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MEMORANDUM

July 27, 2015

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 of the Drill Rig 1-hour NO₂ Monitoring Study Data, Findings, Data Modifications, and Work Completed, Contract No. 15-11

Dear Mr. Moore:

Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler) has completed reviews of continuous emissions, ambient pollutant, and meteorological data and accompanying quality assurance (QA) documents collected for the Drill Rig 1-hour NO₂ Collaborative Monitoring Study. The Scope of Work (SOW) for the referenced contract with the Western States Air Resources (WESTAR) Council identified the following five primary tasks to prepare data for use in evaluating the AERMOD dispersion model:

Task 1: Perform Data Quality Review;

Task 2: Prepare Denver-Julesburg Basin Data for Analyses;

Task 3: Perform Data Analyses on the Denver-Julesburg Basin Data;

Task 4: Format Data for AERMOD Model Evaluation; and

Task 5: Report.

This memorandum serves as the final report as defined in Task 5 and describes the work completed by Amec Foster Wheeler as applicable to Tasks 1 through 4, with a focus on Task 1. Task 1 required a detailed data quality review of data collected in the Denver-Julesburg Basin in Colorado and modifications to the data based on those findings. Due to quality of the data, most of the contract resources were devoted to reviewing the data, resolving data issues, and updating the data. Once the data quality review and updates to the data were completed, WESTAR prioritized the project objectives which are reflected in the work reported in this memorandum. All attachments referenced throughout this memorandum are provided as electronic files that should accompany this document.

WORK COMPLETED

Task 1: Perform Data Quality Review

Task 1 includes a detailed data quality review of 5-minute and 1-hour averaged continuous emissions monitoring (CEM) data, ambient pollutant data, meteorological data, calibration records, and other QA documents from a monitoring study conducted in the Colorado Denver-Julesburg Basin in the Fall of 2014. Subtasks are included to modify the 5-minute and 1-hour Denver-Julesburg data based on the findings of the review. The Denver-Julesburg Basin is a geologic structural basin in northeastern Colorado that extends into Wyoming, Nebraska, and Kansas.

In addition, Task 1 includes a cursory review of similar 1-minute and 1-hour averaged CEM, ambient pollutant, and meteorological data, calibration records and other QA documents from a study conducted at the Kuparuk River Unit (KUP) on the North Slope of Alaska. The purpose of the cursory review is to inspect the data and documents, identify any obvious errors in the data, and to identify any data or documents that were omitted that are needed to perform a detailed quality review and analyses of the KUP data. A detailed review and analyses of the KUP data were not planned under the referenced contract and SOW.

Cursory Review of KUP Data Package

Amec Foster Wheeler completed the cursory review of the KUP data and accompanying QA documents. A draft summary of the findings was provided to WESTAR via email on May 13, 2015. Based on comments received from the WESTAR Study Management Team (SMT), the findings were updated and a revised summary was provided to WESTAR on May 29, 2015. The KUP data and documentation provided by WESTAR and reviewed by Amec Foster Wheeler are included with this memorandum as Attachment 01. A copy of the revised summary of the findings from the cursory review is included with this memorandum as Attachment 02.

Description of the Denver-Julesburg Data Package

CEM, ambient pollutant, and meteorological data were collected during drill rig operations at two well pads (Pad 1 and Pad 2) during separate monitoring periods. During each monitoring period, ambient pollutant concentrations were measured simultaneously at 12 locations near the edge of the well pad on which the drill rig was operating. The same 12 monitors were used at each well pad, and from here on are referenced as Site 1, Site 2, Site 3,..., Site 12. The location of the ambient pollutant monitors was fixed during operations at Pad 1. During operations at Pad 2, four of the monitors (Sites 2, 3, 6 and 8) were relocated half-way through the monitoring period due to forecasted changes in the mean wind direction. Thus, the data collected during operations at Pad 2 are further divided into separate monitoring periods resulting in three monitoring periods and configurations from here on referenced as Pad 1, Pad 2a, and Pad 2b. Listed below are the monitoring periods for the corresponding monitoring configurations:

- Pad 1: October 10, 2014 - October 26, 2014;
- Pad 2a: November 3, 2014 (hour 0) - November 8, 2014 (hour 11); and
- Pad 2b: November 10, 2014 (hour 15) - November 16, 2014.

