An Analysis of the Impacts and Non-Attainment Risks of the Revised Sulfur Dioxide National Ambient Air Quality Standard on the Toledo Core Based Statistical Area Using the American Meteorological Society-Environmental Protection Agency Regulatory Model

by

Greg Francis Myers

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Graduate Supervisory Committee:

Larry Olson, Chair
David Edwards
Kiril Hristovski

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ABSTRACT

The Toledo Core Based Statistical Area (CBSA) presents an interesting case study for the new sulfur dioxide (SO_2) one hour standard. Since no SO_2 monitor within 75 miles to estimate the attainment status of the area, American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) was used in this study to predict potential problems associated with the newly revised standard. The Toledo CBSA is home to two oil refineries, a glass making industry, several coal fired lime kilns, and a sulfuric acid regeneration plant, The CBSA 3 has coal fired power plants within a 30 mile radius of its center. Additionally, Toledo is a major Great Lakes shipping port visited by both lake and ocean going vessels. As a transportation hub, the area is also traversed by several rail lines which feed four rail switching yards. Impacts of older generation freighters, or “steamers", utilizing high sulfur "Bunker C" fuel oil in the area is also an issue. With the unique challenges presented by an SO_2 one hour standard, this study attempted to estimate potential problem areas in advance of any monitoring data being gathered.

Based on the publicly available data as inputs, it appears that a significant risk of non-attainment may exist in the Toledo CBSA. However, future on-the-books controls and currently proposed regulatory actions appear to drive the risk below significance by 2015. Any designation as

non-attainment should be self-correcting and without need for controls other than those used in these models.

The outcomes of this screening study are intended for use as a basis for assessments for other mid-sized, industrial areas without SO_2 monitors. The results may also be utilized by industries and planning groups within the Toledo CBSA to address potential issues in advance of monitoring system deployment to lower the risk of attaining long term or perpetual non-attainment status.

DEDICATION

To my wife, Kara, and my children, Blake, Owen, and Katherine: It was only because of your patience with an absentee husband and father during the pursuit of my degree, and your support and encouragement, that even when this endeavor seemed impossible, I was able to finish.

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Chapter 1, Introduction

The 2010 revision to the long-stagnant sulfur dioxide National Ambient Air Quality Standard (NAAQS) presents several challenging compliance hurdles for local air quality managers and regulated sources. The revision encompasses a new form, level, and averaging time. Combined with the issues associated with a reduced monitoring network coverage resulting in little usable compliance data, the ability to even assess attainment becomes difficult (USEPA 2010c). In this study, the Toledo Ohio core based statistical area (CBSA) was assessed using the dispersion model AERMOD (American Meteorological Society Environmental Protection Agency Regulatory Model) and publically available emission data to determine the risks of non-attainment with this standard and the challenges associated with modeling attainment with an ambient air quality standard.

As attainment of the sulfur dioxide standard became nearly complete across the U.S. following successful implementation of programs such as the Acid Rain program, air quality planners began to de-emphasize sulfur dioxide ambient air monitoring programs, instead focusing on monitoring for compliance with critical regulations dealing with ozone and particulate matter (i.e. PM_{10} and $PM_{2.5}$) (USEPA, 2009a). With limited resources available, planners tended to remove sulfur dioxide monitors in areas with records of long attainment with the older 24 hour and annual standards to save money on their operation and concentrate on those criteria pollutants such as ozone and $PM_{2.5}$ which has had widespread, lingering non-attainment issues. With the newly released sulfur dioxide standard, not only is data in some areas aged beyond usability, but the change to the form and averaging time of the standard allows for only limited the reliance on older monitoring data (USEPA 2009a).

