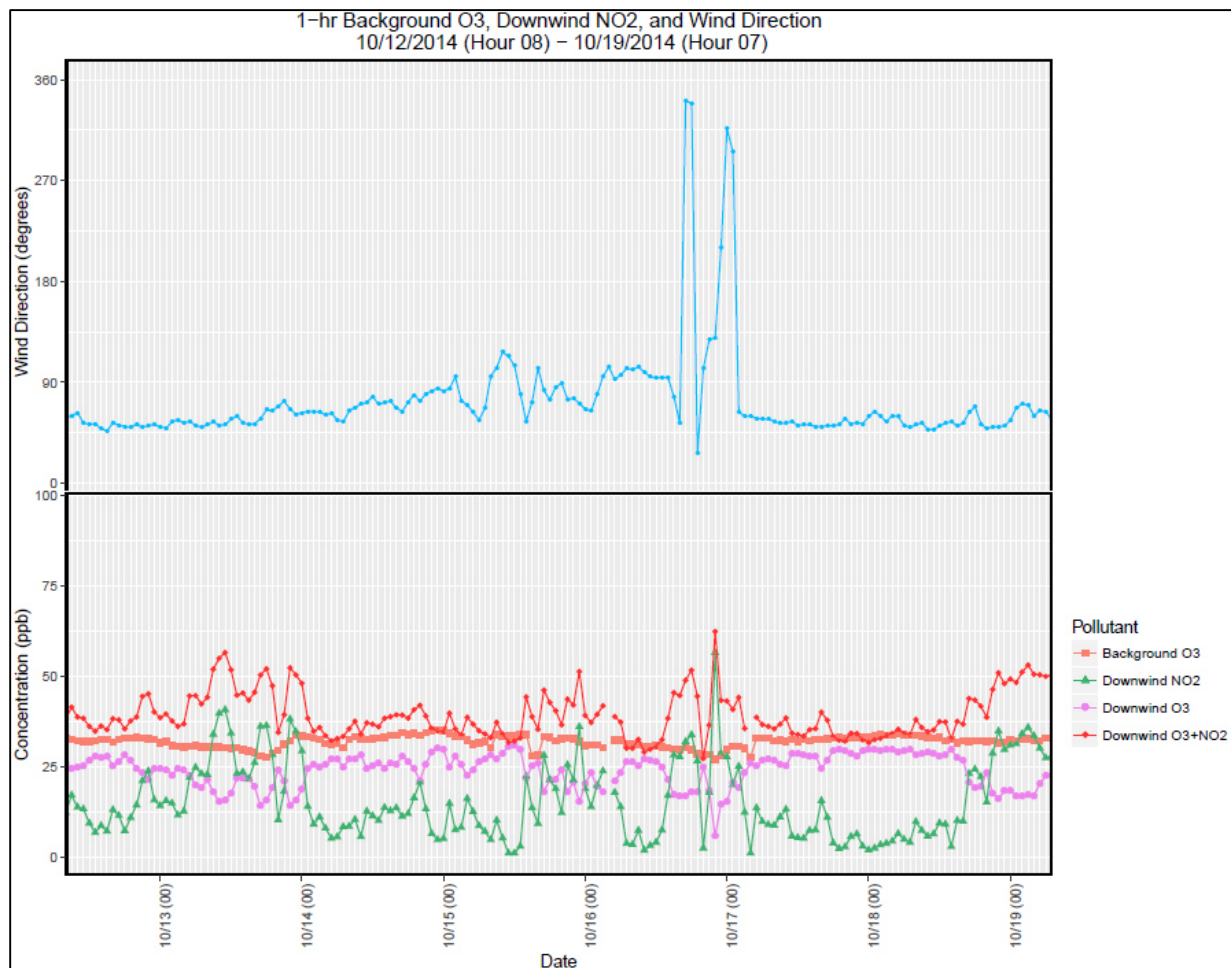


Figure 14. 1-hour Upwind O<sub>3</sub> with Downwind NO<sub>2</sub>, O<sub>3</sub>, NO<sub>2</sub>+O<sub>3</sub> and Wind Direction

### **Task 3: Format Hourly Kuparuk Data for AERMOD Model Evaluation**

The goal of Task 3 was to generate an AERMET-ready hourly meteorological file and AERMOD-ready hourly emissions and hourly background ozone files. Implementing the methods and procedures discussed above for processing the CEMS data and quantifying the background ozone concentrations, Amec Foster Wheeler generated two formatted, time-synchronized sets of files. A separate set was created for each of the two methods for determining the background ozone. The data were processed and the formatted files were generated using R. The R scripts used to process the data and create the AERMOD and AERMET-ready files are included in Attachment 04. The two sets of formatted files are included in Attachment 07.

The following sections describe the processing steps and criteria that were applied to generate each of formatted files.

#### **Step 1: Apply Well Schedule**

After each of the 1-hour data files were read (source-specific CEMS, "downwind" ambient pollutant, "upwind" ozone, and DSF1 surface meteorology), the modified well schedule in Table 12 was applied to omit hours from the dataset when the drill was in transit between wells.

#### **Step 2: Process CEMS - Mass Emission Rate and Exit Velocity Calculations**

The following steps were followed to process the CEMS data.

1. Limit CEMS data to those hours in which at least one of the five emission sources was operating, based on fuel use for the hour (when fuel use is greater than zero).
2. Apply the following criteria, prior to calculating mass emission rates and exit velocities, to treat records where the NO<sub>x</sub>, O<sub>2</sub>, and fuel data were not consistent:
  - Where fuel < 0.1 GPH, set fuel = 0 GPH (assume source was not operating)
  - Where fuel > 0 GPH and O<sub>2</sub> >= 19.5 % (assume ambient O<sub>2</sub>), set NO<sub>x</sub>, NO, NO<sub>2</sub>, and O<sub>2</sub> to NULL, retain fuel value
  - Where fuel = 0 GPH, set NO<sub>x</sub> = 0.0 ppm and O<sub>2</sub> = 20.9 %.
3. Calculate mass emission rate and exit velocities using Method 19 formulas for non-NULL records (records unaffected by criteria above).
4. Calculate hourly emission factor.
5. Calculate source-specific average emission factor and average O<sub>2</sub>%.
6. Calculate hourly mass emission rates and exit velocities using source-specific average emission factor and average O<sub>2</sub>% to fill NULL records. (The R script output is a comma-delimited CSV file of the final data used to generate the formatted emissions file. The CSV file includes all parameters that were used to compute the mass emission rates and exit velocities and a flag that is set to TRUE (T) for those records that were filled using the average emission factor and average O<sub>2</sub> value.)