Refer to the Quality Assurance Project Plan (QAPP) and monitoring report for the locations of the drill rig equipment, ambient pollutant monitors, and meteorological tower for each of the three monitoring configurations. The QAPP and monitoring report are included in Attachment 03, the Denver-Julesburg NO₂ Monitoring Study Data Package, described later in this memorandum.

The CEM data include 5-minute and 1-hour averaged values and maximum values of NO_x (in parts per million, ppm), NO₂ (ppm), NO (ppm), CO₂ (%), O₂ (%), stack temperature (in degrees Fahrenheit, °F), and stack pressure (in inches of water, in. H₂O) though the documentation that accompanied the data is not clear with regard to the stack pressure units. The data include measurements from three generators operating at Pad 1 and the same three generators and a boiler that operated at Pad 2.

The ambient pollutant data include 5-minute and 1-hour averaged concentrations and maximum concentrations of NO_x (in parts per billion, ppb), NO₂ (ppb), NO (ppb) from each of the 12 monitoring sites and 5-minute and 1-hour averaged and maximum concentrations of O₃ (ppb) from Site 1 and 12. The following wind data (5-minute and 1-hour) are also included for Sites 1 and 12:

- Scalar wind speed (miles per hour, mph);
- Unit vector wind direction (decimal degrees);
- Standard deviation of the unit vector wind direction (decimal degrees);
- Vector wind speed (mph);
- Resultant wind direction (decimal degrees);
- Standard deviation of the resultant wind direction (decimal degrees); and
- Maximum wind speed (mph).

The following meteorological parameters were measured on a portable tower for which 5-minute and 1-hour values were provided:

- Scalar wind speed (mph);
- Unit vector wind direction (decimal degrees);
- Standard deviation of the unit vector wind direction (decimal degrees);
- Vector wind speed (mph);
- Resultant wind direction (decimal degrees);
- Maximum wind speed (mph);
- Wind elevation (decimal degrees);

- Wind sonic temperature (°F);
- 10-meter ambient temperature (°F);
- 2-meter ambient temperature (°F);
- Temperature difference, 10-meter minus 2-meter (°F);
- Rainfall total (inches); and
- Barometric pressure (in. Hg).

Amec Foster Wheeler received the final version of the 5-minute and 1-hour data from WESTAR on February 4, 2015. On March 27, 2015 WESTAR provided the QAPP and monitoring report but indicated the documents were not yet final and requested that Amec Foster Wheeler review the QAPP and monitoring report and submit any comments. Amec Foster Wheeler notified WESTAR of several inconsistencies between the tables, figures, and text. WESTAR provided a final data package on April 14, 2015 that included:

- 5-minute and 1-hour CEM, ambient pollutant, and meteorological data;
- Calibration records for ambient pollutant monitors;
- CEM operation logs for emissions sources;
- Plot plans;
- QAPP; and
- Monitoring Report.

The final Denver-Julesburg data and documentation as provided to Amec Foster Wheeler are included with this memorandum as Attachment 03. Amec Foster Wheeler performed a cursory review of the data package and reported the omission of the calibration records for the meteorological sensors. WESTAR confirmed that the calibration records for the meteorological sensors were not available. WESTAR also confirmed the 5-minute and 1-hour data had not changed from the version provided on February 4. The remaining sections under Task 1 describe the initial preparation, the QA procedures, and the modifications to the Denver-Julesburg data performed by Amec Foster Wheeler.

Initial Preparation of the Denver-Julesburg Data

Amec Foster Wheeler used R software¹ for statistical computing and graphics for all data processing including QA and formatting procedures and preparing the data for analyses. The 5-minute and 1-hour data files were provided to Amec Foster Wheeler in Microsoft Excel (.xlsx) and comma-delimited ASCII text (.csv) formats segregated into separate files by averaging period and data source meaning there were separate 5-minute and 1-hour files for each emission source, each ambient monitor, and the meteorological tower. To facilitate the use of R,

¹ R is a free software environment for statistical computing and graphics and is available for a wide variety of computing platforms including UNIX/Linux, Windows, and MacOS. R is available under the terms of the Free Software Foundation's GNU General Public License. For more information on the R Project for Statistical Computing, refer to <https://www.r-project.org/>.

Amec Foster Wheeler re-exported the data from within Microsoft Excel as comma-delimited ASCII text files with a modified date/time format. All R scripts developed for this project, including associated input and output files are included with this memorandum as Attachment 04.