Use of a suite of dispersion models available for studying the impacts of various sources of air contaminants on ambient air quality is a powerful tool available in tackling this problem (Rama Krishna, Reddy, Reddy, & Singh, 2005). Dispersion models such as the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) and the Industrial Source Complex model (ISC) have long been used to assess the impact of pre-construction projects on incremental consumption of specific sources while community scale models such as the Community Multi-Scale Air Quality Model (CMAQ) assist air quality planners with understanding multi-sector, pre-cursor driven problems from mobile, stationary, and natural sources such as ozone and $PM_{2.5}$ (Venkatram, 2008) across a region. The community scale models require significant computing power and are generally reserved for use by regulatory agencies or large research organizations. Dispersion models, on the other hand, have proven to be valuable estimating tools and they are relatively simple to use when assessing stationary sources. Since sulfur dioxide is primarily emitted from large, stationary sources, the use of dispersion models over a limited geographic area provides an efficient estimation tool (Yildrim, Demircioglu, Kobya, & Bayramoglu, 2002) to provide usable ambient air concentration data for comparison in this study. While useful, these models do not produce exact hour-by-hour reproductions of monitored data therefore; their use must be tempered by the acknowledgment of the limitations and the uncertainties that accompany the use of mathematical models of real-world complex problems (Yegnan, Williamson, & Graettinger, 2002). The uncertainties of modeling are especially important in this instance as the revised NAAQS specifically calls for the use of enhanced dispersion modeling as a component of an attainment demonstration, counter to previous NAAQS where only monitoring data could be used to classify non-attainment (USEPA, 2010c).

A high concentration sulfur dioxide emitting source types still exists in the “rust belt” areas of the Great Lakes and Midwest. These include large stationary sources which combust or utilize coal as a fuel or feedstock and those that process sulfur or sulfur bearing materials such as power plants, steel mills, refineries, lime and cement kilns, and chemical plants (US EPA, 2006). The Toledo, Ohio Core Based Statistical Area, is home or is at least adjacent to nearly all of these source types. It is an area that has suffered from economic decline. Understanding the potential risk of non-attainment can help local planners in the area -- both public and private -- to form strategies to address risk points and minimize any potential non-attainment. A clear understanding of the background of the NAAQS as well as of sulfur dioxide atmospheric chemistry is useful in both the assessment of potential sources and their emissions. It is also useful in understanding and interpreting of the model outputs, each of which is provided in this study.

Statement of the Problem

Since the United States has enjoyed widespread compliance with the old 24 hour and annual NAAQS for some time, sulfur dioxide compliance became an afterthought compared to more difficult ozone standard and requirements for fine and coarse particulate NAAQS. With the new form and averaging time of the revised NAAQS standard and its lower, more restrictive concentration local planners, particularly those in areas with a high concentration of large sources of sulfur dioxide, must now pull sulfur dioxide back to the forefront and reassess their attainment status under the new standard. As a result of widespread, lengthy SO_2 compliance based on the old standards, many sulfur dioxide monitors have been removed from service, further limiting local planner’s ability to assess their attainment status (USEPA, 2010a). However, the use of dispersion models can provide an important estimate of air quality impacts in lieu of a monitoring data history (Yildrim et al., 2002). With a concentration of power plants, refineries, and other stationary sources of sulfur dioxide, the Toledo Ohio Core Based Statistical Area (CBSA) is an area that could benefit from such an approach. Lacking any sulfur dioxide ambient air quality monitor, this CBSA can model the contributions of SO_2 sources and provide a view into future compliance for regulators as well as the regulated community.

The objectives of this study were to:

1.) Describe the revised standard and its requirements as they apply to the Toledo CBSA

2.) Assess and characterize local sources of sulfur dioxide in the Toledo CBSA as well as sources in adjoining areas that have a reasonable possibility of contributing to ambient SO_2 air quality impacts

3.) Model the SO_2 sources impacting the CBSA using AERMOD, the regulatory dispersion model preferred by the EPA

4.) Analyze the outputs and characterize the NAAQS non-attainment risk in the Toledo CBSA

5.) Assess future known and reasonably predictable controls which should help to mitigate any non-attainment

This study relied solely on publicly available data sources for inputs to the model.

Need for Project

Given the regulatory burden at hand associated with this revised standard, prompt and detailed analysis of individual communities' compliance may allow for local response and provide feedback to the EPA on the timelines and resources necessary to address likely problems.

Analysis may permit the costs of controls for sources of sulfur dioxide and the risks to business development in areas declared to be in non-attainment to be identified. Identification is the first step toward better control of the costs to businesses and communities. In addition, the revised standard has a very brief window, allowing for identification of those areas of non-attainment or maintenance. While this study is not intended to be a regulatory submission or State Implementation Plant (SIP) quality model, it can be used as the basis for planning such initiatives. With attainment recommendations due to the EPA in the summer of 2011, limited time is available to proactively address problem areas, underscoring the need to have data, such as this study, available to decision makers (USEPA, 2010c).

