Ambient Ratio Method Version 2 (ARM2) for use with AERMOD for 1-hr NO_2 Modeling

Development and Evaluation Report

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Executive Summary

The majority of the oxides of nitrogen (NO_X) emissions from typical air emission sources are in the form of nitric oxide (NO), whereas EPA has established a National Ambient Air Quality Standard (NAAQS) for nitrogen dioxide (NO_2). EPA has approved a three-tiered screening approach to calculating NO_2 concentrations based on AERMOD predictions of total NO_X concentrations, including the Tier 2 Ambient Ratio Method (ARM) and the Tier 3 Ozone limiting Method (OLM) and Plume Volume Molar Ratio Method (PVMRM).

This report discusses the development and evaluation of an updated Ambient Ratio Method, referred to as “ARM2”. EPA’s current recommendation for ARM uses a fixed ambient ratio of 0.8 for modeling of 1-hr averages, which will often overestimate 1-hr NO_2 concentrations. ARM2 incorporates a variable ambient ratio that is a function of model predicted 1-hr NO_X concentration, based on an analysis of hourly ambient NO_X monitoring data from approximately 580 stations over the period 2001-2010.

ARM2 has some advantages over the current EPA Tier 3 conversion methods for 1-hr NO_2 dispersion modeling. Unlike the Tier 3 methods, ARM2 does not require additional input data that is subject to case-by-case review and approval. The model execution time for ARM2 is faster than for these more computationally intensive refined methods. The ARM2 method performs better than the current ARM method, and is comparable to the more refined EPA modeling methods for 1-hour ambient NO_2 concentrations. ARM2 may help reduce the resources expended by both the regulated facility and the reviewing agency to perform and approve 1-hr NO_2 modeling analyses.

This report presents the data and procedures used to develop ARM2. Performance evaluations and sensitivity analyses of ARM2 and the current refined methods are also presented. The key findings of this study are:

1. Plots of ambient NO_2/NO_X ratios as a function of NO_X concentration from various ambient monitoring data sets show a consistent relationship of decreasing ambient ratios

with increasing NO_X concentrations. At NO_X concentrations above approximately 300 ppb, the observed ambient ratios cluster in a range of approximately 0.1 to 0.2.

2. The ARM2 conversion method was developed using 10 years of ambient monitoring data from 580 monitoring sites in EPA's AQS data base. ARM2 uses an empirically derived relationship between the upper limits of the observed NO_2/NO_X ambient ratio versus the ambient NO_X concentration.
3. ARM2 predicted ambient ratios derived from various geographical, land use, and time period data sets were evaluated and found to be similar to, and typically lower than, the ratios predicted by the "All AQS Sites" equation. This indicates that the ARM2 equation derived from the "All AQS Sites" data set is representative of a wide range of geographical or land use categories, and can be used as the basis of the ARM2 method.
4. The ARM2 conversion method has been programmed into the latest version of AERMOD (version 12345).
5. The performance of the ARM2 method has been compared to monitoring observations and predictions from the Tier 3 screening methods, using the same evaluation data sets that have previously been used to test the Tier 3 methods. Plots of ambient ratios versus NO_X concentration indicate that all methods overpredict the observed ambient ratios. Scatter plots of predicted versus observed NO_2/NO_X ratios indicate that all methods have little skill in predicting the ambient ratio on a "paired in space and time" basis. The Q-Q NO_2 plots also indicate that all three methods over-predict the highest NO_2 concentrations by factors ranging from approximately 1.2 to 2.0.
6. The Robust Highest Concentration (RHC) summary of the evaluation results is a measure of model performance based on the top 26 highest modeled and observed NO_2 concentrations (which range from 55 to 196 $\mu g/m^3$). The RHC summary indicates that the AERMOD-ARM2, AERMOD-OLM, and AERMOD-PVMRM methods perform very similar, and all 3 methods are on average over-predicting the observed concentrations by factors of 1.8, 1.7, and 2.0 respectively. The ARM2 RHC result falls between the OLM and PVMRM results.
7. Sensitivity analyses were performed for the ARM2, PVMRM, OLM, and full conversion methods across a range of meteorology and source characteristics. The scenarios modeled included updated versions of those described in the MACTEC report

"Sensitivity Analysis of PVMRM and OLM in AERMOD", 2004, for the diesel generator, gas turbine, and 35-meter stack "single source" scenarios, and the cumulative source scenario. For the single source sensitivity scenarios with low predicted NO_X concentrations (below 20 µg/m^3), all of the conversion methods predicted NO_2/NO_X ratios near 0.9. When the predicted NO_X concentrations were higher (greater than 300 µg/m^3), all the methods predict NO_2/NO_X ratios in the range of 0.2 to 0.4, with ARM2 conservatively predicting the highest NO_2/NO_X ratios of any of the methods. For the multi-source scenario, the model predicted NO_X concentration is 1,774 µg/m^3, and the predicted NO_2/NO_X ratios are 0.13 for OLM, 0.18 for PVMRM, and 0.2 for ARM2.

8. Some additional multi-source scenarios were also analyzed. These scenarios were based on real-world configurations of large diesel IC generators, a refinery, a gas pipeline compressor station, natural gas production fields and processing plants, and a large boiler in complex terrain. The ARM2 method predicts higher or similar ratios when compared to the Tier 3 methods. Two of the cases were further evaluated because of suspiciously high PVMRM predicted ratios, and based on comparisons of PVMRM versus OLM "source-by-source" predicted ratios, it was concluded that PVMRM is predicting unrealistically high concentrations and ratios for those cases. In summary, the additional multi-source sensitivity analysis indicates that the ARM2 method predicts higher or similar ratios when compared to the two Tier 3 methods.

The performance evaluations and sensitivity analyses presented in this report document that the general performance of the ARM2, PVMRM, and OLM methods is similar. The relative performance ranking between the three methods varies depending upon the data set, and there are cases when PVMRM is predicting unrealistically high NO_2/NO_X ratios. PVMRM formulation issues have previously been identified[1], and it is possible that the over-estimation of plume volumes and the resulting number of moles of ozone available for NO conversion may be responsible for the anomalous performance of PVMRM.

[1] Hendrick, E., S. Hanna, B. Egan, V. Tino, 2011, Technical Review of the Ozone Limiting Method (OLM) and Plume Volume Molar Ratio Method (PVMRM) Codes in the ISC3 and AERMOD Models.

Based on the analyses presented herein, it is recommended that ARM2 be approved by EPA as a refinement to the current fixed-ratio ARM method for performing 1-hr NO_2 analyses, or be approved as an additional Tier 3 screening method. Consistent with other recent updates to AERMOD, EPA could implement this refinement by posting a memorandum on the SCRAM website authorizing the use of ARM2 for AERMOD modeling analyses and referencing this report as supporting documentation. An updated version of AERMOD should also be posted that includes the ARM2 model option.

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1.0 Introduction

The majority of the oxides of nitrogen (NO_X) emissions from air emission sources are in the form of nitric oxide (NO), whereas EPA has established a National Ambient Air Quality Standard (NAAQS) for nitrogen dioxide (NO_2). EPA's "Guideline on Air Quality Models" (GAQM), 40 CFR Part 51 Appendix W, describes a three-tiered screening approach to calculating NO_2 concentrations based on dispersion model predictions of NO_X concentrations (NO_X is modeled as if it is a conserved or non-reactive tracer). The three tiers, arranged in order from simplest to most refined, are:

- Tier 1 – Assume full conversion of NO to NO_2, so that the NO_X predicted by AERMOD is 100 % NO_2
- Tier 2 – Ambient Ratio Method (ARM), where model predicted NO_X concentrations are multiplied by a NO_2/NO_X ambient ratio, derived from ambient monitoring data
- Tier 3 – More detailed methods that account for the plume dispersion and chemistry may be considered on a case-by-case basis, including the Ozone Limiting Method (OLM) and the Plume Volume Molar Ratio Method (PVMRM).

EPA's Appendix W guidance regarding NO_2 modeling addresses only annual averages. EPA has issued additional guidance[2] on NO_2 conversion methods for 1-hr NO_2 National Ambient Air Quality Standard (NAAQS) modeling (hereafter referred to as the 2011 Additional Clarifications memo). EPA has stated that the Appendix W tiered methodologies do apply to the 1-hour NO_2 NAAQS, but additional issues must be considered. For example, EPA currently recommends the use of an ambient NO_2/NO_X ratio of 0.80 as a default ARM value for 1-hour NO_2 analyses without additional justification by applicants, and EPA has provided some default values for inputs to the Tier 3 OLM and PVMRM methods. However, use of the Tier 3 screening methods still requires justification of key inputs such as in-stack NO_2/NO_X ratios, and approval for use on a case-by-case basis.

[2] "Additional Clarification Regarding Application of Appendix W Modeling Guidance for the 1-hour NO2 NAAQS", dated March 1, 2011.

NOx is emitted from typical combustion sources primarily as nitric oxide (NO), and in smaller quantities directly as NO_2[3]. NO emissions react with ozone and other oxidants in the atmosphere to convert NO to NO_2. During the early stages of plume dispersion (i.e., at distances ranging from approximately 1 to 10 km over time intervals of 10 to 300 minutes), the principal reaction mechanism for NO_2 formation is oxidation by ozone[4]. Janssen describes how the NO to NO_2 oxidation rate in the atmosphere is limited by both the chemical kinetics and the mixing rate of the plume with ambient air[5].

The ARM method, originally developed by Chu and Meyers[6], hypothesized that the complex NO_X chemistry and mixing processes occurring in the atmosphere can be empirically parameterized through the use of simple relations derived from large amounts of ambient monitoring data. They reviewed data from a number of NO_X monitoring sites throughout the US for the period 1987-1989, and calculated the annual average ambient NO_2 and NO_X concentrations and the annual NO_2/NO_X ratios at each site. They then selected the 90th percentile as an upper bound estimate of the conversion, and recommended the default ambient ratio of 0.75. In the annual average ARM method, the highest modeled annual NO_X concentration is multiplied by the ambient ratio to determine the modeled annual NO_2 concentration, which is added to a representative background concentration and compared to the annual NAAQS.

Chu and Meyers also presented plots of the observed hourly ambient ratio as a function of distance from the emission source, based on measurements reported for power plant plume studies and a wind tunnel experiment. These plots illustrated that higher NO_X concentrations and

[3] Rethinking the Ozone Problem in Urban and Regional Air Pollution; ISBN: 0-309-56037-3; National Academy of Sciences, 1991.

[4] Prakash Karamchandani, Annie Koo, and Christian Seigneur. Reduced Gas-Phase Kinetic Mechanism for Atmospheric Plume Chemistry. Environ. Sci. Technol. 1998, 32 (11), 1709-1720.

[5] L. H. J. M. Janssen, T F. T. M. Nieuwstadt, and M. Donze. Time Scales of Physical and Chemical Processes in Chemically Reactive Plumes. Atmospheric Environment 1990, 24A (11), 2861-2874.

[6] Chu and Meyers, “Use of Ambient Ratios to Estimate Impact of NOx Sources on Annual NO_2 Concentration”, presented at the 1991 Air and Waste Management Association annual meeting.

lower ambient ratios were observed near the source, and as the distance increased the NO_X concentration decreased and ambient ratio increased. Other field studies also show this same pattern. EPA cited two ambient monitoring studies in their 2011 Additional Clarifications memo. The Wang study[7] presents results from four short-term monitoring tests near roadways. The observed ambient NO_2/NO_X ratios varied from approximately 0.3 to 0.8, and the NO_2/NO_X ratios increased with distance from the emission sources while overall NO_X concentrations decreased with distance. Janssen's study[8] of NO_X chemistry in power-plant plumes also reports that NO_2/NO_X ratios increase as a function of distance (time) from source. Day time data plots show ambient ratios varying from about 0.2 within 2.5 km of sources up to about 0.8 at 10 km. Night time data plots show ambient ratios of about 0.1 within 4 km of sources, increasing up to about 0.4 at 20 km.

These observations of increasing NO_2/NO_X ratios and decreasing NO_X concentrations with distance are consistent with the simplified plume dispersion and NO_X chemistry mechanisms that are the basis of the PVMRM method. As a plume containing NO_X is transported downwind over time, there is increased plume dispersion and entrainment of ambient air. The increased entrainment brings additional ambient ozone into the plume, which causes additional conversion of NO to NO_2 through the fast oxidation reaction. These processes result in increased NO_2/NO_X ratios and decreased NO_X concentrations with the plume's increased dispersion over time.

The above studies suggest that using a fixed ARM ratio (NO_2/NO_X) of 0.8 will overestimate 1-hr NO_2 concentrations in the near field. Therefore, an updated version 2 of ARM has been

[7] Wang, Y.J., A. DenBleyker, E. McDonald-Buller, D. Allen and K. Zhang, 2011. Modeling the chemical evolution of nitrogen oxides near roadways. Atmos. Env., 45, 43-52.

[8] Janssen, L.M.J.M., F. Van Haren, P. Bange, and H. Van Duuren, 1991. Measurements and modelling of reactions of nitrogen oxides in power-plant plumes at night. Atmos. Env., 25A, No. 5/6, 829-840.

developed, referred to as “ARM2”. ARM2 is designed to predict more realistic ambient NO_2 concentrations because it incorporates a variable ambient NO_2/NO_X ratio.

Section 2 of this report describes the ambient monitoring data and data processing procedures used to compile 1-hr ambient NO_2/NO_X ratios. Section 3 describes the development of the ARM2 methodology. Section 4 presents evaluations of ARM2 using the same performance evaluation data sets that have previously been used to test the OLM and PVMRM methods. Section 5 presents sensitivity studies and comparisons of ARM2, OLM, and PVMRM for various modeling scenarios. Section 6 presents the overall study conclusions and recommendations.

2.0 Ambient NO_X Data Sources and Analysis

The analysis of ambient monitoring data for ARM2 development used the same basic concepts as Chu and Meyers in their development of the original ARM. The observed ambient NO_2/NO_X ratios from a large number of NO_X monitoring sites throughout the US have been calculated, and these data are used to develop an equation that calculates an upper bound of the ambient ratio as a function of the total NO_X concentration.

Recent 1-hr NO_2 and NO_X data from numerous monitoring sites throughout the US have been evaluated. These include three main monitoring data sets:

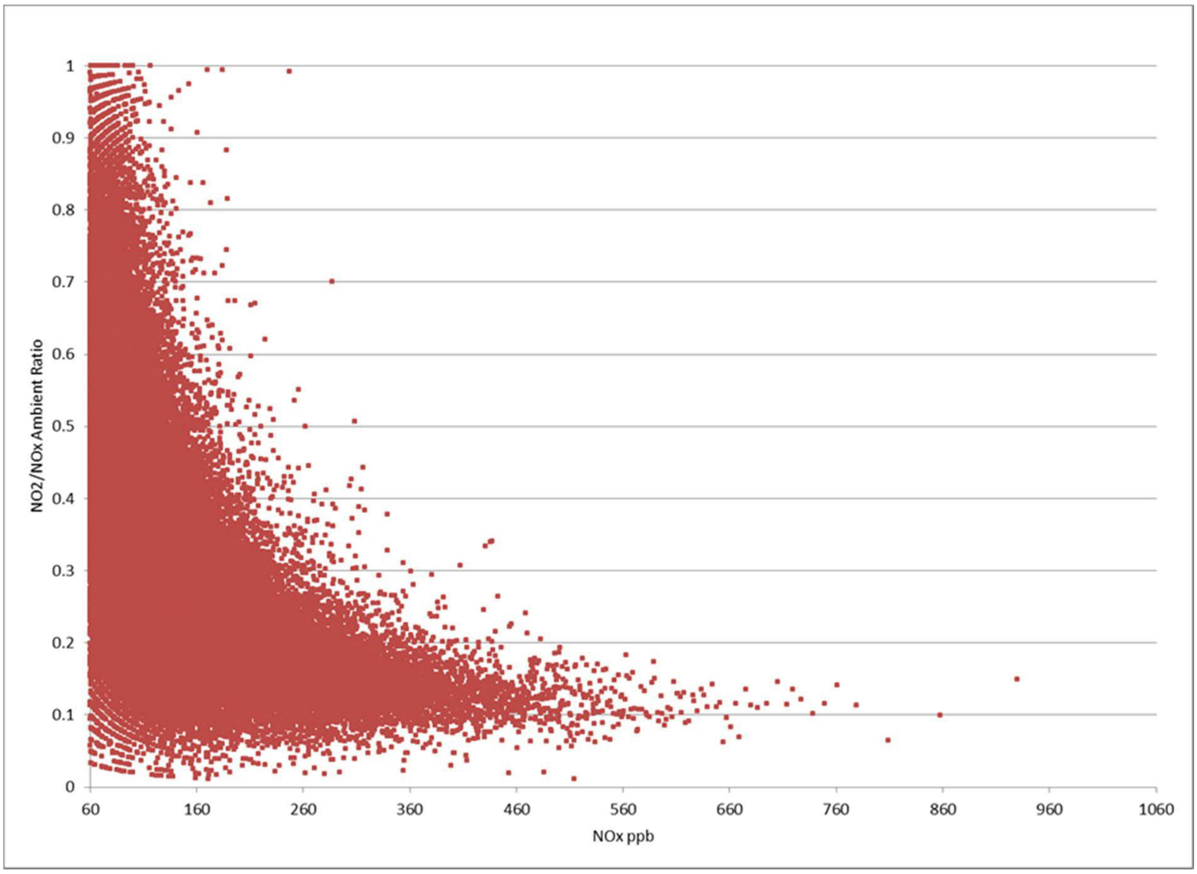
1. EPA's Air Quality System (AQS) 1-hr averaged NO_2 and NO_X ambient air quality data for the entire country from 2001 through 2010. This data is available in AQS "input transaction format" at http://epa.gov/ttn/airs/airsaqs/detaildata/downloadaqsdata.htm. Data from approximately 580 monitoring sites are available in this data set, and the number of valid hours of data with NO_X concentrations greater than 1 ppb is approximately 23,000,000.
2. Monitoring data from the performance evaluation data sets that have previously been used to test the Tier 3 methods, including the Empire Abo, NM, Palaau, HI, and Wainwright, AK, data sets.
3. A monitoring data set collected in the Athabasca Oil Sands region of Alberta, Canada, as reported by Jain[9]. These ambient data have been collected at 16 monitoring stations located throughout the Oil Sands Region, where numerous compressor engines and other NO_X emission sources are located.

[9] Jain, Önder, and Hoeksema in "Comparison of Ambient Ratio Method and Ozone Limiting Method for determining NO2 Concentrations in the Athabasca Oil Sands Region", presented at the 2011 Air and Waste Management Association annual meeting.

The ambient monitoring data were first evaluated by calculating and plotting the hourly ambient NO_2/NO_X ratio. The Wang and Jannsen studies were designed so that ambient ratios were directly measured as a function of distance from the specific emission sources, so that distance was used as the X axis to represent the amount of plume dispersion and entrainment that has occurred. The use of distance as the X variable is not possible for the data sets analyzed herein, because detailed information on the distance to sources is not available for the numerous ambient monitoring sites analyzed (in addition, each monitoring site may be impacted by emission sources at various distances and directions). Therefore, the ambient ratios were plotted against the measured NO_X concentration, which is a variable that, like distance, is directly related to the amount of plume dispersion and entrainment that has occurred.

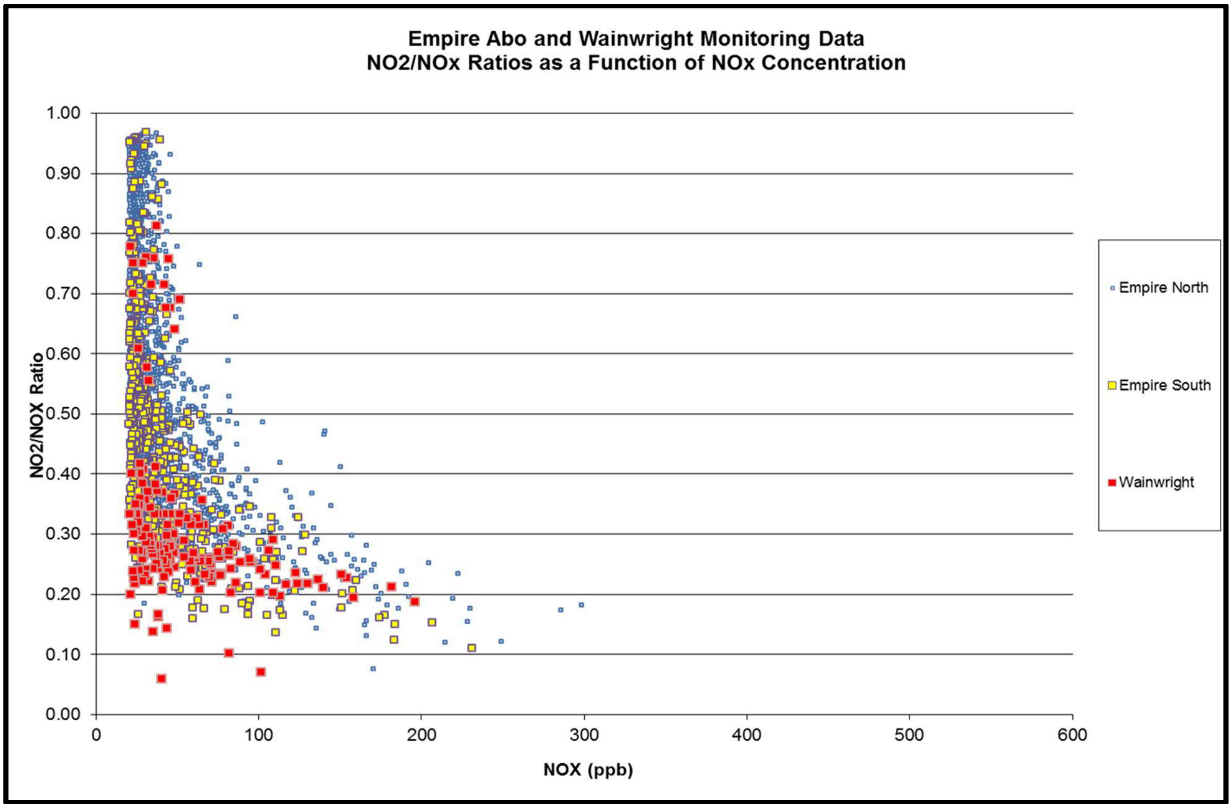
The plots of ambient ratios as a function of NO_X concentration from the three sets of data all show similar relationships, as illustrated in Figures 1 through 3. All plots indicate the same trend in decreasing ambient ratio with increasing NO_X concentrations. At higher NO_X concentrations (greater than 350 ppb), the observed ambient ratios tend to cluster in a range of approximately 0.1 to 0.2, which is similar to a typical “in-stack” NO_2/NO_X ratio and suggests very little NO_2 conversion beyond the in-stack levels. At lower NO_X concentrations (below 150 ppb) there is a much wider range of ambient ratios observed; this is a result of the varying transport and conversion times that are associated with low NO_X concentrations (low NO_X concentrations may be caused by nearby sources with low emissions, as well as more distant sources with higher emissions).

Figure 1– NO_2/NO_X Ratios for All AQS Monitoring Sites for 2001-2010



NOTE: There are approximately 6,800,000 valid hourly data points from 530 monitoring stations in this data plot. The X-axis for this plot begins at 60 ppb to limit the number of hourly data points to a size that the spreadsheet program can process.

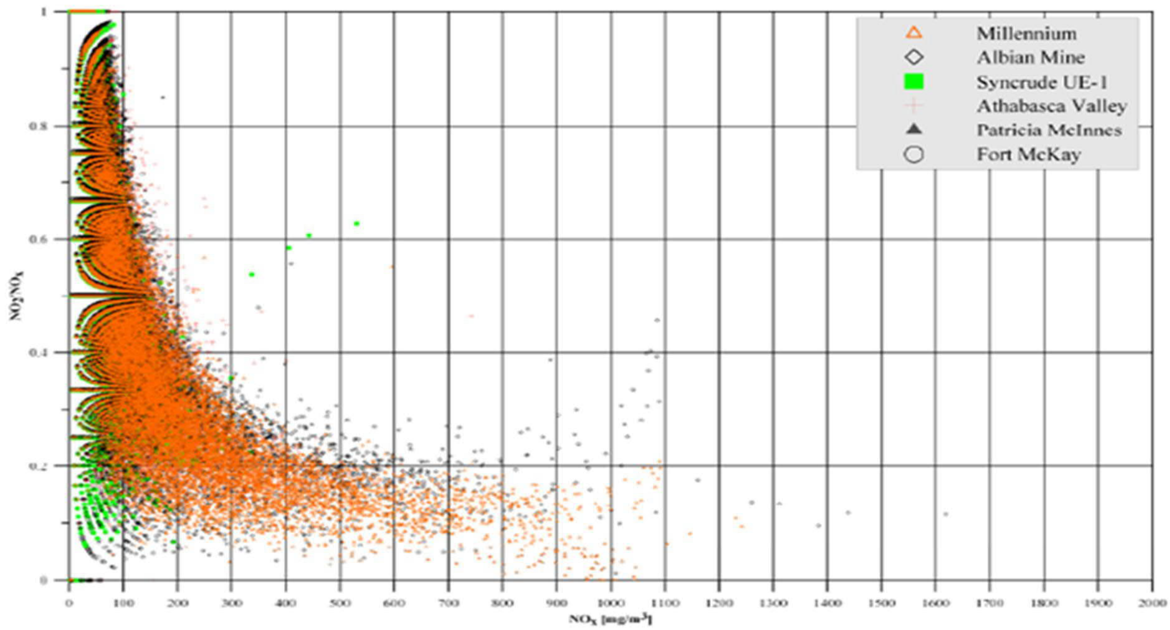
Figure 2 – NO_2/NO_X Ratios for Empire Abo and Wainwright Data



NOTE: There are approximately five years of monitoring data plotted in this graph. The minimum NO_X concentration begins at 20 ppb, which was used as a threshold to address the noise and variability in the measurements at low NO_X concentration ranges.

Figure 3 – NO_2/NO_X Ratios for Athabasca Oil Sands Data Set

Figure 1. Hourly NO_2 and NO_X Measurements at WBEA monitoring Stations



Note: Data from six monitors for the study year of 2006 are plotted. There appears to be an "upward tail" or spike of ambient ratios for NO_X concentrations around 900-1100 µg/m^3 (about 500-600 ppb) at the Albian mine (blue) and Millennium (orange) monitoring stations. Based on discussions with the study author, it is likely that these ambient ratio "spikes" at the 500 ppb NO_X concentration level are caused by the 500 ppb full scale setting of some NO_X analyzers, with NO_X measurements being "saturated" or "flattening out" at concentrations above 500 ppb. If the NO_X concentration measurements are saturated, this will result in increasing NO_2/NO_X ratios that are not representative of actual ambient ratios.

3.0 Development of ARM2 Method

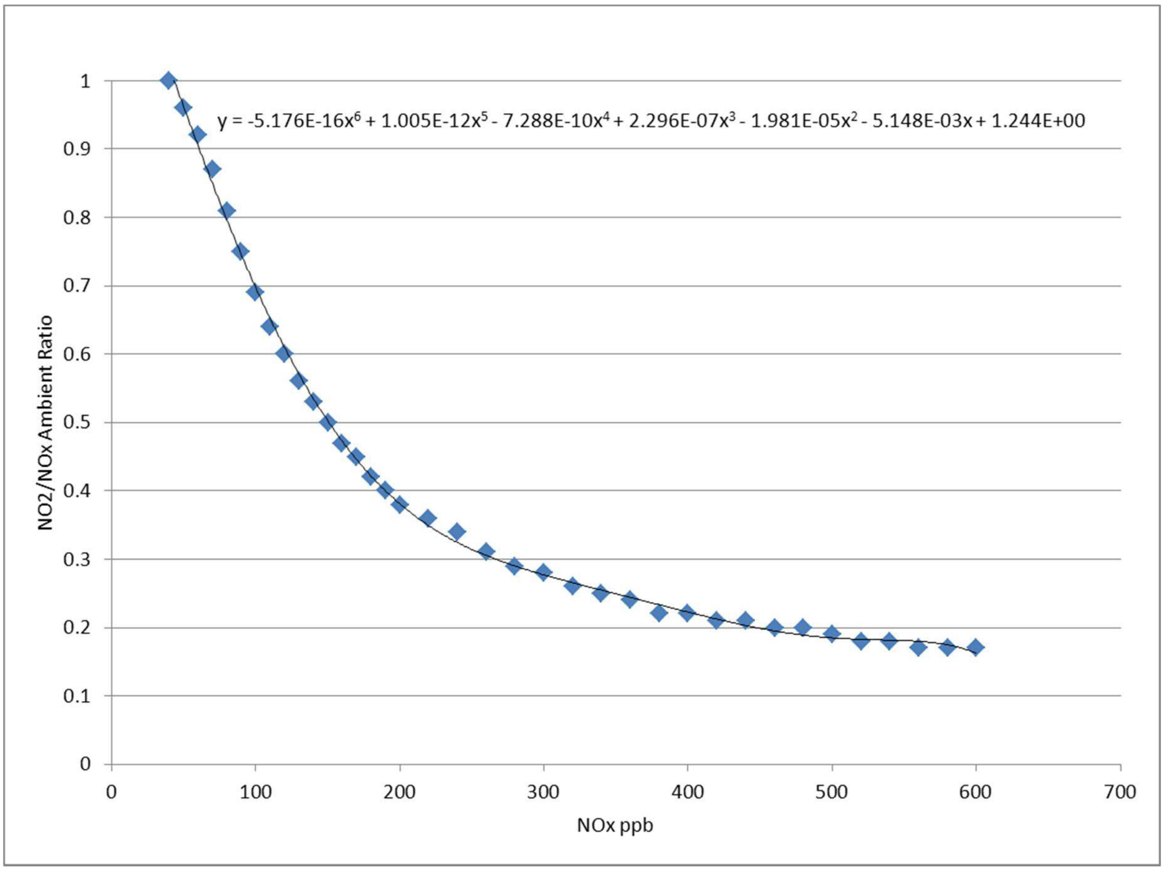
3.1 Initial Data Analysis

Chu and Meyers originally calculated the annual average ambient NO_2/NO_X ratios from a large ambient monitoring data set, and chose the 90th percentile value as a reasonable upper bound estimate for the default ARM ambient ratio. They also used 20 ppb as a lower NO_X concentration threshold to avoid the noise inherent in ambient monitor measurements at low concentration ranges.

For the ARM2 data analysis, hourly ambient NO_2/NO_X ratios were calculated from EPA's large, nationwide AQS data base and sorted into NO_X concentration "bins". A NO_X threshold of 20 ppb was again used as a lower concentration "cut-off". The NO_X concentration bins were 10 ppb wide over the range 20 to 200 ppb, and 20 ppb wide over the range 200 to 600 ppb (note there were very few NO_X measurements greater than 600 ppb). The upper bound of the observed ambient ratios was estimated for each NO_X concentration bin by calculating the 98th percentile of the observed ratios in that bin (see Section 3.3 of this report for a discussion of the use of the 98th percentile value). This results in a conservatively high estimate of the ambient ratio. To address small sample sizes, the data processing program reported the second highest ambient ratio as the 98th percentile value for the cases when there are less than 25 observations in a bin.

Figure 4 presents a plot of the calculated 98th percentile bin values for the entire "All AQS Sites" data set. The 98th percentile NO_2/NO_X ratios for each bin were fitted to a polynomial equation to develop the ARM2 conversion factor equation, which is also shown in Figure 8. ARM2 uses this empirically derived relationship between the upper limits of the observed NO_2/NO_X ambient ratio versus the ambient NO_X concentration. Appendix B presents detailed data from the analysis, including the number of observations in each NO_X concentration bin and the calculated percentile value for each concentration bin.