### **Step 3: Process Ambient Pollutant Data - Determine Background Ozone**

Separate subsets of the ambient pollutant files were created from which to derive the background ozone files using each of the two methods previously described:

**Method 1:** Limit the dataset to only those hours for which there is an NO<sub>2</sub> impact on the "downwind" monitor and use the O<sub>3</sub> value from the "upwind" monitor as the background O<sub>3</sub> value for each hour. A monitored value of 5.0 ppm of NO<sub>2</sub> was used as a threshold to determine whether the plume impacted the monitor.

**Method 2:** Compare the O<sub>3</sub> value from both monitors each hour, and take the higher of the two values as the background value for the hour. Records were limited to those hours with both an "upwind" and "downwind" O<sub>3</sub> value.

The R scripts output is a CSV file of the final datasets from which the formatted background ozone file is generated. The CSV file identifies the O<sub>3</sub> value each hour that is used for background ozone.

### **Step 4: Synchronize CEMS and Ambient Pollutant**

AERMOD requires that the emissions, background ozone, and meteorological input files are synchronized with each other with respect to the hours included in each of the files. They must match exactly. Prior to generating the formatted files, the CEMS and ambient data are further processed to omit any hours that are not common between the two data types. The meteorological data are also synchronized with the CEMS and ambient data, but the formatted meteorological file for input to AERMET is generated from a full version of the 1-hour meteorological file. The AERMET output is post-processed to generate synchronized meteorological files for input to AERMOD.

### **Step 5: Generate AERMOD-ready Hourly Emissions File (*aermd\_1hr\_emis.txt*)**

The following parameters were output to an ASCII text file, in a format compatible with AERMOD:

- Year, Month, Day, Hour,
- Stack ID (BOILER\_1, BOILER\_2, HEATER, ENGINE\_1, ENGINE\_2),
- Mass Emission Rate (g/s),
- Stack Gas Temperature (K), and
- Stack Gas Exit Velocity (m/s).

### **Step 6: Generate AERMOD-ready Hourly Background Ozone File (*backgrnd\_o3.txt*)**

The following parameters were output to an ASCII text file, in a format compatible with AERMOD:

- Year, Month, Day, Hour, and
- Ozone Concentration (ppb).

**Step 7: Generate AERMET-ready Hourly Onsite Meteorological File (dsf1\_1hr\_os\_met.txt)**

The following parameters were output to an ASCII text file, in a format compatible with AERMET, processed as onsite meteorology:

- Year, Month, Day, Hour,
- Wind Speed (m/s),
- Wind Direction (degrees),
- Std. Dev. Wind Dir. (Sigma Theta , degrees),
- Std. Dev. Vertical Wind Speed (Sigma W , m/s),
- 2-m Temperature (C),
- 10-m Temperature (C),
- Delta Temperature (C),
- Solar Radiation (W/m<sup>2</sup>),
- Relative Humidity (%), and
- Barometric Pressure (mb\*10).
- .

**Task 4: Research Upper Air Data, Surface Characteristics, and Building Downwash**

The purpose of Task 4 was to research and obtain or develop additional data that are required by AERMET and AERMOD that will be needed to evaluate AERMOD. These data include upper air meteorological data and surface characteristic values required by AERMET, and building data for AERMOD for the effects of building downwash from the rig. Due to funding constraints, the priority set by the SMT was to develop building parameters representative of the drill rig. In addition, Amec Foster Wheeler was able to obtain upper air data for input to AERMET and specified a set of surface characteristics to use for testing the formatted meteorological data. The next sections describe our effort to obtain or develop these data and the testing that was performed with AERMET and AERMOD to ensure the formatted files developed under Task 3 can be processed successfully.

**Upper Air Data**

Amec Foster Wheeler researched the availability of upper air data provided by the National Oceanic and Atmospheric Administration (NOAA) in a format compatible with AERMET, concurrent with the study monitoring period. NOAA provides archived upper air data through the Earth System Research Laboratory (ESRL) Radiosonde Database<sup>9</sup> in the Forecast Systems Laboratory (FSL) format. The nearest upper air station with data concurrent with the monitoring study is Point Barrow, AK, about 160 miles northwest of DS2N. Amec Foster Wheeler obtained for Point Barrow a complete year of upper air data for 2014. The upper air file is included in Attachment 08 with the AERMET test files discussed later.

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<sup>9</sup> NOAA/ESRL Radiosonde Database can be accessed online at: <http://esrl.noaa.gov/raobs/>

## Surface Characteristics

For testing purposes, Amec Foster Wheeler specified a set of surface values for noon-time albedo, Bowen ratio, and surface roughness length for a single sector. The values used are from the ADEC Modeling Review Procedures Manual.<sup>10</sup> ADEC published approved summer and winter values that represent tundra for onshore dispersion modeling applications on the North Slope. Summer is assumed to be June through September and winter is assumed to be October through May. Amec Foster Wheeler specified the values monthly in order to represent the seasonal values appropriately. Table 16 lists the winter and summer surface values approved by ADEC. The listed surface roughness values relate to an unobstructed boundary layer in Alaska and are not necessarily appropriate for the micrometeorological region between the drill rig and the monitor. In the region between the drill rig and the monitor the structure of the drilling rig will perturb the boundary layer and enhance turbulence. Further evaluation is needed.

**Table 16. Approved ADEC Surface Values for Onshore North Slope**

<b>North Slope Onshore</b>	<b>Winter (Oct. - May)</b>	<b>Summer (June - Sept.)</b>
Albedo	0.8	0.18
Bowen Ratio	1.5	0.8
Surface Roughness Length (m)	0.004	0.02

## AERMET Testing

Amec Foster Wheeler tested all three stages of AERMET with the formatted surface meteorological data files generated from meteorology collected at DSF1. Testing was performed on both versions that resulted from the two methods used for deriving background ozone. DFS1 surface meteorology was supplemented with the Point Barrow upper air data, and the approved ADEC surface characteristics in Table 16 were specified in the Stage 3 control file. AERMET was run with the Bulk Richardson Number (BULKRN) option for stable boundary layer processing. The AERMET control files, meteorological input files, and output files are included in Attachment 08.