Scope of Work

The scope of work of this project is to provide an assessment of the risk of non-attainment with the recently revised sulfur dioxide NAAQS in the Toledo, Ohio CBSA. A base case using publicly available emission data and source characterization information was modeled using the most recent data available as of December, 2010. Additionally, two future case model runs were utilized if risk of non-attainment exists. One model uses on-the-books controls yet to be installed, and one examines use of those controls and other controls in reasonably anticipated from new or proposed regulatory programs. The study was limited to the major stationary sources in and adjacent to the Toledo CBSA. The evaluation of mobile sources is not amenable to AERMOD and is outside of the scope of this project and are considered to be contained in an as yet to be determined background concentration to be added to the modeled results. Modeling the background contribution is discussed in Section 5.

Assumptions and Limitations

The data from the publicly available sources is assumed to be complete and accurate. The sources discussed in this project have the ability and obligation to ensure that their reported data is correct and accurate. More updated and precise data may be available through the use Freedom of Information Act, but that has not been utilized. Every attempt has been made to estimate effective controls that have been installed, but not reflected in the publicly available emission inventories. Estimation calculations are discussed and documentation provided. The EPA does state the requirement to use "enhanced dispersion modeling" is a required part of an attainment designation. However the agency has deferred issuing guidance for such techniques to a later date. Therefore standard modeling practices were utilized. Uncertainties and conservative estimating tools built into the AERMOD model, or any model for that matter must be considered carefully. However, as the preferred regulatory model of the EPA, AERMOD is assumed to be best available model for this purpose and its limitations were deemed acceptable.

Summary

This project focused on estimating the ambient air concentration of the major stationary sources of sulfur dioxide in an area encompassing or adjacent to the Toledo CBSA. The results of the modeling and the risk conclusions given provide a basis for planners and decision makers to engage in more detailed analysis as EPA guidance is published. They also as provide an early glimpse to potential problems, thereby guiding planning and development of attainment strategies. The study is based on the utilization of publicly available emissions data and the use of the AERMOD regulatory dispersion model. The literature review and source background data are presented in Section 2 which also frames the history of the sulfur dioxide NAAQS. The process and methods used to calculate the model inputs and the modeling protocol are detailed in Chapter 3. The model outputs and findings are presented in Chapter 4. The conclusions of the modeling project are presented in Chapter 5. Chapter 5 also includes recommendations for further research to enhance these findings and increase the body of knowledge needed to address this issue and similar problems.

Chapter 2, Literature Review

Regular approaches to dealing with sulfur dioxide as an atmospheric pollutant and precursor to acid rain have historically been considered "poster children" during development and implementation of the Clean Air Act (Belden, 2001). As a deeper understanding of sulfur dioxide pollutant chemistry led to the formation of the Acid Rain Program and the extremely successful reductions accomplished as part of this program, air quality managers began to look at other problems that excessive concentrations of sulfur dioxide was causing, both as a direct pollutant and a pre-cursor. This led to scrutiny of the National Ambient Air Quality Standard for sulfur dioxide over the past 10 years and its subsequent 2009 proposal and 2010 final revision (USEPA, 2009a). The issues that exist in revising a long-stagnant standard, which had a very high level of national compliance, include limited operating monitoring stations, limited current ambient air quality monitoring data, and a growing inattention to the sulfur dioxide NAAQS -- a "pollutant apathy" regarding sulfur dioxide (USEPA, 2009a).

To assess NAAQS compliance of a geographical area with no active sulfur dioxide ambient air quality monitor, modeling is necessary. The key steps for developing this model included:

1.) Assessing sources for their potential to cause attainment issues

2.) Developing the emission data for those sources

3.) Acquiring peripheral model inputs such terrain and meteorological data.

4.) Selection of the best modeling tool

5.) Understanding and properly analyzing the outputs of the model. (Turner & Schulze, 2007).

To meet the goal of this study the background of the atmospheric chemistry of sulfur dioxide as well as the history of the sulfur dioxide NAAQS were also be explored.