Figure 4 – 98th Percentile Ambient Ratios and ARM2 Equation for “All AQS Sites” Data



The ambient ratios calculated by the ARM2 equation were further constrained to a maximum value of 0.9 and a minimum value of 0.2. The maximum value is based on the current EPA recommendation for the maximum “equilibrium” ratio of 0.9 for the refined Tier 3 conversion methods. The minimum ambient ratio is based on two criteria, the analysis of ambient NO_2/NO_X ratios, and consideration of in-stack ratios for typical sources (which represents the minimum ambient ratio “floor”). First, the ambient monitoring data in Figures 1 through 3 were reviewed. At NO_X concentrations above 300 ppb, the observed ambient ratios tended to cluster in a range of approximately 0.1 to 0.2. Second, in-stack ratio information was reviewed to determine typical in-stack ratios for common source types. EPA's "alpha" version of the in-stack ratio data base [10] was reviewed. The available data were sorted by source category and a reasonable upper limit (90^{th} percentile) of the test data was determined. The resulting in-stack ratio for boilers and combustion turbines is approximately 0.1, and for IC engines approximately 0.2. This is consistent with data compiled by both the Alaska DEC [11] and the California Air Pollution Control Officers Association (CAPCOA) [12], which indicate that most in-stack ratios vary between 0.05 and 0.2 for these three source categories. Both the ambient ratio curves and the "consensus" in-stack ratio data indicate that a minimum ambient ratio value of 0.2 would address most applications of ARM2 (as discussed later, ARM2 has been implemented in AERMOD with an optional input value for the minimum ambient ratio, to address unique situations where the in-stack ratio for the modeled source may be higher).

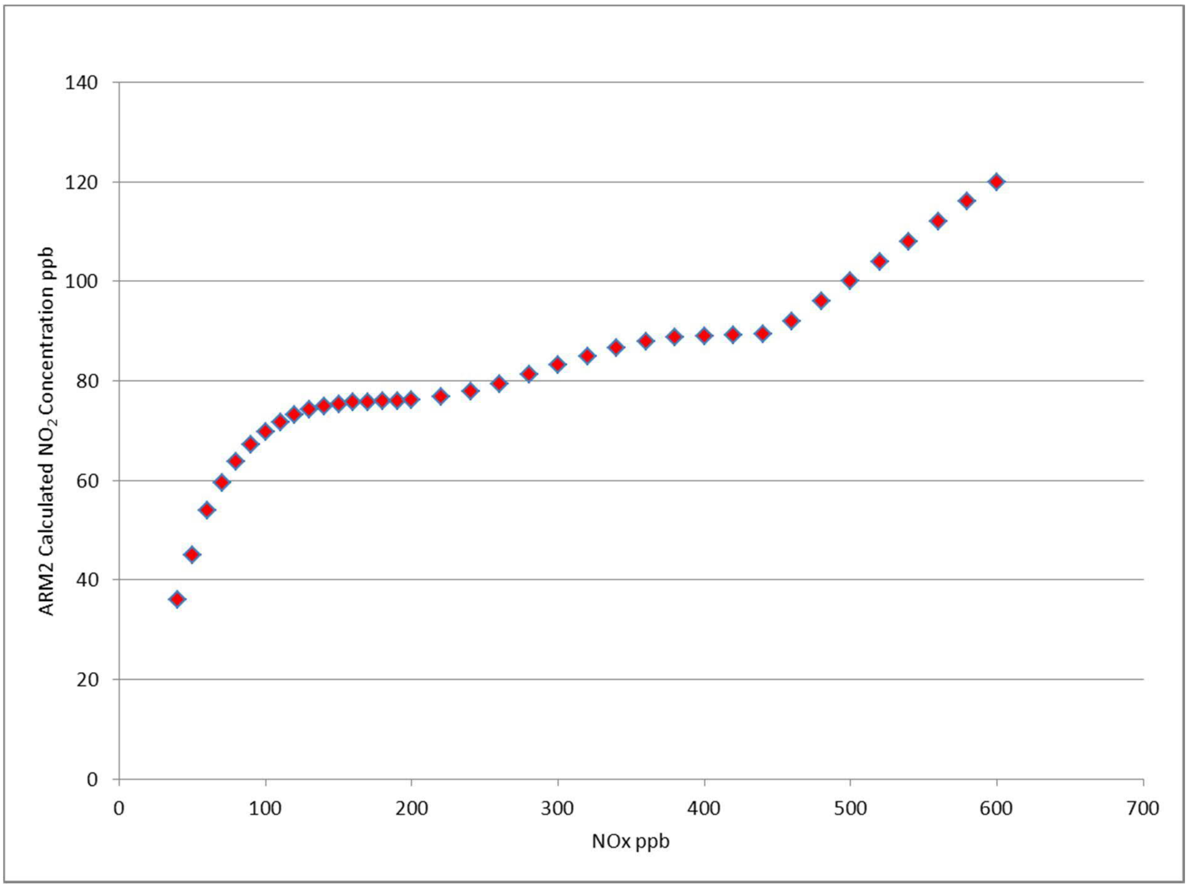
Figure 5 is a plot of the resulting ARM2 calculated NO_2 concentrations as a function of NO_X concentrations. The shape of this graph is consistent with Chu and Meyer's and Janssen's observations that NO_2 formation is limited at higher NO_X concentrations by both chemical kinetics and plume mixing rates. The ARM2 equation results in steadily increasing NO_2 concentrations at NO_X concentrations below approximately 150 ppb. The NO_2 concentration then levels off and slowly increases (the calculated NO_2 concentration never decreases as the NO_X concentration increases). After the NO_X concentration reaches approximately 450 ppb, the NO_2 concentration linearly increases with increasing NO_X concentration which is a result of the minimum ambient ratio of 0.2.

[10] http://www.epa.gov/ttn/scram/no2_isr_database.htm

[11] http://dec.alaska.gov/air/ap/docs/NO2-NOx%20Instack%20Ratios%20from%20Source%20Tests%205-21-12.xlsx

[12] http://www.valleyair.org/busind/pto/Tox_Resources/CAPCOANO2GuidanceDocument10-27-11.pdf

Figure 5 –ARM2 Calculated NO_2 Concentrations



3.2 Sensitivity of Ambient Ratio Equation to Monitoring Data Set

The sensitivity of the ARM2 equation to the data set used in the analysis was evaluated. The ARM2 equation was derived (as described in Section 3.1) using AQS data from different geographical regions, different land use categories (rural/suburban versus urban/city center as defined in the AQS monitor data base), and different time periods (2001-2003, 2004-2007, and 2008-2010). Data subsets were also investigated by selecting monitoring sites that were estimated to be within certain distances from sources with greater than 100 tpy of NO_X emissions (based on source data reported in EPA's 2008 National Emission Inventory data base at http://www.epa.gov/ttn/chief/net/2008inventory.html). For each data subset, a spreadsheet is presented in Appendix B that lists the number of observations in each NO_X concentration bin and the ARM2 calculated ambient ratio for each concentration bin. Again, the ambient ratios were constrained to a minimum of 0.2 and a maximum of 0.9.

For most of the data subsets, there was an elevated value for the 98th percentile ratio at the 500 ppb NO_X concentration bin when compared to the adjacent bins on either side. This is similar to the "upward spike" observed in Figure 3 for ambient ratios near the 500 ppb NO_X concentration level. It is likely that these ambient ratio "spikes" are caused by the 500 ppb full scale setting of most NO_X analyzers, with the NO_X measurements being limited at concentrations above 500 ppb. Therefore, the ambient ratios for the 500 ppb NO_X concentration bin were calculated as the average of the ratios for the two adjacent bins.

Table 1 summarizes the geographical region and land use category results. The first two columns in Table 1 list the number of observations and the "All AQS Sites" derived ambient ratios for the various NO_X concentration bins. The remaining pairs of columns for each of the data sets present first the number of observations in the bins, followed by the relative percent difference (RPD) for the calculated ambient ratio versus the "All AQS Sites" ambient ratio. In addition, at the bottom of the table the mean RPD is calculated over all NO_X concentration bins for each data set. The use of the RPD is a simple indicator for quantifying the differences in ambient ratios between the various data sets relative to the "All AQS Sites" equation. The number of observations in each bin is presented to help weight the significance of any observed differences (large differences in sample size may contribute to observed variability amongst the data sets).

The data in Table 1 indicate that the ratios determined from various geographical and land use data sets are all very similar to the "All AQS Sites" ratios, with mean RPDs within approximately ± 10%. The only data sets with a positive mean RPD (i.e., data sets that result in higher ambient ratios than the full AQS data set) are the Urban data (with a +0.4% mean RPD) and the Midwest region data (with a +1.9% mean RPD). Some of the difference in the Midwest data set may be attributable to the differences in sample size. In summary, Table 1 indicates that the ambient ratios calculated using the "All AQS Sites" data set are generally higher and therefore more conservative than the ratios predicted by the various regional or land use derived equations. There is no need to develop separate ARM2 equations for specific geographical or land use categories.

Table 1 - Calculated Ambient Ratios by Geographical Regions and Land Use Categories

Upper Nox BIN ppb	ALL Sites # Obs	ALL Sites Ambient Ratios	Rural & Suburban # Obs	Rural & Suburban Ambient Ratio RPD	Urban & City Center # Obs	Urban & City Center Ambient Ratio RPD	Northeast Region # Obs	Northeast Region Ambient Ratio RPD	Southeast Region # Obs	Southeast Region Ambient Ratio RPD	Midwest Region # Obs	Midwest Region Ambient Ratio RPD	Mountain Region # Obs	Mountain Region Ambient Ratio RPD	Southwest Region # Obs	Southwest Region Ambient Ratio RPD
30	2,330,786	0.90	1,295,731	0%	1,020,825	0%	643,420	0%	179,401	0%	283,397	0%	84,000	0%	324,695	0%
40	1,310,767	0.90	703,035	0%	601,939	0%	375,722	0%	82,728	0%	156,803	0%	51,663	0%	161,405	0%
50	817,380	0.90	426,294	0%	388,295	0%	236,081	0%	45,511	0%	95,480	0%	35,255	0%	92,570	0%
60	546,757	0.90	280,390	0%	264,973	0%	157,607	-3%	27,839	-3%	62,403	-3%	25,925	-6%	58,213	-3%
70	385,505	0.85	194,496	0%	190,229	0%	110,023	-5%	18,693	-5%	43,440	-4%	19,801	-8%	39,442	-6%
80	282,446	0.80	142,124	0%	139,879	0%	79,065	-6%	13,197	-8%	30,934	-4%	15,568	-9%	28,437	-8%
90	214,245	0.75	107,859	0%	106,102	0%	58,733	-7%	9,866	-10%	22,693	-3%	12,591	-10%	21,170	-9%
100	164,999	0.70	82,582	0%	82,251	0%	44,084	-8%	7,427	-11%	16,907	-3%	10,148	-10%	16,697	-11%
110	130,316	0.65	64,674	0%	65,527	0%	34,197	-9%	5,635	-13%	12,983	-2%	8,258	-11%	12,993	-12%
120	104,093	0.61	52,123	0%	51,895	0%	26,539	-10%	4,433	-14%	10,210	-2%	6,866	-10%	10,358	-13%
130	84,056	0.57	41,692	0%	42,318	0%	21,049	-11%	3,688	-16%	7,780	-1%	5,671	-10%	8,458	-14%
140	68,350	0.54	34,307	0%	34,009	0%	16,665	-11%	2,971	-17%	6,191	0%	4,531	-9%	6,830	-15%
150	56,801	0.50	28,242	0%	28,542	0%	13,535	-12%	2,566	-17%	4,955	1%	3,961	-8%	5,833	-16%
160	46,956	0.47	23,148	0%	23,785	0%	10,935	-13%	2,110	-18%	3,948	1%	3,313	-7%	4,844	-17%
170	39,220	0.45	19,288	0%	19,921	0%	9,027	-13%	1,762	-18%	3,332	2%	2,781	-6%	4,107	-17%
180	32,769	0.42	15,995	0%	16,761	0%	7,477	-13%	1,475	-19%	2,692	2%	2,278	-5%	3,519	-17%
190	27,696	0.40	13,403	0%	14,290	0%	6,202	-13%	1,350	-19%	2,158	3%	1,953	-4%	2,952	-18%
200	23,436	0.38	11,235	0%	12,192	0%	5,107	-13%	1,156	-18%	1,816	3%	1,630	-3%	2,524	-18%
220	36,618	0.35	17,754	0%	18,854	0%	8,093	-13%	1,775	-18%	2,811	3%	2,584	-1%	3,780	-17%
240	26,373	0.32	12,477	0%	13,893	1%	5,695	-12%	1,331	-17%	2,010	2%	1,784	0%	2,748	-17%
260	19,349	0.31	9,007	-1%	10,338	1%	4,234	-10%	1,026	-16%	1,387	1%	1,270	1%	2,048	-16%
280	14,204	0.29	6,700	-1%	7,503	1%	3,116	-9%	813	-16%	952	1%	849	2%	1,487	-15%
300	10,468	0.28	4,853	-1%	5,615	1%	2,312	-7%	583	-16%	780	0%	631	2%	1,124	-14%
320	7,816	0.27	3,571	-1%	4,245	2%	1,772	-6%	512	-16%	536	0%	422	2%	874	-13%
340	5,774	0.25	2,538	-1%	3,236	2%	1,322	-5%	356	-16%	387	1%	308	2%	653	-12%
360	4,293	0.24	1,883	-1%	2,409	2%	960	-4%	318	-16%	310	3%	199	2%	494	-11%
380	3,287	0.23	1,430	-1%	1,857	2%	772	-4%	275	-14%	224	5%	125	2%	374	-11%
400	2,524	0.22	1,029	-1%	1,494	1%	606	-4%	228	-10%	200	8%	74	2%	271	-10%
420	1,880	0.21	769	-1%	1,111	1%	444	-4%	156	-6%	148	12%	63	2%	200	-6%
440	1,401	0.20	578	-1%	823	0%	332	-1%	130	-1%	111	14%	24	1%	155	-1%
460	1,079	0.20	447	0%	632	0%	282	0%	99	0%	100	13%	25	0%	122	0%
480	810	0.20	336	0%	474	0%	187	0%	80	0%	91	9%	12	0%	85	0%
500	658	0.20	283	0%	375	0%	173	0%	61	0%	99	4%	5	0%	53	0%
520	413	0.20	173	0%	240	0%	111	0%	44	0%	25	0%	2	0%	41	0%
540	310	0.20	122	0%	188	0%	82	0%	32	0%	10	0%	4	0%	22	0%
560	239	0.20	91	0%	148	0%	74	0%	27	0%	16	0%	1	0%	29	0%
580	159	0.20	57	0%	102	0%	41	0%	14	0%	10	0%	2	0%	14	0%
600	115	0.20	47	0%	68	0%	36	0%	13	0%	7	0%	1	0%	5	0%
Total # Points	6,804,348	NA	3,600,763	NA	3,177,338	NA	1,886,112	NA	419,681	NA	778,336	NA	304,578	NA	819,626	NA
Mean % Difference	NA	NA	NA	-0.2%	NA	0.4%	NA	-6.3%	NA	-10.2%	NA	1.9%	NA	-2.8%	NA	-9.4%

NOTE: Column 3 presents the ARM2 ambient ratio based on the "ALL AQS Sites" data set. The odd columns from 5 to 17 present the relative percent difference between the calculated ambient ratio for the specified data subsets versus the "ALL AQS Sites" ambient ratio for each NO_X concentration bin.

Table 2 presents the ambient ratio comparison data for different time periods extracted from the AQS data base. The mean RPD is higher (+7%) in the 2001-2003 time period versus the complete 2001-2010 data period, while the mean RPD for the 2004-2007 and 2008-2010 time periods are lower (-1%) versus the complete 2001-2010 data period. This could be related to natural variability in meteorological and ozone background conditions, or it may indicate that higher ambient ozone concentrations occurred throughout the US during 2000-2003 as compared to more recent years, which would have resulted in higher oxidation rates of NO emissions.

Table 3 presents the ambient ratio comparison data based on varying distances of the monitoring site from 100 tpy or greater NO_X emission sources, as determined by processing the 2008 NEI source emission data base. These data indicate that the calculated 98^{th} percentile ambient ratios for monitoring sites within 1 km of an emission sources are generally lower than the “All AQS Sites” ambient ratios. The data subsets for monitoring sites located from 1 to 5 km distance, and greater than 5 km from NO_X sources, are similar to the All Sites ambient ratios. These results are consistent with the basic plume dispersion, entrainment, and chemistry conceptual mechanisms in the near field, and with the field observations reported in the Wang et al. and Janssen reports (i.e., at distances nearer to the emission source, the ambient ratios are lower than at further distances).

The overall conclusion of this sensitivity analysis is that the ARM2 conversion equation derived from the “All AQS Sites” data set generally results in higher ambient ratios than equations derived from the other data subsets. Therefore, the “All AQS Sites” equation can be conservatively used as the basis of the ARM2 method.

Table 2 - Ambient Ratio Comparison for Different Time Period Subsets of AQS Data

Upper Nox BIN ppb	2001-2010 # Obs	2001-2010 Ambient Ratios	2001-2003 # Obs	2001-2003 Ambient Ratio RPD	Normalized 2004-2007 # Obs	2004-2007 Ambient Ratio RPD	2008-2010 # Obs	2008-2010 Ambient Ratio RPD
30	2,330,786	0.90	744,455	0%	716,871	0%	630,503	0%
40	1,310,767	0.90	443,379	0%	404,004	0%	328,716	0%
50	817,380	0.90	287,844	0%	250,812	0%	195,120	0%
60	546,757	0.90	197,928	0%	166,304	-1%	127,090	-4%
70	385,505	0.85	142,352	4%	116,393	-2%	87,963	-5%
80	282,446	0.80	105,246	5%	85,073	-2%	63,770	-7%
90	214,245	0.75	80,624	6%	64,244	-3%	47,963	-8%
100	164,999	0.70	63,110	7%	49,059	-3%	36,477	-8%
110	130,316	0.65	50,459	8%	38,781	-4%	28,149	-9%
120	104,093	0.61	41,019	8%	30,625	-4%	22,241	-9%
130	84,056	0.57	33,297	9%	24,730	-5%	17,786	-10%
140	68,350	0.54	27,659	9%	20,171	-5%	13,796	-10%
150	56,801	0.50	23,192	9%	16,855	-6%	11,136	-10%
160	46,956	0.47	19,517	9%	13,895	-6%	8,913	-10%
170	39,220	0.45	16,682	9%	11,472	-7%	7,242	-10%
180	32,769	0.42	14,130	9%	9,564	-7%	5,887	-10%
190	27,696	0.40	12,315	9%	7,937	-7%	4,798	-9%
200	23,436	0.38	10,569	9%	6,761	-8%	3,853	-9%
220	36,618	0.35	16,807	8%	10,649	-8%	5,613	-8%
240	26,373	0.32	12,542	7%	7,590	-7%	3,711	-6%
260	19,349	0.31	9,452	6%	5,578	-6%	2,460	-5%
280	14,204	0.29	7,207	5%	4,040	-6%	1,611	-3%
300	10,468	0.28	5,515	5%	2,902	-5%	1,084	-2%
320	7,816	0.27	4,223	4%	2,134	-4%	748	0%
340	5,774	0.25	3,259	4%	1,521	-4%	487	1%
360	4,293	0.24	2,452	3%	1,098	-3%	377	3%
380	3,287	0.23	1,907	3%	855	-3%	240	4%
400	2,524	0.22	1,501	2%	618	-4%	199	5%
420	1,880	0.21	1,163	2%	446	-4%	122	5%
440	1,401	0.20	822	1%	344	-1%	120	5%
460	1,079	0.20	672	3%	248	3%	76	4%
480	810	0.19	510	6%	176	6%	66	6%
500	658	0.18	414	8%	147	8%	48	8%
520	413	0.18	267	9%	85	9%	33	9%
540	310	0.18	222	10%	58	10%	11	10%
560	239	0.18	153	11%	55	11%	13	11%
580	159	0.17	116	14%	26	14%	8	14%
600	115	0.16	82	23%	20	23%	7	23%
Total # Points	3,162,795	NA	1,195,229	NA	951,261	NA	699,218	NA
Mean % Difference	NA	NA	NA	6.8%	NA	-1.1%	NA	-1.2%

NOTE: Column 3 presents the ARM2 ambient ratio based on the “ALL AQS Sites” data set for the complete time period 2001-2010. Columns 5, 7, and 9 present the relative percent difference between the ambient ratio calculated for the specified time period data sets versus the “ALL AQS Sites” 2001-2010 ambient ratios.

Table 3 - Ambient Ratio Comparison for Varying Distances from NO_X Emission Sources

Upper Nox BIN ppb	All Sites # Obs	All Sites Ambient Ratios	Within 1 km of 100 tpy Sources # Obs	Within 1 km Ambient Ratio RPD	1 to 5 km from 100 tpy Sources # Obs	1 to 5 km Ambient Ratio RPD	Greater than 5 km from 100 tpy Sources # Obs	Greater than 5 km Ambient Ratio RPD
30	2,330,786	0.90	83,331	0%	714,815	0%	1,357,621	0%
40	1,310,767	0.90	52,394	0%	418,088	0%	744,075	0%
50	817,380	0.90	35,868	0%	264,623	0%	459,651	0%
60	546,757	0.90	25,553	0%	178,340	-1%	306,175	0%
70	385,505	0.85	18,735	-1%	126,521	-1%	215,051	1%
80	282,446	0.80	13,573	0%	92,234	-1%	158,346	1%
90	214,245	0.75	10,272	0%	69,529	-1%	120,705	1%
100	164,999	0.70	7,653	-1%	53,237	-2%	93,413	1%
110	130,316	0.65	5,898	-1%	41,333	-2%	74,751	1%
120	104,093	0.61	4,460	-2%	32,402	-2%	60,579	1%
130	84,056	0.57	3,442	-3%	25,844	-2%	49,353	1%
140	68,350	0.54	2,702	-3%	20,827	-2%	40,396	1%
150	56,801	0.50	2,234	-4%	17,099	-2%	33,857	1%
160	46,956	0.47	1,735	-5%	13,951	-1%	28,214	1%
170	39,220	0.45	1,420	-6%	11,679	-1%	23,554	1%
180	32,769	0.42	1,200	-7%	9,635	-1%	19,841	1%
190	27,696	0.40	979	-8%	8,117	-1%	16,808	1%
200	23,436	0.38	858	-9%	6,813	-1%	14,292	1%
220	36,618	0.35	1,361	-10%	10,550	0%	22,451	0%
240	26,373	0.32	934	-11%	7,633	1%	16,135	0%
260	19,349	0.31	652	-11%	5,666	1%	11,747	0%
280	14,204	0.29	480	-11%	4,082	2%	8,728	0%
300	10,468	0.28	434	-10%	3,102	2%	6,311	0%
320	7,816	0.27	300	-9%	2,271	3%	4,766	0%
340	5,774	0.25	224	-8%	1,753	2%	3,414	-1%
360	4,293	0.24	169	-7%	1,311	2%	2,532	-1%
380	3,287	0.23	129	-6%	967	2%	1,992	-1%
400	2,524	0.22	118	-5%	776	1%	1,482	-2%
420	1,880	0.21	103	-5%	599	1%	1,080	-2%
440	1,401	0.20	65	-1%	430	0%	825	-1%
460	1,079	0.20	57	3%	354	3%	605	3%
480	810	0.19	51	6%	245	6%	482	6%
500	658	0.18	45	8%	218	8%	364	8%
520	413	0.18	25	9%	128	9%	242	9%
540	310	0.18	13	10%	83	10%	199	10%
560	239	0.18	19	11%	80	11%	132	11%
580	159	0.17	5	14%	47	14%	97	14%
600	115	0.16	7	23%	33	23%	71	23%
Total # Points	3,162,795	NA	141,773	NA	1,012,507	NA	1,798,641	NA
Mean % Difference	NA	NA	NA	-1.7%	NA	2.3%	NA	2.6%

NOTE: Column 3 presents the ARM2 ambient ratio based on the “ALL AQS Sites” data set. Columns 5, 7, and 9 present the relative percent difference between the ambient ratio calculated for the specified “distance from source” data sets versus the “ALL AQS Sites” ambient ratios.

3.3 Sensitivity of Ambient Ratio to Percentile Selection

The ARM2 method is based on the 98^{th} percentile ambient ratios for the entire AQS data base. Note that the use of the 98^{th} percentile is not related to the form of the 1-hr NO_2 NAAQS. EPA's OAQPS Air Quality Modeling Group requested a sensitivity analysis for the use of different percentile values for establishing the ARM2 ambient ratios. Table 4 presents the results of the sensitivity analysis on the use of the 99^{th} and 95^{th} percentiles versus the 98^{th} percentile, all based on the "All AQS Sites" main data set. As expected, the 99^{th} percentile ARM2 equation results in higher ARM2 calculated ambient ratios (mean RPD of +9%), while the 95^{th} percentile ARM2 equation results in lower ARM2 calculated ambient ratios (mean RPD of -9%).

The selection of the percentile value used to represent the upper bound of the observed ambient ratios in each NOx concentration bin is arbitrary. The 98th percentile rather than the maximum value was used because this value is more stable and not subject to extreme variations that could be associated with artifacts in the data, including calibrations, audits, span checks, power restarts, or other analyzer operations that were not screened from the AQS data base. Using the 98th percentile removes these potentially spurious data points, while still providing a robust upper bound estimate of the ambient ratio for each bin. The original ARM method used the 90^{th} percentile to determine the conversion factor, and the ARM2 method uses a more conservative 98^{th} percentile.

Based on consideration of the above factors, the 98^{th} percentile value has been selected as a reasonable estimator of the upper bound ambient ratios, and is the basis for the performance evaluations of the ARM2 method.

Table 4 - Sensitivity of ARM2 Ambient Ratios to the Percentile Value

Upper Nox BIN ppb	ALL Sites # Obs	Ratios for 98th Percentile	Ratios for 99th Percentile	RPD	Ratios for 95% Percentile	RPD
30	2,330,786	0.90	0.90	0%	0.90	0%
40	1,310,767	0.90	0.90	0%	0.90	0%
50	817,380	0.90	0.90	0%	0.90	0%
60	546,757	0.90	0.90	0%	0.84	-6%
70	385,505	0.85	0.90	5%	0.78	-9%
80	282,446	0.80	0.85	7%	0.72	-10%
90	214,245	0.75	0.80	8%	0.66	-11%
100	164,999	0.70	0.76	9%	0.61	-12%
110	130,316	0.65	0.72	10%	0.57	-13%
120	104,093	0.61	0.68	11%	0.53	-14%
130	84,056	0.57	0.64	11%	0.49	-14%
140	68,350	0.54	0.60	12%	0.46	-15%
150	56,801	0.50	0.56	12%	0.43	-15%
160	46,956	0.47	0.53	12%	0.40	-15%
170	39,220	0.45	0.50	13%	0.38	-15%
180	32,769	0.42	0.48	13%	0.36	-15%
190	27,696	0.40	0.45	13%	0.34	-15%
200	23,436	0.38	0.43	13%	0.33	-14%
220	36,618	0.35	0.39	12%	0.30	-14%
240	26,373	0.32	0.36	12%	0.28	-13%
260	19,349	0.31	0.34	12%	0.27	-13%
280	14,204	0.29	0.32	12%	0.25	-13%
300	10,468	0.28	0.31	12%	0.24	-12%
320	7,816	0.27	0.30	12%	0.23	-12%
340	5,774	0.25	0.29	12%	0.22	-12%
360	4,293	0.24	0.27	12%	0.22	-12%
380	3,287	0.23	0.26	13%	0.21	-12%
400	2,524	0.22	0.25	13%	0.20	-10%
420	1,880	0.21	0.24	14%	0.20	-6%
440	1,401	0.20	0.23	14%	0.20	-1%
460	1,079	0.20	0.22	11%	0.20	0%
480	810	0.20	0.22	8%	0.20	0%
500	658	0.20	0.21	5%	0.20	0%
520	413	0.20	0.21	3%	0.20	0%
540	310	0.20	0.20	1%	0.20	0%
560	239	0.20	0.20	0%	0.20	0%
580	159	0.20	0.20	0%	0.20	0%
600	115	0.20	0.20	0%	0.20	0%
Mean % Difference	NA	NA	NA	9.0%	NA	-9.0%

3.4 ARM2 Implementation into AERMOD

The “All AQS Sites” ARM2 ambient ratio equation was coded directly into the AERMOD model. Because the monitoring data are expressed in ppb units but modeled concentrations are in µg/m^3 units, the ARM2 equation coefficients were recalculated for use with µg/m^3 NO_X concentration inputs. Refer to Section 4.2 of this report for additional details on the method for converting from ppb to µg/m^3 units. The final ARM2 ambient ratio equation in units of ug/m3 is:

$$y = -1.1723E\text{-}17x^6 + 4.2795E\text{-}14x^5 - 5.8345E\text{-}11x^4 + 3.4555E\text{-}08x^3 - 5.6062E\text{-}06x^2 - 2.7383E\text{-}03x + 1.2441E{+}00,$$

Where x is the NOx concentration in ug/m3, and y is the calculated ambient ratio.

The Fortran source code for the AERMOD dispersion model was edited to include the ARM2 method as a model option using the keyword “ARM2”. Under this option, AERMOD calculates the cumulative 1-hr NO_X concentration (i.e., based on the source group “ALL”) at each receptor on an hour-by-hour basis. Each hourly NO_X concentration for the “ALL” source group is input to the ARM2 equation to determine the ARM2 ambient ratio for that hour. The ARM2 ambient ratio for that hour is then multiplied by the NO_X concentration for any other source groups in the model run to determine that hour’s NO_2 concentration for each source group. The hourly NO_2 concentrations for each receptor and source group are then stored as usual into the appropriate AERMOD data array for subsequent output processing. The ARM2 maximum and minimum ratios are set by default to 0.9 and 0.2; however, the NO2EQUIL and NO2STACK keywords (typically used for the PVMRM method) can be used to change these default settings.

The ARM2 coding changes in AERMOD have been highlighted with comments that include the word “ARM2”. Since the ARM2 ambient ratio is determined from the cumulative modeled NO_X concentration, there must be an “ALL” source group in the AERMOD run (if an “ALL” source group is not included in a run, AERMOD halts with an error message). User instructions for the AERMOD-ARM2 option are presented in Appendix C.

4.0 ARM2 Performance Evaluation

4.1 Evaluation Data Sets

The performance of the ARM2 method was evaluated with three test data sets that have previously been used to evaluate PVMRM and OLM (Hanrahan[13], Brode[14], and Hanna[15] et. al.). It is important to note that there are significant uncertainties and assumptions in the emission inventories for all of these data sets. The Empire Abo and Palaau data sets assumed a fixed emission rate over the entire time period evaluated, while the Wainwright data set contains hourly estimates of power station load which were used to scale vendor data emission tests to estimate hourly emissions. The evaluation data sets are described below:

Empire Abo, New Mexico Data Set – The operators of the Empire Abo Gas plant in southeastern New Mexico collected ozone, NO_X, and meteorological data at two sites for a two year period (June 1993 through June 1995). The objective of this program was to collect representative ozone monitoring data not influenced by NO scavenging for use in NO_2 modeling with the OLM method. The North monitoring site was located 1.6 km north of the plant with a direct transport wind direction from the plant to the monitor of 220 degrees, and the South monitoring site was located 2.5 km to the south of the facility with a direct transport wind direction of 340 degrees.

[13] Hanrahan, P.L., 1999b. "The plume volume molar ratio method for determining NO2/NOx ratios in modeling. Part II: Evaluation Studies," J. Air & Waste Manage. Assoc., 49, 1332- 1338.

[14] "Evaluation of Bias in AERMOD-PVMRM", Alaska DEC Contract No. 18-9010-12, MACTEC Report, June 2005, and "Additional Clarification Regarding Application of Appendix W Modeling Guidance for the 1-hour NO2 NAAQS", dated March 11, 2011.

[15] "PVMRM and OLM Evaluation using a New Data Set", Steven Hanna, Elizabeth Hendrick, Vincent Tino, and Bruce Egan, presented at the 10th EPA Air Modeling Conference on March 14, 2012.

The Empire Abo Gas plant consists of 15 compressor engines, five boilers, two heaters, a sulfur recovery unit flare, an inlet flare, an acid gas flare, and a diesel fire pump. Typical stack heights are approximately 30 feet, and there are squat buildings with approximate heights of 20 feet, so downwash is a factor at this facility. Of the 26 emission sources, there is no one dominant source of emissions but the compressor engines are the largest type of emission source. There are numerous other emission sources in the area from gas wells, compressors, and gas treatment plants, but these are more distant from the ambient monitors and were not included in the modeling input files.