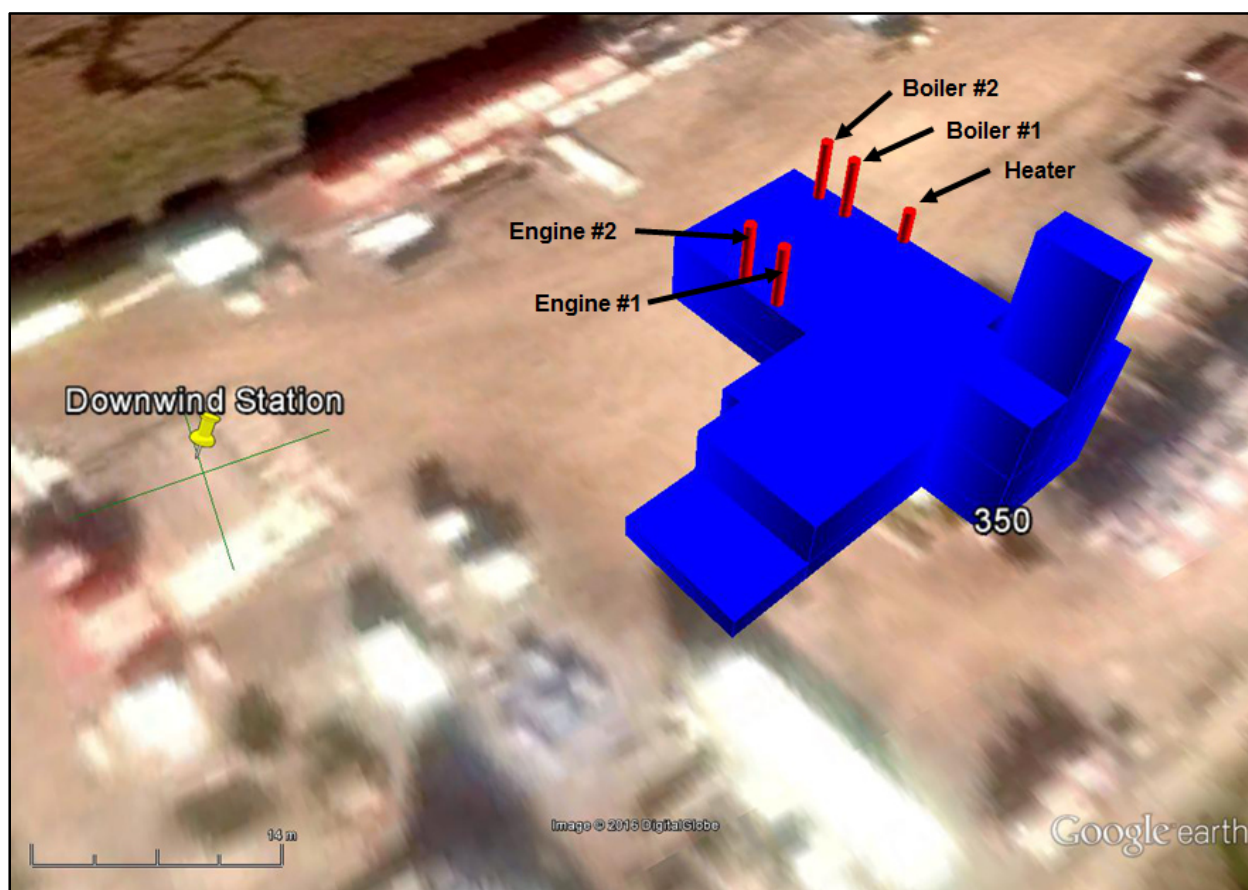
During processing, AERMET inserts records for any omitted hours so that the timestamps in the AERMOD-ready meteorological surface and profile files are consecutive, and there are no hours omitted from files. The meteorological parameters are filled with missing data codes that are understood by AERMOD. The files must then be synchronized with formatted emissions and background ozone files. A Fortran program, CUTMET, was developed that processes the AERMET output files and reduces the files based on a list of timestamps input to the program. The R scripts used to process the raw 1-hour files and generate the formatted data, creates the CUTMET timestamp file based on the hours in the final file. CUTMET and the timestamp files are also included in Attachment 08 with instructions for running CUTMET.

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<sup>10</sup> ADEC Modeling Review Procedures Manual, Alaska Department of Environmental Conservation, June 30, 2013. <http://dec.alaska.gov/air/ap/modeling.htm>

### **Building Downwash**

Building input parameters that represent the 9ES drill rig were developed for BPIPPRM from scaled drawings provided by Nabors (see Attachment 03). Building and tier coordinates and a separate BPIPPRM control file were developed for each well location and processed with BPIPPRM (version 04274). The BPIPPRM control files and output are included in Attachment 09. Figure 15 shows a 3-dimensional representation of the 9ES rig overlain in Google Earth at DS2N on well 350, with the emission sources identified. Figure 16 is a similar graphic showing 9ES at 4 of the 5 wells. (Well 337 was omitted from the figure due to its close proximity to well 336.)



**Figure 15. BPIPPRM Representation of Nabors Drill Rig 9ES at DS2N on Well 350**





Figure 16. BPPIPRM Representations of Nabors Drill Rig 9ES at DS2N

### **AERMOD Testing**

Amec Foster Wheeler developed AERMOD control files to test the formatted hourly emissions and background ozone files and the processed meteorological files. A separate set was developed for each of the two sets of formatted files, differentiated based on the method used to derive background ozone. A separate AERMOD control file was developed for each well location based on the modified drill schedule in Table 12. The well-specific building downwash parameters from BPPIPRM were incorporated into the corresponding AERMOD control file. To test the format of the background ozone files, the Plume Volume Molar Ratio Method (PVMRM) for converting NO<sub>x</sub> to NO<sub>2</sub> was specified. An arbitrary value of 0.5 was entered as the in-stack NO<sub>2</sub>/NO<sub>x</sub> ratio (NO<sub>2</sub>STACK), and the default value of 0.9 was entered as the ambient equilibrium NO<sub>2</sub>/NO<sub>x</sub> ratio (NO<sub>2</sub>EQUIL). Each of the control files was tested with AERMOD (version 15181). The AERMOD control files, and all input and output files are included in Attachment 10.

## **Task 5: Construct a Modeling Database**

The purpose of Task 5 was to incorporate the Kuparuk data into an archive storage format such as a Microsoft Excel file. The format was to be developed under the guidance of the technical adviser and the SMT. As tasks were prioritized, this was set by the SMT as a low priority and was not addressed.

## **RECOMMENDATIONS FOR NEXT STEPS**

### ***Further Evaluate the Hourly Mass Emission Rate and Exit Velocity Calculations***

Though several approaches for handling the data issues encountered with the CEMS data have been explored, additional evaluation of these methods and others is warranted, particularly the method implemented to compute the exit velocity for those records in which the monitored NO<sub>x</sub>, O<sub>2</sub>, and fuel values are inconsistent with each other. Additional refinements may be needed to more fully handle these problem records. The SMT has offered another possible method for computing the exit velocities from the engines for those records which was mentioned previously and included as Attachment 11.

Since the completion of this work by Amec Foster Wheeler, the SMT has obtained stack moisture data for each of the emission sources. This data should be used to replace the approximated moisture fraction of 0.1 used in the Method 19 calculations (Equation 6).