QA Procedures Applied to the Denver-Julesburg Data and Findings

Many of the data elements in the 5-minute and 1-hour data have a corresponding status flag which gives some indication of the quality of the data or the reason why data are missing or not valid for use. Some data elements are grouped in which case there is a single status flag that pertains to the group of elements (e.g., wind data, temperature data, NO_x/NO/NO₂). The status flags used in the CEMS, ambient pollutant, and meteorological data as provided to Amec Foster Wheeler by WESTAR include:

- 0** = Valid
- 1** = The analyzer experienced an irregular event such as an irregular temperature or sample flow (assigned by the data logger)
- 2** = One or more measurements approached or exceeded the analyzer span value
- N** = Invalid data
- M** = Missing data
- C** = Calibration period
- D** = Maintenance/Downtime

The QA procedures used to verify the Denver-Julesburg 5-minute and 1-hour data are described in the sections that follow. The procedures were applied to all data records within the date/time period of October 10, 2014 (hour 0) through November 16, 2014 (hour 23) which correspond with the start of the monitoring period at Pad 1 and the end of the monitoring period on Pad 2 (configuration Pad 2b), respectively. Data outside of this date/time range were ignored. The data quality review focused on emissions concentrations, ambient concentrations, and meteorological parameters measured at the meteorological tower and Sites 1 and 12 for which there are status flags.

Verify Calibration Flags

Included in the QA documents were NO_x calibration forms for each of the 12 ambient pollutant monitoring sites and ozone calibration forms for Sites 1 and 12. CEM operation logs were provided for each of the three generators and a boiler (Pad 2 only). The CEM logs and calibration forms indicate that calibrations and performance checks were conducted for each of the 12 ambient monitor sites and the four emission sources almost daily. Amec Foster Wheeler extracted all records from the 5-minute and 1-hour CEM and ambient pollutant data in which the status flag for any data element or group of elements was marked as "C." Each calibration was manually matched with the related records in the 5-minute and 1-hour data and the data were

visually inspected to ensure the records were appropriately flagged during times when calibrations were performed. While some of the ambient monitor calibration forms reported both the start and end time of a calibration, many forms reported only the start time. Overall, the flagged records were consistent with the calibration forms. However, Amec Foster Wheeler identified several records in the 5-minute CEM and ambient pollutant data that were flagged as valid while a calibration or check was performed. We also identified records in the 1-hour ambient pollutant data flagged with a lowercase "c" rather than uppercase "C." This is not consistent with the documentation provided with the data and could be misinterpreted or ignored by a program that extracts data based on the value of the status flag. Amec updated the affected records so flags are consistent with documentation.

Verify Status Flags

Upon identifying status flags that are inconsistent with the accompanying documentation, Amec Foster Wheeler inspected all status flags in the data to ensure there were no other occurrences of undocumented status flags. No additional inconsistencies were found.

Verify 1-hour Averages

Amec Foster Wheeler calculated 1-hour averages for all averaged scalar parameters in the 5-minute data and compared them with the averaged values in the 1-hour data to ensure invalid data records were not included in the original 1-hour averages. A 1-hour average was calculated for a parameter if the parameter in the 5-minute data was at least 75% complete for the hour meaning at least nine records had to be considered usable for the hour (i.e., status flag = "0", "1", or "2"). To account for rounding, the calculated 1-hour average and the original 1-hour average were assumed equivalent if the absolute difference between the two values was less than or equal to 0.01. Discrepancies were identified including:

- Hours in which all 5-minute values for an hour are flagged as valid but the original 1-hour average is not consistent with the 5-minute data.
- Hours in which all 5-minute values for an hour are flagged as valid but a 1-hour average is not included in the 1-hour data. This occurs in the CEM data.
- Hours in which the all of the 5-min data are flagged invalid but a 1-hour average is included in the 1-hour data.
- Hours for which the 1-hour average is not consistent with the values in the 5-minute data and there are duplicate records (same date/time) in the 5-minute data.

The CEM data include two columns of 5-minute and 1-hour averages of stack temperature and pressure and corresponding maximum values measured during the averaging period. These data do not include status flags. Where data are missing, the data fields in the 5-minute data files contain the missing value indicator, -7999, rather than a blank field. There are cases in which the missing value indicator in the 5-minute CEM data has been included in the calculation of the 1-hour average. In addition, the 1-hour averages of temperature and pressure associated with the boiler emission source (Pad 2 only), are stored in incorrect fields in the original data. Amec corrected the affected records. The corrective action taken is discussed in more detail in

the section "Updates to the Denver-Julesburg Data." Documentation that accompanies the data indicates pressure values are reported in units of inches. Further clarification obtained indicates that the pressure is recorded in inches of water.