EPA provided the Empire Abo AERMOD modeling files and ambient monitoring data for the period June 1993 through June 1994 that were used for the PVMRM and OLM 1-hr NO_2 performance evaluations reported in EPA's 2011 Additional Clarifications memo. The AERMOD input files included source and stack parameters, building parameters as calculated by the BPIP-PRIME program, and the model receptor location. The AERMET meteorological data was processed by EPA using AERMET version 11059. The ambient NO_X and ozone monitoring data were also provided. The AERMOD files include input files for both the North and South monitor locations. The meteorological data from the 10-meter tower located at the North monitor were used for both sets of model runs, as these data were representative for both the source and the two monitoring site locations.

Palaau, Hawaii Data Set – NO_X, ozone, and meteorological data were collected at a site near the Palaau Generating Station on the island of Molokai. The facility consisted of four diesel-engine generators and an oil-fired combustion turbine. The engine and CT stack heights range from 25 to 32 feet tall. The building heights affecting these stacks ranged from 25 feet to 70 feet high, so downwash is a factor at this facility. In contrast to the New Mexico monitors, this ambient monitor was located closer to the source (220 m distant), with a direct transport wind direction of 120 degrees. Data were collected from January 1, 1993 through December 31, 1993.

EPA provided the Palaau AERMOD modeling files and ambient monitoring data that were used for the PVMRM and OLM 1-hr NO_2 performance evaluations reported in EPA's 2011 Additional Clarifications memo. The AERMOD input files included source and stack parameters, building parameters as calculated by the BPIP-PRIME program, and the model receptor location. The AERMET meteorological data was processed using AERMET version 11059. The ambient NO_X and ozone monitoring data were also provided.

Wainwright, Alaska Data Set - This data set consists of hourly observations of ozone, NO_X, and meteorological data from September 16, 2009, through September 30, 2010, from an ambient monitoring station located near a power plant site in Wainwright, Alaska. The power plant consists of five diesel generators (rated from 425 to 950kW), each vented through its own stack, all located in a single building. The stack heights are about the same as the building height at 30 feet tall. There were few other sources of NO_X emissions in the area. The monitoring station is located about 500 m to the east-south-east of the plant (the direct transport wind direction is 280 degrees). By focusing this data set on those hours when the wind direction would transport plant emission to the monitor (defined as a 60 degree sector centered on 280 degrees), a total of 594 hours of data were available for the performance evaluation data set. Hourly surface meteorological data from the ambient monitoring station and data from the nearby NWS ASOS station (including 1-minute ASOS wind data) were used with AERMET version 11059 to create the meteorological data input files for AERMOD.

The Wainwright data set contains hourly estimates of power station load which were used to scale vendor data emission tests to estimate hourly emissions. Modeling results and monitoring data for the Wainwright test data set were provided in a spreadsheet format by Epsilon Associates, Inc., who performed the AERMOD (version 11103) modeling for the "PVMRM and OLM Evaluation using a New Data Set" study presented at the EPA 10th Modeling Conference in March 2012. The total modeled NO_X concentrations reported in the spreadsheet were input to the ARM2 equation to calculate ARM2 NO_2 concentrations, which were then compared to the Tier 3 concentrations and ambient monitoring data compiled by Epsilon.

4.2 Updates to Previously Used In-stack Ratios and Ozone Data

The in-stack NO_2/NO_X ratio values previously used in the Empire Abo and Palaau evaluations were updated to reflect current guidance. The value originally used by Hanrahan and Brode was 0.1 for all modeled sources, even though the majority of the larger emission sources in these data sets are internal combustion engines. As discussed in Section 3.1 of this report, EPA is currently developing a database of in-stack NO_2/NO_X ratios, and in the interim some state agencies have developed in-stack ratio data and guidance. The in-stack ratio generally recommended for boilers, combustion turbines, and IC engines ranges from approximately 0.1 to 0.2. Therefore, the in-stack ratio used for the Empire Abo and Palaau Tier 3 evaluations performed for this study was revised from the original 0.1 value to 0.2 (the Wainwright modeling evaluations also used an in-stack ratio of 0.2). This is much less conservative than EPA's recommended default in-stack ratio of 0.5, and if the default in-stack ratio were to be used in this study the NO_2/NO_X ratios predicted by the PVMRM and OLM methods would be substantially higher than what is reported herein.

The ozone data that is input for the Tier 3 analyses must be representative of background ozone concentrations, without "ozone scavenging" from local NO_X emission sources that bias the ozone data low. For the Empire Abo data set, ozone data were collected at two stations. For periods when NO_X plumes are impacting one of the monitor stations, the plumes are also causing "scavenging" or "consumption" of ozone at that site that lowers the ambient ozone concentrations. Therefore, to minimize the effects of ozone scavenging, the higher of the North or South ozone hourly averages was used to create the "maximum hourly ozone" data file for the Empire Abo data sets that was used for subsequent Tier 3 modeling. In addition, the relative few hours of missing ozone data were filled in with the maximum hourly observation of 74.7 ppb, using the OZONEVAL setting in AERMOD.

These two updates reflect current in-stack ratio guidance and account for ozone "scavenging", and will likely result in higher predicted NO_2/NO_X ratios for the Tier 3 methods than have been reported in the 2011 Additional Clarifications memo.

4.3 Converting Monitoring Data from ppb to μg/m^3 Units

The NO_X ambient monitoring data is typically reported in units of ppb by volume, while the air quality dispersion models output NO and NO_2 concentrations in units of μg/m^3. Therefore, to compare modeled concentrations to monitoring data, it is necessary to convert the monitored data from ppb to μg/m^3 units. The New Mexico Environmental Department (NMED) Air Dispersion Modeling Guidelines provide a good discussion of conversion equations and the need to account for site pressure and temperature. These guidelines note that the convention for the NAAQS is defined at 40 CFR 50.3 "Reference conditions", which states that air quality measured in units of mass per unit volume shall be corrected to STP conditions of 25 degrees C and 760 millimeters of mercury. In addition, the California Air Pollution Control Officers Association (CAPCOA) has developed the guidance document "Modeling Compliance of the Federal 1-Hour NO_2 NAAQS", and section 4 discusses how background NO_2 data should be converted from ppb to μg/m^3 units. Like the NMED guidance, CAPCOA recommends that the conversion be performed assuming STP conditions, rather than converting to μg/m^3 in "actual temperature and pressure units" based on monitoring site conditions. Therefore, the following equation was used to convert the monitored $NO/NO_2/NO_X$ concentrations from ppb to μg/m^3 at STP:

$$C = (ppb/1000) \times MW \times 40.8727,$$

where MW is the molecular weight of the pollutant in grams/mole.

For NO_X, the two species are NO and NO_2, which have different molecular weights (30 and 46 grams/mole, respectively). However, it must be noted that the convention for the NO_X mass emission rate input to dispersion models is "as NO_2" (i.e., using the molecular weight of NO_2), and the model predicted NO_X concentrations do not weight the relative percentages and molecular weights of the NO and NO_2 species. Therefore, the ambient NO, NO_2, and NO_X concentrations should be converted using the molecular weight for NO_2 (the same as how the model treats the various species). The STP conversion equation for both NO_2 and NO_X then is simplified to $\mu g/m^3 = ppb * 1.88$.

This ambient data unit conversion method differs from the "actual $\mu g/m^3$" method previously used in both EPA's 1-hr NO_2 performance evaluation presented in the 2011 Additional Clarifications memo, and in the "Updated Tier 2 Ambient Ratio Method (ARM) for 1-hr NO_2 NAAQS Analyses" presentation at EPA's 10th Modeling Conference. Those analyses used site temperature and pressure in the ppb to $\mu g/m^3$ conversion equation. For the Empire Abo site located at approximately 3500 foot elevation, the "standard $\mu g/m^3$" monitored concentrations are about 10% higher than the "actual $\mu g/m^3$" concentrations, which has implications on the previously reported model performance at Empire Abo. For the Palaau site near sea level, there is little difference between the "standard $\mu g/m^3$" and "actual $\mu g/m^3$", and the Wainwright analysis has always used "standard $\mu g/m^3$" monitored concentrations.

4.4 Evaluation Procedures

When evaluating the various NO_2 model conversion options, it is important to recall that the modules for predicting the NO_2/NO_X ratio (ARM2, PVMRM, and OLM) are only one part of the modeling system. The agreement between the prediction of NO_2 versus actual observations is a result of both AERMOD's ability to estimate the NO_X concentration, as well as the ability to estimate the NO_2/NO_X ambient ratio. For example, PVMRM may be accurately predicting the NO_2/NO_X ratio, but the overall AERMOD NO_2 predictions might be poor because of AERMOD performance. Conversely, PVMRM may be poorly predicting the ambient ratio, but compensating errors in AERMOD's performance may result in good overall agreement with NO_2 observations. Therefore, the evaluation procedures look at both the performance of the methods for predicting the ambient ratio, as well as the overall ability of the modeling system (AERMOD NO_X predictions and ambient ratio predictions).

The source inputs, building downwash parameters, and meteorological data for each evaluation data set were input to AERMOD (version 12345) to calculate hourly NO_X concentrations at a single receptor located at the respective ambient monitor location. In addition, the AERMOD-ARM2, AERMOD-PVMRM, and AERMOD-OLM methods were also used to calculate hourly NO_2 concentrations (all reported OLM concentrations are based on the Group All option). The hourly model predicted NO_2 and NO_X concentrations were input to a spreadsheet, along with the concurrent observations of hourly NO_2, NO_X, wind speed, and wind direction.

The data set was first sorted by wind direction, and hours were selected when the wind direction was within a 60 degree sector centered on the direct transport wind direction from the modeled source to the monitoring station. This focused the analysis on direct impacts from the source on the ambient monitor, and helped reduced the potential effects of other background sources on the monitoring data. A minimum or "threshold" NO_X concentration of 20 µg/m^3 (approximately 10 ppb) was then applied to both the monitoring and modeling data. This was done to remove the measurement variability at low monitored concentrations, and to reduce the potential effects of other background sources at low monitored concentrations.

Scatter plots were prepared of the model predicted versus observed NO_2/NO_X ratios, paired in time (the data is already paired in space since a single receptor at the monitor location is used in the modeling). These plots were reviewed to evaluate the amount of variability in the model predicted ratios, as well as any overall bias in the predictions.

Scatter plots were also prepared for model predictions of the NO_2/NO_X ratio as a function of model predicted NO_X concentration. The observed NO_2/NO_X ratio as a function of observed NO_X concentration was also plotted on these graphs (note in these plots, the modeled and monitored data points are not paired in time). These plots help evaluate the agreement between model predicted and monitored ratios as a function of NO_X concentration.

Quantile-Quantile (Q-Q) plots of model predicted NO_2 concentrations versus observations were prepared to evaluate the overall ability of the modeling methods to match the frequency distribution of the NO_2 observations, especially in the high range concentrations near the NAAQS.

The model predicted hourly NO_2 and NO_X concentrations for each of the test data sets were also compared to observations using the Robust Highest Concentration (RHC). The RHC represents a smoothed estimate of the highest concentrations, based on a tail exponential fit to the upper end of the concentration distribution. This reduces the effect of extreme values on the comparison of model predicted concentrations to ambient monitoring concentrations. The RHC is calculated as follows:

$RHC = \chi\{n\} + (\bar{\chi} - \chi\{n\}) \ln((3n-1)/2)$

where $n = 26$,

$\bar{\chi}$ is the average of the n - 1 largest values, and

$\chi\{n\}$ is the nth largest value.

In the Q-Q and RHC performance evaluations, the combined performance of AERMOD and the conversion methods is evaluated against NO_2 monitoring data. To help determine the performance of AERMOD itself, and to identify potential compensating errors between the dispersion model and the NO_2 conversion methodology, RHC statistics are also presented for the AERMOD predicted NO_X concentration versus monitored NO_X observations (without any conversion ratios applied).

4.5 Empire Abo Evaluation Results

For the North monitoring site data set, there were 2137 hours that met the “direct transport” wind direction criteria. There were 734 of those hours that also had monitored NO_X concentrations greater than the 20 µg/m^3 threshold, and 329 hours with both monitored and modeled NO_X concentrations greater than the threshold. For the 329 hour data set, the maximum monitored NO_X concentration was 561 µg/m^3, and the maximum monitored NO_2 concentration was 125 µg/m^3.

For the South monitoring site data set, there were 1206 hours that met the “direct transport” wind direction criteria. There were 376 of those hours that also had monitored NO_X concentrations greater than the 20 µg/m^3 threshold, and 128 hours with both monitored and modeled NO_X concentrations greater than the threshold. For the 128 hour data set, the maximum monitored NO_X concentration was 388 µg/m^3, and the maximum monitored NO_2 concentration was 59 µg/m^3.

The scatter plots of predicted versus observed NO_2/NO_X ratios, paired on an hour-by-hour basis, are presented in Figures 6 and 7 for the Empire Abo North and South data sets. These plots indicate that there is a wide range in predicted and observed ratios and a large amount of scatter for all of the methods evaluated (ARM2, PVMRM, and OLM). The PVMRM data points, and OLM data points for the South data set, are roughly evenly distributed on either side of the 1:1 line. The OLM data points for the North data set, and the ARM2 data points from both data sets, are predominately distributed above the 1:1 line. This indicates that OLM and ARM2 have a greater tendency towards overprediction of the ambient ratio than PVMRM. However, the large amount of scatter in these paired data plots suggests that none of the methods have much skill in predicting the ratios on a paired in space and time basis.

Figure 6 – Scatter Plot of NO_2/NO_X Ratio for Empire Abo North Data Set

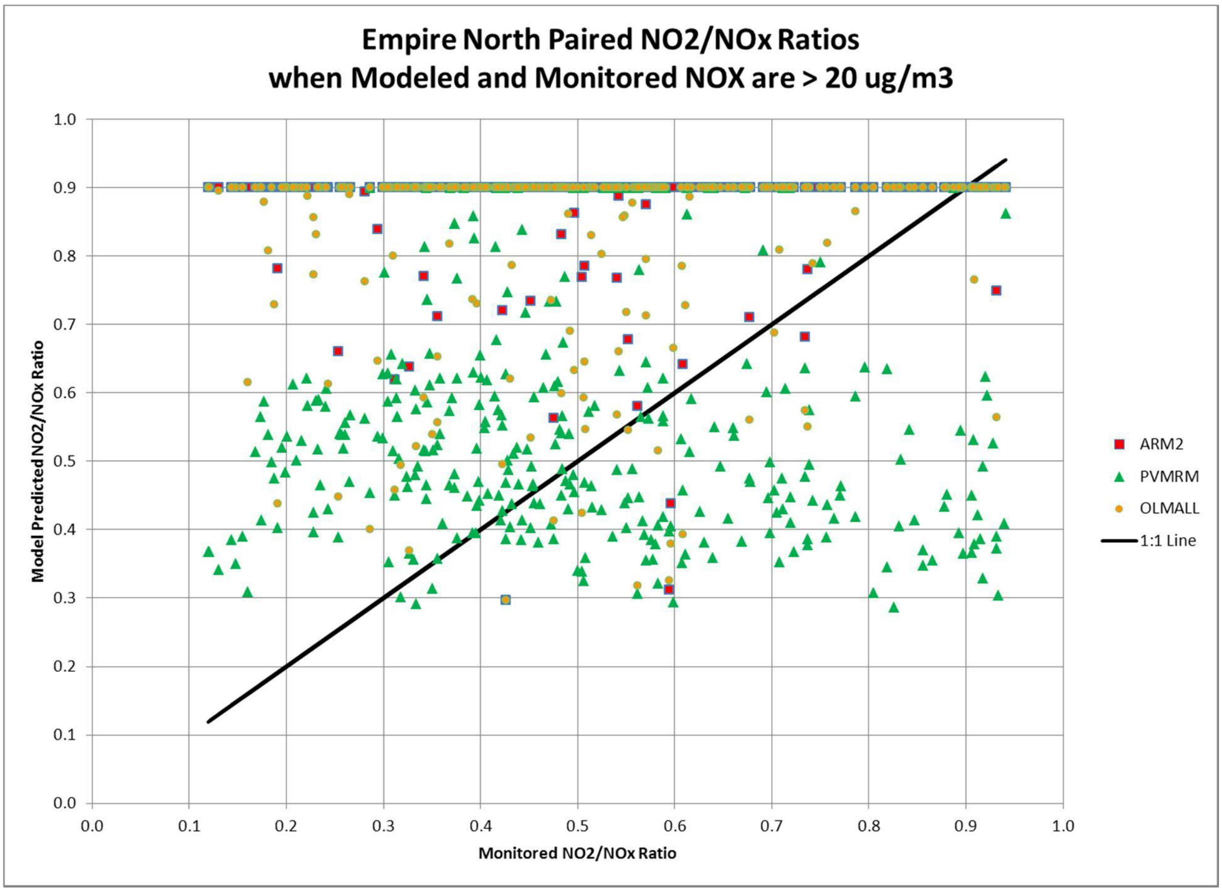
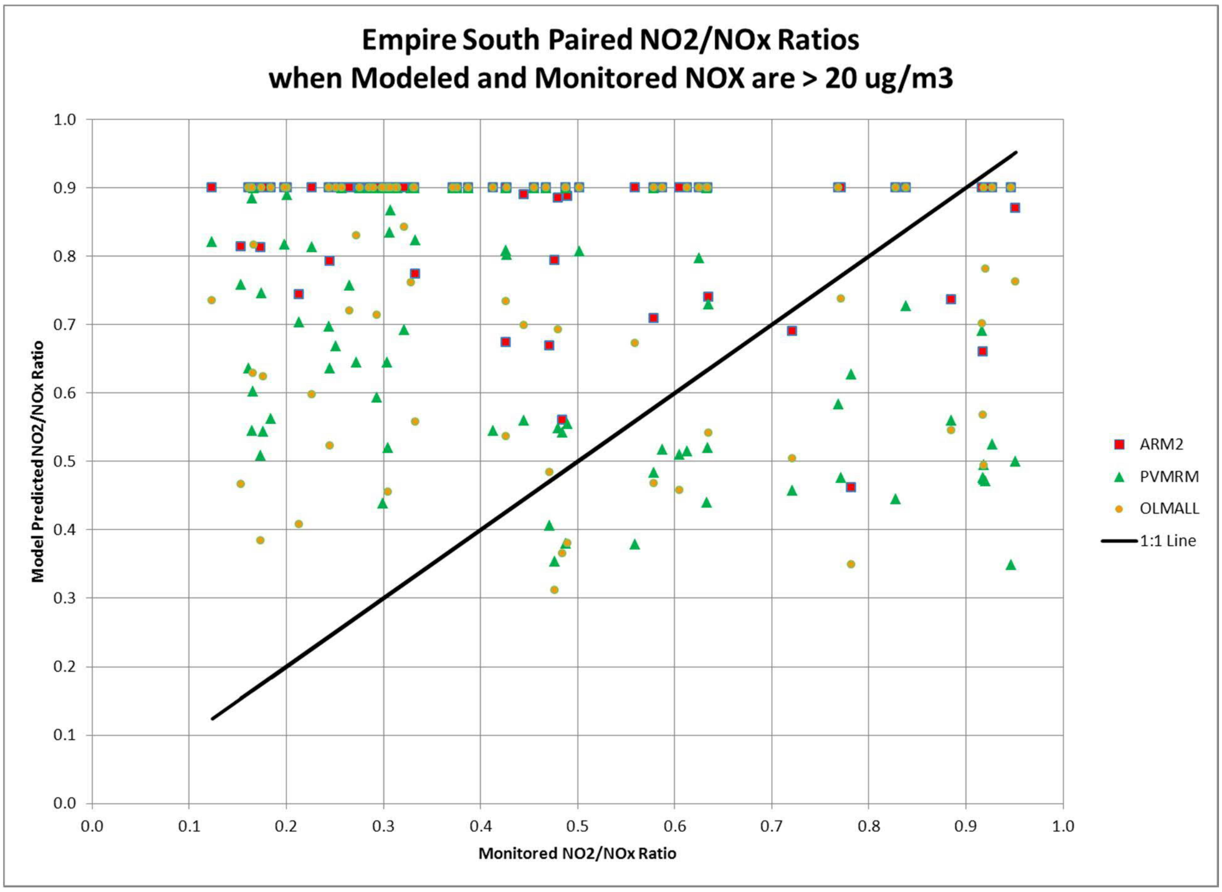


Figure 7 – Scatter Plot of NO_2/NO_X Ratio for Empire Abo South Data Set



Plots of the predicted NO_2/NO_X ratio as a function of AERMOD predicted NO_X concentration were prepared. The observed NO_2/NO_X ratios plotted as a function of observed NO_X concentrations are also included in these plots (the monitoring data are not paired in time with the modeling predictions). Figures 8 and 9 present the plots for the Empire Abo North and South data sets, respectively. The North site plot indicates that the PVMRM predicted ratios generally match the observed ratios the best, and the OLM predicted ratios are typically higher than the observed ratios. The ARM2 predicted ratios follow the "ARM2 curve" equation, and generally are the highest estimate of the NO_2/NO_X ratio. However, at the highest NO_X concentrations, the ratios predicted by the three methods exhibit different behavior, with the PVMRM predicting the highest ratios followed by OLM and ARM2. Importantly, all three methods are overpredicting the observed NO_2/NO_X ratios at the higher NO_X concentrations. The South site plot exhibits these same general relationships. The significant finding of this portion of the analysis is that for the elevated NO_X concentrations, the monitoring data indicate the ambient ratios are less than 0.2, while the three methods predict ambient ratios ranging from approximately 0.3 to 0.6. Thus, at the upper end of the NO_X frequency distribution, the methods are not able to accurately estimate NO_2 conversion.

Figures 10 and 11 present the hourly unpaired Q-Q plots for NO_2 for the Empire North and South monitor data sets, respectively. These data were for those hours that met the "direct transport" wind direction criteria and had monitored or modeled concentrations greater than 1 $\mu g/m^3$. These results show the conservatism of the full conversion option, with a significant bias to over-predict hourly NO_2 concentrations. The AERMOD-ARM2 curve indicates significant over-prediction at lower concentrations, but the Q-Q plot then flattens out and results in good performance at the extreme high concentrations (this flattened shape is a result of the power function shape of the ARM2 ambient ratio curve). The AERMOD-OLM method exhibits better performance than the other Tier 3 method, AERMOD-PVMRM. The AERMOD-ARM2 combination performs as well as, if not better, than the Tier 3 methods for the Empire Abo data sets. All methods are over-predicting at the highest NO_2 concentrations when compared to monitoring data.

Figure 8 –Plot of NO_2/NO_X Ratio vs NO_X for Empire Abo North Data Set

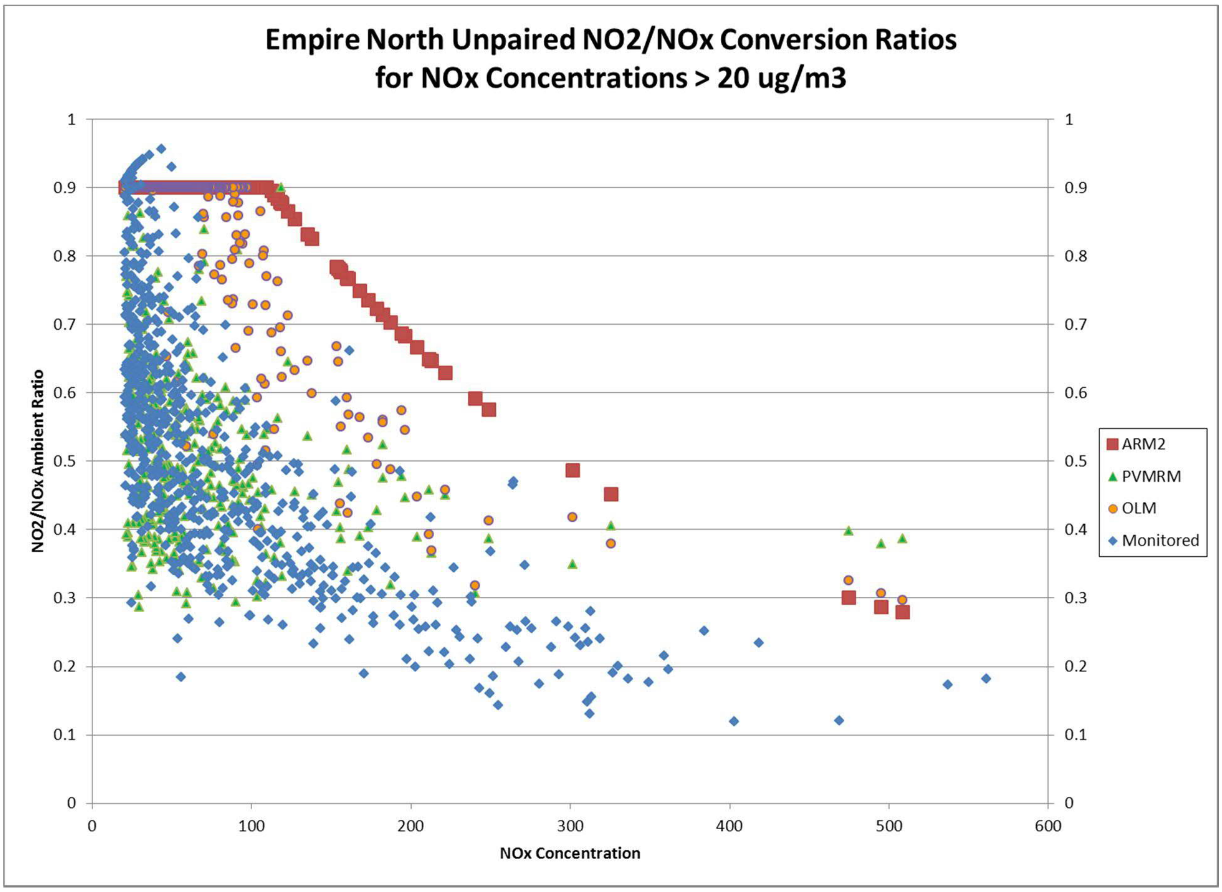


Figure 9 –Plot of NO_2/NO_X Ratio vs NO_X for Empire Abo South Data Set

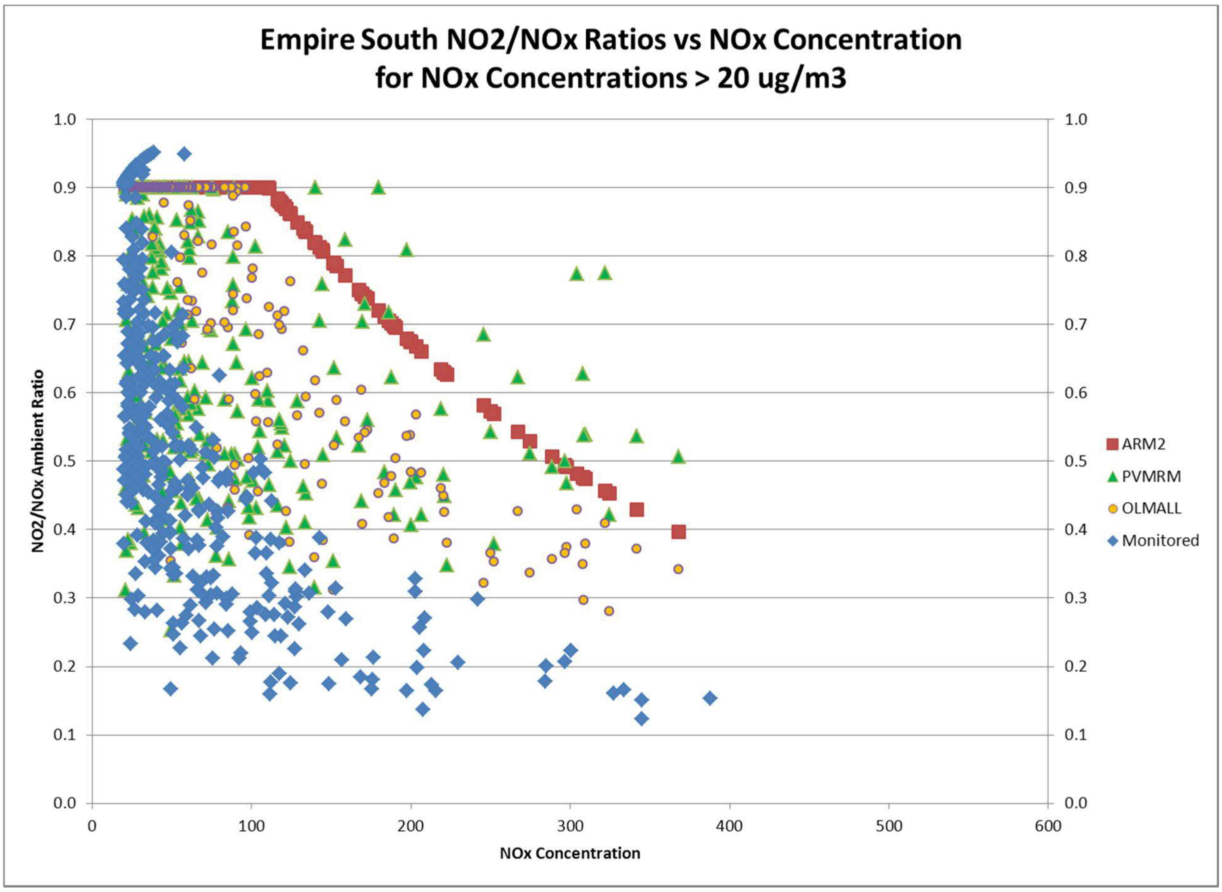


Figure 10 – Q-Q NO_2 Plots for the Empire North Data Set

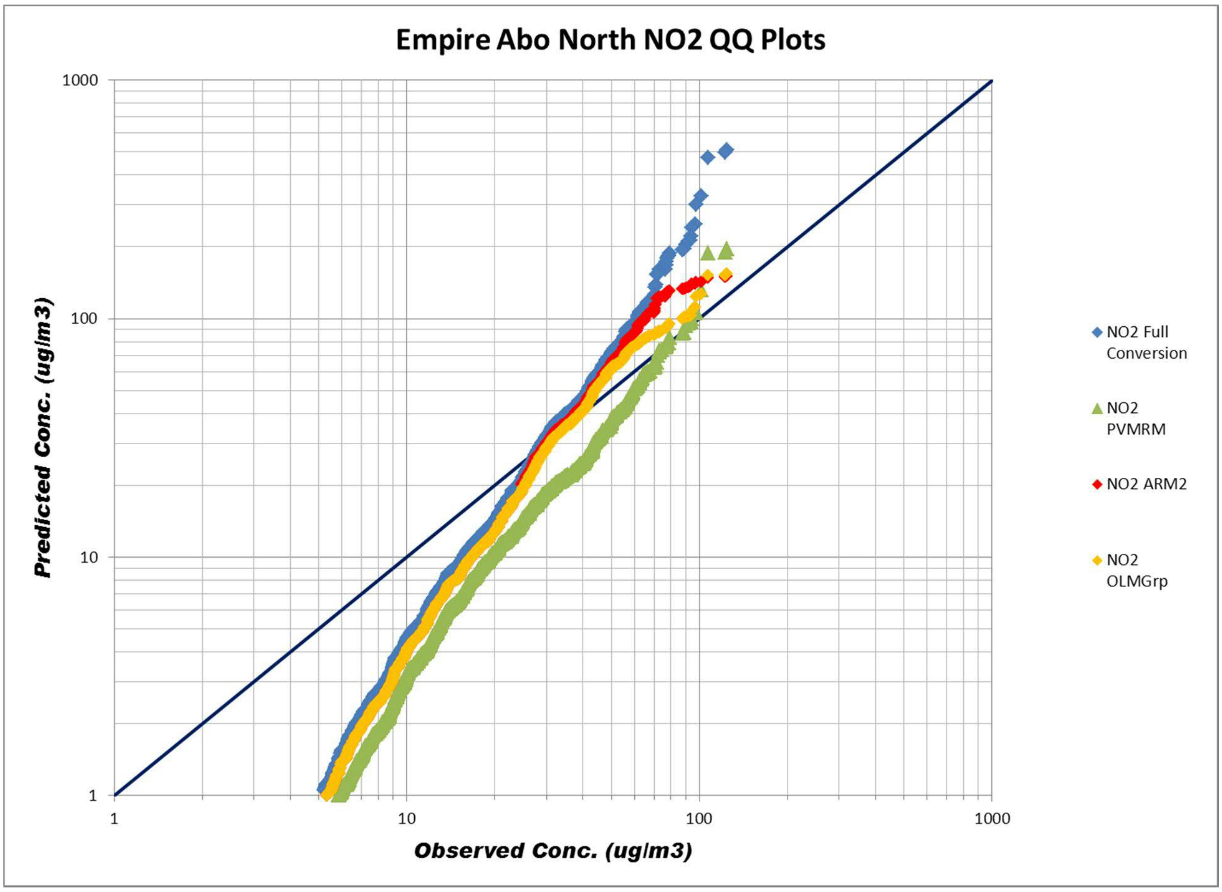
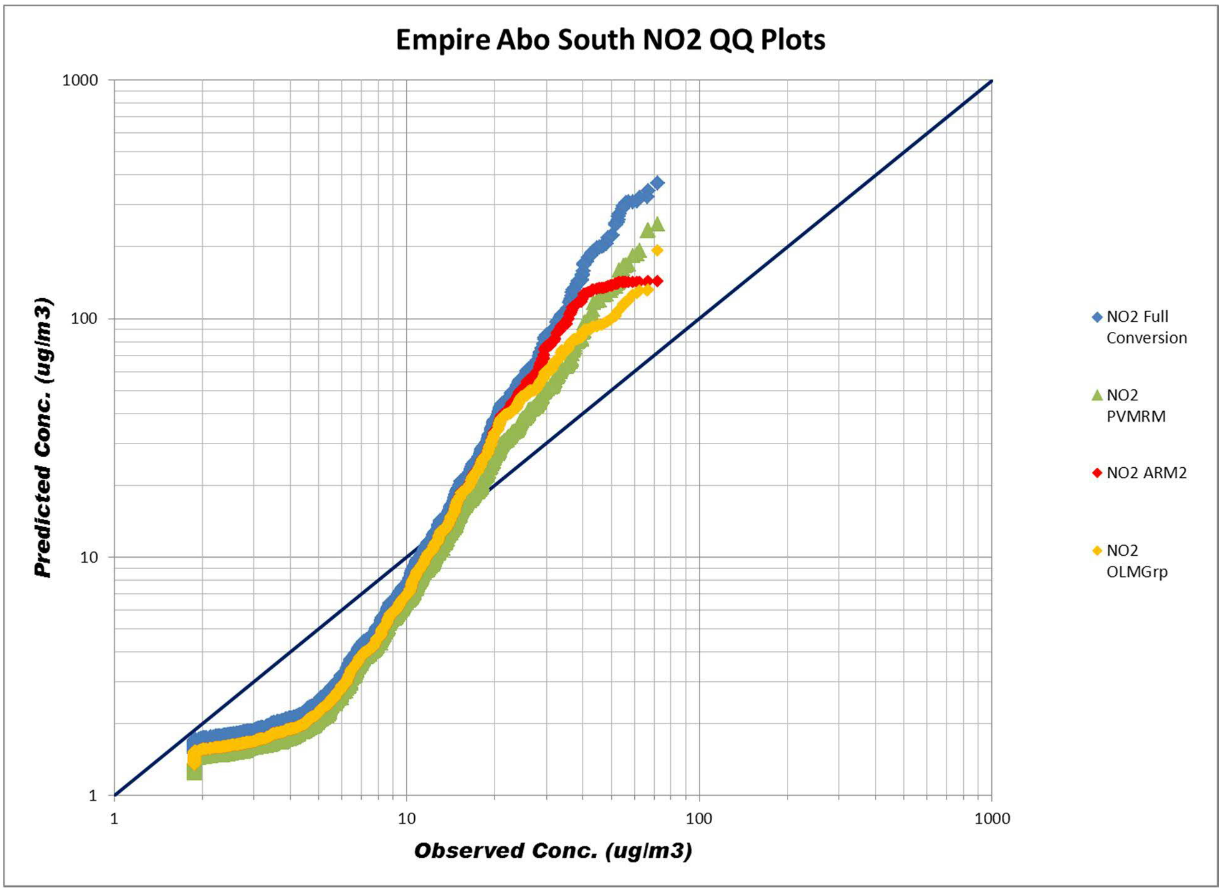


Figure 11 – Q-Q NO_2 Plots for the Empire South Data Set



4.6 Palaau Evaluation Results

There were 699 hours that met the "direct transport" wind direction criteria. There were 466 of those hours that also had monitored NO_X concentrations greater than the 20 µg/m^3 threshold, and 441 hours with both monitored and modeled NO_X concentrations greater than the 20 µg/m^3 threshold. For the 441 hour data set, the maximum monitored NO_X concentration was 642 µg/m^3, and the maximum monitored NO_2 concentration was 85 µg/m^3.