Oxides of Sulfur Environmental and Atmospheric Chemistry

Understanding of the chemical processes that occur in the atmosphere is a critical tool in order to properly assess local SO_2 sources outcomes of modeling. Sulfur dioxide in and of itself is an irritant and has health effects on sensitive populations, such as asthmatics. This is the primary driver for the recent revision. Historically, however, the oxidation products of sulfur dioxide has drawn significant media and scientific attention (USEPA, 2008). Sulfates that result from oxidation reactions form sulfuric acid, lowering the pH of precipitation ("acid rain"), and they also combine with anionic species forming fine particulate,"$PM_{2.5}$" (Vallero, 2008).

Sulfur dioxide and sulfur trioxide are the only forms of the family of oxides of sulfur that are of interest in the environmental and atmospheric chemistry of the troposphere and thus this study. Sulfur trioxide can be emitted in a gaseous form, although it reacts almost instantaneously with any available water to form sulfuric acid mist. A small particle of this mist can form a larger droplet, in a process called nucleation, or combine with other existing particulate matter species in the atmosphere In either case, the sulfuric acid mist falls out very near the source (USEPA, 2008). Therefore, only sulfur dioxide is present in the lower atmosphere or planetary boundary layer (PBL) at an exposure concentration significant enough to be of concern to humans (USEPA, 2009a).

Ultimately, sulfur dioxide is oxidized by a series of atmospheric chemistry reactions to also form sulfuric acid. However, this reaction is slower and, due to transport of the original sulfur dioxide molecule, exposure to the general public, including sensitive populations and environments, occurs at distances from the source (USEPA, 2009a). Although still controversial, long range transport of sulfur dioxide has been studied. Sulfur dioxide emitted in the Ohio River Valley, Great Lakes, and Upper Midwest may be carried as far as eastern Quebec, Ontario, and New England before it is converted to sulfuric acid and subsequently deposited. Removal through deposition or through chemical oxidation results in depletion of SO_2 in the atmosphere in less than a day to as long as four days following emission from the source. The exact lifetime is dependent upon site specific meteorology, physical conditions, and altitude (Jet Propulsion Laboratory, 2003).

Two forms of oxidation dominate conversion of sulfur dioxide to either sulfate (sulfuric acid/acid rain) or sulfite (fine particulates or mist) are those in the gas phase and those in the aqueous phase (Vallero, 2008). The gas phase oxidation conversion from sulfur dioxide to sulfuric acid is represented by the following reactions:

eqn 2.1) $SO_2 + OH + M \rightarrow HSO_3 + M + O2 \rightarrow SO_3 + HO_2$

eqn 2.2) $SO_3 + H2O \rightarrow H2SO_4$

…where M represents a stabilizing constituent present in the atmosphere such as N_2 or O_2 and HO_2 (hydroperoxyl) (USEPA, 2008). Since the vapor pressure of sulfuric acid is very low, it is removed rapidly from the gas phase by either nucleation, transfer to aerosol particles, or cloud droplets. Sulfur dioxide does not react directly with hydroperoxyl or other atmospheric oxidants in any significant amounts, since reaction is characterized by very low rate coefficients (Jet Propulsion Laboratory, 2003).

While both sulfate and sulfite forms exist in the atmosphere, sulfates are the dominant form. Ozone (O_3), hydrogen peroxide (H_2O_2), organic peroxides ($R\text{-}O_2$), hydroxyl radicals ($OH^{\bullet}$), and transitional metal are the more important oxidizing agents for the sulfite to sulfate reaction in cloud water droplets. (Jet Propulsion Laboratory, 2003) The steps involved in the aqueous phase oxidation of SO_2 can be summarized as Dissolution of SO_2:

$SO_2 + H_2O \rightarrow H_2SO_4$

The formation and dissociation of H_2SO_3

$SO_2(aq) + H_2O(aq) \leftrightarrow H_2SO_3 \leftrightarrow H^+ HSO_3^- \leftrightarrow 2H^+ + SO_3^{2-}$