With the approaches explored, and the approach reflected in the formatted hourly emissions file, there are still records that are suspect and may contain unlikely or unreasonable values. This could be due to the criteria that were applied initially that identified a discrepancy between the measured values of NO<sub>x</sub>, O<sub>2</sub>, and fuel use. The criteria used to identify these records may need to be updated to be more stringent. Suspect records need to be identified and further investigated. Based on the findings, additional criteria may need to be applied to identify these records during processing so they are treated or omitted.

### ***Ambient Pollutant Data Analyses***

Only a nominal amount of analyses have been performed on the ambient pollutant data. Analyses that were specified in the SOW but not addressed include:

1. Evaluate wind direction alignment to the actual source azimuth.
2. Evaluate NO<sub>2</sub>/NO<sub>x</sub> ratio based on what portion of the plume impacts the monitor.
3. Identify the potential influence from mobile source emissions.
4. Review ambient ozone data and evaluate ozone scavenging.
5. Identify peak concentrations (daily, weekly, and monthly).

### ***Refinement of Surface Characteristics and Building Downwash Parameters***

For testing purposes, Amec Foster Wheeler used monthly sector independent values for noon-time albedo, Bowen ratio, and surface roughness length that are approved by ADEC for onshore North Slope applications. Typically, the surface values should be representative of the site where the meteorological data are collected. Specifically, surface roughness should be derived based on land cover and land characteristics within a 1 km radius of the meteorological



tower, since the wind data and surface roughness are closely related to each other. However, given the proximity of the drill rig to the ambient monitor, there are concerns that a roughness value representative of tundra, does not adequately represent conditions on the well pad, such as the equipment which will influence dispersion. In this regard, surface roughness needs further evaluation and possible refinement. It may be necessary to vary roughness by wind sector given the layout of the well pad and the location of static equipment.

Similarly, the representation of the drill rig as a building and the influence of building downwash should be evaluated. We understand from discussions with the SMT that previous modeling conducted for the drill rig used in this study indicated that BPIP-PRIME (BPIP-PRM) did not accurately estimate the ambient turbulence generated by the rig. BPIP-PRM assumes a solid structure and does not adjust for the lattice design common to drill rigs. The 9ES rig is primarily solid, very similar to a building, but in the current representation, much of the mast which is primarily a lattice structure, was ignored. Additional structures on the well pad should be evaluated,

## **ELECTRONIC ATTACHMENTS**

Attachment 01: Original Kuparuk River Unit NO<sub>2</sub> Monitoring Study Data Package

Attachment 02: Findings of the cursory Review of the Kuparuk River Unit NO<sub>2</sub> Data

Attachment 03: Drill Rig 9ES Drawings

Attachment 04: Project Related R Scripts

Attachment 05: Ambient Pollutant Time-series Plots

Attachment 06: Time-series Plot of "Upwind" O<sub>3</sub> with "Downwind" NO<sub>2</sub>, O<sub>3</sub>, NO<sub>2</sub>+O<sub>3</sub> with Wind Direction

Attachment 07: AERMET and AERMOD-ready Formatted Hourly Data Files

Attachment 08: AERMET Test Files

Attachment 09: BPIP-PRM Test Files

Attachment 10: AERMOD Test Files

Attachment 11: Analysis and Comments of Kuparuk, AK Database, Earth System Sciences, LLC

## FILE LIST FOR ELECTRONIC ATTACHMENTS

*This is a Table of Contents for Electronic Attachments included with the Memorandum Report for the Review and Analyses of the Kuparuk, Alaska Drill Rig 1-hour NO<sub>2</sub> Monitoring Study. File names highlighted in yellow indicates files that include or used as their data source calculated mass emission rates and/or exit velocities.*

### Attachment 01: Original Kuparuk River Unit NO<sub>2</sub> Monitoring Study Data Package

Attachment 01 contains the original Kuparuk, AK data package as provided from SLR via WESTAR.

The files downloaded that make up data package, as described by SLR include the following:

- Boiler2.csv (8 MB) Checksum (SHA1):  
518b998aa6b1616c5c3be08485fda783017acc5a
- DownwindAmbientAQ.csv (16 MB) Checksum (SHA1):  
811f7f287f9322d56910dca0636a05982349a61c
- Engine1.csv (8 MB) Checksum (SHA1):  
958b8c0017ab7172ed1d89f0510ba877a42d5e9e
- Engine2.csv (7.9 MB) Checksum (SHA1):  
c17dbeb662640dede0128454ac3fef8a440c6720
- Heater.csv (7.9 MB) Checksum (SHA1):  
5b4489ec202a7660ba9ae46d2de424d0e3bc9bd5
- UpwindOzone.csv (4.2 MB) Checksum (SHA1):  
ba0c515a2c128af8d1dd55c6a524fa85a16d11f6
- 1Hr Data Correction Summary.xlsx (14 KB) Checksum (SHA1):  
3e7c586b8a92facbad8472edf5fbd17a70db2aa7
- DrillRigStudy\_1-HrData (Corrected).xlsx (1.2 MB) Checksum (SHA1):  
733a8f35e4e9a5733254ee26db986a9194b4a375
- Data Validation Code Descriptions.docx (13 KB) Checksum (SHA1):  
1e99e711387933d1ee4e70bf2e472f8230b6a473
- DrillRigStudy\_Events-DataDecisions (1MinuteData).docx (27 KB) Checksum (SHA1):  
e8cb7a21ebd2e103b7fe25ae5e5e197e17533178

- Drill Rig Study QA Records.zip (18 MB) Checksum (SHA1):  
33771ac63af94f6ee23659f446a7852aec4df16f
- Boiler1.csv (8 MB) Checksum (SHA1):  
213e69002b068efc347ee69078324b3ac0ffeeb7

The contents of the data package, as described by SLR include the following:

1. Corrected 1-Hour Drill Rig Data File which corrects errors identified during the 1-minute data validation process. These errors are described in documents #4 and #5 below;
2. Separate 1-minute average.csv data files for each measurement system (7 files - 1 each for boiler 1&2, heater, engine 1&2, downwind ambient station, and upwind ozone sampler);
3. An index describing the data validation codes used to replace invalid measurements in the data files;
4. A Microsoft Word document describing the 1-minute average data validation decisions and corrections to the 1-hour average data set;
5. A Microsoft Excel document summarizing the corrections to the originally reported 1-hour data record; and
6. A compressed zip file containing relevant quality assurance / quality control records documented during the drill rig study.

More detailed descriptions of the contents of the Kuparuk, AK data package can be found in Attachment 02: Findings of the Cursory Review of the Kuparuk River Unit NO<sub>2</sub> Data.

### **Attachment 02: Findings of the Cursory Review of the Kuparuk River Unit NO<sub>2</sub> Data**

Attachment 02 contains a single file, Amec Foster Wheeler's findings of the cursory review of the Kuparuk, AK data package as provided in Attachment 01.