The scatter plot of predicted versus observed NO_2/NO_X ratios, paired on an hour-by-hour basis, is presented in Figure 12. This plot indicates that the observed ratios are clustered between 0.1 and 0.3. The PVMRM predicted ratios are clustered between 0.2 and 0.3 and are distributed above the 1:1 line. The OLM predicted ratios are found between 0.2 and 0.9, and the ARM2 predicted ratios are found between approximately 0.4 and 0.9. A large amount of scatter is observed for the OLM and ARM2 methods, but the scatter for PVMRM is appreciably less. These plots suggest that PVMRM has better skill than OLM or ARM2 for predicting the ratios on a paired in space and time basis for this data set, and that OLM and ARM2 have a greater tendency towards overprediction of the ambient ratio than does PVMRM.

Figure 13 is the scatter plot of the predicted NO_2/NO_X ratio as a function of AERMOD predicted NO_X concentration. The observed NO_2/NO_X ratios plotted as a function of observed NO_X concentrations are also included (the monitoring data are not paired in time with the modeling predictions). This plot indicates that the PVMRM predicted ratios generally match the observed ratios the best, followed by OLM predictions, and the ARM2 predicted ratios are generally the highest estimate of the NO_2/NO_X ratio. At the extreme high end of the observed NO_X concentrations, the predicted ratios from the three methods cluster together in the range 0.25 to 0.35, while the observed ambient ratios are all less than 0.2. Therefore, at the upper end of the NO_X frequency distribution, all the methods are overestimating the NO_2 conversion.

Figure 12 – Scatter Plot of NO_2/NO_X Ratio for Palaau Data Set

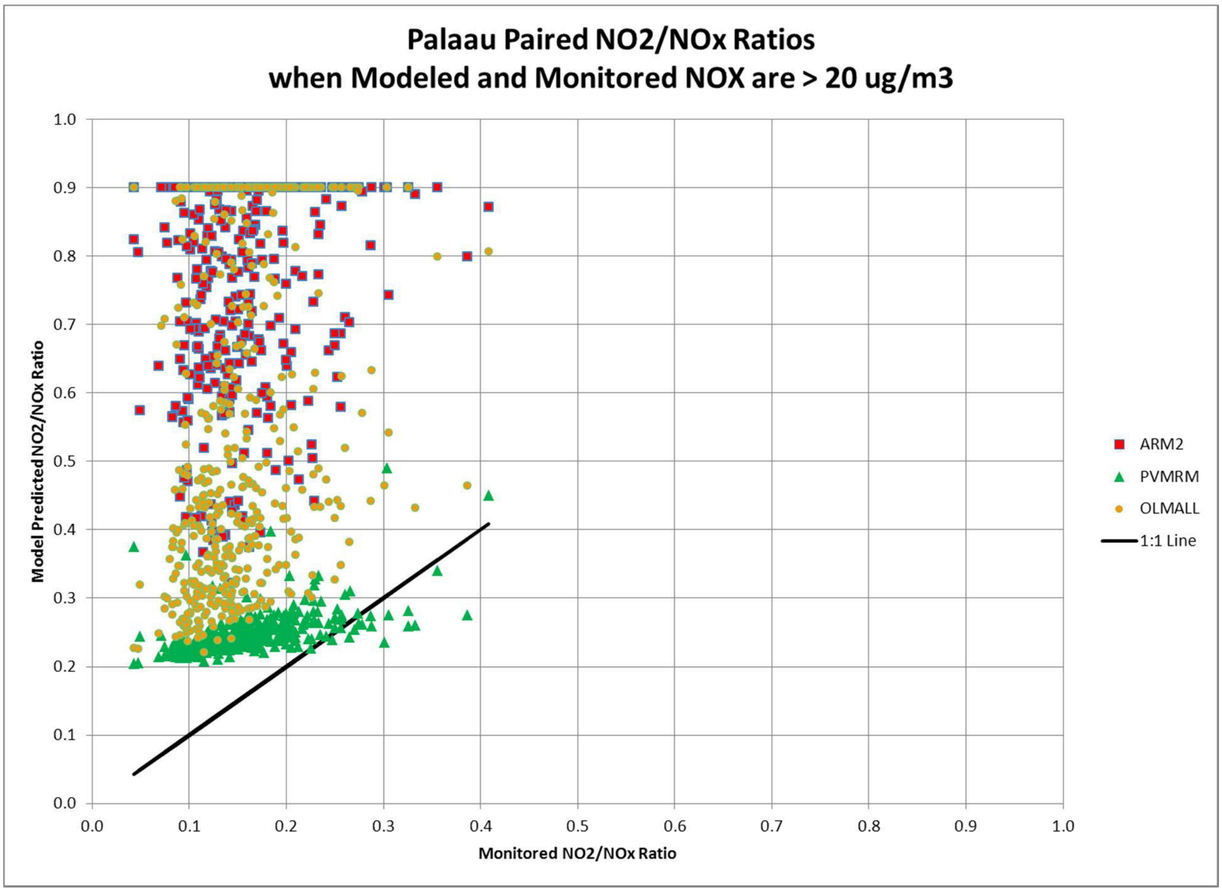


Figure 13 –Plot of NO_2/NO_X Ratio vs NO_X for Palaau Data Set

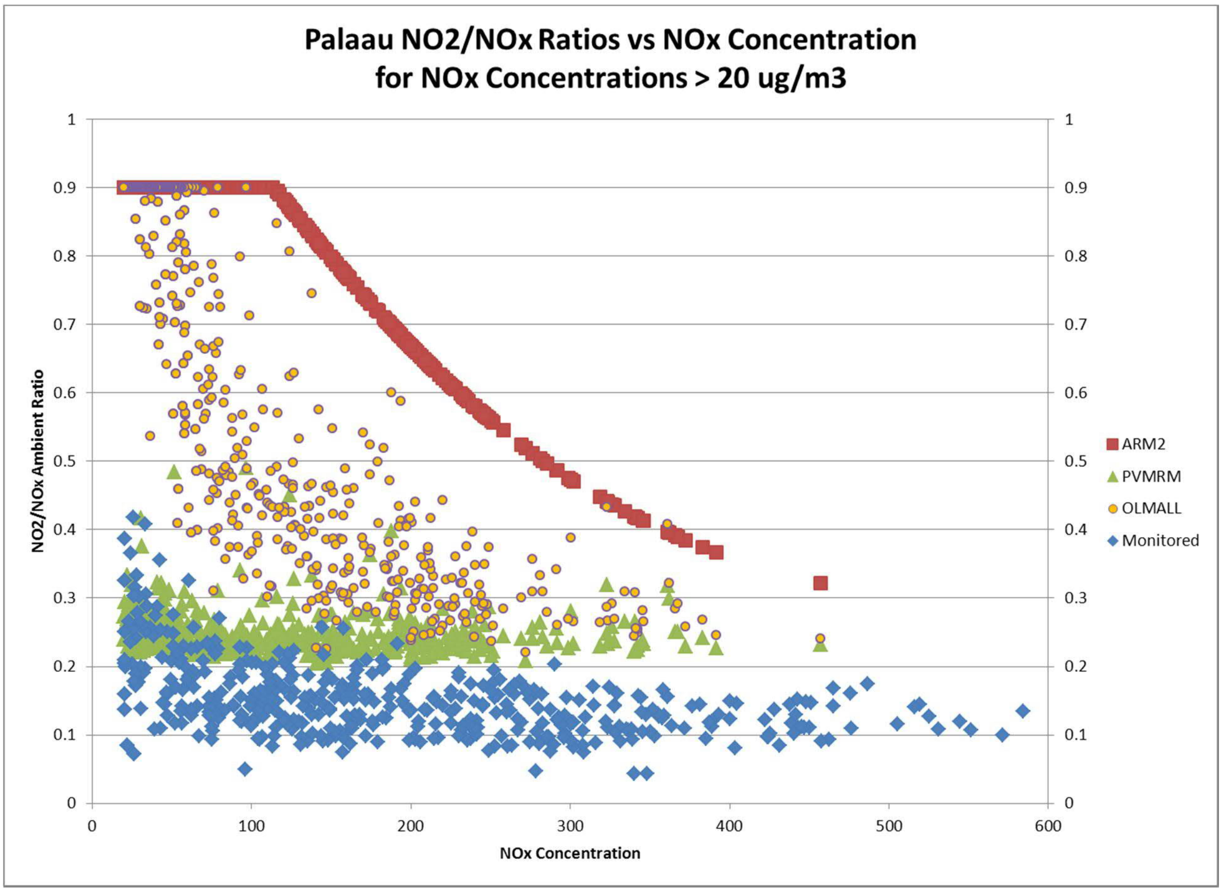


Figure 14 is the hourly Q-Q plot for NO_2. These data were for those hours that met the "direct transport" wind direction criteria and had monitored or modeled concentrations greater than 1 µg/m^3. All the methods exhibit a similar over-prediction at the highest NO_2 concentrations (an approximate factor of 2). As was the case with the Empire Abo data sets, the AERMOD-ARM2 plot shows significant over-prediction at lower concentrations, but the curve then flattens out and predicts high concentrations at similar levels as AERMOD-PVMRM.

4.7 Wainwright Evaluation Results

There were 458 hours that met the "direct transport" wind direction criteria (and had non-zero concentrations for both modeled and monitored NO_X concentrations). There were 185 of those hours that also had monitored NO_X concentrations greater than the 20 µg/m^3 threshold, and 97 hours with both monitored and modeled NO_X concentrations greater than the 20 µg/m^3 threshold. For the 97 hour data set, the maximum monitored NO_X concentration was 298 µg/m^3, and the maximum monitored NO_2 concentration was 66 µg/m^3.

The paired scatter plot of predicted versus observed NO_2/NO_X ratios is presented in Figure 15. This plot indicates that the observed ratios are clustered between 0.2 and 0.4. The PVMRM predicted ratios are clustered between 0.3 and 0.5, the OLM predicted ratios are found between 0.2 and 0.9, and the ARM2 predicted ratios are found between approximately 0.4 and 0.9. The OLM and ARM2 data points are predominately distributed above the 1:1 line. A large amount of scatter is observed for the OLM and ARM2 methods, but the scatter for PVMRM is appreciably less. These plots suggest that, for this data set, PVMRM has better skill than OLM or ARM2 for predicting the ratios on a paired in space and time basis, and that OLM and ARM2 have a greater tendency towards overprediction of the ambient ratio than PVMRM.

Figure 14 – Q-Q NO_2 Plot for the Palaau Data Set

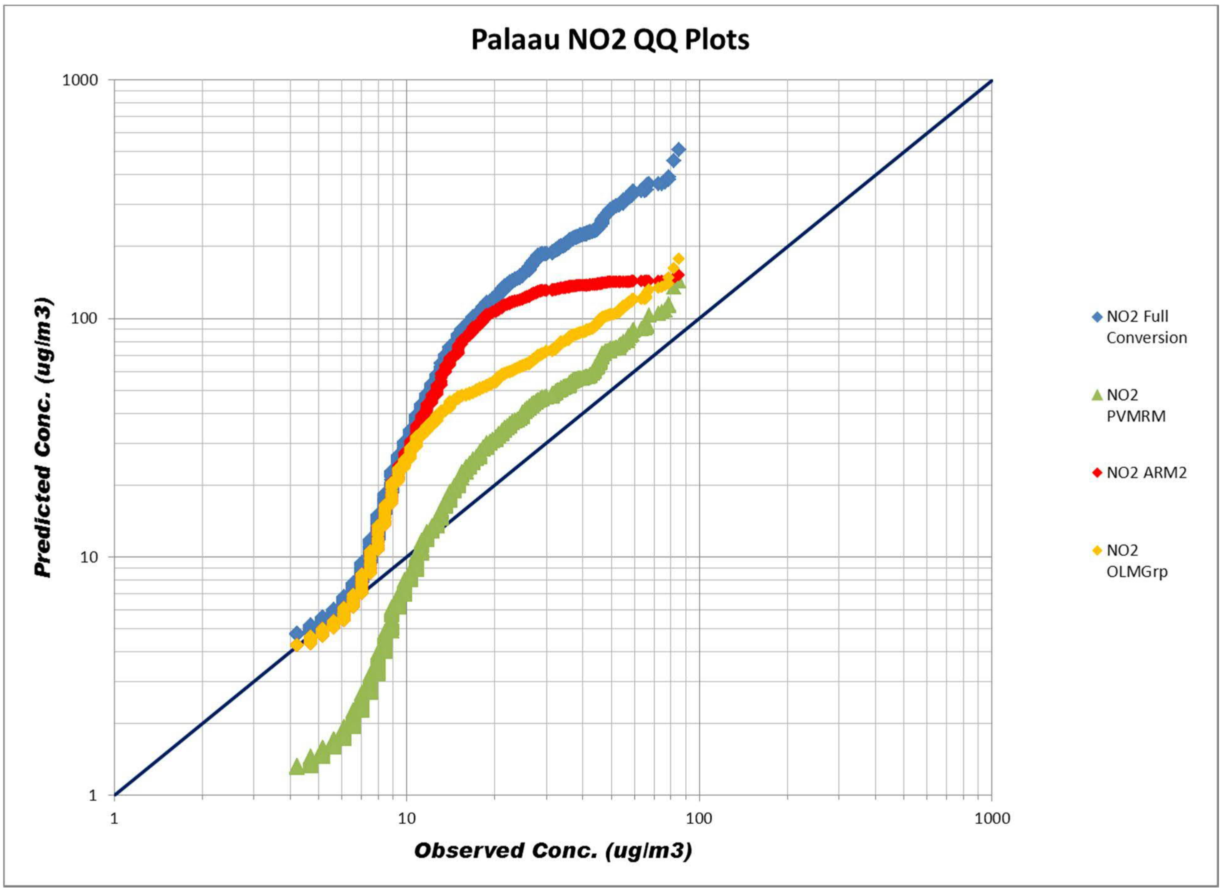


Figure 15 – Scatter Plot of NO_2/NO_X Ratio for Wainwright Data Set

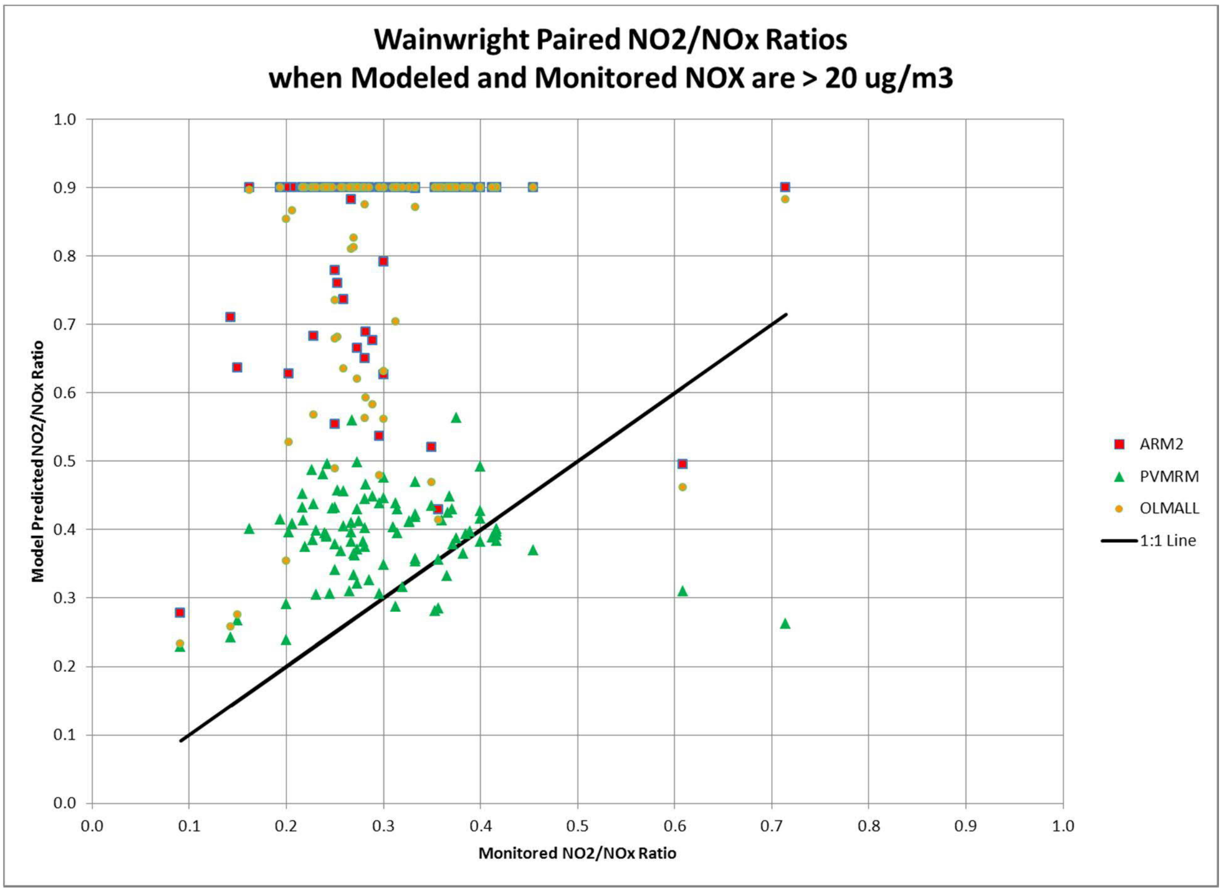


Figure 16 is the scatter plot of the predicted NO_2/NO_X ratio as a function of AERMOD predicted NO_X concentration. The observed NO_2/NO_X ratios plotted as a function of observed NO_X concentrations are also included (the monitoring data are not paired in time with the modeling predictions). This plot indicates that the PVMRM predicted ratios generally match the observed ratios the best, while the OLM and ARM2 predicted ratios are typically higher than the observed ratios. However, at the extreme high end of the NO_X concentration range, the predicted ratios from the three methods cluster closer together.

Figure 17 presents the hourly Q-Q plot for NO_2 for the Wainwright data set. Similar to the previous plots, when combined with the AERMOD predictions of NO_X, the Tier 1 option of full conversion has a significant bias to overpredict NO_2. The AERMOD-ARM2 and AERMOD-OLM methods show significant over-prediction at lower concentrations, but then predict the highest concentrations at very similar levels as AERMOD-PVMRM. All of the methods exhibit a similar over-prediction at the highest NO_2 concentrations (an approximate factor of 2).

Figure 16 –Plot of NO_2/NO_X Ratio vs NO_X for Wainwright Data Set

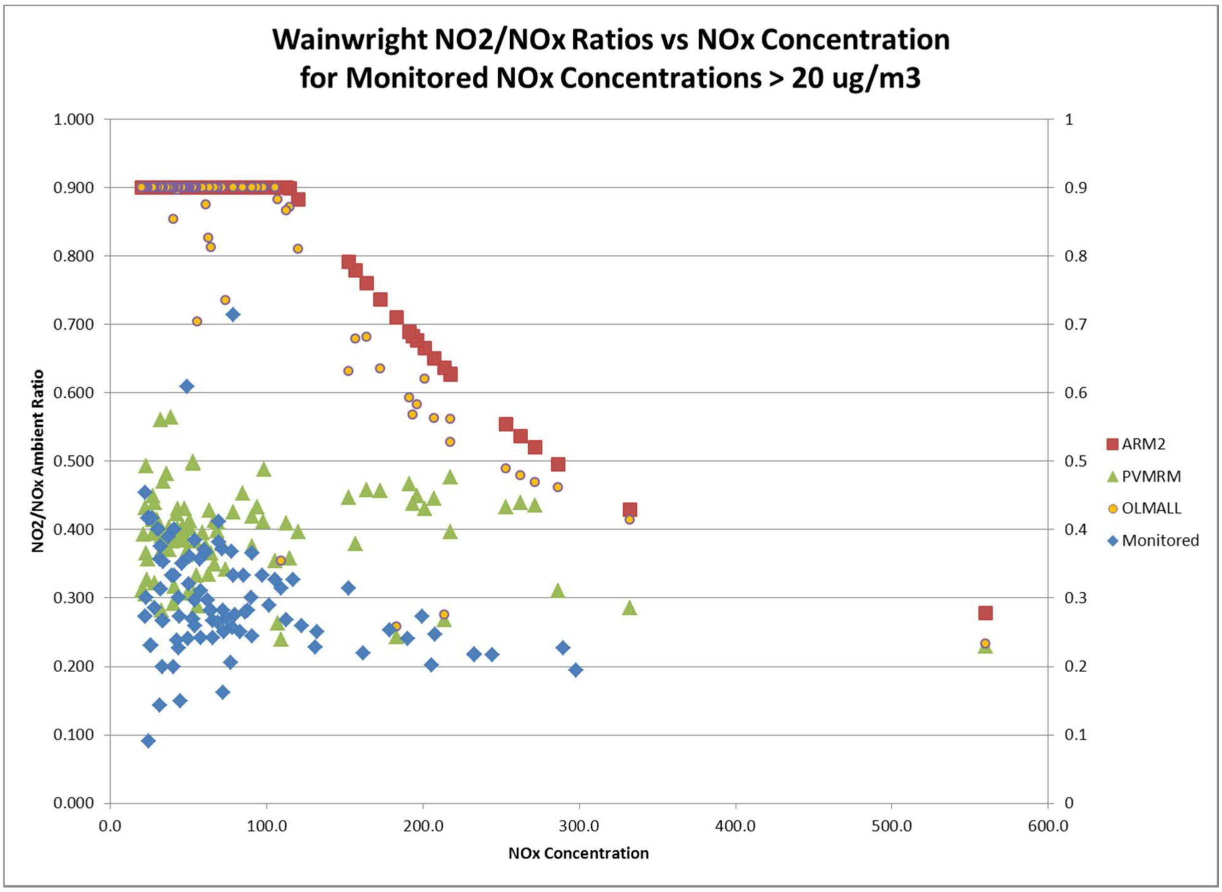
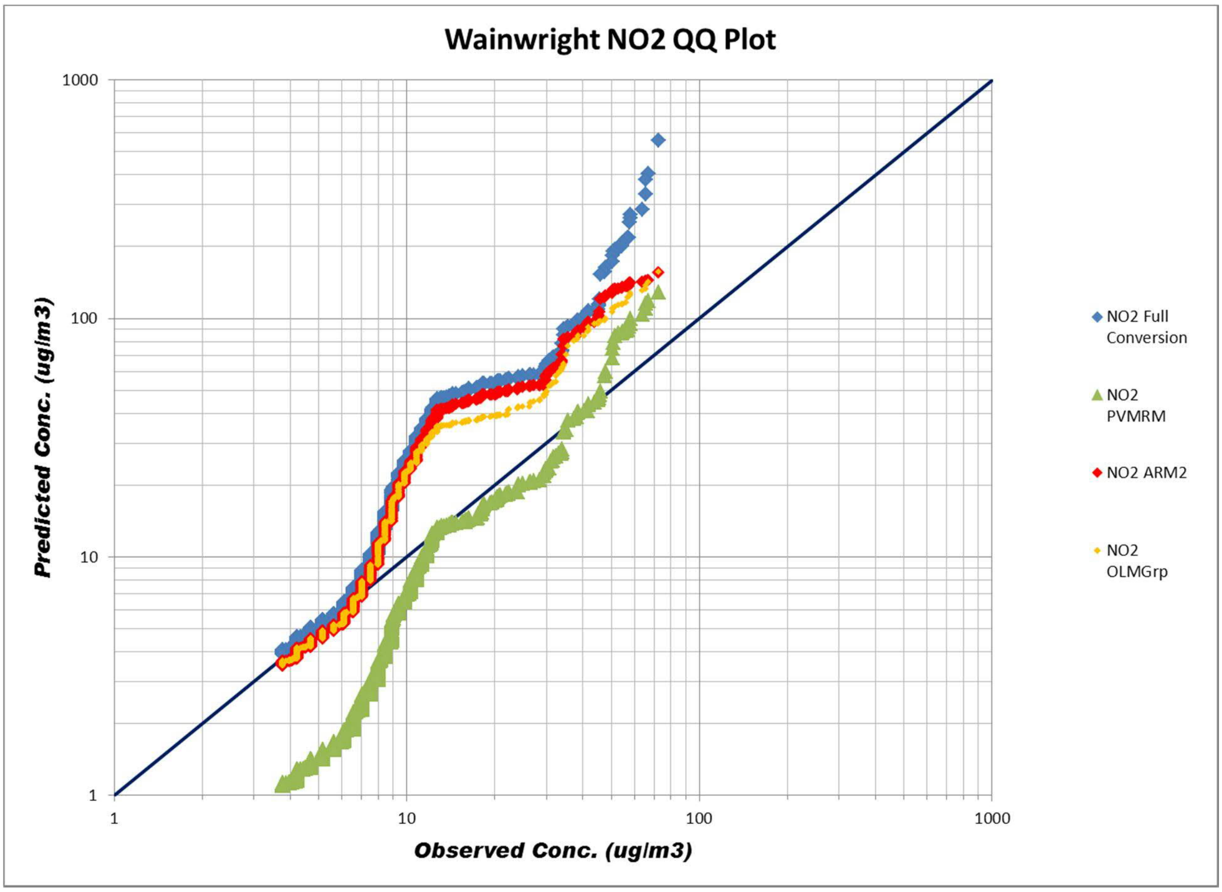


Figure 17 – Q-Q Plot for NO_2 for Wainwright Data Set



4.8 RHC and Performance Evaluation Summary

The RHC represents a smoothed estimate of the highest concentrations, based on a tail exponential fit to the upper end of the concentration distribution. The RHC summary is presented in Table 5 for all of the evaluation data sets, along with the geometric means of the predicted RHC concentration divided by the observed RHC concentration across all data sets. These results are consistent with the relative performance illustrated in the Q-Q plots for NO_2. AERMOD predictions of NO_X combined with the full conversion option significantly over-predict NO_2 concentrations by an approximate factor of 5. Based on the RHC geometric means, the NO_2 performance of the AERMOD-ARM2, AERMOD-OLM, and AERMOD-PVMRM methods are all very similar at the elevated concentrations that are represented by the RHC, with the 3 methods over-predicting on average by factors of 1.8, 1.7, and 2.0 respectively. AERMOD-ARM2 performs better than AERMOD-PVMRM but not as well as AERMOD-OLM over all of these data sets.

Table 5 - Summary of RHCs for Evaluation Data Sets (µg/m^3)

	Observed NO_X	Observed NO_2	AERMOD NO_X (FULL NO_2)	AERMOD-PVMRM NO_2	AERMOD-OLM NO_2	AERMOD-ARM2 NO_2
New Mexico Abo North	532.5	128.9	436.8	184.2	149.3	163.8
New Mexico Abo South	462.3	79.9	446.2	264.7	163.9	156.2
Hawaii Palaau	650.9	93.5	465.1	138.7	166.3	145.7
Wainwright	393.6	82.0	528.1	177.0	169.4	215.2
Geometric Mean for Pred/Obs NO_2 RHC	N/A	N/A	4.96	1.97	1.72	1.78
Geometric Mean for Pred/Obs NO_X RHC	N/A	N/A	0.93	N/A	N/A	N/A

The geometric mean ratios for AERMOD-PVMRM and AERMOD-OLM are higher than what was previously reported in the 2011 Additional Clarifications memo. This is likely caused by the updates to the in-stack ratios (increased from 0.1 to 0.2), and for the Empire Abo data sets the use of "un-scavenged" ozone data. Since these changes are intended to better reflect current 1-hr NO_2 modeling guidance, these updated performance results better reflect the accuracy of the Tier 3 screening methods using current guidance.