In the pH range commonly found in rainwater (pH 2 to 6), the most important reaction converting sulfites to sulfates becomes:

$$HSO_3^- + H_2O_2 + H^+ <=> SO_4^{2-} + H_2O + 2H^+$$

because SO_3^{2-} is much less abundant than HSO_3^- (Jet Propulsion Laboratory, 2003). For pH up to about 5.3, H_2O_2 is the dominant oxidant. At pH > 5.3, O_3 becomes dominant although, oxidation by O_3 and O_2 tends to be self-limiting. This is due to the fact that as sulfate is formed, the pH decreases below 5.3 and the rates of these reactions decrease, causing peroxide to become the more dominant and thus rate limiting reagent. The ammonium ion also becomes important in this reaction due to its buffering/acid neutralizing acidity (Jet Propulsion Laboratory, 2003). Areas with heavy agricultural development tend to have an excess of ammonium ion and therefore have a neutralizing capacity, slowing down the reaction. Areas that are more ammonium limited, such as the dry, high desert (Colorado Plateau) and boreal forests of New England, have less buffering capacity and thus sulfur dioxide tends to be oxidized at a higher rate (Vallero, 2008). Studies indicate that gas phase oxidation only accounts for 20% of the sulfur dioxide on average; however local conditions will impact the variability of this number (Jet Propulsion Laboratory, 2003).

Background of Clean Air Act and National Ambient Air Quality Standards

The first steps in regulating air quality on a national level began with the Air Pollution Control Act of 1955 promulgated under the Eisenhower administration. This time period predated the Environmental Protection Agency by nearly 15 years (Belden, 2001). This program was primarily concerned with researching the effects of air pollution on the general population, and it provided federal monies to do so. Since it was primarily associated with health effects and not regulating or controlling any source, and since the formation of an environmental regulatory agency was nearly two decades away, the United States Surgeon General was tasked with implementing the 1955 Act (Belden, 2001). In the 1960's several critical air pollution emergencies occurred resulting in the deaths of hundreds of people in New York and London, this lead to public outcry for further strengthening of air pollution laws. This publicity resulted in the Air Quality Act of 1967. Program oversight was moved from the United States Surgeon General to the United States Health, Education, and Welfare Department (HEW) and the United States Public Health Service (Martineau & Novello, 2004). The 1967 version of the Act had four primary goals which represented the first steps to regulating sources of airborne contaminants:

1.) Protect the nation's resources to promote health and welfare

2.) Stimulate research on pollution prevention and the reduction of pollutants

3.) Assist States in building and implementing their own programs

4.) Begin the regional air planning process

In the 1967 Act were provisions which directed HEW to develop the first national air quality criteria. From these criteria, the states would then develop air quality standards in their airsheds based on these federal standards and submit the first rudimentary implementation plans to HEW. Several deficiencies and limitations which included the lack of effective enforcement prohibited the 1967 Act from achieving meaningful reductions in air pollutants. However, the most important contribution was the introduction of several key concepts such as national air standards, federal – state environmental partnerships, state implementation plans, and a real emphasis on developing an effective enforcement mechanism (Belden, 2001).

Understanding that the shortfall of the previous two attempts at managing national air quality centered on the absence of a central environmental regulatory body, Congress established the Environmental Protection Agency (EPA) in 1970. The newly formed agency was charged with all air quality management issues including studying and investigating health effects of air contaminant releases, control technology and science, and for the first time, centralizing implementation and enforcement into one body (Martineau & Novello, 2004). Also in 1970, Congress passed the Clean Air Act Amendments of 1970. Although sometimes referred to as "*THE* Clean Air Act", the 1970 legislation is actually a set of amendments to the 1967 Air Quality Act (Belden, 2001). In Title I, Section 7409 of these amendments, Congress instructed the Agency to continue the formalization of the establishment of concentrations of certain air pollutants in the ambient air. This list became the list of Criteria Pollutants and the accepted concentrations became the first National Ambient Air Quality Standards, or NAAQS. Also part of Title I was the responsibility for the EPA to assist and guide states in establishing a suite of control technologies, programs, and systems to reduce ambient concentrations in geographical areas where they exceeded the NAAQS. This agglomeration of programs, referred to as the State Implementation Plan, or SIP, is the EPA's primary tool for enforcing the NAAQS. The NAAQS themselves are generally not directly enforceable on a single stationary source, but the programs written into a SIP are the enforcement tools (Martineau & Novello, 2004).