- *Amec Cursory Review\_Kup Field Data\_Rev01\_20150529.pdf*

### Attachment 03: Drill Rig 9ES Drawings

Attachment 03 contains a JPEG image of drill rig 9ES and drawings of drill rig 9ES with horizontal and vertical dimensions and the location of the emission release points (engines, boilers, heater).

Filenames and descriptions:

- *\_README\_Attachment\_03.txt*: README file describes contents of Attachments
- *7ES-9ES.jpg*: Drill rig in the background is 9ES
- *9ES Elev.pdf*: Drill rig tier elevations
- *9ES Plan Dims.pdf*: Drill rig lateral dimensions
- *9ES Plan Stack.pdf*: Drill rig lateral dimensions and stack locations

### Attachment 04: Project Related R Scripts

Attachment 04 contains project related R scripts and script output. Included are scripts that generate various time-series plots from the ambient pollutant data including plots of individual pollutants, comparisons of NO<sub>x</sub>, NO, and NO<sub>2</sub>, comparisons of the ozone data from the upwind and downwind monitors, and plots to evaluate background ozone. There are also scripts that process the data and generate the hourly emissions and background ozone files formatted for input to AERMOD and the hourly onsite meteorological data file formatted for input to AERMET. The data are processed and the hourly formatted files are generated based on two different methods for deriving the background ozone data. The methods include:

**Method 1:** Choose maximum ozone value from the two ozone monitors (upwind and downwind)

**Method 2:** Limit data to those hours where plume impacted the monitor and use upwind monitor for background ozone

The files, by folder, contained in Attachment 02 and their descriptions include:

- **Root Directory**
  - *\_README\_Attachment\_04.txt*: README that describes Attachment contents

The following R scripts generate ambient pollutant time-series plots (the files generated are located in the subfolder *amb\_plots*, described further down, and in Attachment 05):

- *amb\_plots\_co.R*: Generates combined time-series plots of 1-min and 1-hr CO (*amb\_plots\plt\_co\_1min\_1hr.pdf*)

- *amb\_plots\_no.R*: Generates combined time-series plots of 1-min and 1-hr NO (*amb\_plots\plt\_no\_1min\_1hr.pdf*)
- *amb\_plots\_no2.R*: Generates combined time-series plots of 1-min and 1-hr NO<sub>2</sub> (*amb\_plots\plt\_no2\_1min\_1hr.pdf*)
- *amb\_plots\_nox-no-no2.R*: Generates combined time-series plots to compare 1-min NO<sub>x</sub>/NO<sub>2</sub>/NO (*amb\_plots\plt\_nox\_no2\_no\_1min.pdf*) and combined time-series to compare 1-hr NO<sub>x</sub>/NO<sub>2</sub>/NO (*amb\_plots\plt\_nox\_no2\_no\_1hr.pdf*)
- *amb\_plots\_nox-no-no2\_wd\_1hr.R*: Generates combined time-series plots to compare 1-hr NO<sub>x</sub>/NO<sub>2</sub>/NO and wind direction from DSF1 (*amb\_plots\plt\_nox-no-no2\_wd\_1hr.pdf*)
- *amb\_plots\_nox.R*: Generates combined time-series plots of 1-min and 1-hr NO<sub>x</sub> (*amb\_plots\plt\_nox\_1min\_1hr.pdf*)
- *amb\_plots\_o3\_alt.R*: Generates combined time-series plots of 1-min and 1-hr upwind ozone (*amb\_plots\plt\_o3\_upw\_1min\_1hr.pdf*) and downwind ozone (*amb\_plots\plt\_o3\_dwn\_1min\_1hr.pdf*)
- *amb\_plots\_o3\_upw\_dwn\_wd\_1hr.R*: Generates combined time-series plots of 1-1-hr upwind and downwind ozone and 1-hr wind direction from DSF1 (*amb\_plots\plt\_o3\_upw\_dwn\_wd\_1hr.pdf*)
- *amb\_plots\_so2.R*: Generates combined time-series plots of 1-min and 1-hr SO<sub>2</sub> (*amb\_plots\plt\_so2\_1min\_1hr.pdf*)

The following R script generates time-series fuel plots that include 1-minute and 1-hour fuel use for a 12-hour period when all five emission sources were operating. A separate plot is generated for each source. Output can be found in the folder *cems\_plots*.

- *cems\_plots\_fuel.R*: Generates time-series fuel plots that include 1-minute and 1-hour fuel use for a 12-hour period when all five emission sources were operating. A separate plot is generated for each source.

The following R script generates ozone plots to evaluate background ozone:

- *eval\_background\_ozone.R*: Generates a combined time-series plot of 1-hr ozone from upwind monitor, 1-hr NO<sub>2</sub>, O<sub>3</sub>, NO<sub>2</sub>+O<sub>3</sub> from downwind monitor, and wind direction from DSF1 (*background\_o3\plt\_upwo3\_no2\_wd\_1hr.pdf* - also provided as Attachment 05). Also outputs a comma-delimited file of the 1-hour ambient data (*background\_o3\amb\_1hr.csv* - Note: wind data contained in this file is not the wind data from DSF1)

The following R scripts process the 1-hour CEMS, Ambient, Met data to generate the formatted hourly AERMET and AERMOD-ready input files (emission, background ozone, and meteorology) based on the two ozone background methods described above:

- *format\_all\_no2\_impact\_only.R*: Method 1 - Choose maximum ozone value from the two ozone monitors
- *format\_all\_no2\_impact\_only.R*: Method 2 - Limit data to those hour where plume impacted the monitor and use upwind monitor for background ozone

The following files were used to compute the azimuth from each source to the monitoring stations:

- *azimuths.R*: R script to compute azimuths. Reads in *source\_coordinates.csv*, outputs *azimuths.csv*.
- *source\_coordinates.csv*: Comma-delimited file containing emission source coordinates at each well.
- *azimuths.csv*: Calculated azimuths.

#### Miscellaneous

- *WESTAR AK Coordinates\_20160101.xlsx*: Contains coordinates in lat/lon and UTM's for all sources at each well, well heads, and monitoring stations. Includes distances from sources to monitoring stations.