To help determine the performance of AERMOD itself and identify potential compensating errors between the dispersion model and the NO_2 conversion methodology, RHC statistics for NO_X concentrations are also presented in Table 5. The geometric mean of the AERMOD predicted RHC NO_X concentration (equivalent to the full conversion option) divided by the Observed RHC NO_X concentration is 0.939. This indicates that on average AERMOD is under predicting the total NO_X concentration by approximate 6%, while all of the "AERMOD plus Tier 2 or 3" combinations are over-predicting the NO_2 concentration by 70% to 100%. This suggests that for these data sets, the NO_2 conversion methodologies are the most important factor in the observed over-prediction of NO_2 concentrations.

5.0 ARM2 Sensitivity Analyses

The ARM2 sensitivity analyses compare the predicted NO_2 concentrations using AERMOD and the ARM2, PVMRM, OLM, and full conversion methods across a wide range of meteorology and emissions source characteristics. The scenarios modeled include updated versions of those in the MACTEC report "Sensitivity Analysis of PVMRM and OLM in AERMOD", 2004 for the diesel generator, gas turbine, and "35-meter stack" single source scenarios, and the cumulative source scenario. In addition, some scenarios were analyzed that are representative of large diesel generators, a refinery, a gas pipeline compressor station, natural gas production fields and processing plants, and a large boiler.

5.1 Updates to 2004 Sensitivity Scenarios

The 2004 MACTEC sensitivity analysis modeled a variety of single source scenarios, including a generic 35m buoyant point source, a diesel generator source, and a gas turbine source. A range of buoyancy and momentum fluxes are represented by these sources, with the diesel generator representing a relatively low buoyancy/low momentum release, the 35m stack representing medium buoyancy and momentum, and the gas turbine representing relatively high buoyancy and momentum. The emission rates for the diesel generator and gas turbine sources are considered typical uncontrolled rates for those source types. The 35m stack was modeled with two different emission rates to test the sensitivity of the ARM2, PVMRM, and OLM algorithms to the NO_X emission rate. In addition to these single source scenarios, a hypothetical multiple-source scenario was included in the 2004 MACTEC sensitivity analysis to test the plume merging algorithm of PVMRM. This multiple-source scenario included a total of 65 point sources with 1,598 receptors (note that the area sources were removed from the original input files for this updated analysis). For additional information on these scenarios, refer to http://www.epa.gov/ttn/scram/7thconf/aermod/pvmrm_sens.pdf.

EPA provided the AERMOD input files, meteorological data, and ozone data from these previous sensitivity analyses. The diesel generator, gas turbine, and "35-meter source" scenarios have been rerun using the current version of AERMOD (12345). Note that the meteorological data files were simply edited to reflect an AERMET version of 11059 so that AERMOD version 12345 could be run with these meteorological files. The in-stack NO_2/NO_X ratio of 0.1 in the original analysis was updated to a value of 0.2 to better reflect current guidance. While the MACTEC study evaluated the maximum 1-hr and annual concentrations, this updated sensitivity analysis focused on the 1-hr NO_2 design concentrations directly reported by AERMOD (the design concentration is defined as the multiyear average of the 98^{th} percentile of the annual distribution of daily maximum 1-hour values).

Table 6 and Figure 18 present the results for the single source scenarios. In general, the modeled concentrations and distance to maximum impacts are similar to the 2004 results. A comparison of the 35m stack with 1g/s versus 50g/s emission rate shows the sensitivity of the predicted NO_2/NO_X ratio to the level of NO_X emissions. For the 1g/s source, and for other scenarios with lower predicted NO_X concentrations, the ratio of predicted NO_2 concentration versus full conversion NO_X concentration was close to 1.0 for all methods (for the PVMRM and ARM2 methods the maximum ratio of 0.90 is reached). For other scenarios with larger predicted NO_X concentrations (i.e., when the full conversion NO_X concentrations are greater than 100 µg/m^3) such as the downwash and complex terrain cases, ARM2 predicts the highest ratios, followed by OLM and then PVMRM. This is true for scenarios with both close-in impact locations with little time for entrainment of ozone (for example, the diesel generator with downwash in rural location), as well as more distant impact locations that allow more time for ozone entrainment and reaction (for example, the gas turbine in complex terrain). The average ratios of predicted NO_2 concentration versus full conversion concentration for all scenarios with predicted NO_X concentrations equal to or greater than 100 µg/m^3 are 0.67 for ARM2, 0.54 for OLM, and 0.35 for PVMRM.

Table 6 - Comparison of 1-hr NO_2 Design Concentrations for Single Source Scenarios

Source Scenario	Conversion Option	NO_2 Design Conc. ($\mu g/m^3$)	Distance to Maximum (m)	Ratio of NO_2 vs. Full Conversion
35m Stack, 1g/s Rural, No Downwash	FULL	2.7	500	1.00
	OLM	2.7	500	1.00
	PVMRM	2.4	500	0.90
	ARM2	2.4	500	0.90
35m Stack, 50g/s Rural, No Downwash	FULL	133.0	500	1.00
	OLM	73.2	750	0.55
	PVMRM	33.2	3000	0.25
	ARM2	112.4	500	0.84
Diesel Generator Rural, No Downwash	FULL	56.5	300	1.00
	OLM	47.5	300	0.84
	PVMRM	21.8	1500	0.38
	ARM2	50.9	300	0.90
Diesel Generator Rural, Downwash	FULL	386.5	50	1.00
	OLM	126.5	50	0.33
	PVMRM	88.0	50	0.23
	ARM2	143.5	50	0.37
Diesel Generator Urban, No Downwash	FULL	76.1	200	1.00
	OLM	55.0	200	0.72
	PVMRM	23.0	3000	0.30
	ARM2	68.5	200	0.90
Diesel Generator Flat Terrain	FULL	64.0	200	1.00
	OLM	61.1	200	0.96
	PVMRM	26.7	1000	0.42
	ARM2	57.6	200	0.90
Diesel Generator Complex Terrain	FULL	99.6	1500	1.00
	OLM	85.1	1500	0.85
	PVMRM	52.8	3000	0.53
	ARM2	89.7	1500	0.90
Gas Turbine Rural, No Downwash	FULL	15.8	750	1.00
	OLM	15.8	750	1.00
	PVMRM	10.8	3000	0.68
	ARM2	14.3	750	0.90
Gas Turbine Rural, Downwash	FULL	348.1	100	1.00
	OLM	98.0	100	0.28
	PVMRM	68.9	200	0.20
	ARM2	142.8	100	0.41
Gas Turbine Urban, No Downwash	FULL	54.9	1500	1.00
	OLM	50.5	1500	0.92
	PVMRM	37.1	1500	0.68
	ARM2	49.5	750	0.90
Gas Turbine Flat Terrain	FULL	20.4	750	1.00
	OLM	20.4	750	1.00
	PVMRM	14.8	750	0.72
	ARM2	18.4	750	0.90
Gas Turbine Complex Terrain	FULL	146.7	2000	1.00
	OLM	97.3	2000	0.66
	PVMRM	76.9	2000	0.52
	ARM2	118.3	2000	0.81

Figure 18 – Results from Single Source Sensitivity Analyses

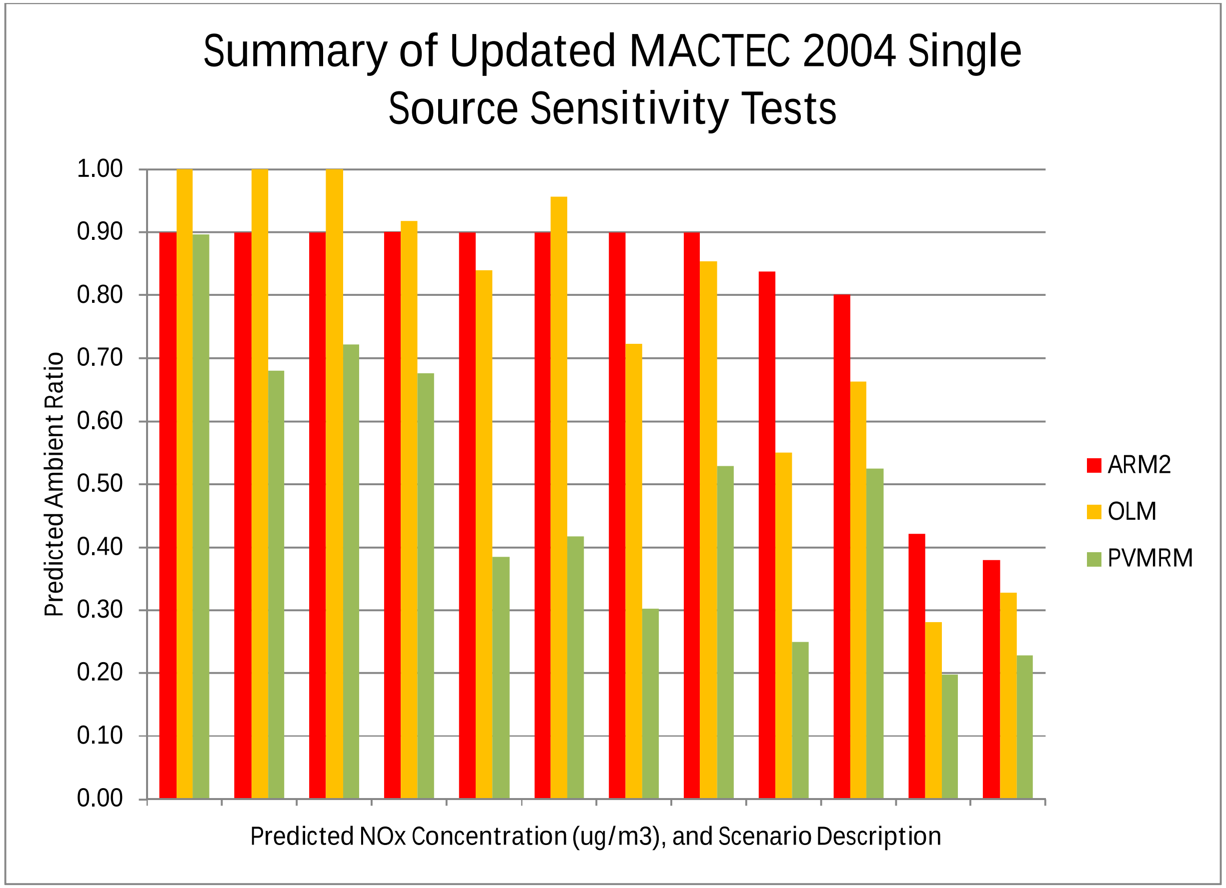


Table 7 presents the results of the multiple-source scenario, showing the 1-hour NO_2 design concentration and the ratio of predicted NO_2 concentration versus full conversion concentration for each of the conversion options. The modeled NO_X concentrations for this scenario are high. The results indicate that the predicted NO_2/NO_X ratios for all three methods are similar, with the OLM method being the lowest, and PVMRM and ARM2 being very similar. The distance to maximum modeled impact for this multi-source scenario is 500 meters for ARM2 and OLM, and 1950 meters for PVMRM.

Table 7 - Comparison of 1-hr NO_2 Design Concentrations for Multi-Source Scenario

Conversion Option	Maximum NO_2 Concentration (μg/m^3)	Distance to Maximum (m)	Predicted NO_2/NO_X Ratio
Full Conversion	1774	502	1
OLM-GroupAll	238	502	0.13
PVMRM	322	1953	0.18
ARM2	355	502	0.20

5.2 Analysis of Additional Scenarios

Some additional multi-source scenarios were analyzed that are based on actual configurations of large diesel IC generators, a refinery, a gas pipeline compressor station, natural gas production fields and processing plants, and a large boiler in complex terrain. The first five of these additional cases were originally presented at the EPA 10th Modeling Conference in the paper "Updated Tier 2 Ambient Ratio Method (ARM) for 1-hr NO_2 NAAQS Analyses", March 12, 2012. They have been updated with the AERMOD version 12345, and the version of AERMOD that includes the ARM2 code changes. For each of these cases except the large boiler, the assumed in-stack ratio was 0.2. For the large boiler, the assumed in-stack ratio was 0.1 (a more representative value for large boilers).

A brief description of each of these additional scenarios follows:

- Diesel IC Generators – This scenario includes five IC engine generators rated at approximately 2500 kW, with NO_X emission rates of 2.6 g/hp-hr. The stack heights are approximately 100 feet and there is a large 200 foot tall building nearby, so downwash is a factor for this scenario.

- Refinery – This scenario includes 59 emission units with stack heights ranging from 80 to 350 feet tall, representing typical refinery distillation, cracking, treating, and reforming emission sources including a fluid catalytic cracking (FCC) unit. Building structures are not included in this scenario.

- Gas Pipeline Compressor station – This scenario includes a 10 Mw combustion turbine with a 35 foot tall stack and a 30 foot tall nearby building, and a 500 hp IC engine generator with a 15 foot tall stack and a 15 foot tall nearby building.

- Gas Plant and Production Scenario A – This scenario includes 84 sources that represent typical natural gas plant and gas field production sources, including IC engines (for pumps and compressors), heaters, and dehydration units. The stack heights range from 8 to 100 feet, and no buildings or structures were included.

- Gas Field Production Scenario B – This scenario examines the close-in impacts from two IC engines, one with an 8 foot stack and the second with a 25 foot stack. There is no building downwash, but the receptor is located approximately 20 meters distant from the emission units.

- Large Boiler with Complex Terrain – This scenario examines the impacts from a large 3,000 MMBtu/hr boiler with NO_X emissions equal to 0.2 lb/MMBtu, and a 300 foot tall stack. A 150 foot tall adjacent building was included in the analysis. This emission source was located at three distances (1, 3, and 10 km) from an elevated ridge approximately 300 to 500 feet tall.

Table 8 presents the results from these additional scenario analyses, including the ratio of the predicted 1-hr NO_2 design concentration versus the predicted full conversion 1-hr NO_X design concentration for each method. Four of the scenarios have predicted NO_X concentrations that are moderately high (ranging from 190 to 461 µg/m^3), and the other four scenarios have NO_X concentrations that are very high (ranging from 1080 to 2823 µg/m^3).

For the first two scenarios (generators and refinery examples), the OLM and ARM2 predicted concentrations are very similar, while the PVMRM predicted concentrations are slightly lower. For the third scenario (compressor station), the PVMRM predicted concentration is significantly higher than either OLM or ARM2. A supplemental model run was made for this scenario using OLM on a "source-by-source" conversion basis; this should establish an upper limit for ozone limited conversion. The OLM "source-by-source" concentration was still substantially lower than the PVMRM predicted concentration. Therefore, the PVMRM result for the compressor station scenario appears unrealistically high. This scenario included downwash, and the maximum impact receptor for all of the methods was located at the nearby fence line, within the wake zone of the building. Under these conditions, PVMRM may be having difficulty calculating the plume volume that ambient ozone is entrained into.

Table 8 - 1-hr NO_2 Design Concentrations for Additional Sensitivity Scenarios

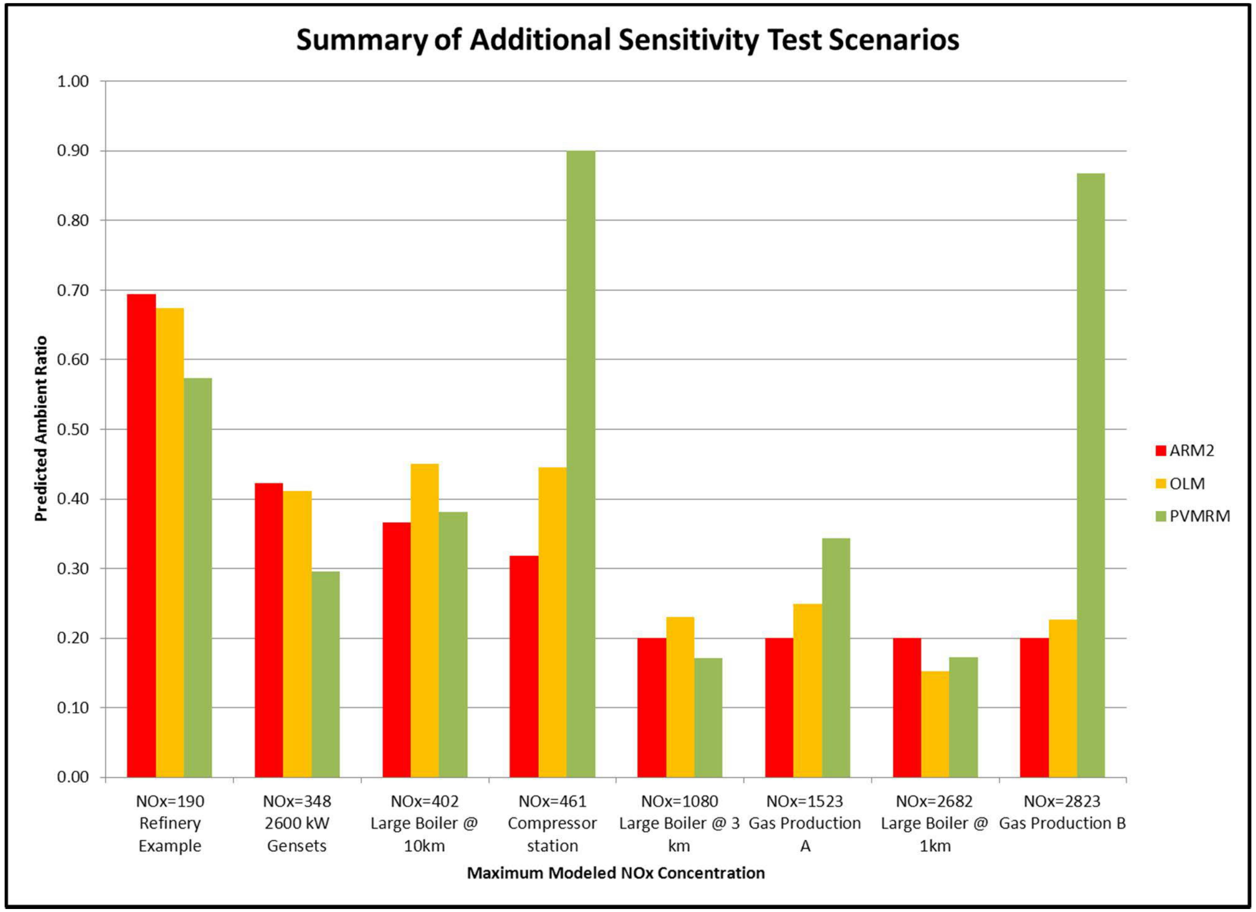
Description of Scenario	Full NO_X µg/m^3	OLM µg/m^3	PVMRM µg/m^3	ARM2 µg/m^3	OLM Ratio	PVMRM Ratio	ARM2 Ratio
2600 kW Gensets	348	143	103	145	0.41	0.30	0.42
Refinery Example	190	128	109	129	0.67	0.57	0.68
Compressor station	461	205	415	147	0.44	0.90	0.32
Gas Production A	1523	380	524	305	0.25	0.34	0.20
Gas Production B	2823	640	2450	565	0.23	0.87	0.20
Large Boiler @ 1km	2682	352	352	422	0.13	0.13	0.16
Large Boiler @ 3 km	957	237	174	191	0.25	0.18	0.20
Large Boiler @ 10km	334	174	129	143	0.52	0.39	0.43

For the gas production field scenarios, the OLM and ARM2 concentrations are similar, while the PVMRM concentrations and ratios are substantially higher. In particular, the PVMRM ratio for the gas production B scenario is very high, similar to the situation discussed above for the compressor station scenario. Like that scenario, the receptor with the maximum predicted impact for the gas production B scenario is located close to the source (approximately 20 meters distant), and the stack heights are low (8 to 25 feet). OLM on a source-by-source method was run for the gas production B scenario to determine an upper limit for the conversion, and the result was the same as the OLM Group All concentration (the gas production B scenario does consist of only two sources, so this is not surprising). Therefore, once again the PVMRM predicted concentration and ratio appear to be unrealistically high for the gas production B scenario.

The large boiler examples evaluate the relative performance of the various methods at three distances. As the distance increases, the NO_X concentrations decrease with the additional time for dispersion, and the NO_2/NO_X ratios should increase with additional time for entrainment and reaction. The predicted ambient ratios do increase with each distance value for all three methods. For all of the boiler cases, the ARM2 predicted ratios are higher or equal to the lower of the two Tier 3 methods.

Figure 19 presents the ratio of the predicted 1-hr NO_2 design concentration versus the predicted full conversion 1-hr NO_X design concentration for these additional scenarios, sorted by the predicted NO_X concentration. This plot shows the general tendency of all the methods to predict lower ambient ratios as the modeled NO_X concentration increases. The two cases with unrealistic PVMRM predicted concentrations are readily evident. For all other cases, the ARM2 method predicts higher or similar concentrations and ratios than the lower of the two Tier 3 methods.

Figure 19 – Results from Additional Scenario Sensitivity Analyses



6.0 Conclusions and Recommendations

6.1 Summary of Key Findings

The key findings from the ambient monitoring data analyses, performance evaluations, and sensitivity analyses are:

1. Plots of ambient NO_2/NO_X ratios as a function of NO_X concentration from various ambient monitoring data sets all show the same relationship of decreasing ambient ratios with increasing NO_X concentrations. At NO_X concentrations above approximately 300 ppb, the observed ambient ratios tend to cluster in a range of approximately 0.1 to 0.2.
2. The ARM2 conversion method was developed using 10 years of ambient monitoring data from 580 monitoring sites in EPA's AQS data base. ARM2 uses an empirically derived relationship between an upper limit of the observed NO_2/NO_X ambient ratio versus the ambient NO_X concentration.
3. ARM2 predicted ambient ratios derived from various geographical, land use, and time period data sets were evaluated and found to be similar to, and typically lower than, the ratios predicted by the "All AQS Sites" equation. This indicates that the ARM2 equation derived from the "All AQS Sites" data set is representative of a wide range of geographical or land use categories, and can be used as the basis of the ARM2 method.
4. The ARM2 conversion method has been programmed into the latest version of AERMOD (version 12345).
5. The performance of the ARM2 method has been compared to monitoring observations and predictions from the Tier 3 screening methods, using the same evaluation data sets that have previously been used to test the Tier 3 methods. Plots of ambient ratios versus NO_X concentration indicate that all three methods overpredict the observed ambient ratios. Scatter plots of predicted versus observed NO_2/NO_X ratios indicate that all methods have little skill in predicting the ambient ratio on a "paired in space and time" basis. The Q-Q

NO_2 plots indicate that all methods overpredict the highest NO_2 concentrations by factors ranging from approximately 1.2 to 2.

6. The Robust Highest Concentration (RHC) summary of the evaluation results is a measure of model performance based on the top 26 highest modeled and observed NO_2 concentrations (which range from 55 to 196 $\mu g/m^3$). The RHC summary indicates that the AERMOD-ARM2, AERMOD-OLM, and AERMOD-PVMRM methods perform very similar, with all 3 methods over-predicting the highest NO_2 concentrations by factors of 1.8, 1.7, and 2.0 respectively. The ARM2 RHC result falls between the OLM and PVMRM results.
7. Sensitivity analyses were performed for the ARM2, PVMRM, OLM, and full conversion methods across a range of meteorology and source characteristics. The scenarios modeled included updated versions of those described in the MACTEC report "Sensitivity Analysis of PVMRM and OLM in AERMOD", 2004 for the diesel generator, gas turbine, and 35-meter stack "single source" scenarios, and the cumulative source scenario. For the single source sensitivity scenarios with low predicted NO_X concentrations (below 20 $\mu g/m^3$), all of the conversion methods predicted NO_2/NO_X ratios near 0.9. When the predicted NO_X concentrations were higher (greater than 300 $\mu g/m^3$), all the methods predict NO_2/NO_X ratios in the range of 0.2 to 0.4, with ARM2 conservatively predicting the highest NO_2/NO_X ratios of any of the methods. For the multi-source scenario, the model predicted NO_X concentration is 1,774 $\mu g/m^3$, and the predicted NO_2/NO_X ratios are 0.13 for OLM, 0.18 for PVMRM, and 0.2 for ARM2.
8. Some additional multi-source scenarios were also analyzed. These scenarios were based on real-world configurations of large diesel IC generators, a refinery, a gas pipeline compressor station, natural gas production fields and processing plants, and a large boiler in complex terrain. The ARM2 method predicts higher or similar ratios when compared to the Tier 3 methods. Two of the cases were further evaluated because of suspiciously high PVMRM predicted ratios, and based on comparisons of PVMRM versus OLM "source-by-source" predicted ratios, it was concluded that PVMRM is predicting unrealistically high concentrations and ratios for those cases. In summary, the additional

multi-source sensitivity analysis indicates that the ARM2 method predicts higher or similar ratios when compared to the two Tier 3 methods.

6.2 Recommendation

The performance evaluations and sensitivity analyses presented in this report document that the performance of the ARM2, PVMRM, and OLM methods is very similar. The relative performance ranking can vary depending upon the data set, and there can be cases when PVMRM is predicting unrealistically high NO_2/NO_X ratios.

The ARM2 method has some advantages over the Tier 3 methods. ARM2 does not require case-by-case review and approval of special input data such as in-stack NO_2/NO_X ratios and ambient ozone data. There is no concern over possible ozone scavenging in data used to estimate NO_2 conversion. The model execution times are faster than the Tier 3 methods. ARM2 can reduce the resources expended by both the facility and the reviewing agency to perform and review 1-hr NO_2 NAAQS modeling analyses.

Based on the analyses presented herein, it is recommended that ARM2 be approved as a refinement to the current fixed-ratio ARM method for performing 1-hr NO_2 analyses. Given its model performance as detailed in this report, ARM2 could also be considered a Tier 3 screening method equivalent to the other two Tier 3 screening methods. Consistent with other recent updates to AERMOD, EPA could implement the ARM2 refinement by posting a memorandum on the SCRAM website authorizing its use for AERMOD modeling analyses, and providing an updated version of AERMOD that includes the ARM2 model option.

APPENDIX A

List of AQS NO_X monitoring sites and available data periods by site

List of AQS NOx Monitoring Stations and Number of Valid Observations by Year

State Code	County Code	Site ID	Total Obs	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
1	33	1002	8,285		6,298	1,987							
1	71	20	8,162				7,451	711					
1	83	4	8,261			6,174	2,087						
4	7	10	18,046		2,529	3,668	3,933	4,107	3,809				
4	12	8000	8,167					3,091	5,076				
4	13	9993	18,830	3,398	5,172	5,155	5,105						
4	13	9997	82,126	6,817	8,597	8,471	8,653	8,698	8,701	8,554	8,217	8,307	7,111
4	19	1011	2,186										2,186
4	19	1028	2,070										2,070
4	21	8001	25,458	3,612	4,848	4,941	4,306	3,761	3,990				
4	27	6	17,377					6,549	8,483	2,345			
5	35	5	25,759								8,464	8,712	8,583
5	119	7	73,755		7,852	8,131	7,815	7,921	8,337	8,307	8,234	8,484	8,674
5	119	1002	7,042	7,042									
5	119	1005	457		457								
6	1	7	33,027							8,309	8,352	8,213	8,153
6	1	9	25,825							1,378	8,096	8,158	8,193
6	1	10	12,056	1,214	8,091	2,751							
6	1	11	15,004									6,920	8,084
6	1	1001	31,615							8,265	8,356	8,138	6,856
6	1	2004	25,392							537	8,321	8,315	8,219
6	7	2	82,478	8,319	8,163	8,342	8,353	8,324	8,349	7,608	8,305	8,342	8,373
6	13	2	33,053							8,315	8,316	8,304	8,118
6	13	10	10,989	1,203	7,357	2,429							
6	13	1002	33,060							8,238	8,333	8,270	8,219
6	13	1004	23,069							8,253	7,929	1,788	5,099
6	13	3001	16,384							8,147	8,237		
6	17	11	27,573	8,370	8,249	8,237	2,717						
6	17	12	19,775	3,719	5,045	5,933	5,078						
6	19	7	77,732	8,145	7,043	8,039	8,317	8,264	8,035	7,963	8,289	7,771	5,866
6	19	8	82,276	8,301	8,267	8,286	8,321	7,900	8,231	8,297	8,110	8,247	8,316
6	19	242	76,219	7,844	8,144	8,238	7,960	8,221	7,916	7,993	6,506	7,206	6,191
6	19	243	5,131			5,131							
6	19	244	4,929			4,929							
6	19	4001	78,208	8,000	8,263	8,066	8,291	8,294	7,913	8,257	8,005	6,976	6,143
6	19	5001	79,051	8,016	8,105	7,728	8,204	8,190	8,203	8,012	7,961	6,685	7,947
6	25	5	81,336	6,956	8,263	8,253	8,323	8,258	8,223	8,270	8,298	8,207	8,285
6	25	6	69,556	6,646	6,723	7,705	8,093	6,646	8,180	6,998	8,187	7,720	2,658
6	25	1003	57,303	1,603	4,247	6,721	6,659	8,005	7,191	7,395	5,873	6,843	2,766
6	29	7	80,709	7,758	8,368	8,177	7,981	8,293	8,282	8,188	7,946	7,985	7,731
6	29	10	69,727	7,732	7,944	7,150	5,938	8,295	8,294	8,159	8,146	7,970	99
6	29	11	33,645	8,233	7,152	7,742	7,435	3,083					
6	29	14	81,972	8,027	8,240	8,230	7,619	8,355	8,248	8,243	8,315	8,345	8,350
6	29	232	40,648	8,289	8,047	8,248	7,759	8,305					
6	29	5001	79,141	8,301	8,376	8,304	8,222	8,141	8,166	8,222	7,115	7,691	6,603
6	29	6001	82,308	8,223	8,252	8,195	8,245	8,294	8,262	8,284	8,297	8,307	7,949
6	31	1004	54,688	5,930	8,241	7,916	8,287	8,285	8,242	6,839			948
6	37	2	80,870	8,337	8,021	7,997	7,766	8,285	8,275	8,276	8,248	7,729	7,936
6	37	16	79,234	8,297	8,076	8,165	8,013	8,172	8,120	8,260	8,283	6,215	7,633
6	37	30	10,018	6,786	3,232								
6	37	31	9,108	4,240	4,868								
6	37	113	81,092	8,395	8,285	8,118	7,643	8,284	8,070	7,940	8,229	8,034	8,094
6	37	1002	80,389	8,390	8,164	7,922	8,023	8,337	8,340	8,265	8,262	7,692	6,994
6	37	1103	80,154	8,334	8,330	8,285	7,498	8,236	8,216	8,167	7,820	7,116	8,152
6	37	1201	81,400	8,047	8,334	8,298	8,086	7,979	8,005	7,914	8,318	8,256	8,163
6	37	1301	64,605	8,392	8,305	8,131	8,191	8,194	8,243	8,265	6,884		
6	37	1302	16,402								1,123	7,333	7,946
6	37	1601	35,691	8,388	8,268	8,250	8,142	2,643					
6	37	1602	32,186						3,861	7,925	7,493	6,937	5,970
6	37	1701	82,294	8,365	8,312	8,342	8,271	8,349	8,144	8,275	8,341	8,133	7,762
6	37	2005	81,423	8,351	8,376	8,146	8,153	8,239	8,369	8,335	8,289	8,304	6,861
6	37	4002	80,025	8,384	8,050	7,775	8,114	8,329	8,100	7,983	8,279	7,224	7,787
6	37	5001	26,215	8,257	7,684	8,247	2,027						
6	37	5005	45,428				4,712	6,204	7,824	7,397	7,198	5,678	6,415
6	37	6002	2,783	2,783									
6	37	6012	77,052	5,181	7,736	8,317	8,131	7,890	8,217	7,816	8,221	8,134	7,409
6	37	9002	6,492	6,492									
6	37	9033	74,427	1,394	8,151	7,606	8,137	8,265	8,127	8,227	8,327	8,215	7,978