Identify Duplicate Records in the 5-minute Data

As noted above, duplicate records were discovered in the 5-minute data while verifying the 1-hour averages. In response, Amec Foster Wheeler inspected all of the 5-minute data and identified duplicate records in the 5-minute CEM, ambient pollutant, and meteorological data. In some cases the duplicate records displayed identical values for all parameters. In other cases the duplicate records had only the date/time in common.

Verify Data Ranges

The data were inspected to determine if any parameters were outside of the expected range of values by examining the minimum and maximum values of each parameter. Records were found in the 5-minute CEM data in which the NO_x, NO, or NO₂ value was reported as -7999. As indicated earlier, the temperature and pressure fields also reported -7999. Other records reporting a large negative pollutant concentration were found in the CEM and ambient pollutant data. In general, the CEM and ambient pollutant data were found to have a large number of negative pollutant concentrations. We also observed negative temperatures (e.g., -389 °F) outside of an expected range.

Evaluate Records with Status Flag "1" or "2"

Records with either a status flag "1" or "2" exist in the CEM and ambient pollutant data. A "1" indicates the analyzer encountered an exception at least once during the averaging period, such as an irregular temperature, shelter temperature or sample flow rate. The exact cause was not retained in the data. A "2" indicates a measurement was either close to or outside of the lower or upper bounds of the range of the instrument at least once during the averaging period. Neither of these flags indicates the data are invalid but are suspect and should be evaluated. These records were identified and evaluated. Amec Foster Wheeler found no clear justification for invalidating any of the records with a status flag "1" or "2."

Time-series and Scatter Plots

Time-series and scatter plots were generated to aid in verifying and validating meteorological parameters, emission values and ambient pollutant concentrations by emission source and monitoring site. Separate sets of plots were generated for the 5-minute and 1-hour data collected during operations at Pad 1 and Pad 2, though the data collected during operations at Pad 2 were not further delineated by monitoring configuration. The plots illustrate some of the issues discovered from other QA procedures such as the negative values that occur in the CEM and ambient pollutant data files. The following time-series plots were generated from the 5-minute and 1-hour averaged data:

- CEM NO_x, NO, NO₂, O₂, CO₂
- Ambient NO_x, NO, NO₂, O₃

- Scalar Wind Speed
- Vector Wind Speed
- Unit Vector Wind Direction
- Resultant Wind Direction
- 2-meter and 10-meter Temperature (from meteorological tower)
- Barometric Pressure
- 1-hour Scalar Wind Speed Difference (Tower minus Site 1, Tower minus Site 12)

The following scatter plots were generated from the 5-minute and 1-hour averaged data:

- Scalar Wind Speed (Site 1 vs Site 12)
- Unit Vector Wind Direction (Site 1 vs Site 12)
- Vector Wind Speed (Site 1 vs Site 12)
- Resultant Wind Direction (Site 1 vs Site 12)
- 10-meter vs 2-meter Temperature (from meteorological tower).

The time-series and scatter plots generated from the original 5-minute and 1-hour data, prior to applying updates to the data, are included with this memorandum as Attachment 05.

Verify Ambient Pollutant Monitor Locations

In addition to QA procedures specific to the 5-minute and 1-hour data, Amec Foster Wheeler confirmed the geographic coordinates provided in the monitoring report for each of the emission sources and ambient pollutant monitors for each monitoring period and configuration. Coordinates from the monitoring report were converted to Universal Transverse Mercator (UTM) coordinates (Zone 13), plotted, and the locations verified with the plot plans provided with the data.

Updates Applied to the Denver-Julesburg Data

Based on the findings of the data quality review discussed in the previous section, the 5-minute and 1-hour Denver-Julesburg CEM, ambient pollutant, and meteorological data were updated to address the following:

- Duplicate records in the 5-minute data;
- 1-hour averages not consistent with 5-minute data;
- Erroneous measurement values flagged as valid (e.g., -7999);
- Status flags not consistent with calibration records;
- Treatment of negative CEM and ambient pollutant concentrations; and
- 1-hour CEM boiler temperature and pressure data stored in incorrect fields (Pad 2 only).