- **Folder: *amb\_plots***

The following files contain ambient time-series plots generated by R scripts as described above (also in Attachment 05):

- *plt\_co\_1min\_1hr.pdf*: Combined time-series plots of 1-min and 1-hr CO
- *plt\_no2\_1min\_1hr.pdf*: Combined time-series plots of 1-min and 1-hr NO<sub>2</sub>
- *plt\_nox-no-no2\_wd\_1hr.pdf*: Combined time-series plots to compare 1-hr NO<sub>x</sub>/NO<sub>2</sub>/NO and wind direction from DSF1
- *plt\_nox\_1min\_1hr.pdf*: Combined time-series plots of 1-min and 1-hr NO<sub>x</sub>
- *plt\_nox\_no2\_no\_1hr.pdf*: Combined time-series plots to compare 1-hr NO<sub>x</sub>/NO<sub>2</sub>/NO



- *plt\_nox\_no2\_no\_1min.pdf*: Combined time-series plots to compare 1-min NO<sub>x</sub>/NO<sub>2</sub>/NO
- *plt\_no\_1min\_1hr.pdf*: Combined time-series plots of 1-min and 1-hr NO
- *plt\_o3\_dwn\_1min\_1hr.pdf*: Combined time-series plots of 1-min and 1-hr downwind ozone
- *plt\_o3\_upw\_1min\_1hr.pdf*: Combined time-series plots of 1-min and 1-hr upwind ozone
- *plt\_o3\_upw\_dwn\_wd\_1hr.pdf*: Combined time-series plots of 1- 1-hr upwind and downwind ozone and 1-hr wind direction from DSF1
- *plt\_so2\_1min\_1hr.pdf*: Combined time-series plots of 1-min and 1-hr SO<sub>2</sub>
- *README.txt*: Descriptions of files listed above
- **Folder: *cems\_plots***
  - *cems\_fuel.pdf*: Time-series fuel plots that include 1-minute and 1-hour fuel use for a 12-hour period when all five emission sources were operating. A separate plot is generated for each source.
- **Folder: *background\_o3***
  - *plt\_upwo3\_no2\_wd\_1hr.pdf*: Combined time-series plot of 1-hr ozone from upwind monitor, 1-hr NO<sub>2</sub>, O<sub>3</sub>, NO<sub>2</sub>+O<sub>3</sub> from downwind monitor, and wind direction from DSF1
  - *amb\_1hr.csv*: Comma-delimited file of ambient data (Note: wind data in this file is not the wind data from DSF1)

- **Folder: *data***

This direction contains the 1-minute and 1-hour CEMS, ambient, and met data files read by R scripts. Data in original data package were segregated into individual comma-delimited files with simple column headers. Also includes well drilling schedule, data definitions, and units of measure.

The following files are contained in this directory:

- *ambient\_1hr.csv*: 1-hour ambient pollutant from downwind monitor (western end of pad)
- *ambient\_1min.csv*: 1-minute ambient pollutant from downwind monitor (western end of pad)
- *upwind\_ozone\_1hr.csv*: 1-hour ozone from upwind monitor (eastern end of pad)
- *upwind\_ozone\_1min.csv*: 1-minute ozone from upwind monitor (eastern end of pad)
- *boiler\_1\_1hr.csv*: boiler #1 1-hour CEMS and fuel
- *boiler\_1\_1min.csv*: boiler #1 1-minute CEMS and fuel
- *boiler\_2\_1hr.csv*: boiler #2 1-hour CEMS and fuel
- *boiler\_2\_1min.csv*: boiler #2 1-minute CEMS and fuel
- *engine\_1\_1hr.csv*: engine #1 1-hour CEMS and fuel
- *engine\_1\_1min.csv*: engine #1 1-minute CEMS and fuel
- *engine\_2\_1hr.csv*: engine #2 1-hour CEMS and fuel
- *engine\_2\_1min.csv*: engine #2 1-minute CEMS and fuel
- *heater\_1hr.csv*: heater 1-hour CEMS and fuel
- *heater\_1min.csv*: heater 1-minute CEMS and fuel
- *dsf1\_met\_1hr.csv*: 1-hour met from DSF1
- *README\_1-hr\_Avg\_Convention.txt*: Explanation of 1-hour averaging convention
- *README\_Data\_Units.txt*: Data definitions and units
- *well\_schedule\_orig.csv*: Original well schedule
- *well\_schedule\_6hrs.csv*: Modified well schedule to account for time rig is in transit

- **Folders: *formatted\_max\_o3\_backgrnd* and *formatted\_no2\_impacts\_only***

Both directories contain the same files/filenames generated from the data processing R scripts *format\_all\_no2\_impact\_only.R* and *format\_all\_no2\_impact\_only.R*. The content of the files differ based on the method used to derive background ozone.

- *Addl\_Data\_Defs.txt*: Data definitions for additional columns not defined data directory where data are stored.
- *cems\_1hr\_abbr.csv*: Subset of CEMS 1-hr data synchronized with background ozone file. Used to generate formatted 1-hour emissions file. Includes calculated mass emission rates. Average emission factor and average O<sub>2</sub> value used for all sources to fill inconsistent data records.
- *aermd\_1hr\_emis.txt*: Formatted AERMOD-ready 1-hour emissions input file, synchronized with formatted background ozone file. Average emission factor and average O<sub>2</sub> value used for all sources to fill inconsistent data records.
- *aermd\_1hr\_emis.csv*: Same data as formatted AERMOD-ready 1-hour emissions input file but in comma-delimited format and includes header to view in Excel. Average emission factor and average O<sub>2</sub> value used for all sources to fill inconsistent data records.
- *avg\_ef\_o2\_stats.txt*: Statistics for hourly emission factors and O<sub>2</sub> values. Provides the mean value used to fill inconsistent data records for which Method 19 could not be used.
- *cems\_1hr\_alt\_abbr.csv*: Subset of 1-hour CEMS data. Includes calculated mass emission rates and exit velocities for all sources. SMT regression equations were used to recalculate NO<sub>x</sub> and O<sub>2</sub> for boiler #1. Average emission factor and average O<sub>2</sub> value used for all other sources to fill inconsistent data records. Mass emission rates and exit velocities for all sources except boiler #1 should match values in *cems\_1hr\_abbr.csv*.
- *cems\_1hr\_qs\_vs\_compare.csv*: Compares regression based emission rates and velocities to original calculated values using Method 19 for the data records where Method 19 could be applied for boiler #1
- *amb\_1hr\_abbr.csv*: Subset of ambient pollutant data synchronized with background ozone and CEMS file.
- *backgrnd\_o3.txt*: Formatted AERMOD-ready 1-hour background ozone file
- *backgrnd\_o3.csv*: Same data as formatted AERMOD background ozone file in comma-delimited format, includes header for viewing in Excel.
- *dates.pgr*: dates for CUTMET program, date/times included in formatted files. Used to synchronize AERMET output with formatted 1-hour emissions and background ozone files. (See Attachment 08)