List of AQS NOx Monitoring Stations and Number of Valid Observations by Year

State Code	County Code	Site ID	Total Obs	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
6	39	4	80,501	8,144	8,135	8,093	7,553	8,110	8,302	8,130	7,870	8,283	7,881
6	41	1	33,188							8,350	8,306	8,328	8,204
6	43	3	4,388						2,228	2,160			
6	43	33	3,813		2,660	1,153							
6	45	8	1,496									1,496	
6	47	3	78,228	5,472	8,198	8,236	8,248	8,280	8,109	8,189	7,872	7,711	7,913
6	53	1003	80,845	7,927	7,257	7,654	7,763	8,547	8,278	8,460	8,326	8,230	8,403
6	55	3	33,169							8,253	8,355	8,269	8,292
6	57	5	17,379								6,248	4,606	6,525
6	59	1	3,497	3,497									
6	59	7	75,483	2,711	8,244	8,147	8,162	8,277	7,786	8,179	8,345	8,218	7,414
6	59	1003	80,837	8,391	8,356	8,286	7,812	7,786	8,201	8,196	8,262	8,237	7,310
6	59	5001	78,177	8,342	7,517	8,303	7,736	8,189	8,210	8,329	8,187	8,042	5,322
6	61	6	82,349	8,129	8,198	7,972	8,365	8,270	8,372	8,210	8,262	8,293	8,278
6	61	7	1,393				1,393						
6	65	4	18,616								7,344	5,714	5,558
6	65	9	18,578								3,571	7,994	7,013
6	65	12	76,214	7,962	6,992	7,741	7,451	6,882	8,057	8,192	7,757	7,714	7,466
6	65	1003	17,103								1,591	8,264	7,248
6	65	5001	80,024	8,394	8,063	7,903	7,857	8,008	7,958	8,064	8,155	7,724	7,898
6	65	8001	77,716	8,325	7,456	8,181	7,317	8,257	8,356	8,275	8,142	7,713	5,694
6	65	8005	23,042								8,305	7,062	7,675
6	65	9001	78,923	8,244	8,114	7,425	7,425	8,018	7,896	7,949	8,084	8,224	7,544
6	67	2	72,946	7,947	8,293	8,291	8,047	6,759	4,890	6,472	5,953	8,151	8,143
6	67	6	73,005	7,759	7,845	5,590	2,894	8,246	8,223	7,966	8,118	8,330	8,034
6	67	10	80,924	7,918	8,120	7,103	8,141	8,373	8,345	8,134	8,148	8,346	8,296
6	67	11	74,667	8,003	6,824	5,176	8,283	7,907	6,926	8,057	8,292	7,561	7,638
6	67	12	80,151	7,432	7,985	8,103	8,255	8,107	8,296	7,960	8,103	8,132	7,778
6	67	13	59,179	7,149	7,771	6,863	8,242	8,057	8,293	8,005	4,799		
6	67	14	17,041								1,083	7,990	7,968
6	71	1	80,568	7,826	7,849	8,065	8,201	8,182	7,828	8,003	8,320	8,265	8,029
6	71	306	81,883	7,863	8,159	8,129	8,310	8,242	8,238	8,348	8,328	8,288	7,978
6	71	1004	80,064	8,379	8,277	8,300	8,319	8,293	7,700	7,410	8,245	7,222	7,919
6	71	1234	72,409	6,891	7,665	6,823	7,914	6,951	7,610	6,939	7,097	7,125	7,394
6	71	2002	77,474	8,389	7,051	7,966	7,044	8,196	8,220	7,765	7,431	8,097	7,315
6	71	9004	80,180	8,341	7,995	8,214	8,000	8,366	8,250	8,022	8,316	8,234	6,442
6	73	1	81,990	8,195	8,192	8,205	8,241	8,098	8,143	8,081	8,295	8,235	8,305
6	73	3	80,351	8,254	7,934	8,051	8,307	8,255	7,772	7,581	7,940	8,240	8,017
6	73	5	8,411	8,411									
6	73	6	81,301	8,048	7,977	8,140	8,309	8,283	8,093	8,047	8,061	8,090	8,253
6	73	1002	82,915	8,490	8,642	8,486	8,644	8,611	8,207	7,885	7,554	8,311	8,085
6	73	1006	80,065	8,308	8,141	7,626	8,265	8,077	8,237	8,189	8,340	6,785	8,097
6	73	1007	35,815	7,246	8,241	7,990	8,167	4,171					
6	73	1008	81,981	8,600	8,431	8,516	8,538	8,164	8,152	8,098	8,021	7,540	7,921
6	73	1009	1,353	1,353									
6	73	1010	43,563					3,817	8,104	8,193	7,796	8,134	7,519
6	73	2007	79,622	7,965	7,887	8,065	8,246	7,555	7,922	8,221	7,872	7,735	8,154
6	75	5	32,193							8,166	7,907	8,129	7,991
6	77	1002	82,853	8,361	8,335	8,353	8,272	8,218	8,344	8,206	8,338	8,122	8,304
6	77	3003	28,932	8,241	8,222	7,995	4,474						
6	77	3005	40,233						8,241	7,922	8,285	7,940	7,845
6	79	2001	30,921	6,979	6,027	6,426	7,034	4,455					
6	79	2002	37,181	8,111	8,155	6,761	8,191	5,963					
6	79	2006	9,263					2,336	6,927				
6	79	3001	70,159	2,775	8,202	8,123	8,014	7,799	7,584	7,479	7,394	5,829	6,960
6	79	4002	74,032	6,755	8,088	8,120	8,131	8,002	6,946	6,922	7,667	7,039	6,362
6	79	8001	78,257	7,654	8,009	8,227	7,922	7,393	8,070	8,243	8,141	7,221	7,377
6	81	1001	32,621							8,219	8,210	8,169	8,023
6	83	8	78,059	8,225	8,263	8,248	8,220	8,118	8,266	7,745	8,263	6,549	6,162
6	83	11	51,904			3,158	8,153	8,334	4,826	2,804	8,160	8,206	8,263
6	83	1008	59,881		3,787	8,117	7,482	8,282	4,808	2,752	8,128	8,346	8,179
6	83	1013	63,510	6,976	6,221	6,156	8,263	7,076	5,752	5,510	4,064	7,277	6,215
6	83	1014	67,452	7,764	8,035	7,913	7,917	6,882	7,066	6,545	6,830	5,822	2,678
6	83	1018	80,185	8,158	8,277	8,211	8,187	8,142	8,071	8,013	7,936	7,678	7,512
6	83	1021	63,115	7,363	4,540	4,531	3,677	7,931	8,114	8,018	6,892	6,824	5,225
6	83	1025	78,307	8,102	8,163	8,120	8,142	7,976	7,807	8,178	7,949	7,004	6,866
6	83	2004	69,839	7,884	4,275	7,869	7,802	8,080	7,919	7,387	4,910	6,856	6,857
6	83	2011	80,800	8,214	8,224	7,521	8,287	8,180	8,244	7,986	7,871	8,263	8,010

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State Code	County Code	Site ID	Total Obs	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
6	83	4003	42,798	1,745	3,605	5,478	7,041	5,971	5,014	4,668	4,040	2,934	2,302
6	85	5	32,697							8,324	8,351	7,845	8,177
6	87	3	78,266	8,275	8,377	6,468	7,005	8,187	8,283	8,561	8,402	7,846	6,862
6	95	4	32,930							8,284	8,264	8,111	8,271
6	95	6	14,338							6,211	8,127		
6	97	3	33,115							8,336	8,364	8,133	8,282
6	99	5	41,496	8,194	8,382	8,257	8,295	8,368					
6	99	6	79,937	7,199	8,265	8,202	8,288	7,318	8,227	8,272	8,096	8,079	7,991
6	101	3	79,681	7,590	8,242	8,226	7,978	8,092	7,751	8,128	8,091	7,487	8,096
6	107	2002	82,846	8,352	8,324	8,300	8,326	8,068	8,255	8,278	8,374	8,315	8,254
6	111	5	11,518	6,622	4,896								
6	111	7	29,167	8,069	8,331	8,100	4,667						
6	111	1004	28,984	7,755	8,239	8,270	4,720						
6	111	2002	79,481	8,025	8,010	8,000	7,576	7,749	7,879	7,755	8,095	8,250	8,142
6	111	2003	27,909	7,483	7,862	7,981	4,583						
6	111	3001	79,110	7,687	7,409	7,671	7,909	7,966	8,102	8,003	7,974	8,164	8,225
6	113	4	80,169	6,871	8,241	8,264	8,321	8,363	8,349	8,328	8,109	8,299	7,024
8	41	6001	6,377	6,377									
8	41	6004	6,184	6,184									
8	41	6011	6,380	6,380									
8	41	6018	6,336	6,336									
8	67	1004	49,337				5,652	7,994	8,286	7,218	6,981	7,204	6,002
8	67	7001	49,277	3,267	657	5,738	758	1,529	8,515	7,222	8,352	5,059	8,180
8	67	7003	63,260	2,048	7,996	7,291	7,614	4,541	7,818	7,888	4,795	6,535	6,734
9	1	9003	81,542	8,231	8,506	8,602	8,182	8,179	8,046	7,815	8,187	7,679	8,115
9	3	1003	83,849	8,648	8,280	8,452	8,569	8,371	8,312	8,560	8,320	8,307	8,030
9	5	4	31,040						2,074	8,127	8,107	7,573	5,159
9	9	27	57,439				7,557	8,444	8,474	8,620	8,046	8,036	8,262
9	9	1123	26,723	8,609	8,603	8,551	960						
9	9	9005	13,052	4,321	4,210	4,521							
9	13	1001	4,022	4,022									
10	3	2004	64,453	23	7,774	7,835	6,213	7,892	7,428	5,462	8,062	5,751	8,013
11	1	25	85,348	8,512	8,220	8,661	8,711	8,483	8,647	8,608	8,585	8,400	8,521
11	1	41	85,522	8,390	8,657	8,484	8,532	8,470	8,708	8,611	8,534	8,572	8,564
11	1	43	85,478	8,278	8,658	8,498	8,710	8,496	8,653	8,638	8,324	8,577	8,646
12	11	31	31,906						697	7,507	7,150	8,394	8,158
12	11	8002	21,863						490	5,280	4,695	5,676	5,722
12	31	32	27,378						696	7,962	2,066	8,211	8,443
12	33	4	26,965						659	8,327	8,249	8,341	1,389
12	57	81	13,502						729	8,491	2,114	2,168	
12	57	1065	20,407						742	8,450	2,168	2,177	6,870
12	57	3002	13,520						723	7,364	5,433		
12	81	4012	10,000						711	7,661	1,628		
12	86	27	26,992						604	7,011	6,320	6,418	6,639
12	86	4002	33,572						736	7,951	8,427	8,190	8,268
12	95	2002	20,927						729	7,912	2,089	2,062	8,135
12	99	20	16,191								1,532	7,396	7,263
12	99	1004	12,273						734	8,657	2,882		
12	103	18	20,077						731	8,127	2,050	2,066	7,103
12	115	1006	1,750										1,750
13	89	2	81,508	8,485	8,227	6,487	8,613	8,588	8,587	7,907	7,990	8,110	8,514
13	89	3001	49,202	8,596	8,600	6,719	8,476	8,589	8,222				
13	121	48	69,278	8,537	8,575	8,433	8,407	8,179	8,049	8,103	8,224	2,771	
13	223	3	80,494	8,538	6,134	8,347	8,050	8,375	8,044	8,510	7,807	8,259	8,430
13	247	1	84,026	8,605	8,415	8,476	8,578	8,434	8,150	8,331	8,519	8,051	8,467
16	1	10	13,275									5,498	7,777
16	1	16	740	740									
16	1	19	4,345							1,114			3,231
16	21	3	10,031		1,446	8,585							
16	39	2	16,442		6,646	8,376	1,420						
16	55	3	25,762					8,180	7,853	3,825	2,658	1,365	1,881
17	31	63	84,356	8,643	8,656	8,486	8,486	8,383	8,425	7,906	8,595	8,347	8,429
17	31	72	33,422	3,211	3,162	3,449	3,189	3,889	3,524	3,602	2,904	3,163	3,329
17	31	75	8,360	8,360									
17	31	76	77,073		8,640	8,574	8,415	8,608	8,686	8,510	8,714	8,648	8,278
17	31	3103	84,120	8,421	8,413	8,440	8,251	8,530	8,612	8,185	8,491	8,381	8,396
17	31	4002	85,664	8,676	8,234	8,635	8,655	8,602	8,691	8,632	8,430	8,650	8,459
17	31	4201	55,096	7,953	3,575	5,307	3,553	3,850	4,143	4,152	5,772	8,577	8,214

List of AQS NOx Monitoring Stations and Number of Valid Observations by Year

State Code	County Code	Site ID	Total Obs	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
17	31	8003	17,306	8,655	8,651								
17	97	1007	4,909	2,586	2,323								
17	163	10	84,570	8,661	8,257	8,566	8,667	8,364	8,059	8,575	8,081	8,703	8,637
17	197	1011	24,775	3,110	3,751	3,383	3,193	4,260	3,884	3,194			
18	51	10	32,440	8,319	8,187	7,807	8,127						
18	63	1	28,741				7,987	8,062	8,441	4,251			
18	63	2	39,172				6,324	7,346	7,758	7,747	7,899	2,098	
18	63	3	25,742				7,196	7,269	7,597	3,680			
18	89	22	74,335	7,430	7,166	8,254	7,280	8,533	7,489	5,022	7,475	7,836	7,850
18	97	73	81,182	8,274	7,086	7,939	7,474	8,583	8,403	8,474	8,534	8,228	8,187
18	141	15	35,876						4,918	8,467	8,196	7,835	6,460
18	141	1008	44,199	8,698	8,585	8,533	8,187	6,637	3,559				
18	147	8	5,978	5,978									
18	163	12	68,818	8,697	8,701	8,690	6,661	8,711	8,668	6,372	8,397	3,921	
18	163	21	10,798									3,582	7,216
19	113	33	16,329	2,045	5,020	4,598	4,666						
19	153	30	33,514						676	7,725	8,667	8,586	7,860
19	153	58	43,845	5,320	7,384	8,555	8,324	7,419	6,843				
19	163	14	38,454	6,048	8,137	8,400	8,670	7,199					
19	163	15	41,754						8,107	8,614	8,412	8,553	8,068
20	107	2	47,280	7,400	7,891	6,828	3,320	5,368	4,437	4,994	2,710	2,550	1,782
20	173	10	72,461		4,863	8,681	8,405	8,294	8,008	8,314	8,629	8,673	8,594
20	191	2	75,760	6,608	6,466	8,350	6,058	8,178	8,071	7,262	8,624	8,568	7,575
20	209	21	83,554	8,111	8,581	8,184	8,144	8,551	8,647	8,316	8,104	8,686	8,230
21	111	67	6,695										6,695
21	177	1004	8,373	5,609	2,764								
21	221	8001	8,240							6,911	1,329		
22	5	4	48,571					7,276	8,270	8,326	8,158	8,399	8,142
22	19	8	46,269					7,173	8,284	7,630	7,621	8,190	7,371
22	19	9	32,038	8,423	7,844	7,327	8,444						
22	33	3	82,866	8,396	8,331	8,256	8,201	8,304	8,252	8,317	8,181	8,311	8,317
22	33	9	83,828	8,309	8,524	8,486	8,474	8,418	8,413	8,459	8,210	8,277	8,258
22	33	13	77,479	8,075	6,126	7,732	8,211	8,033	7,792	8,117	7,800	8,136	7,457
22	33	1001	81,071	7,738	8,008	8,261	8,371	8,314	8,458	8,386	8,191	8,191	7,153
22	47	7	76,639	7,906	7,861	7,886	7,242	8,183	8,099	7,760	7,113	8,166	6,423
22	47	9	78,433	6,968	7,707	7,964	7,653	8,092	8,487	7,865	7,904	8,411	7,382
22	47	12	77,588	7,448	7,110	7,832	7,723	7,544	7,649	8,110	7,798	8,277	8,097
22	51	1001	79,489	8,292	8,169	8,362	8,048	7,867	8,214	8,008	6,926	7,858	7,745
22	63	2	77,817	7,858	7,626	7,593	7,831	6,936	7,804	8,441	7,744	8,381	7,603
22	71	12	37,129	8,095	7,050	8,199	8,321	5,464					
22	121	1	81,716	8,309	7,833	8,299	8,032	8,077	8,351	8,432	7,937	8,077	8,369
23	3	1100	25,505						5,053	5,945	6,048	4,884	3,575
23	5	27	47,206	4,921	8,641	8,488	8,544	8,450	8,162				
23	5	29	23,872								7,580	8,048	8,244
23	9	102	5,510				1,250	1,575	1,256	1,429			
23	31	3002	31,322	6,742	7,276	7,578	5,621	4,105					
24	3	19	9,448	4,838	3,874	736							
24	5	3001	76,488	8,107	8,209	8,250	8,048	7,530	4,617	7,341	8,419	7,781	8,186
24	33	30	22,285					4,150	6,499	8,400	3,236		
24	510	40	79,911	7,933	8,182	8,099	8,035	8,265	8,248	6,255	8,339	8,471	8,084
24	510	50	1,263	1,263									
25	1	2	19,329	4,484	1,266	1,244	4,199	3,944	4,192				
25	5	1002	3,269		3,269								
25	5	1005	5,979	5,979									
25	9	5	3,563		3,563								
25	9	2006	80,336	8,017	7,873	8,232	7,650	7,989	8,233	7,959	7,949	8,084	8,350
25	9	4004	34,807	7,516	6,062	3,716	3,720	3,627	3,305	2,780	2,872	1,209	
25	9	5005	53,835				4,820	7,865	8,063	8,303	8,457	8,428	7,899
25	13	3	10,288	8,162	2,126								
25	13	8	80,831	8,232	8,367	8,069	7,523	7,410	8,277	8,249	8,206	8,265	8,233
25	13	16	83,234	8,387	8,378	8,184	8,422	8,104	8,375	8,363	8,414	8,355	8,252
25	15	4002	75,045	7,985	6,664	8,397	6,936	8,225	7,825	5,938	7,685	7,516	7,874
25	21	3003	34,300		4,121	3,334	3,392	2,893	3,604	4,141	4,162	3,974	4,679
25	25	2	77,852	8,155	6,770	6,392	8,199	8,333	8,250	8,214	8,372	6,938	8,229
25	25	21	15,048	7,799	7,249								
25	25	40	75,497	8,544	8,505	8,348	8,543	8,168	5,550	2,259	8,544	8,512	8,524
25	25	41	43,330	7,593	5,701	4,142	3,674	4,051	3,854	1,172	4,170	4,185	4,788
25	25	42	81,337	8,012	7,431	8,341	7,631	8,342	8,307	8,423	8,402	8,234	8,214

List of AQS NOx Monitoring Stations and Number of Valid Observations by Year

State Code	County Code	Site ID	Total Obs	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
25	27	20	22,367	8,355	8,266	5,746							
25	27	23	56,863				7,779	8,295	8,145	8,329	8,119	8,270	7,926
26	65	12	10,776	6,551									4,225
26	81	20	41,555		7,123	8,032	7,952	7,931	8,567	1,950			
26	113	1	1,266										1,266
26	163	16	43,731	1,679	8,470	8,012	6,777	8,344	8,627	1,822			
26	163	19	76,690	2,525	8,024	8,431	7,735	7,455	8,607	8,462	8,506	8,657	8,288
27	3	1002	63,681			7,796	8,296	8,162	8,313	8,132	7,649	7,169	8,164
27	17	7416	20,815		2,485	6,879	6,275						5,176
27	37	20	74,725	8,527	8,010	8,097	6,956	6,526	8,343	5,234	7,031	8,194	7,807
27	37	423	74,590	8,646	8,641	8,609	7,870	7,931	7,610	6,852	6,131	6,427	5,873
27	49	5302	1,682			1,134	548						
27	53	957	16,618	7,990	8,628								
27	123	864	16,271	8,239	8,032								
28	3	4	8,379	6,042	2,337								
28	33	2	11,687	7,657	4,030								
28	45	1	26,137	6,202	5,934	6,939	7,062						
28	45	3	1,858					1,858					
28	59	6	46,602				5,937	7,098	5,592	5,935	7,296	6,665	8,079
28	93	1	8,142				6,788	1,354					
29	39	1	7,889	2,934	3,324	1,631							
29	47	5	79,685	8,041	7,801	7,889	7,931	7,996	8,409	8,569	8,197	8,462	6,390
29	47	6	13,489			7,362	6,127						
29	77	36	31,999							8,414	8,657	8,571	6,357
29	95	34	63,962			4,723	7,752	8,471	8,639	8,687	8,733	8,653	8,304
29	129	1	6,478	6,478									
29	165	23	15,422			8,134	7,288						
29	183	1002	79,648	7,974	7,760	8,089	7,547	8,603	8,549	8,579	7,932	8,354	6,261
29	186	5	65,244	3,308	5,424	4,485	7,145	8,549	8,126	6,889	7,957	7,492	5,869
29	189	4	49,414					8,318	8,608	8,666	8,720	8,644	6,458
29	189	6	7,115					7,115					
29	189	14	44,481					5,645	8,626	8,116	7,597	8,012	6,485
29	189	3001	48,987					8,659	8,370	8,323	8,666	8,586	6,383
29	189	5001	2,056					2,056					
29	211	1	2,545	2,545									
29	510	86	1,167										1,167
30	31	17	4,171										4,171
30	63	36	16,053	4,005	8,191	3,857							
30	65	4	9,719		4,728	4,991							
30	83	1	1,822								371	1,109	342
30	111	86	13,955					3,138	5,732	5,085			
32	31	16	46,666					5,767	6,485	8,580	8,667	8,530	8,637
32	31	2002	9,551	8,244	1,307								
33	11	1011	20,352				3,883	2,781	2,942	3,394	3,709	1,799	1,844
33	11	5001	4,297							1,581	1,254	538	924
33	15	13	15,143	7,601	5,823	1,719							
33	15	14	20,815			4,658	7,894	7,627			636		
34	3	6	25,531							531	8,294	8,116	8,590
34	7	3	62,322	8,285	8,631	6,026	8,140	7,813	8,513	8,529	6,385		
34	21	5	85,539	8,516	8,690	8,664	8,609	8,577	8,447	8,245	8,622	8,545	8,624
34	23	11	85,816	8,452	8,550	8,581	8,633	8,618	8,497	8,615	8,649	8,691	8,530
35	1	23	67,865		2,063	8,165	8,277	8,449	8,080	8,301	8,270	8,233	8,027
35	1	24	28,136				1,421	7,765	7,849	7,588	3,513		
35	1	5010	596				596						
35	13	21	41,707						8,409	8,504	8,416	8,130	8,248
35	13	22	33,628						6,779	7,158	6,691	6,464	6,536
35	15	1004	22,509						4,290	8,386	8,129	1,704	
35	15	1005	30,353						3,793	7,084	6,909	5,995	6,572
35	25	8	37,004						4,390	8,323	8,219	8,089	7,983
35	29	3	33,398						3,747	7,647	7,275	7,341	7,388
35	43	1003	25,623						4,293	8,570	7,947	4,813	
35	45	9	35,720						8,654	8,624	8,650	3,159	6,633
35	45	18	40,870						8,321	8,581	8,351	7,646	7,971
35	45	1005	37,500						7,840	8,393	6,523	6,945	7,799
36	5	83	49,512	6,830	8,271	8,597	8,675	7,755	8,504	880			
36	5	110	72,407	4,945	7,169	6,875	8,557	7,801	8,542	8,420	8,343	7,941	3,814
36	5	133	33,464							7,552	8,579	8,623	8,710
36	29	2	76,276	7,617	8,093	8,341	7,896	7,796	8,458	8,560	5,289	6,203	8,023

List of AQS NOx Monitoring Stations and Number of Valid Observations by Year

State Code	County Code	Site ID	Total Obs	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
36	29	5	84,079	8,455	8,563	8,428	8,602	8,535	8,337	8,531	8,289	8,126	8,213
36	33	7003	8,499									3,488	5,011
36	59	5	79,927	8,284	8,487	7,483	6,458	8,281	8,405	7,773	8,466	8,583	7,707
36	61	10	3,414	3,414									
36	61	56	55,420	6,683	8,337	5,118	5,507	8,525	8,521	8,551	4,178		
36	81	97	8,363	8,363									
36	81	98	40,109	7,897	8,167	7,674	7,758	8,509	104				
36	81	124	76,324	3,710	7,715	7,894	7,759	7,778	8,240	8,089	8,583	8,189	8,367
37	67	22	72,061	8,530	8,358	8,477	8,409	6,501	6,207	7,263	6,960	3,704	7,652
37	119	41	83,052	7,804	8,220	8,637	8,528	8,585	7,038	8,524	8,586	8,539	8,591
38	13	4	21,713							5,192	5,247	5,480	5,794
38	15	3	33,373							8,580	8,427	8,441	7,925
38	17	1004	29,764							7,816	7,420	7,233	7,295
38	25	3	20,399							6,034	6,554	6,080	1,731
38	53	2	15,193							2,793	3,907	3,887	4,606
38	57	4	29,316							7,266	7,526	7,380	7,144
38	57	102	22,133								7,146	7,407	7,580
38	57	124	19,713								6,862	6,206	6,645
38	65	2	28,333							6,829	7,080	7,030	7,394
39	9	4	31,284							7,964	7,891	7,508	7,921
39	35	60	11,528									3,486	8,042
39	103	4	6,275									2,643	3,632
40	1	9009	17,332								3,495	7,081	6,756
40	21	9002	63,658	7,805	6,760	4,196	7,953	8,451	7,989	8,186	8,100	4,218	
40	27	49	12,515		8,307	4,208							
40	71	9003	29,138	7,939	8,507	7,934	4,758						
40	97	9014	28,915				3,814	5,739	7,042	2,582	6,138	3,600	
40	101	167	11,784		8,278	3,506							
40	109	33	75,342		8,697	8,099	8,610	8,493	8,432	8,355	8,264	8,347	8,045
40	109	1037	74,096		7,969	7,677	8,564	8,601	8,119	8,408	8,425	8,434	7,899
40	115	9004	34,517	8,394	7,975	5,944	7,954	4,250					
40	135	9015	21,749						6,196	5,714	5,377	4,462	
40	143	174	10,752		8,009	2,743							
40	143	1127	64,708		8,317	8,330	4,201	8,320	8,533	7,794	3,576	7,676	7,961
41	51	80	48,213		3,558	3,626	3,068	3,590	3,638	5,619	8,303	8,222	8,589
41	59	1003	8,585							7,045	1,540		
42	1	1	42,398	3,043	3,637	2,951	4,897	4,817	5,099	5,063	3,444	4,805	4,642
42	3	8	83,673	8,553	8,173	8,552	8,618	8,603	8,549	8,092	8,562	8,698	7,273
42	3	10	83,085	8,323	8,733	8,481	8,647	8,497	8,620	8,088	7,804	8,103	7,789
42	3	31	4,140	4,140									
42	3	1005	79,360	3,672	8,442	8,633	8,416	8,372	7,666	8,092	8,709	8,714	8,644
42	7	14	84,148	8,577	8,641	8,708	8,678	8,683	8,415	8,654	8,202	8,346	7,244
42	11	9	46,152	8,670	8,664	8,645	8,617	8,675	2,881				
42	11	11	29,270							4,381	8,430	8,135	8,324
42	13	801	68,895	8,616	8,563	8,478	8,680	8,655	8,622	8,699	8,582		
42	17	12	82,953	8,633	8,441	8,265	8,526	8,537	8,300	8,503	7,234	8,006	8,508
42	21	11	85,965	8,507	8,332	8,607	8,671	8,677	8,675	8,712	8,583	8,697	8,504
42	27	100	72,403		6,833	7,858	8,623	8,343	8,665	8,132	7,665	8,460	7,824
42	43	401	85,819	8,657	8,407	8,547	8,695	8,655	8,509	8,658	8,513	8,538	8,640
42	45	2	81,863	8,510	7,960	8,202	8,452	7,125	8,107	8,104	8,158	8,604	8,641
42	49	3	82,078	8,173	8,459	8,280	8,363	8,527	8,513	8,208	8,250	8,384	6,921
42	63	4	35,222				1,390	8,299	8,294	8,582	8,657		
42	69	2006	83,384	8,673	8,461	8,574	8,291	8,219	7,731	7,790	8,549	8,580	8,516
42	71	7	84,941	8,386	8,650	8,640	8,430	8,667	8,646	8,568	8,446	8,415	8,093
42	73	15	69,159	8,670	8,686	8,675	8,711	8,650	8,663	8,566	8,538		
42	77	4	68,252	8,563	8,687	8,629	8,669	8,690	8,490	7,941	8,583		
42	79	1101	66,399	8,538	8,371	8,583	8,436	7,811	8,113	7,939	8,608		
42	91	13	65,657	8,305	7,857	7,805	8,460	8,522	8,177	7,914	8,617		
42	95	25	84,845	8,676	8,589	8,558	8,441	8,694	7,927	8,378	8,674	8,492	8,416
42	99	301	76,664	8,048	7,290	7,616	8,496	7,277	7,579	7,996	7,809	7,512	7,041
42	125	5	86,265	8,591	8,619	8,542	8,681	8,593	8,703	8,452	8,756	8,624	8,704
42	125	200	68,561	8,734	8,680	8,654	8,668	8,677	8,184	8,736	8,228		
42	125	5001	64,554	8,318	6,897	8,376	8,361	8,252	8,045	8,476	7,829		
42	129	8	66,658	7,755	8,484	8,622	8,437	8,441	8,487	8,508	7,924		
42	133	8	86,184	8,710	8,676	8,525	8,707	8,646	8,564	8,475	8,598	8,637	8,646
44	3	2	12,286	560	1,259	989	814	2,016	1,860	1,462	988	1,214	1,124
44	7	12	79,298	8,019	8,035	8,038	7,599	8,166	7,100	7,990	8,254	8,084	8,013
44	7	1010	19,094	1,684	1,932	1,528	1,867	1,978	2,072	1,999	2,032	1,973	2,029