Updates to the data were applied both manually and with the use of an R script depending on the type of data modification required. Manual updates were applied first to both the 5-minute

and 1-hour data, then the R script was run to further update the manually augmented files and recalculate 1-hour averages from the 5-minute data, where applicable. 1-hour averages were recomputed for only those hours with modified 5-minute data records for the parameters that were changed, with the exception of the CEM temperature and pressure data. To address issues specific to the CEM boiler temperature and pressure data in which the 1-hour data were stored in the wrong fields, all 1-hour averages were recalculated and updated from the 5-minute data. For all other parameters, 1-hour averages for which the 5-minute data were not updated were preserved.

Modified records were flagged in both the updated 5-minute and 1-hour files. Update flag fields were appended to the end of each record to correspond with each of the status fields in the original data. The column names for the added update flag fields were prefixed with "Upd_" (e.g., Upd_NO, Upd_O2, Upd_CO2, Upd_O3, Upd_Met, etc.). The update flags, description, and action taken are as follows.

N = Invalid value (e.g., NO_x < -10)

R = Either the 1-hour average does not match average computed from 5-minute data or another field was altered which affects 1-hour average of current field

D = Duplicate record in 5-minute data.

C = Calibration was performed during time interval.

Z = Negative ambient pollutant or emission value set to zero.

5 = (1-hour data only) Corresponding 5-minute data records were updated and 1-hour average was recalculated. Refer to corresponding 5-minute data records to see the reason for the update.

Manual Updates

The following manual updates were applied:

1. Where the 1-hour average was not consistent with 5-minute data (based on the unit of measure), the corresponding update flag in the 5-minute data was set to "R" to indicate 1-hour average has been recalculated.
2. Where a calibration was performed and the record was not flagged appropriately, the corresponding status flag was set to "C" and the corresponding update flag was set to "C" to indicate the 1-hour has been recalculated.
3. Duplicate records were removed from 5-minute data and the corresponding update flag was set to "D" for remaining records to indicate the 1-hour average has been recalculated.

Scripted Updates using R

The following updates were automated using R:

Invalidate negative values (5-minute CEM and ambient pollutant data):

1. Where any one of NO_x, NO, or NO₂ was less than -10 (ppm for CEM, ppb for ambient pollutant data), the value of NO_x, NO, and NO₂ and the corresponding maximum value was set to NULL, the corresponding status flag was set to "N", and the corresponding update flag was set to "N".
2. Where O₂ was less than -10%, the value for O₂ was set to NULL and the corresponding update flag was set to "N".
3. Where CO₂ was less than -10%, the value for CO₂ was set to NULL and the corresponding update flag was set to "N".
4. Where O₃ was less -10 ppb, the value for O₃ was set to NULL and the corresponding update flag was set to "N".

Zero negative values (5-minute emissions and ambient pollutant data):

5. For NO_x, NO, NO₂, O₂, CO₂ and O₃: where the value was between -10 (ppm for CEM, ppb for ambient pollutant data) and zero, the value was changed to zero and the corresponding update flag was set to "Z". *(Note: Instrument zero drift was not analyzed and the data were not shifted on the basis of instrument drift.)*
6. For the maximum value of NO_x, NO, NO₂, O₂, CO₂ and O₃: where the maximum value was less than zero (ppm or ppb for CEM or ambient pollutant data, respectively), the value was reset to zero. *(Note: Instrument zero drift was not analyzed and the data were not shifted on the basis of instrument drift.)*

Recalculate 1-hour averages from 5-minute data (CEM, ambient pollutant, and meteorology)

7. 1-hour averages were recalculated for each parameter (or group of parameters) for which the update flag in a 5-minute data record was set to N, Z, R, D, or C, either manually or via the update script. A new 1-hour average was calculated only if the 5-minute data were at least 75% complete for the hour (i.e., there were nine valid data values within the hour).
8. To correct issues specific to the stack temperatures and pressures in the CEM data, all occurrences of the missing value indicator -7999 were reset to NULL and 1-hour averages were recalculated for all hours using the same 75% completeness criteria described previously.
9. 1-hour data were updated with recalculated 1-hour averages where applicable.

Updates were applied to data records within the date/time period of October 10, 2014 (hour 0) through November 16, 2014 (hour 23), corresponding with the starting and ending hours of the Denver-Julesburg monitoring study across all three monitoring periods. Data outside of this

date/time range were not considered valid and were ignored. The R script used to update the original data along with the corresponding input and output files are included in Attachment 04. The updated 5-minute and 1-hour CEM, ambient pollutant, and meteorological data files generated with the update script are also included separate from the R scripts as Attachment 06.