- *met\_1hr\_abbr.csv*: Subset of 1-hour met data from DSF1, synchronized with formatted 1-hour emissions and background ozone input files.
  - *dsf1\_1hr\_os\_met.txt*: Formatted AERMET-ready 1-hour onsite surface met file (DSF1 met). Includes all hours, i.e., not synchronized with emission and background ozone files.
  - *dsf1\_1hr\_os\_met.csv*: Same data values as *dsf1\_1hr\_os\_met.txt* in comma-delimited format and header to view in Excel. Includes all hours, i.e., not synchronized with emission and background ozone files.
  - *plt\_bg-o3\_dwnwnd-o3\_no2\_wd\_1hr.pdf*: Time-series plots of ozone, NO<sub>2</sub>, and wind direction
  - *plt\_cems-nox\_amb-no2-no\_1hr.pdf*: Time-series plots of 1-hour CEMS NO<sub>x</sub>, ambient NO<sub>2</sub> and NO (average emission factor and O<sub>2</sub>)
  - *plt\_cems-nox\_amb-no2-no\_1hr\_alt.pdf*: Time-series plots of 1-hour CEMS NO<sub>x</sub>, ambient NO<sub>2</sub> and NO (based on regression equations for boiler #1)
  - *plt\_qs.pdf*: Time-series plot of calculated mass emission rates in lb/hr for all five sources based on approach where data were filled based on an average emission rate and average in-stack O<sub>2</sub> value
  - *plt\_qs\_12hr.pdf*: 12-hour time-series plot of calculated mass emission rates in lb/hr for all five sources for a period when all five sources were operating, based where data were filled based on an average emission rate and average in-stack O<sub>2</sub> value.
  - *plt\_qs\_alt.pdf*: Time-series plot of calculated mass emission rates in lb/hr for all five sources. Boiler #1 is based on regression equations provided by the SMT (not used in final formatted data). All other sources are based on method using average emission factor and average O<sub>2</sub> value to fill inconsistent records.
  - *plt\_qs\_qsalt\_blr1.pdf*: Time-series plot of calculated emission rates in lb/hr for boiler #1 comparing rates calculated using regression equations to recalculate NO<sub>x</sub> and O<sub>2</sub> for all hours vs average emission factor and average O<sub>2</sub> to fill inconsistent data records.
- **Folder: *r\_common***

This directory contains common user-defined R function scripts that are reused by multiple scripts

The following load raw 1-minute and 1-hour data into R:

- *load\_raw\_1hr\_amb\_data.fun.R*: Load 1-hr ambient data
- *load\_raw\_1hr\_emis\_data.fun.R*: Load 1-hr CEMS data
- *load\_raw\_1hr\_met\_data.fun.R*: Load 1-hr met data from DSF1

- *load\_raw\_1min\_amb\_data.fun.R*: Load 1-min ambient data
- *load\_raw\_1min\_emis\_data.fun.R*: Load 1-min CEMS data

The following computes mass emission rates and exit velocities based on EPA Method 19:

- *qsvs.fun.R*: Call to function requires a prepared dataset to be passed as an argument. Returns mass emission rates, exit velocities, and all intermediate values.

## **Attachment 05: Ambient Pollutant Time-series Plots**

Attachment 05 contains the time-series plots identical to those in Attachment 04 under the *amb\_plots* folder.

- *\_README\_Attachment\_05.txt*: README that describes the Attachment contents
- *plt\_co\_1min\_1hr.pdf*: Combined time-series plots of 1-min and 1-hr CO
- *plt\_no2\_1min\_1hr.pdf*: Combined time-series plots of 1-min and 1-hr NO<sub>2</sub>
- *plt\_nox-no-no2\_wd\_1hr.pdf*: Combined time-series plots to compare 1-hr NO<sub>x</sub>/NO<sub>2</sub>/NO and wind direction from DSF1
- *plt\_nox\_1min\_1hr.pdf*: Combined time-series plots of 1-min and 1-hr NO<sub>x</sub>
- *plt\_nox\_no2\_no\_1hr.pdf*: Combined time-series plots to compare 1-hr NO<sub>x</sub>/NO<sub>2</sub>/NO
- *plt\_nox\_no2\_no\_1min.pdf*: Combined time-series plots to compare 1-min NO<sub>x</sub>/NO<sub>2</sub>/NO
- *plt\_no\_1min\_1hr.pdf*: Combined time-series plots of 1-min and 1-hr NO
- *plt\_o3\_dwn\_1min\_1hr.pdf*: Combined time-series plots of 1-min and 1-hr downwind ozone
- *plt\_o3\_upw\_1min\_1hr.pdf*: Combined time-series plots of 1-min and 1-hr upwind ozone
- *plt\_o3\_upw\_dwn\_wd\_1hr.pdf*: Combined time-series plots of 1- 1-hr upwind and downwind ozone and 1-hr wind direction from DSF1
- *plt\_so2\_1min\_1hr.pdf*: Combined time-series plots of 1-min and 1-hr SO<sub>2</sub>

## **Attachment 06: Time-series Plot of "Upwind" O<sub>3</sub> with "Downwind" NO<sub>2</sub>, O<sub>3</sub>, NO<sub>2</sub>+O<sub>3</sub> with Wind Direction**

Attachment 06 contains the time-series plots identical to those in Attachment 04 under the *background\_o3* folder.

- *\_README\_Attachment\_06.txt*: README describing the contents of this Attachment.
- *plt\_upwo3\_no2\_wd\_1hr.pdf*: Combined time-series plot of 1-hr ozone from upwind monitor, 1-hr NO<sub>2</sub>, O<sub>3</sub>, NO<sub>2</sub>+O<sub>3</sub> from downwind monitor, and wind direction from DSF1

## **Attachment 07: AERMET and AERMOD-ready Formatted Hourly Data Files**

Attachment 07 contains the AERMET and AERMOD-ready formatted hourly data files generated with the R scripts described in Attachment 04 and also located in the similarly named folders in Attachment 04.

- *\_README\_Attachment\_07.txt*: README file describing the contents of this Attachment.

Included are two folders, one for each method used to derive background ozone using either *format\_all\_max\_o3\_backgrnd.R* or *format\_all\_max\_o3\_backgrnd.R*. Filenames in each of the folders are the same. The content of the files differ based on the method from which the content was derived.

- *max\_o3\_backgrnd*: Contains formatted files generated based on Method 1 - Choose maximum ozone value from the two ozone monitors (upwind and downwind)
- *no2\_impacts\_only*: Contains formatted files generated based on Method 2 - Limit data to those hour where plume impacted the monitor and use upwind monitor for background ozone

Each folder contains the following formatted files:

- *dsf1\_1hr\_os\_met.txt*: AERMET-ready onsite hourly meteorological file. Includes all hours for AERMET processing..