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State Code	County Code	Site ID	Total Obs	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
46	33	132	11,822							5,411	1,070	4,473	868
46	71	1	13,490							2,918	5,178	3,121	2,273
46	99	7	6,071							6,071			
46	99	8	24,484								8,079	7,810	8,595
46	109	4003	5,701	1,019	4,682								
46	127	1	11,276									4,103	7,173
46	127	2	11,127									3,602	7,525
47	9	101	4,115								966	1,946	1,203
47	31	4	8,075				6,722	1,353					
47	63	3	16,549	6,636	1,552				8,361				
47	75	3	17,215		5,105	2,749			6,753	2,608			
47	85	20	7,765			7,765							
47	93	1030	823	823									
47	121	104	16,270		5,846	2,172		6,914	1,338				
47	125	1010	10,877	2,054				6,804	2,019				
47	131	4	8,055			6,679	1,376						
47	141	4	8,348							6,973	1,375		
47	157	2005	8,315					5,569	2,746				
48	29	46	79,505	8,421	8,287	7,038	8,026	8,342	8,499	8,420	8,208	8,283	5,981
48	29	52	71,911	7,194	3,515	5,531	7,699	8,120	8,371	8,360	8,369	7,265	7,487
48	29	55	20,949								8,124	8,555	4,270
48	29	59	73,166	5,323	7,140	8,343	6,903	6,791	8,513	8,322	7,975	6,723	7,133
48	29	622	20,750								6,222	8,274	6,254
48	39	1004	70,917	2,777	7,437	8,364	8,403	7,761	7,446	7,528	7,584	6,706	6,911
48	39	1016	51,490			2,967	6,710	6,865	6,943	7,451	7,032	6,349	7,173
48	113	69	80,653	7,729	8,341	8,489	8,494	8,054	7,799	7,854	7,465	8,147	8,281
48	113	75	80,998	6,263	8,203	8,322	8,253	8,137	8,521	8,215	8,510	8,048	8,526
48	113	87	75,542	7,769	6,892	7,776	8,482	6,359	8,242	8,203	7,575	6,488	7,756
48	121	34	79,612	7,393	6,531	8,556	8,472	8,519	8,517	8,409	8,100	7,259	7,856
48	139	15	44,542	3,906	4,344	8,247	8,298	8,225	7,239	4,283			
48	139	16	62,197			6,630	6,884	7,632	8,508	8,393	8,550	8,024	7,576
48	139	17	12,056				1,652	8,419	1,985				
48	139	1044	25,716							2,593	8,509	7,812	6,802
48	141	37	83,667	8,203	8,565	8,595	8,610	8,562	8,258	8,402	8,333	8,453	7,686
48	141	44	77,153	6,848	8,398	7,677	7,266	7,658	8,366	8,219	6,810	8,506	7,405
48	141	55	76,873	6,936	7,857	7,215	8,510	6,481	7,628	7,843	8,118	8,070	8,215
48	141	57	56,682	8,278	8,429	6,708	7,870	8,549	8,181	8,587	80		
48	141	58	52,142	6,646	7,286	7,990	7,908	8,072	7,210	7,010	20		
48	167	14	41,499	6,277	5,754	6,409	7,417	6,866	6,945	1,831			
48	167	1034	25,154							6,630	5,288	6,880	6,356
48	183	1	81,323	7,473	7,879	8,524	8,523	8,531	8,411	8,417	8,326	7,333	7,906
48	201	24	81,902	8,065	8,253	8,375	8,558	7,807	7,604	8,191	8,239	8,473	8,337
48	201	26	77,906	3,525	8,235	7,865	8,550	8,346	8,476	8,421	8,394	8,428	7,666
48	201	29	81,632	7,993	7,504	8,279	8,261	8,272	8,322	8,525	8,117	8,056	8,303
48	201	47	82,540	8,309	7,722	8,381	8,342	8,098	8,528	8,431	8,273	8,306	8,150
48	201	55	76,158	7,573	7,274	8,173	8,304	7,243	7,331	8,451	6,176	7,305	8,328
48	201	75	79,690	6,136	7,711	8,227	8,556	8,295	7,233	8,429	8,271	8,353	8,479
48	201	416	35,916						6,501	8,524	8,391	4,203	8,297
48	201	1015	56,482			5,760	7,989	7,629	7,444	8,317	4,874	8,424	6,045
48	201	1034	82,994	8,118	8,553	8,129	8,491	8,278	8,404	8,513	8,105	8,271	8,132
48	201	1035	76,536	7,730	7,666	7,659	6,846	6,612	6,807	8,360	7,955	8,368	8,533
48	201	1037	1,930	1,930									
48	201	1039	78,681	7,656	8,383	7,476	7,605	7,091	8,035	8,005	8,244	8,110	8,076
48	201	1041	5,634		3,193	2,441							
48	201	1050	75,033	3,336	7,937	8,109	8,260	8,095	7,983	8,342	8,180	7,788	7,003
48	203	2	72,310	2,414	5,714	8,267	7,903	8,337	8,422	8,378	8,114	6,863	7,898
48	209	614	29,097			4,969	1,207	3,904	4,114	4,833	4,144	3,485	2,441
48	231	1006	64,481			6,351	8,604	8,308	8,301	8,394	8,465	7,936	8,122
48	245	9	77,776	7,447	7,577	7,304	8,407	7,710	8,099	7,862	7,753	7,341	8,276
48	245	18	7,849					2,353	5,496				
48	245	22	65,326	6,443	5,959	6,146	7,700	7,514	7,818	7,684	6,081	4,301	5,680
48	245	1035	32,469						2,877	8,459	7,442	6,474	7,217
48	257	5	79,833	8,178	7,514	7,931	8,208	8,233	7,285	7,286	8,408	8,363	8,427
48	309	1037	17,245							3,636	5,477	3,082	5,050
48	315	50	1,785	1,785									
48	339	78	73,710	1,240	7,402	7,831	7,988	8,311	8,437	8,188	8,302	8,300	7,711
48	339	89	5,903	5,903									
48	349	1051	12,403									4,321	8,082

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State Code	County Code	Site ID	Total Obs	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
48	361	1001	75,567	7,417	6,362	8,318	7,315	7,676	7,941	8,376	7,798	7,012	7,352
48	423	7	79,708	8,353	7,352	8,099	6,211	8,254	8,291	8,209	8,469	8,311	8,159
48	439	57	4,347	4,347									
48	439	1002	79,929	6,732	7,622	7,888	8,480	8,400	8,526	8,434	8,496	8,232	7,119
48	439	3009	83,230	8,060	7,598	8,494	8,449	8,497	8,482	8,444	8,510	8,294	8,402
48	439	3011	74,868		7,790	8,559	8,491	8,008	8,367	8,510	8,485	8,333	8,325
48	453	20	75,674	6,223	6,920	8,199	8,047	8,365	8,150	7,546	7,944	6,781	7,499
48	453	613	14,593			4,967	823	4,497	4,306				
49	5	4	62,787		1,446	8,520	8,346	5,977	7,016	7,990	8,375	7,441	7,676
49	11	1	20,681	8,344	8,476	3,861							
49	11	4	62,444			3,417	8,521	8,396	8,338	8,376	8,370	8,479	8,547
49	35	3	83,525	8,256	8,535	8,493	8,550	8,463	7,372	8,511	8,593	8,346	8,406
49	35	3006	81,937	8,520	8,593	8,584	8,631	8,579	8,571	8,565	8,527	8,523	4,844
49	47	2002	10,565									3,186	7,379
49	47	2003	9,241									2,739	6,502
49	49	2	81,152	8,498	8,174	7,683	8,256	8,483	7,332	8,385	8,418	8,411	7,512
49	53	6	8,650								1,876	3,218	3,556
49	57	2	77,474	3,770	8,495	8,210	8,603	8,581	6,949	8,609	8,320	8,152	7,785
50	7	13	9,819	2,772	7,047								
50	7	14	62,389			7,714	8,274	7,788	8,156	8,028	7,692	7,354	7,383
50	21	2	76,380	7,837	7,646	6,019	7,185	8,215	7,762	8,091	8,045	7,766	7,814
51	13	20	33,922							8,442	8,362	8,604	8,514
51	33	1	23,734	7,738	6,191		2,335			2,154	1,863	1,617	1,836
51	36	2	31,252							7,774	7,868	7,599	8,011
51	87	14	19,663								3,015	8,086	8,562
51	107	1005	31,603							8,237	7,950	7,262	8,154
51	153	9	31,154							7,558	7,404	8,038	8,154
51	161	1004	32,568							7,854	7,967	8,488	8,259
51	165	3	33,327							8,173	8,480	8,324	8,350
51	510	9	31,846							6,823	8,424	8,524	8,075
51	700	13	2,658									542	2,116
51	710	24	23,020							8,067	8,564	6,389	
51	760	24	33,712							8,262	8,582	8,532	8,336
53	33	23	1,029			1,029							
53	33	32	13,444	8,101	5,343								
53	33	80	38,652	8,179	7,519	7,305	8,004	6,444	1,201				
55	71	7	13,289				2,026	2,187	1,757	2,019	1,944	1,342	2,014
55	79	7	1,327	1,327									
55	79	26	64,133			5,109	8,648	8,499	8,115	8,529	8,169	8,461	8,603
55	79	41	8,490	8,097	393								
55	89	9	4,455				2,180	2,275					
55	111	7	9,112			6,299	2,813						
56	5	123	58,130	5,416	6,844	6,015	7,116	6,821	6,504	6,533	3,379	3,706	5,796
56	5	456	49,432			2,778	7,747	7,387	5,618	6,692	6,480	5,504	7,226
56	5	789	1,227				1,227						
56	5	892	23,750			5,782	2,209	3,608	4,851			2,061	5,239
56	7	99	5,526							836	3,618	1,072	
56	9	819	12,853			6,471	1,188	1,898	1,642			558	1,096
56	13	99	7,908							2,737	2,280	1,282	1,609
56	35	98	24,869				1,300	6,871	7,193	7,195	2,310		
56	35	99	23,147					5,535	3,712	2,669	2,648	4,775	3,808
56	35	100	5,652					245	1,326	1,269	362	1,534	916
56	35	101	8,776									2,437	6,339
56	37	200	36,121						6,759	7,783	7,596	6,942	7,041
56	41	101	19,013							3,846	4,642	6,091	4,434

APPENDIX B

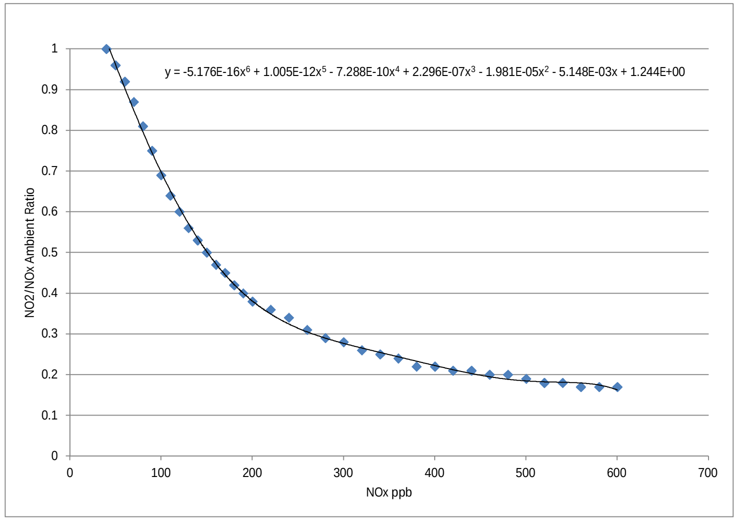
Bin Data and Ambient Ratios for Data Sets

ARM2 Poly Curve Fitting Analysis
ALL Sites

Min Ratio 0.2 Maximum Ratio 0.9
Total # Obs 6804348

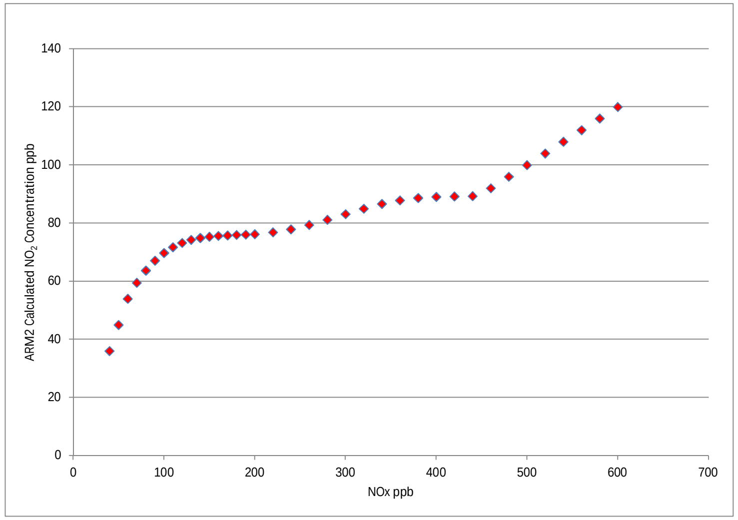
Upper Nox BIN ppb	Number in Bin	Observed 98% Perc ARM	Step 1 Fitted ARM Ratio	Final Adjusted ARM Ratio	ARM2 Calculated NO2 ppb	Delta Change ppb
30	2330786	1	1.077	0.900	27	
40	1310767	1	1.019	0.900	36	9.0
50	817380	0.96	0.962	0.900	45	9.0
60	546757	0.92	0.905	0.900	54	9.0
70	385505	0.87	0.850	0.850	59	5.5
80	282446	0.81	0.796	0.796	64	4.2
90	214245	0.75	0.746	0.746	67	3.4
100	164999	0.69	0.697	0.697	70	2.6
110	130316	0.64	0.652	0.652	72	2.0
120	104093	0.6	0.610	0.610	73	1.5
130	84056	0.56	0.571	0.571	74	1.0
140	68350	0.53	0.535	0.535	75	0.7
150	56801	0.5	0.502	0.502	75	0.4
160	46956	0.47	0.473	0.473	76	0.3
170	39220	0.45	0.446	0.446	76	0.2
180	32769	0.42	0.422	0.422	76	0.1
190	27696	0.4	0.400	0.400	76	0.1
200	23436	0.38	0.381	0.381	76	0.2
220	36618	0.36	0.349	0.349	77	0.6
240	26373	0.34	0.325	0.325	78	1.1
260	19349	0.31	0.305	0.305	79	1.5
280	14204	0.29	0.290	0.290	81	1.8
300	10468	0.28	0.277	0.277	83	1.9
320	7816	0.26	0.266	0.266	85	1.9
340	5774	0.25	0.255	0.255	87	1.6
360	4293	0.24	0.244	0.244	88	1.2
380	3287	0.22	0.233	0.233	89	0.8
400	2524	0.22	0.223	0.223	89	0.4
420	1880	0.21	0.212	0.212	89	0.1
440	1401	0.21	0.203	0.203	89	0.1
460	1079	0.2	0.195	0.200	92	2.7
480	810	0.2	0.189	0.200	96	4.0
500	658	0.190	0.185	0.200	100	4.0
520	413	0.18	0.183	0.200	104	4.0
540	310	0.18	0.182	0.200	108	4.0
560	239	0.17	0.180	0.200	112	4.0
580	159	0.17	0.175	0.200	116	4.0
600	115	0.17	0.162	0.200	120	4.0
	6804348					

ARM2 Poly Curve Fitting Analysis - ALL Sites



Linest and Logest Functions		a	b	c	d			
Cubic	=LINEST(,X_1^{1,2,3,4,5,6})	-5.176E-16	1.005E-12	-7.288E-10	2.296E-07	-1.98144E-05	-0.00514793	1.24409

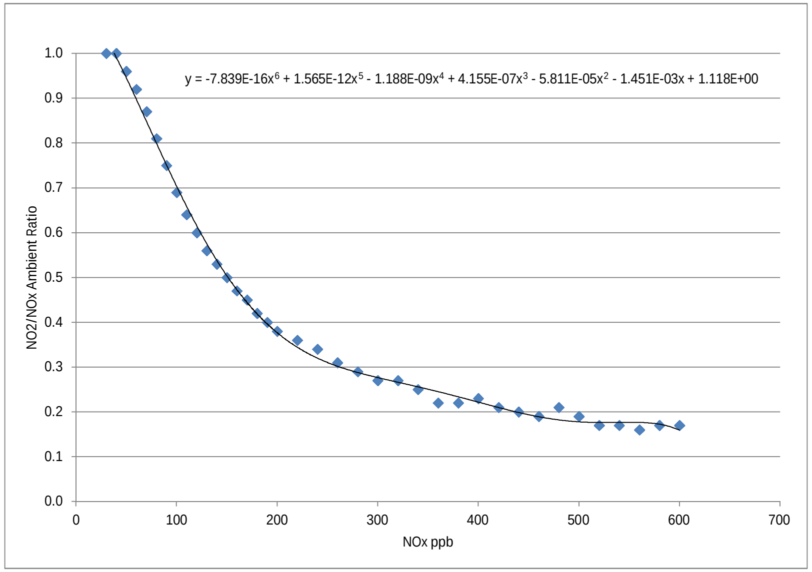
equation =(((a7^3*-5.17597743179288E-16)+(a7^2*1.00504244687937E-12)+(a7*-7.2884004876291E-10)+2.29606193106293E-07)



ARM2 Poly Curve Fitting Analysis
Rural & Suburban

Min Ratio	0.2	Maximum Ratio		0.9	
Total # Obs	3600763				
Mid Pt. Nox BIN ppb	Number in Bin	Observed 98% Perc ARM	Step 1 Fitted ARM Ratio	Final Adjusted ARM Ratio	ARM2 Calculated NO2 ppb
30	1295731	1.000	1.080	0.900	27
40	703035	1.000	1.020	0.900	36
50	426294	0.960	0.962	0.900	45
60	280390	0.920	0.904	0.900	54
70	194496	0.870	0.849	0.849	59
80	142124	0.810	0.796	0.796	64
90	107859	0.750	0.745	0.745	67
100	82582	0.690	0.697	0.697	70
110	64674	0.640	0.652	0.652	72
120	52123	0.600	0.610	0.610	73
130	41692	0.560	0.571	0.571	74
140	34307	0.530	0.536	0.536	75
150	28242	0.500	0.503	0.503	75
160	23148	0.470	0.473	0.473	76
170	19288	0.450	0.446	0.446	76
180	15995	0.420	0.422	0.422	76
190	13403	0.400	0.401	0.401	76
200	11235	0.380	0.381	0.381	76
220	17754	0.360	0.349	0.349	77
240	12477	0.340	0.324	0.324	78
260	9007	0.310	0.304	0.304	79
280	6700	0.290	0.288	0.288	81
300	4853	0.270	0.275	0.275	82
320	3571	0.270	0.263	0.263	84
340	2538	0.250	0.253	0.253	86
360	1883	0.220	0.242	0.242	87
380	1430	0.220	0.232	0.232	88
400	1029	0.230	0.221	0.221	89
420	769	0.210	0.211	0.211	89
440	578	0.200	0.201	0.201	89
460	447	0.190	0.193	0.200	92
480	336	0.210	0.186	0.200	96
500	283	0.190	0.180	0.200	100
520	173	0.170	0.177	0.200	104
540	122	0.170	0.175	0.200	108
560	91	0.160	0.173	0.200	112
580	57	0.170	0.170	0.200	116
600	47	0.170	0.163	0.200	120

ARM2 Poly Curve Fitting Analysis - Rural & Suburban

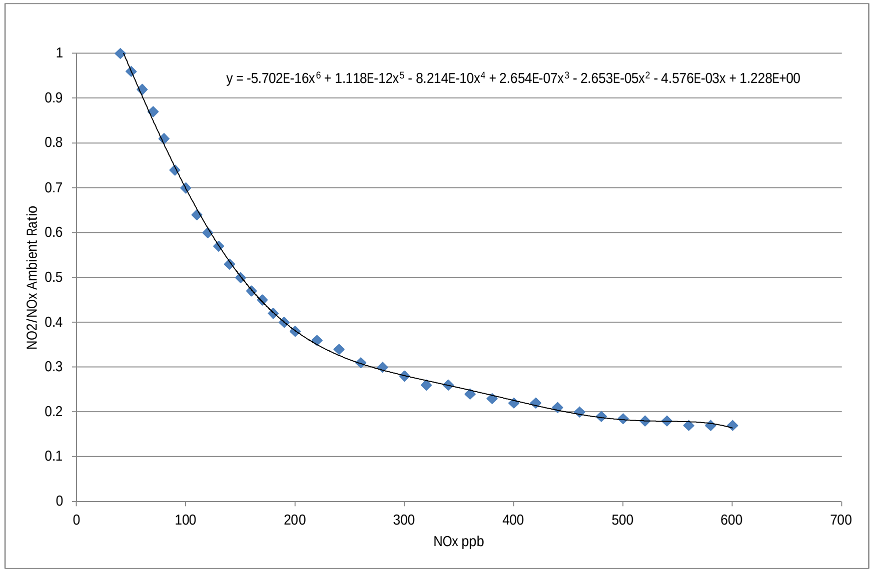


Linest and Logest Functions		a	b	c	d			
Cubic	=LINEST(,X_1^{1,2,3,4,5,6})	-4.214E-16	8.317E-13	-6.091E-10	1.899E-07	-1.33492E-05	-0.005623261	1.256021

ARM2 Poly Curve Fitting Analysis
Urban & City Center

Min Ratio	0.2	Maximum Ratio		0.9	
Total # Obs	3177338				
Mid Pt. Nox BIN ppb	Number in Bin	Observed 98% Perc ARM	Step 1 Fitted ARM Ratio	Final Adjusted ARM Ratio	ARM2 Calculated NO2 ppb
30	1020825	1	1.073	0.900	27
40	601939	1	1.017	0.900	36
50	388295	0.96	0.961	0.900	45
60	264973	0.92	0.905	0.900	54
70	190229	0.87	0.851	0.851	60
80	139879	0.81	0.798	0.798	64
90	106102	0.74	0.747	0.747	67
100	82251	0.7	0.699	0.699	70
110	65527	0.64	0.653	0.653	72
120	51895	0.6	0.611	0.611	73
130	42318	0.57	0.572	0.572	74
140	34009	0.53	0.536	0.536	75
150	28542	0.5	0.503	0.503	75
160	23785	0.47	0.473	0.473	76
170	19921	0.45	0.446	0.446	76
180	16761	0.42	0.422	0.422	76
190	14290	0.4	0.401	0.401	76
200	12192	0.38	0.382	0.382	76
220	18854	0.36	0.350	0.350	77
240	13893	0.34	0.326	0.326	78
260	10338	0.31	0.308	0.308	80
280	7503	0.3	0.293	0.293	82
300	5615	0.28	0.281	0.281	84
320	4245	0.26	0.270	0.270	86
340	3236	0.26	0.259	0.259	88
360	2409	0.24	0.249	0.249	89
380	1857	0.23	0.237	0.237	90
400	1494	0.22	0.226	0.226	90
420	1111	0.22	0.214	0.214	90
440	823	0.21	0.204	0.204	90
460	632	0.2	0.195	0.200	92
480	474	0.19	0.188	0.200	96
500	375	0.185	0.183	0.200	100
520	240	0.18	0.180	0.200	104
540	188	0.18	0.179	0.200	108
560	148	0.17	0.178	0.200	112
580	102	0.17	0.174	0.200	116
600	68	0.17	0.164	0.200	120

ARM2 Poly Curve Fitting Analysis - Urban & City Center

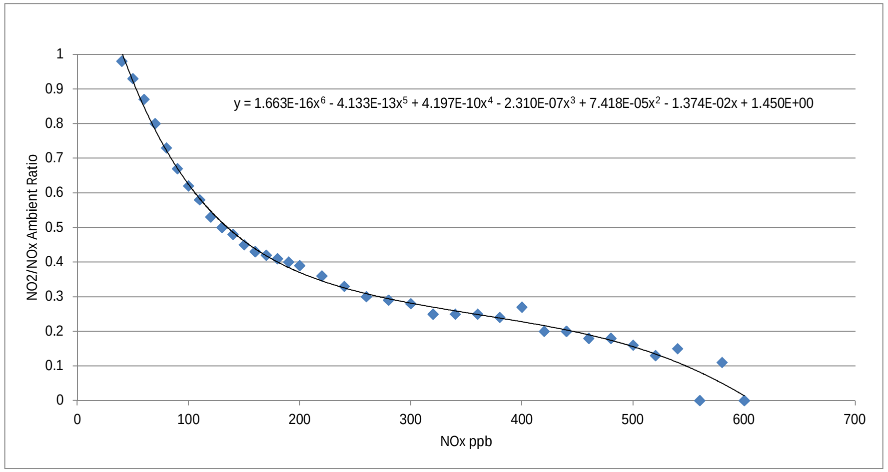


Linest and Logest Functions		a	b	c	d			
Cubic	=LINEST(,X_1^{1,2,3,4,5,6})	-5.702E-16	1.118E-12	-8.214E-10	2.654E-07	-2.65265E-05	-0.004576385	1.227829

ARM2 Poly Curve Fitting Analysis
Mountain Region

Min Ratio	0.2	Maximum Ratio	0.9		
Total # Obs	304578				
Mid Pt. Nox BIN ppb	Number in Bin	Observed 98% Perc ARM	Step 1 Fitted ARM Ratio	Final Adjusted ARM Ratio	ARM2 Calculated NO2 ppb
30	84000	1	1.099	0.900	27
40	51663	0.98	1.006	0.900	36
50	35255	0.93	0.922	0.900	45
60	25925	0.87	0.848	0.848	51
70	19801	0.8	0.782	0.782	55
80	15568	0.73	0.723	0.723	58
90	12591	0.67	0.671	0.671	60
100	10148	0.62	0.625	0.625	62
110	8258	0.58	0.584	0.584	64
120	6866	0.53	0.547	0.547	66
130	5671	0.5	0.515	0.515	67
140	4531	0.48	0.486	0.486	68
150	3961	0.45	0.461	0.461	69
160	3313	0.43	0.439	0.439	70
170	2781	0.42	0.419	0.419	71
180	2278	0.41	0.401	0.401	72
190	1953	0.4	0.385	0.385	73
200	1630	0.39	0.370	0.370	74
220	2584	0.36	0.346	0.346	76
240	1784	0.33	0.326	0.326	78
260	1270	0.3	0.309	0.309	80
280	849	0.29	0.295	0.295	82
300	631	0.28	0.282	0.282	85
320	422	0.25	0.270	0.270	86
340	308	0.25	0.259	0.259	88
360	199	0.25	0.249	0.249	90
380	125	0.24	0.239	0.239	91
400	74	0.27	0.228	0.228	91
420	63	0.2	0.217	0.217	91
440	24	0.2	0.204	0.204	90
460	25	0.18	0.190	0.200	92
480	12	0.18	0.174	0.200	96
500	5	0.16	0.156	0.200	100
520	2	0.13	0.135	0.200	104
540	4	0.15	0.110	0.200	108
560	1	0	0.082	0.200	112
580	2	0.11	0.050	0.200	116
600	1	0	0.014	0.200	120

ARM2 Poly Curve Fitting Analysis - Mountain Region

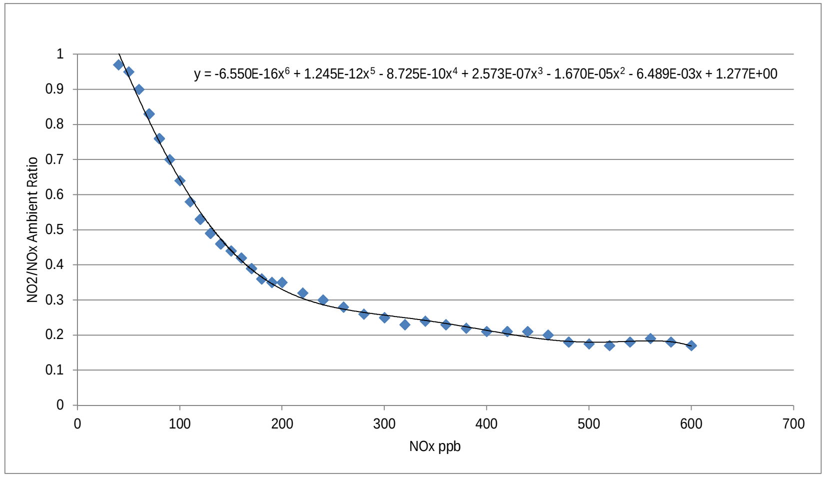


Linest and Logest Functions		a	b	c	d			
Cubic	=LINEST(,X_1^{1,2,3,4,5,6})	1.663E-16	-4.133E-13	4.197E-10	-2.310E-07	7.41799E-05	-0.013744247	1.450436

ARM2 Poly Curve Fitting Analysis
Northeast Region

Min Ratio	0.2	Maximum Ratio		0.9	
Total # Obs	1886112				
Mid Pt. Nox BIN ppb	Number in Bin	Observed 98% Perc ARM	Step 1 Fitted ARM Ratio	Final Adjusted ARM Ratio	ARM2 Calculated NO2 ppb
30	643420	1	1.073	0.900	27
40	375722	0.97	1.005	0.900	36
50	236081	0.95	0.938	0.900	45
60	157607	0.9	0.873	0.873	52
70	110023	0.83	0.810	0.810	57
80	79065	0.76	0.751	0.751	60
90	58733	0.7	0.695	0.695	63
100	44084	0.64	0.643	0.643	64
110	34197	0.58	0.595	0.595	65
120	26539	0.53	0.550	0.550	66
130	21049	0.49	0.510	0.510	66
140	16665	0.46	0.474	0.474	66
150	13535	0.44	0.442	0.442	66
160	10935	0.42	0.413	0.413	66
170	9027	0.39	0.388	0.388	66
180	7477	0.36	0.366	0.366	66
190	6202	0.35	0.347	0.347	66
200	5107	0.35	0.330	0.330	66
220	8093	0.32	0.305	0.305	67
240	5695	0.3	0.287	0.287	69
260	4234	0.28	0.274	0.274	71
280	3116	0.26	0.265	0.265	74
300	2312	0.25	0.257	0.257	77
320	1772	0.23	0.250	0.250	80
340	1322	0.24	0.242	0.242	82
360	960	0.23	0.233	0.233	84
380	772	0.22	0.224	0.224	85
400	606	0.21	0.214	0.214	86
420	444	0.21	0.204	0.204	86
440	332	0.21	0.195	0.200	88
460	282	0.2	0.187	0.200	92
480	187	0.18	0.182	0.200	96
500	173	0.175	0.180	0.200	100
520	111	0.17	0.181	0.200	104
540	82	0.18	0.183	0.200	108
560	74	0.19	0.184	0.200	112
580	41	0.18	0.181	0.200	116
600	36	0.17	0.169	0.200	120

ARM2 Poly Curve Fitting Analysis - Northeast Region

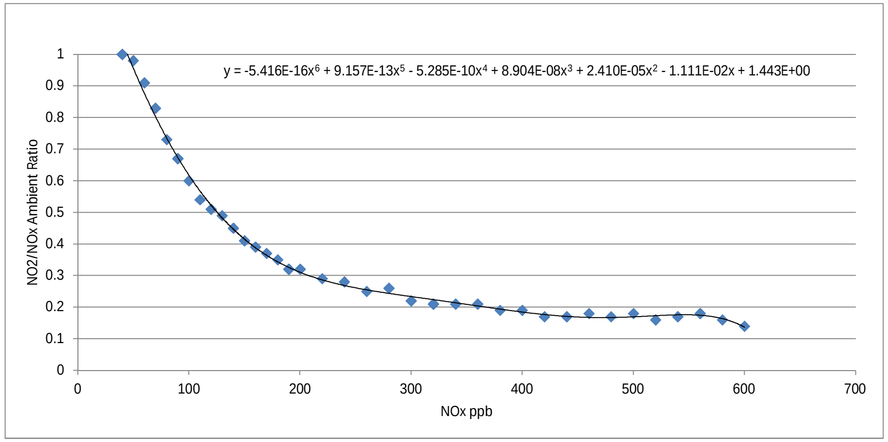


Linest and Logest Functions		a	b	c	d			
Cubic	=LINEST(,X_1^{1,2,3,4,5,6})	-6.550E-16	1.245E-12	-8.725E-10	2.573E-07	-1.66953E-05	-0.006489282	1.276762

ARM2 Poly Curve Fitting Analysis
Southeast Region

Min Ratio	0.2	Maximum Ratio		0.9	
Total # Obs	419681				
Mid Pt. Nox BIN ppb	Number in Bin	Observed 98% Perc ARM	Step 1 Fitted ARM Ratio	Final Adjusted ARM Ratio	ARM2 Calculated NO2 ppb
30	179401	1.05	1.133	0.900	27
40	82728	1	1.042	0.900	36
50	45511	0.98	0.956	0.900	45
60	27839	0.91	0.876	0.876	53
70	18693	0.83	0.803	0.803	56
80	13197	0.73	0.735	0.735	59
90	9866	0.67	0.674	0.674	61
100	7427	0.6	0.618	0.618	62
110	5635	0.54	0.568	0.568	62
120	4433	0.51	0.523	0.523	63
130	3688	0.49	0.482	0.482	63
140	2971	0.45	0.447	0.447	63
150	2566	0.41	0.416	0.416	62
160	2110	0.39	0.388	0.388	62
170	1762	0.37	0.364	0.364	62
180	1475	0.35	0.344	0.344	62
190	1350	0.32	0.326	0.326	62
200	1156	0.32	0.311	0.311	62
220	1775	0.29	0.287	0.287	63
240	1331	0.28	0.269	0.269	64
260	1026	0.25	0.255	0.255	66
280	813	0.26	0.244	0.244	68
300	583	0.22	0.234	0.234	70
320	512	0.21	0.224	0.224	72
340	356	0.21	0.214	0.214	73
360	318	0.21	0.204	0.204	73
380	275	0.19	0.194	0.200	76
400	228	0.19	0.185	0.200	80
420	156	0.17	0.177	0.200	84
440	130	0.17	0.171	0.200	88
460	99	0.18	0.168	0.200	92
480	80	0.17	0.168	0.200	96
500	61	0.18	0.170	0.200	100
520	44	0.16	0.173	0.200	104
540	32	0.17	0.176	0.200	108
560	27	0.18	0.175	0.200	112
580	14	0.16	0.164	0.200	116
600	13	0.14	0.137	0.200	120