Time-series and Scatter Plots

The time-series and scatter plots generated with the original 5-minute and 1-minute data were regenerated from the updated 5-minute and 1-hour data as an added measure to QA the changes that were applied. The time-series and scatter plots generated from the updated 5-minute and 1-hour data are included with this memorandum as Attachment 07.

Task 2: Prepare Denver-Julesburg Basin Data for Analyses

The purpose of Task 2 was to further prepare the updated data for analyses and formatting. Subtasks include: 1) replacing invalid/missing data values with NULL, blank, or a missing value indicator as needed to perform the analyses; 2) identify missing date/times where records were omitted from the original 5-minute and 1-hour data and insert records such that the data are consecutive without gaps; and 3) delineate the data into three distinct subsets defined by the three monitoring configurations and corresponding monitoring periods (i.e., Pad 1, Pad 2a, and Pad 2b).

Replacing Invalid Values and Missing Data with NULL, blank, or Missing Value Indicator

Data values with a status flag of "N", "C", "M", or "D" are considered invalid and should not be included in any analyses or input to AERMOD. The reported value for any data element flagged as such was set to "NA" which has special significance in R, meaning the data are "not available." This treatment of the data was included in the R scripts developed under Task 1 when the data were loaded into R to perform the QA procedures and is maintained throughout the completion of Task 2.

Identify and Fill Missing Date/Times

Updated 5-minute and 1-hour data generated under Task 1 were processed with R to identify date/times omitted from the original data. Where omitted, records were inserted to fill missing date/times to ensure the data records are consecutive throughout each of the monitoring periods. For inserted records, data fields were set to "NA" and status flags were set to "M" to indicate the data are missing. Data were filled within the date/time period of October 10, 2014 (hour 0) through November 16, 2014 (hour 23). Data outside of this date/time range were ignored since they were outside of the three study monitoring periods. The filled 5-minute and 1-hour CEM, ambient pollutant, and meteorological data files are included with this memorandum as Attachment 08.

Delineate Data by Monitoring Period and Ambient Monitor Configuration

The R scripts developed under Task 1 and 2 require a beginning and ending date/time specified by the user. Therefore, the data can be processed for any time span specified. To facilitate further processing using R, the updated and filled 5-minute and 1-hour data files generated under Task 1 and Task 2, respectively, are not delineated by monitoring period or monitoring configuration. Rather, they are consecutive from the start of monitoring at Pad 1 through the end of monitoring at Pad 2. A "Site" column in the data identifies the source of each 5-minute and 1-hour record. However, the data have been delineated and output as needed under Task 3 and Task 4.

Task 3: Perform Data Analyses on the Denver-Julesburg Basin Data

Some of the analyses identified in Task 3 are dependent on the results of another so that they must be completed successively. Amec Foster Wheeler completed some of the initial steps in the succession of analyses, discussed below, on which several of the subsequent analyses will depend.

Compute Azimuth between Emission Sources and Ambient Pollutant Monitors

For each monitoring configuration (Pad 1, Pad 2a, and Pad 2b), Amec Foster Wheeler computed the centroid coordinates for each group of sources, the azimuth from the source centroid to each ambient pollutant monitor site, the distance from the centroid to each monitor site, and the equivalent azimuth wind direction (i.e., direction of the wind if the wind was blowing from the emission source centroid directory toward the monitor site). The results are stored in a comma-delimited ASCII text file included with this memorandum as Attachment 09.

Identify Site of Hourly Peak Ambient Concentration and Relationship to Emission Source

For each monitoring configuration (Pad 1, Pad 2a, and Pad 2b) and pollutant (NO_x, NO, and NO₂), Amec Foster Wheeler identified the hourly peak concentration, the ambient monitoring site where the peak concentration occurred, and computed the sum of the hourly emissions across all sources. Presented along with these data are the hourly wind speed, wind direction, the azimuth equivalent wind direction, and the measured concentration at each ambient monitoring site. These data were compiled and output separately for each of the three monitoring configurations and each pollutant in comma-delimited ASCII text files that can be imported into Microsoft Excel for viewing or further processed and utilized with subsequent analyses. These data files are included with this memorandum as Attachment 10.

Task 4: Format Data for AERMOD Model Evaluation

The goals of Task 4 were to format the Denver-Julesburg hourly CEM and meteorological data for use with the AERMOD dispersion model. AERMET, the meteorological preprocessor for AERMOD can process onsite hourly and sub-hourly meteorological data, supplemented with archived surface and upper air data from the National Oceanic and Atmospheric Administration (NOAA). Similarly, AERMOD can read a variable hourly emission rate file when supplied to the model in a compatible format.