Includes the following columns:

- Year, Month, Day, Hour
- Wind Speed (m/s) {missing: 99}
- Wind Direction (degrees) {missing: 999}
- Std. Dev. Wind Dir., Sigma Theta (degrees) {missing:99}
- Std. Dev. Vert. Wind Speed, Sigma W (degrees) {missing:99}



- 2-m Temperature (C) {missing: 99}
  - 10-m Temperature (C) {missing: 99}
  - Delta Temperature (C) {missing: 9}
  - Solar Radiation (W/m<sup>2</sup>) {missing: 9999}
  - Relative Humidity (%) {missing: 999}
  - Barometric Pressure (mb\*10) {missing: 99999}
- **aermd\_1hr\_emis.txt**: Formatted AERMOD-ready 1-hour emissions input file, synchronized with formatted background ozone file.

Includes the following columns:

- Year, Month, Day, Hour,
  - Stack ID (BOILER\_1, BOILER\_2, HEATER, ENGINE\_1, ENGINE\_2),
  - Mass Emission Rate (g/s),
  - Stack Gas Temperature (K), and
  - Stack Gas Exit Velocity (m/s).
- *backgrnd\_o3.txt*: AERMOD-ready hourly background ozone file, synchronized with formatted emissions file.

Includes the following columns:

- Year, Month, Day, Hour, and
- Ozone Concentration (ppb)

## Attachment 08: AERMET Test Files

Attachment 08 contains the AERMET test files (input and output files) to test the hourly AERMET-ready formatted onsite meteorological file generated from the meteorological data collected at DSF1.

- *\_README\_Attachment\_08.txt*: README file describing the contents of this Attachment.

Also included are two folders, one for each method used to derive background ozone using either *format\_all\_max\_o3\_backgrnd.R* or *format\_all\_max\_o3\_backgrnd.R*. Filenames in each of the folders are the same. The content of the files differ based on the method from which the content was derived.

- *max\_o3\_backgrnd*: Contains formatted files generated based on Method 1 - Choose maximum ozone value from the two ozone monitors (upwind and downwind)

- *no2\_impacts\_only*: Contains formatted files generated based on Method 2 - Limit data to those hour where plume impacted the monitor and use upwind monitor for background ozone

Each folder contains the following:

- *aermet.exe*: AERMET v.15181 executable
- *BRW\_27502\_70026\_00012\_2014.fsl*: upper air input file
- *dsf1\_1hr\_os\_met.txt*: Formatted onsite surface meteorology collected at DSF1
- *\*.inp*: Stage 1 through Stage 3 AERMET control files
- *\*.MSG*: Message files generated by AERMET
- *\*.RPT*: Report files generated by AERMET
- *\*.MET*: Extract and QA files generated by AERMET
- *DSF1.PFL*: Profile met file generated by AERMET (formatted for AERMOD)
- *DSF1.SFC*: Surface met file generated by AERMET (formatted for AERMOD)
- *CUTMET.EXE*: Program to reads dates.pgr, removes unwanted records from DSF1.PFL and DSF1.SFC to sync met with emissions and background ozone files
- *CUTMET.FOR*: Fortran source code for CUTMET
- *CUTMET.DAT*: Input control file for CUTMET (list file inputs/outputs)
- *dates.pgr*: Datetime stamps to be included in met files (synced with emissions and background ozone files, input to CUTMET.EXE, output from R script when formatted files are created)
- *DSF1\_CUT.PFL*, *DSF1\_CUT.SFC*: Synchronized output from CUTMET.EXE
- *run\_aermet.bat*: Batch file to run AERMET Stages 1 through 3

To replicate AERMET output and run CUTMET to sync AERMET output with emissions and background ozone:

1. In Command Prompt, navigate to one of the subdirectories in this folder.
2. At prompt, type *run\_aermet*, then hit Enter key
3. When AERMET finishes, at the prompt, type: *CUTMET < CUTMET.DAT*

## Attachment 09: BPIPPRM Test Files

Attachment 09 contains BPIPPRM input and output files to generate building downwash parameters for drill 9ES positioned on each of the 5 wells associated with the monitoring study on pad DS2N including wells 303, 319, 336, 337, and 350.

- *\_README\_Attachment\_09.txt*: README describing the contents of this Attachment.
- *Bpipprm.exe*: BPIPPRM v.04274 executable
- *\*.inp*: BPIPPRM control files, one for each well by well number
- *\*.out*: BPIPPRM output files, by well number
- *\*.sum*: BPIPPRM summary output files, by well number
- *run\_bpipprm.bat*: batch file to run BPIPPRM (runs BPIPPRM for each well location)

To run BPIPPRM:

1. Open Command Prompt and navigate to this folder
2. At the prompt, type *run\_bpipprm*, then hit Enter key.

## Attachment 10: AERMOD Test Files

Attachment 10 contains the AERMOD input and output files to test the AERMOD-ready hourly formatted emissions and background ozone file, preprocessed meteorological data files output from AERMET, and the building downwash parameters output from BPIPPRM.

- *\_README\_Attachment\_10.txt*: README describing the contents of this Attachment

Also included are two folders, one for each method used to derive background ozone using either *format\_all\_max\_o3\_backgrnd.R* or *format\_all\_max\_o3\_backgrnd.R*. Filenames in each of the folders are the same. The content of the files differ based on the method from which the content was derived.

- *max\_o3\_backgrnd*: Contains formatted files generated based on Method 1 - Choose maximum ozone value from the two ozone monitors (upwind and downwind)
- *no2\_impacts\_only*: Contains formatted files generated based on Method 2 - Limit data to those hour where plume impacted the monitor and use upwind monitor for background ozone

Each folder contains the following files:

- *aermod.exe*: AERMOD v.15181 executable
- *\*.inp*: AERMOD control files, one for each well, by well number
- *aermd\_1hr\_emis.txt*: Formatted hourly emissions file

- *backgrnd\_o3.txt*: Formatted hourly background ozone file
- *DSF1\_CUT.SFC*: AERMOD-ready surface met file, from AERMET then post-processed with CUTMET
- *DSF1\_CUT.PFL*: AERMOD-ready profile met file, from AERMET then post-processed with CUTMET
- *\*.FIL*: AERMOD output, rank files, contain top 10 highest modeled 1-hour concentrations
- *\*.PST*: AERMOD output, post files, contain modeled 1-hour concentration for every hour modeled
- *\*.PLT*: AERMOD output, plot files, contain highest modeled 1-hour concentration at each receptor (only one receptor modeled)
- *\*.out*: AERMOD default output file contains overall highest modeled 1-hour concentration
- *run\_aermod.bat*: Batch file to run AERMOD

To run AERMOD:

1. Open Command Prompt and navigate to one of the subfolders
2. At the prompt, type *run\_aermod*, then hit Enter key

#### **Attachment 11: Analysis and Comments of Kuparuk, AK Database, Earth System Sciences, LLC**

- *memo\_Amec AK data review appendix\_db.pdf*