ARM2 Poly Curve Fitting Analysis - Southeast Region



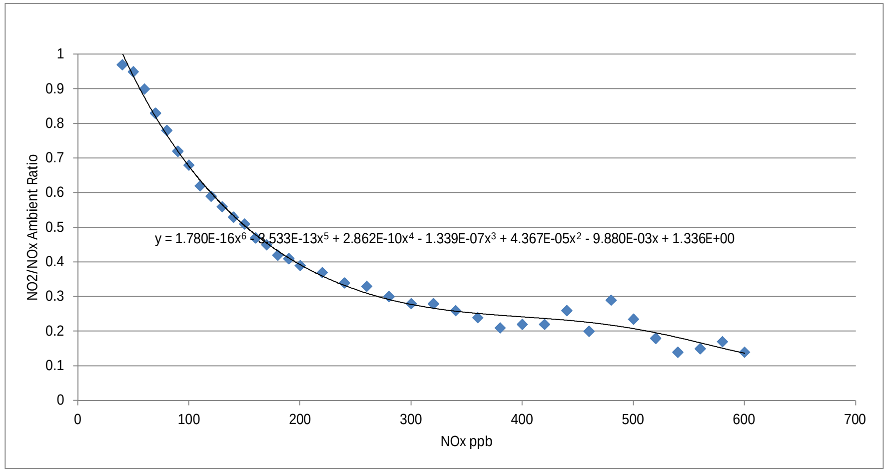
Linest and Logest Functions		a	b	c	d			
Cubic	=LINEST(,X_1^{1,2,3,4,5,6})	-5.416E-16	9.157E-13	-5.285E-10	8.904E-08	2.41047E-05	-0.011108125	1.443045

ARM2 Poly Curve Fitting Analysis
Midwest Region

Min Ratio	0.2	Maximum Ratio	0.9
Total # Obs	778336		

Mid Pt. Nox BIN ppb	Number in Bin	Observed 98% Perc ARM	Step 1 Fitted ARM Ratio	Final Adjusted ARM Ratio	ARM2 Calculated NO2 ppb
30	283397	1	1.076	0.900	27
40	156803	0.97	1.003	0.900	36
50	95480	0.95	0.937	0.900	45
60	62403	0.9	0.875	0.875	53
70	43440	0.83	0.819	0.819	57
80	30934	0.78	0.768	0.768	61
90	22693	0.72	0.720	0.720	65
100	16907	0.68	0.677	0.677	68
110	12983	0.62	0.636	0.636	70
120	10210	0.59	0.599	0.599	72
130	7780	0.56	0.565	0.565	74
140	6191	0.53	0.534	0.534	75
150	4955	0.51	0.505	0.505	76
160	3948	0.47	0.479	0.479	77
170	3332	0.45	0.454	0.454	77
180	2692	0.42	0.432	0.432	78
190	2158	0.41	0.411	0.411	78
200	1816	0.39	0.393	0.393	79
220	2811	0.37	0.360	0.360	79
240	2010	0.34	0.332	0.332	80
260	1387	0.33	0.310	0.310	81
280	952	0.3	0.292	0.292	82
300	780	0.28	0.278	0.278	83
320	536	0.28	0.266	0.266	85
340	387	0.26	0.258	0.258	88
360	310	0.24	0.251	0.251	91
380	224	0.21	0.246	0.246	94
400	200	0.22	0.242	0.242	97
420	148	0.22	0.237	0.237	100
440	111	0.26	0.232	0.232	102
460	100	0.2	0.226	0.226	104
480	91	0.29	0.218	0.218	104
500	99	0.24	0.208	0.208	104
520	25	0.18	0.196	0.200	104
540	10	0.14	0.182	0.200	108
560	16	0.15	0.167	0.200	112
580	10	0.17	0.151	0.200	116
600	7	0.14	0.137	0.200	120

ARM2 Poly Curve Fitting Analysis - Midwest Region

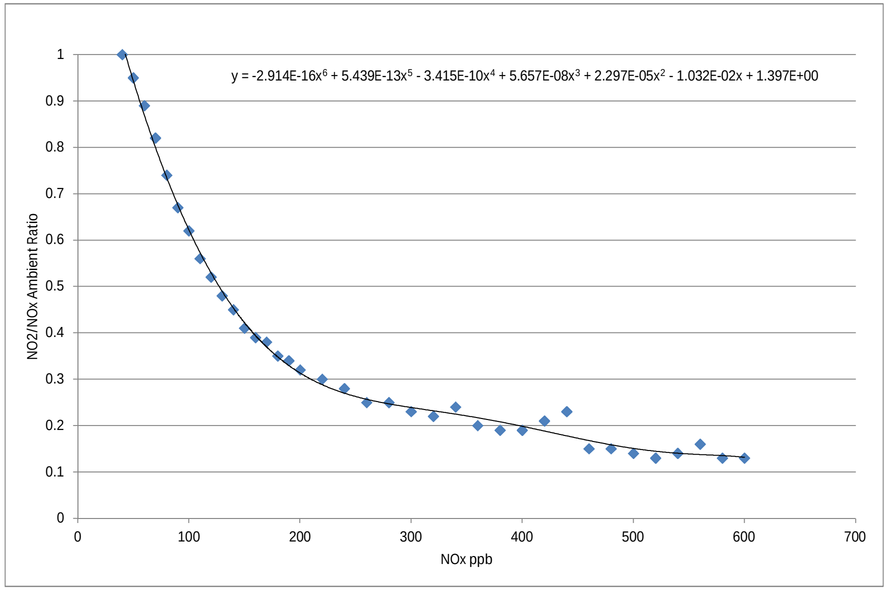


Linest and Logest Functions		a	b	c	d			
Cubic	=LINEST(,X_1^{1,2,3,4,5,6})	1.780E-16	-3.533E-13	2.862E-10	-1.339E-07	4.36678E-05	-0.00987988	1.336483

ARM2 Poly Curve Fitting Analysis
Southwest Region

Min Ratio	0.2	Maximum Ratio	0.9		
Total # Obs	819626				
Mid Pt. Nox BIN ppb	Number in Bin	Observed 98% Perc ARM	Step 1 Fitted ARM Ratio	Final Adjusted ARM Ratio	ARM2 Calculated NO2 ppb
30	324695	1.01	1.109	0.900	27
40	161405	1	1.024	0.900	36
50	92570	0.95	0.944	0.900	45
60	58213	0.89	0.869	0.869	52
70	39442	0.82	0.799	0.799	56
80	28437	0.74	0.735	0.735	59
90	21170	0.67	0.676	0.676	61
100	16697	0.62	0.622	0.622	62
110	12993	0.56	0.573	0.573	63
120	10358	0.52	0.529	0.529	63
130	8458	0.48	0.489	0.489	64
140	6830	0.45	0.454	0.454	64
150	5833	0.41	0.422	0.422	63
160	4844	0.39	0.394	0.394	63
170	4107	0.38	0.370	0.370	63
180	3519	0.35	0.348	0.348	63
190	2952	0.34	0.330	0.330	63
200	2524	0.32	0.314	0.314	63
220	3780	0.3	0.288	0.288	63
240	2748	0.28	0.270	0.270	65
260	2048	0.25	0.257	0.257	67
280	1487	0.25	0.247	0.247	69
300	1124	0.23	0.239	0.239	72
320	874	0.22	0.232	0.232	74
340	653	0.24	0.225	0.225	76
360	494	0.2	0.217	0.217	78
380	374	0.19	0.208	0.208	79
400	271	0.19	0.199	0.200	80
420	200	0.21	0.189	0.200	84
440	155	0.23	0.178	0.200	88
460	122	0.15	0.168	0.200	92
480	85	0.15	0.159	0.200	96
500	53	0.140	0.151	0.200	100
520	41	0.13	0.145	0.200	104
540	22	0.14	0.141	0.200	108
560	29	0.16	0.138	0.200	112
580	14	0.13	0.135	0.200	116
600	5	0.13	0.132	0.200	120

ARM2 Poly Curve Fitting Analysis - Southwest Region



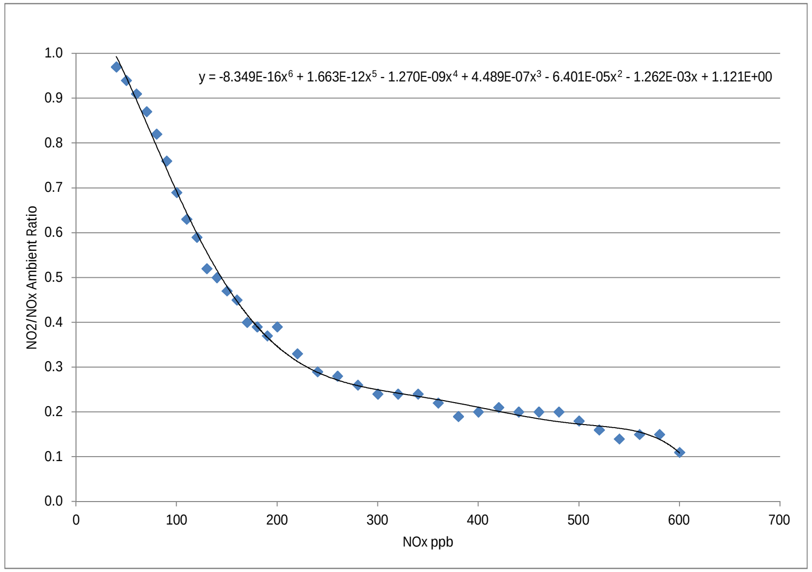
Linest and Logest Functions		a	b	c	d			
Cubic	=LINEST(,X_1^{1,2,3,4,5,6})	-2.914E-16	5.439E-13	-3.415E-10	5.657E-08	2.29691E-05	-0.010318222	1.396971

ARM2 Poly Curve Fitting Analysis
Within 1 km of 100 tpy Sources

Min Ratio 0.2 Maximum Ratio 0.9
Total # Obs 277498

Mid Pt. Nox BIN ppb	Number in Bin	Observed 98% Perc ARM	Step 1 Fitted ARM Ratio	Final Adjusted ARM Ratio	ARM2 Calculated NO2 ppb
30	83331	1.000	1.036	0.900	27
40	52394	0.970	0.994	0.900	36
50	35868	0.940	0.946	0.900	45
60	25553	0.910	0.896	0.896	54
70	18735	0.870	0.845	0.845	59
80	13573	0.820	0.793	0.793	63
90	10272	0.760	0.742	0.742	67
100	7653	0.690	0.692	0.692	69
110	5898	0.630	0.644	0.644	71
120	4460	0.590	0.599	0.599	72
130	3442	0.520	0.556	0.556	72
140	2702	0.500	0.517	0.517	72
150	2234	0.470	0.480	0.480	72
160	1735	0.450	0.447	0.447	72
170	1420	0.400	0.417	0.417	71
180	1200	0.390	0.391	0.391	70
190	979	0.370	0.367	0.367	70
200	858	0.390	0.346	0.346	69
220	1361	0.330	0.313	0.313	69
240	934	0.290	0.289	0.289	69
260	652	0.280	0.271	0.271	71
280	480	0.260	0.259	0.259	73
300	434	0.240	0.250	0.250	75
320	300	0.240	0.242	0.242	78
340	224	0.240	0.235	0.235	80
360	169	0.220	0.228	0.228	82
380	129	0.190	0.220	0.220	83
400	118	0.200	0.211	0.211	84
420	103	0.210	0.202	0.202	85
440	65	0.200	0.193	0.200	88
460	57	0.200	0.185	0.200	92
480	51	0.200	0.178	0.200	96
500	45	0.180	0.173	0.200	100
520	25	0.160	0.169	0.200	104
540	13	0.140	0.164	0.200	108
560	19	0.150	0.155	0.200	112
580	5	0.150	0.139	0.200	116
600	7	0.110	0.109	0.200	120

ARM2 Poly Curve Fitting Analysis - Within 1 km of 100 tpy Sources

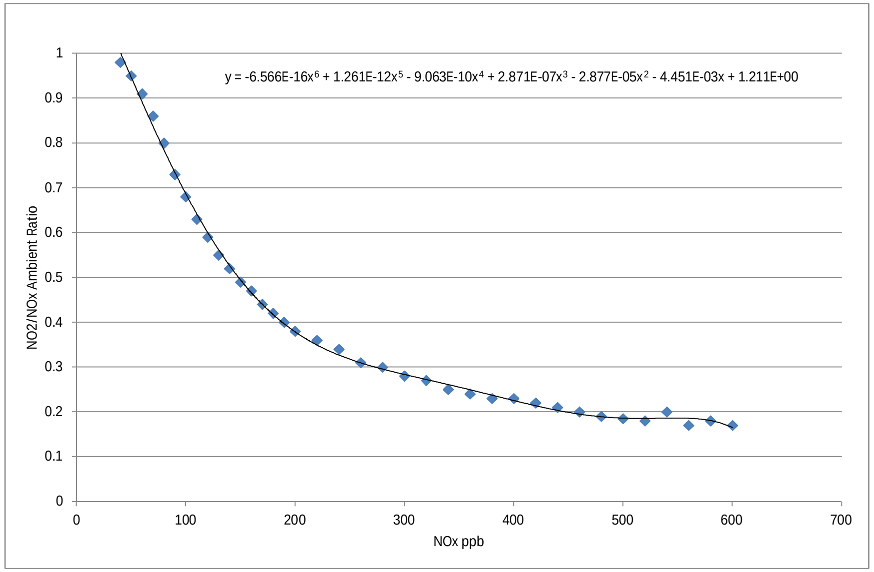


		a	b	c	d			
Linest and Logest Functions								
Cubic	=LINEST(,X_1^{1,2,3,4,5,6})	-8.349E-16	1.663E-12	-1.270E-09	4.489E-07	-6.40058E-05	-0.001261712	1.120815

ARM2 Poly Curve Fitting Analysis
1 to 5 km from 100 tpy Sources

Min Ratio	0.2	Maximum Ratio		0.9	
Total # Obs	2860546				
Mid Pt. Nox BIN ppb	Number in Bin	Observed 98% Perc ARM	Step 1 Fitted ARM Ratio	Final Adjusted ARM Ratio	ARM2 Calculated NO2 ppb
30	953087	1	1.059	0.900	27
40	557450	0.98	1.003	0.900	36
50	352830	0.95	0.947	0.900	45
60	237786	0.91	0.892	0.892	54
70	168694	0.86	0.837	0.837	59
80	122978	0.8	0.785	0.785	63
90	92705	0.73	0.735	0.735	66
100	70982	0.68	0.687	0.687	69
110	55110	0.63	0.642	0.642	71
120	43202	0.59	0.601	0.601	72
130	34459	0.55	0.562	0.562	73
140	27769	0.52	0.527	0.527	74
150	22799	0.49	0.495	0.495	74
160	18601	0.47	0.466	0.466	75
170	15572	0.44	0.440	0.440	75
180	12847	0.42	0.417	0.417	75
190	10823	0.4	0.397	0.397	75
200	9084	0.38	0.379	0.379	76
220	14067	0.36	0.349	0.349	77
240	10177	0.34	0.327	0.327	78
260	7555	0.31	0.310	0.310	80
280	5442	0.3	0.296	0.296	83
300	4136	0.28	0.284	0.284	85
320	3028	0.27	0.272	0.272	87
340	2337	0.25	0.261	0.261	89
360	1748	0.24	0.250	0.250	90
380	1289	0.23	0.238	0.238	90
400	1034	0.23	0.225	0.225	90
420	798	0.22	0.214	0.214	90
440	573	0.21	0.204	0.204	90
460	472	0.2	0.195	0.200	92
480	326	0.19	0.189	0.200	96
500	291	0.185	0.186	0.200	100
520	171	0.18	0.186	0.200	104
540	111	0.2	0.186	0.200	108
560	107	0.17	0.186	0.200	112
580	62	0.18	0.181	0.200	116
600	44	0.17	0.165	0.200	120

ARM2 Poly Curve Fitting Analysis - 1 to 5 km from 100 tpy Sources

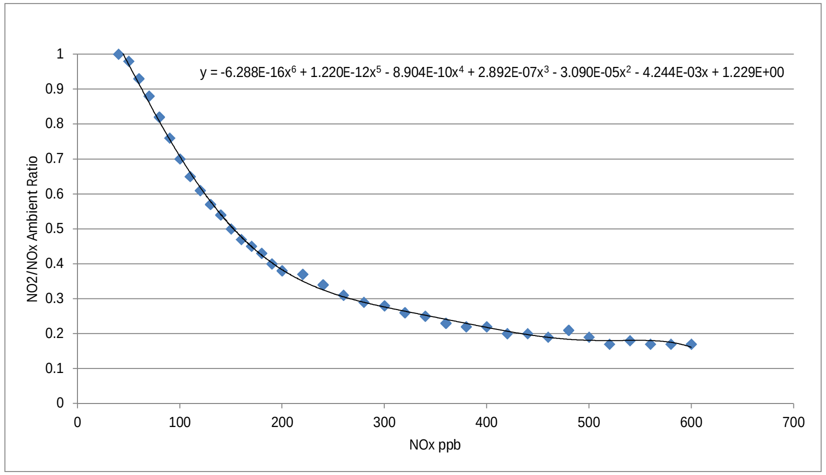


Linest and Logest Functions		a	b	c	d			
Cubic	=LINEST(,X_1^{1,2,3,4,5,6})	-6.566E-16	1.261E-12	-9.063E-10	2.871E-07	-2.87686E-05	-0.00445067	1.211233

ARM2 Poly Curve Fitting Analysis
Greater than 5 km from 100 tpy Sources

Min Ratio	0.2	Maximum Ratio		0.9	
Total # Obs	3900337				
Mid Pt. Nox BIN ppb	Number in Bin	Observed 98% Perc ARM	Step 1 Fitted ARM Ratio	Final Adjusted ARM Ratio	ARM2 Calculated NO2 ppb
30	1357621	1	1.081	0.900	27
40	744075	1	1.027	0.900	36
50	459651	0.98	0.971	0.900	45
60	306175	0.93	0.915	0.900	54
70	215051	0.88	0.861	0.861	60
80	158346	0.82	0.808	0.808	65
90	120705	0.76	0.756	0.756	68
100	93413	0.7	0.708	0.708	71
110	74751	0.65	0.662	0.662	73
120	60579	0.61	0.619	0.619	74
130	49353	0.57	0.579	0.579	75
140	40396	0.54	0.542	0.542	76
150	33857	0.5	0.508	0.508	76
160	28214	0.47	0.478	0.478	76
170	23554	0.45	0.450	0.450	76
180	19841	0.43	0.425	0.425	77
190	16808	0.4	0.403	0.403	77
200	14292	0.38	0.383	0.383	77
220	22451	0.37	0.351	0.351	77
240	16135	0.34	0.326	0.326	78
260	11747	0.31	0.306	0.306	80
280	8728	0.29	0.290	0.290	81
300	6311	0.28	0.277	0.277	83
320	4766	0.26	0.265	0.265	85
340	3414	0.25	0.253	0.253	86
360	2532	0.23	0.242	0.242	87
380	1992	0.22	0.230	0.230	87
400	1482	0.22	0.218	0.218	87
420	1080	0.2	0.207	0.207	87
440	825	0.2	0.198	0.200	88
460	605	0.19	0.190	0.200	92
480	482	0.21	0.184	0.200	96
500	364	0.190	0.181	0.200	100
520	242	0.17	0.181	0.200	104
540	199	0.18	0.181	0.200	108
560	132	0.17	0.181	0.200	112
580	97	0.17	0.176	0.200	116
600	71	0.17	0.161	0.200	120

ARM2 Poly Curve Fitting Analysis - Greater than 5 km from 100 tpy Sources

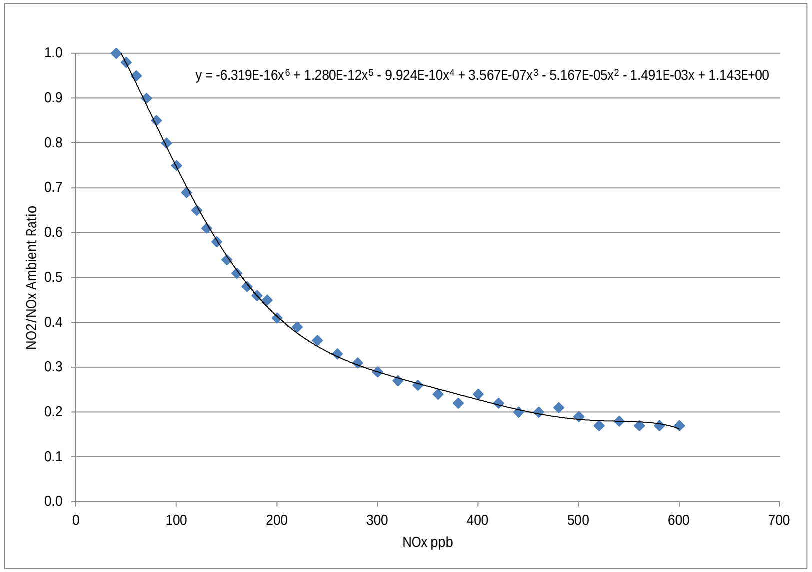


Linest and Logest Functions		a	b	c	d			
Cubic	=LINEST(,X_1^{1,2,3,4,5,6})	-6.288E-16	1.220E-12	-8.904E-10	2.892E-07	-3.09044E-05	-0.00424388	1.229419

ARM2 Poly Curve Fitting Analysis
2001-2003
Min Ratio 0.2 Maximum Ratio 0.9
Total # Obs 2383063

Mid Pt. Nox BIN ppb	Number in Bin	Observed 98% Perc ARM	Step 1 Fitted ARM Ratio	Final Adjusted ARM Ratio	ARM2 Calculated NO2 ppb
30	744455	1.000	1.061	0.900	27
40	443379	1.000	1.021	0.900	36
50	287844	0.980	0.978	0.900	45
60	197928	0.950	0.933	0.900	54
70	142352	0.900	0.886	0.886	62
80	105246	0.850	0.839	0.839	67
90	80624	0.800	0.793	0.793	71
100	63110	0.750	0.747	0.747	75
110	50459	0.690	0.703	0.703	77
120	41019	0.650	0.661	0.661	79
130	33297	0.610	0.621	0.621	81
140	27659	0.580	0.584	0.584	82
150	23192	0.540	0.549	0.549	82
160	19517	0.510	0.516	0.516	83
170	16682	0.480	0.487	0.487	83
180	14130	0.460	0.460	0.460	83
190	12315	0.450	0.436	0.436	83
200	10569	0.410	0.414	0.414	83
220	16807	0.390	0.377	0.377	83
240	12542	0.360	0.347	0.347	83
260	9452	0.330	0.324	0.324	84
280	7207	0.310	0.305	0.305	85
300	5515	0.290	0.290	0.290	87
320	4223	0.270	0.276	0.276	88
340	3259	0.260	0.264	0.264	90
360	2452	0.240	0.252	0.252	91
380	1907	0.220	0.240	0.240	91
400	1501	0.240	0.228	0.228	91
420	1163	0.220	0.216	0.216	91
440	822	0.200	0.206	0.206	91
460	672	0.200	0.196	0.200	92
480	510	0.210	0.189	0.200	96
500	414	0.190	0.184	0.200	100
520	267	0.170	0.181	0.200	104
540	222	0.180	0.180	0.200	108
560	153	0.170	0.179	0.200	112
580	116	0.170	0.174	0.200	116
600	82	0.170	0.163	0.200	120

ARM2 Poly Curve Fitting Analysis - 2001-2003

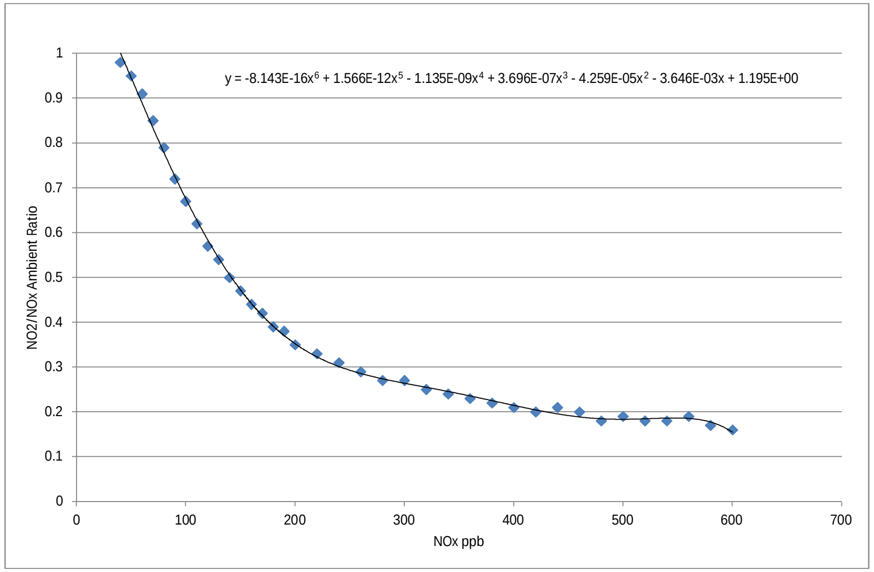


Linest and Logest Functions		a	b	c	d			
Cubic	=LINEST(,X_1^{1,2,3,4,5,6})	-6.319E-16	1.280E-12	-9.924E-10	3.567E-07	-5.16661E-05	-0.001490704	1.143189

ARM2 Poly Curve Fitting Analysis
2004-2007

Min Ratio	0.2	Maximum Ratio		0.9	
Total # Obs	2762848				
Mid Pt. Nox BIN ppb	Number in Bin	Observed 98% Perc ARM	Step 1 Fitted ARM Ratio	Final Adjusted ARM Ratio	ARM2 Calculated NO2 ppb
30	955828	1	1.057	0.900	27
40	538672	0.98	1.002	0.900	36
50	334416	0.95	0.946	0.900	45
60	221739	0.91	0.890	0.890	53
70	155190	0.85	0.833	0.833	58
80	113430	0.79	0.779	0.779	62
90	85658	0.72	0.726	0.726	65
100	65412	0.67	0.676	0.676	68
110	51708	0.62	0.628	0.628	69
120	40833	0.57	0.584	0.584	70
130	32973	0.54	0.544	0.544	71
140	26895	0.5	0.506	0.506	71
150	22473	0.47	0.473	0.473	71
160	18526	0.44	0.442	0.442	71
170	15296	0.42	0.415	0.415	71
180	12752	0.39	0.391	0.391	70
190	10583	0.38	0.370	0.370	70
200	9014	0.35	0.352	0.352	70
220	14198	0.33	0.323	0.323	71
240	10120	0.31	0.302	0.302	72
260	7437	0.29	0.286	0.286	74
280	5386	0.27	0.274	0.274	77
300	3869	0.27	0.264	0.264	79
320	2845	0.25	0.255	0.255	82
340	2028	0.24	0.246	0.246	84
360	1464	0.23	0.236	0.236	85
380	1140	0.22	0.225	0.225	86
400	824	0.21	0.215	0.215	86
420	595	0.2	0.205	0.205	86
440	459	0.21	0.196	0.200	88
460	331	0.2	0.189	0.200	92
480	234	0.18	0.185	0.200	96
500	196	0.19	0.184	0.200	100
520	113	0.18	0.185	0.200	104
540	77	0.18	0.186	0.200	108
560	73	0.19	0.186	0.200	112
580	35	0.17	0.177	0.200	116
600	26	0.16	0.155	0.200	120

ARM2 Poly Curve Fitting Analysis - 2004-2007

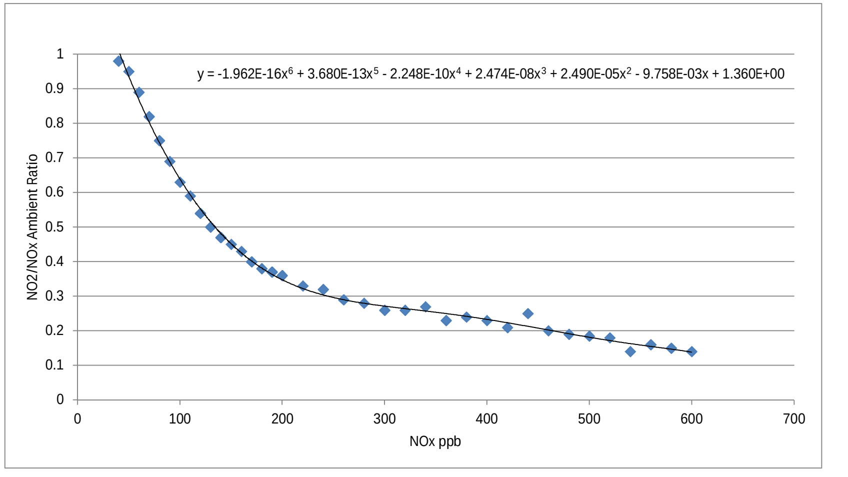


Linest and Logest Functions		a	b	c	d			
Cubic	=LINEST(,X_1^{1,2,3,4,5,6})	-8.143E-16	1.566E-12	-1.135E-09	3.696E-07	-4.25882E-05	-0.003645685	1.195252

ARM2 Poly Curve Fitting Analysis
2008-2010

Min Ratio	0.2	Maximum Ratio		0.9	
Total # Obs	1658437				
Mid Pt. Nox BIN ppb	Number in Bin	Observed 98% Perc ARM	Step 1 Fitted ARM Ratio	Final Adjusted ARM Ratio	ARM2 Calculated NO2 ppb
30	630503	1	1.090	0.900	27
40	328716	0.98	1.011	0.900	36
50	195120	0.95	0.936	0.900	45
60	127090	0.89	0.867	0.867	52
70	87963	0.82	0.803	0.803	56
80	63770	0.75	0.744	0.744	59
90	47963	0.69	0.689	0.689	62
100	36477	0.63	0.639	0.639	64
110	28149	0.59	0.594	0.594	65
120	22241	0.54	0.553	0.553	66
130	17786	0.5	0.515	0.515	67
140	13796	0.47	0.482	0.482	67
150	11136	0.45	0.452	0.452	68
160	8913	0.43	0.426	0.426	68
170	7242	0.4	0.402	0.402	68
180	5887	0.38	0.382	0.382	69
190	4798	0.37	0.364	0.364	69
200	3853	0.36	0.348	0.348	70
220	5613	0.33	0.323	0.323	71
240	3711	0.32	0.304	0.304	73
260	2460	0.29	0.290	0.290	75
280	1611	0.28	0.280	0.280	78
300	1084	0.26	0.272	0.272	82
320	748	0.26	0.265	0.265	85
340	487	0.27	0.258	0.258	88
360	377	0.23	0.250	0.250	90
380	240	0.24	0.242	0.242	92
400	199	0.23	0.234	0.234	93
420	122	0.21	0.224	0.224	94
440	120	0.25	0.213	0.213	94
460	76	0.2	0.203	0.203	93
480	66	0.19	0.192	0.200	96
500	48	0.185	0.182	0.200	100
520	33	0.18	0.172	0.200	104
540	11	0.14	0.163	0.200	108
560	13	0.16	0.155	0.200	112
580	8	0.15	0.147	0.200	116
600	7	0.14	0.139	0.200	120

ARM2 Poly Curve Fitting Analysis - 2008-2010



Linest and Logest Functions		a	b	c	d			
Cubic	=LINEST(,X_1^{1,2,3,4,5,6})	-1.962E-16	3.680E-13	-2.248E-10	2.474E-08	2.48951E-05	-0.009757621	1.360263

APPENDIX C

User Instructions for AERMOD-ARM2

User Instructions for AERMOD-ARM2

A new model option is available in AERMOD-ARM2 version 12345. The model option keyword "ARM2" can be selected (not in combination with either of the PVMRM or OLM options). The ARM2 maximum and minimum conversion ratios are set by default to 0.9 and 0.2; however, the keywords NO2EQUIL and NO2STACK can be used to change these default settings if necessary (if these keywords are missing, the default values will be used). The following AERMOD control input example illustrates the setup of the ARM2 option:

```
CO STARTING
   TITLEONE AERMOD-ARM2 Model Run
   TITLETWO
   MODELOPT CONC ARM2
   AVERTIME 1
   POLLUTID NO2
   RUNORNOT RUN
   NO2STACK 0.2
   NO2EQUIL 0.9
CO FINISHED
```

Since the ARM2 ambient ratio is determined from the cumulative modeled NO_X concentration, there must be an "ALL" source group in the AERMOD run (if an "ALL" source group is not included in a run, AERMOD halts with an error message).

When the ARM2 option is enabled, AERMOD calculates the cumulative 1-hr NO_X concentration (i.e., based on the source group "ALL") at each receptor on an hour-by-hour basis. Each hourly NO_X concentration for the "ALL" source group is input to the ARM2 equation to determine the ARM2 ambient ratio for that hour. The ARM2 ambient ratio for that hour is then multiplied by the NO_X concentration for any other source groups in the model run to determine that hour's NO_2 concentration for each source group. The hourly NO_2 concentrations for each receptor and source group are then stored as usual into the appropriate AERMOD data array for subsequent output processing.