Format 1-hour Meteorological Data for AERMET

Amec Foster Wheeler formatted the applicable Denver-Julesburg 1-hour meteorological parameters measured on the meteorological tower for input to AERMET. The following meteorological parameters were extracted from the updated, date-filled 1-hour data file generated under Task 2 (Attachment 08), the units of measure were converted to the units listed that are required by AERMET, and fields that were missing data were filled with the default missing value recognized by AERMET:

- Year, Month, Day, Hour
- Scalar Wind Speed (meters per second, m/s), missing = 99
- Unit Vector Wind Direction (decimal degrees), missing = 999
- Standard Deviation of Unit Vector Wind Direction (decimal degrees), missing = 99
- 2-meter Temperature (degrees Celsius, °C), missing = 99
- 10-meter Temperature (°C), missing = 99
- Delta-Temperature (10-meter minus 2-meter, °C), missing = 9
- Rainfall (millimeters x 100), missing = -9
- Barometric Pressure (millibars x 10) , missing = 99999

AERMET assumes all meteorological data follow the hour-ending convention. The hour-ending convention assumes the 1-hour average is computed from the higher resolution data since the last hour leading up to the current hour. AERMET also uses a 1-24 representation of the hour rather than a 0-23 hour representation. The Denver-Julesburg 1-hour meteorological data were averaged from the 5-minute data based on the hour-beginning convention and a 0-23 hour representation. 1-hour averages using the hour-beginning convention are computed using the data from the current hour leading up to the next hour. For AERMET to properly pair the hourly Denver-Julesburg data with NOAA surface and upper air data that may be required as input to AERMET, the hour in the AERMET formatted data file was incremented by one hour. This simulates the hour-ending convention assumed by AERMET and converts the hour to a 1-24 hour representation.

The data were delineated by monitoring period and configuration, and separate files were created for each of the three configurations (i.e., Pad 1, Pad 2a, and Pad 2b). Two file formats were generated for each monitoring configuration: 1) comma-delimited ASCII text file (.csv) with column headers to view in Microsoft Excel and 2) fixed-length ASCII text file (.txt) with column headers removed for input to AERMET. The formatted hourly meteorological data files are included with this memorandum as Attachment 11.

Amec Foster Wheeler tested the format of the fixed-length ASCII text files with the AERMET meteorological preprocessor, version 14134, to ensure AERMET would properly read and process the files. AERMET processes the meteorological data in three stages (Stage 1, Stage 2, and Stage 3), each of which requires a separate control file. All three stages were run successfully. The message and report files generated during each stage were reviewed for errors and significant warning messages and corrections were made as needed. The AERMET

test files which include the control file for each processing stage, input data, and output files are included with this memorandum as Attachment 12. To process the Denver-Julesburg onsite meteorological data, the following keywords and parameters should be included in the AERMET Stage 1 control file within the ONSITE pathway definition:

- OSHEIGHTS 2.0 10.0
- DELTA_TEMP 1 2.0 10.0
- READ 1 OSYR OSMO OSDY OSHR PRCP PRES DT01 TT01 TT02 WS02 WD02 SA02
- FORMAT 1 FREE

Refer to the current *AERMET User's Guide*² and the *Addendum to the AERMET User's Guide*³ for keyword definitions.

Depending on the meteorological parameters supplied to AERMET as onsite data, AERMET may also require representative surface measurements taken at a nearby airport as well as upper air sounding data to supplement the onsite data. For testing purposes, Amec Foster Wheeler supplemented the formatted onsite data with 2014 NOAA surface and upper air data from the Denver International Airport. The third stage of processing performed by AERMET also requires the input of surface characteristics (albedo, Bowen ratio, and surface roughness length) that are representative of the location where the onsite and NOAA surface data are collected. Arbitrary values for surface characteristics were input to AERMET for test purposes only. It should be noted, prior to running AERMET to process the Denver-Julesburg onsite meteorological data to evaluate the AERMOD model, nearby surface and upper air stations should be researched and evaluated to determine the most suitable data to supplement the Denver-Julesburg onsite data, and representative surface characteristics should be developed.

Format 1-hour CEM Data for AERMOD

Amec Foster Wheeler was not able to format the 1-hour CEM data as an hourly emission rate file for input to AERMOD. The parameters required in the hourly emission file for point sources include a mass emission rate (in grams per second, g/s), stack gas exit temperature (in degrees Kelvin, K), and stack gas exit velocity (m/s). Hourly flow rates are needed to convert the emission concentrations reported in parts per million to a mass emission rate in units of grams per second and to derive the stack gas exit velocity. Flow rate, stack gas velocity, and mass emissions data were not provided in the CEM data. Further review and evaluation is needed.

² User's Guide for the AERMOD Meteorological Preprocessor (AERMET). U.S. Environmental Protection Agency. EPA-454/B-03-002. November 2004.

³ Addendum: User's Guide for the AERMOD Meteorological Preprocessor (AERMET). U.S. Environmental Protection Agency. May 2014.

RECOMMENDATIONS FOR NEXT STEPS

Additional QA of the CEM Stack Temperature and Pressure Data

The 5-minute and 1-hour CEM stack pressure and temperature data were updated as a result of the findings of the QA performed under Task 1. However, uncertainty remains in the quality of the updated data and further QA is warranted. Amec Foster Wheeler noted previously the existence of large negative temperature values. The temperature data are required in an hourly emission rate file when hourly variable emission rates are input to AERMOD. Amec Foster Wheeler also noted the units of measure for the pressure data are not clear in the monitoring report, but further clarification obtained indicates that the pressure was recorded in inches of water.

Analyses of the Denver-Julesburg Data

Amec Foster Wheeler completed the initial steps in the analyses of the Denver-Julesburg 5-minute and 1-hour data defined under Task 3. Amec Foster Wheeler recommends that additional effort be focused on the completion of the Task 3 analyses which include:

- Identify "Impact" hours in which one or more monitors were impacted by an emission source and "Background" hours in which no monitor was impacted by an emission source.
- Categorize "Impact" hours based on emission source (drill rig or mobile equipment).
- For "Impact" hours, evaluate plume characteristics (e.g., plume centerline and plume half width, NO₂/NO_x ratio across plume width, cross-wind integrated concentrations).
- Quantify hourly background concentrations of NO, NO₂, NO_x, and O₃.
- Compile statistics on the frequency of "Impact" versus "Background" hours.
- Compare on-site ozone data with nearby AQS monitors and evaluate historical AQS monitors to develop a plan for ozone data substitution for missing ozone.
- Prepare proposed ozone dataset for consideration.
- Characterize NO_x/NO/NO₂ relationship based on emissions, meteorological, and background data.

Format 1-hour Denver-Julesburg CEM Data for AERMOD

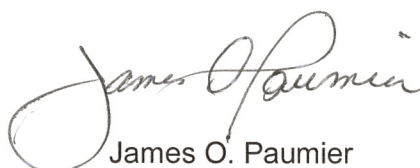
Flow rate data, needed to convert the Denver-Julesburg CEM data to hourly mass emission rates and format the data for input to AERMOD, were not provided and will need to be calculated. The CEM stack temperature data, also required by AERMOD, need further review.

Amec Foster Wheeler has appreciated the opportunity to work with WESTAR on this effort to review data collected for the Drill Rig 1-hour NO₂ Collaborative Monitoring Study, and we look forward to opportunities to work with WESTAR on future projects. Please feel free to contact us with any questions regarding the content of this memorandum.

Sincerely,



Clint R. Tillerson
Project Manager



James O. Paumier
Technical Reviewer

ELECTRONIC ATTACHMENTS

Attachment 01: Original Kuparuk River Unit NO₂ Monitoring Study Data Package

Attachment 02: Findings of the Cursory Review of the Kuparuk River Unit NO₂ Data

Attachment 03: Original Denver-Julesburg NO₂ Monitoring Study Data Package

Attachment 04: Project Related R Scripts Developed (Including Input and Output Files)

Attachment 05: Time-series and Scatter Plots, Original Denver-Julesburg Data

Attachment 06: Updated Denver-Julesburg 5-minute and 1-hour Data

Attachment 07: Time-series and Scatter Plots, Updated Denver-Julesburg Data

Attachment 08: Updated Consecutive (Date/Time Filled) Denver-Julesburg 5-minute and 1-hour Data

Attachment 09: Azimuths between Emissions Source Centroids and Monitoring Sites

Attachment 10: Site of Hourly Peak Ambient Concentration, Relationship to Emission Source

Attachment 11: Denver-Julesburg 1-hour Meteorological Data Files for Input to AERMET

Attachment 12: Denver-Julesburg AERMET Test Files