Part 108 of the Clean Air Act provides for the legal basis and direction for listing of the Criteria Pollutants and subsequent NAAQS development. Although no specific procedural requirements exist in the Act for the listing of a criteria pollutants for NAAQS development, two phrases dictate the consideration that must be given in determining what pollutants are listed. Under the Act, if a pollutant is:

…emitted by numerous and diverse sources…

and

…reasonably anticipated to endanger public health and welfare...

...then under the Act the EPA is required to list said the pollutant and develop a NAAQS. The “numerous and diverse” clause is an important concept as Congress did not intend for NAAQS to be issued for pollutants of only a local or regional nature. Those would be regulated as hazardous air pollutant in Section 112 or under the new source performance standard under Section 111 (Martineau & Novello, 2004). The timeline given to the EPA to establish the NAAQS for the initial criteria pollutants was very aggressive. Without the benefit of the technical support available to the EPA in its regulatory actions today, the Agency was able to successfully promulgate the first NAAQS by the congressionally mandated deadlines in the 1970 Amendments, relying largely on academic work and research completed by earlier government entities (Martineau & Novello, 2004). The initial list of NAAQS promulgated in 1971 included

1.) Photochemical Oxidants (or Ozone)
2.) Carbon Monoxide
3.) Sulfur Dioxide
4.) Nitrogen Oxides (as Nitrogen Dioxide)
5.) Particulate Matter
6.) Hydrocarbons

Subsequent to the 1970 amendments, and as a result of decisions made regarding *Natural Resources Defense Council vs. Train* in 1976, the courts required EPA to list lead as a Criteria Pollutant. However, in 1983, hydrocarbons were delisted because no direct adverse health effects could be linked to hydrocarbons. Nevertheless, certain hydrocarbon compounds, reactive volatile organic compound, or reactive VOCs, are regulated as precursors to ozone. The NAAQS are codified in Part 50 of Chapter 40 of the Code of Federal regulations (40 CFR Part 50) (Belden, 2001).

Following the establishment of these initial standards, a wave of lawsuits ensued challenging everything from the constitutionality under “federalism” of a national standard to the science used to establish the standards. In most of these cases, the courts deferred to the EPA’s method and science, validating the NAAQS and the process used to set the standards (Martineau & Novello, 2004). Since the original list, and the addition of lead, no new pollutants have had NAAQS established, although several modifications to the list have occurred as a result of the required review of the NAAQS under the 1970 Amendments.

The NAAQS consist of two classes, a “primary NAAQS” intended to protect human health, and a “secondary NAAQS” designed to protect “welfare”, which may include protection of plant life, buildings or structures, visibility, etc… Each class may also include different values, such as a short term (e.g., one-hour, three hour rolling average, etc…), daily or rolling 24 hour average, and long term such as 30 day or annual average. Throughout the various iterations of modifying NAAQS over the last few decades, only sulfur dioxide has a secondary standard that differs from its primary standard. Carbon monoxide does not have a secondary standard. Particulate matter, ozone, nitrogen dioxide, and lead all have secondary standards equal to the respective primary standards, which has been the trend in NAAQS modification by the Agency (Belden, 2001).

Following the 1970 amendments, another suite of amendments were promulgated by Congress in 1977. While not impacting the form and function of NAAQS themselves, the 1977 amendments were intended to deal with the very slow progress toward NAAQS attainment in areas in violation of the standards (i.e., non-attainment) and the regression of certain areas into non-attainment from attainment. These strategies included adding time for attaining compliance and the addition of new emission control requirement for non-attainment areas known as a non-attainment new source review (NNSR). Additionally, in 1977, Congress added the Prevention of Significant Deterioration (PSD) program which together with non-attainment New Source Review (NNSR) is known as the New Source Review (NSR) program codified in 40 CFR Part 51 (Belden, 2001). While initially an obscure regulation, the PSD program leapt to the forefront of enforcement activity and penalty issuance after the (Wisconsin Electric Power Co (WEPCo). v. Reilly decision (Martineau & Novello, 2004). Since then, the PSD regulations have been responsible for some of the largest fines and penalties issued including the $4.6 Billion American Electric Power settlement on October 9, 2007. Following the 1977 amendments, Congress left the Clean Air Act alone until 1990. The 1990 Amendments have been called the most significant environmental regulatory program, increasing both the depth and breadth of EPA's reach into regulating air emissions from both mobile and stationary sources (Belden, 2001). The 1990 Amendments were divided into seven "Titles" summarized below:

- Title I impacted the NAAQS program by requiring offsets for new sources of air pollutants being constructed in area of non-attainment for that pollutant. This action creates an incremental approach for reaching attainment.
- Title II is related to mobile source regulations
- Title III dramatically revised the hazardous air pollutant program creating the technology based approach currently used
- Title IV created the Acid Rain program creating a market based compliance program
- Title V revised the air permit system in the US to mimic the National Pollutant Discharge Elimination System Program in the water program and gave the EPA the ability to veto any permit not meeting the requirements of the Act, even if issued by a local or state entity

- Title VI created the Stratospheric Ozone Program which promulgated into the Code of Federal Regulations, the Montreal Protocol
- Title VII granted the EPA more enforcement power by upgrading environmental violations which had been deemed “criminal” from misdemeanors to felonies and increased the ceiling of administrative penalties (Belden, 2001).

Again, the form and function of the NAAQS system was largely left untouched, although Title I added the offset program giving an additional strategy to assist state and local air quality managers an ability to move non-attainment areas to attainment.

The Sulfur Dioxide NAAQS

The National Ambient Air Quality Standard for Sulfur Dioxide has been unchanged since the original promulgation on April 30, 1971. The current primary standard has been set at 0.14 parts per million averaged over 24 hours and not to be exceeded more than once and a 0.030 units annual arithmetic mean. The secondary standard 0.5 ppm averaged over 3 hours and not to be exceeded more than once per year. As described earlier the secondary standard is not affected by the Agency's proposed modification, only the primary standard (USEPA, 2009a). However, even though the standard is the same as what was originally promulgated over 35 years ago, there have been multiple events surrounding the sulfur dioxide standard over the years. Beginning in 1978, the EPA reviewed the initial *Air Quality Criteria for Particulate Matter and Sulfur Oxides*. (Martineau & Novello, 2004). In 1982, CASAC issued a closure letter on the criteria document review. The final revised criteria document was issued on March 20 1982 with the administrator of the EPA taking no action on the closure letter (Martineau & Novello, 2004).

In 1985, six states and environmental organizations sued the EPA pursuant to section 304 of the CAA in the Southern District Court of New York to force the EPA to make a decision on the revised criteria document. The plaintiffs felt the information in the revised criteria document indicated that short term exposure was harmful to asthmatics and that transformation to sulfate aerosols caused damage to vegetation and building materials. Further, the plaintiffs felt the secondary NAAQS did not reflect this data. Initially the district court dismissed the suit, stating that the administrator has significant discretion to act or not act if desired, on a NAAQS revision action (Martineau & Novello, 2004). However, the plaintiffs appealed and the Second Circuit affirmed a portion of the administration's discretion in deciding on the form and substance of a NAAQS, but also said that there exists a certain non-discretionary obligation to make some formal decision on the data present. Based on this rationale, the appellate court remanded to the district courts which then issued an order to the EPA to continue the rulemaking to final decision. While the case was being decided, however, the EPA had begun to take final action. On April 23, 1993, the EPA announced its final decision not to revise the standard (Martineau & Novello, 2004). Based largely on the input from the public comments in 1998, the Agency issued a second proposal in 1994 which incorporated new data on 5-10 minute exposure to sulfur dioxide in persons with pulmonary auto-immune diseases such as asthma (USEPA, 2009b). Once more, the agency sought comments on regulatory alternatives to address the health risks of short term (5-10 minute) bursts or peak concentrations of sulfur dioxide. The alternatives were:

1.) Revision of the Standard by the addition of a 5 minute standard of 0.6 ppm (600 ppb)
2.) Establishment of a new regulatory program of section 303 of the Clean Air Act to supplement protection of the existing Standard by adding a 0.6 ppm trigger level for said program
3.) Focus implementation of existing standards on those sources likely to produce a high 5 minute peak, basically, an “emphasis program” which has since become popular in many regulatory programs (USEPA, 2009a).

In a proposed decision promulgated on November 15, 1994, the EPA stated it was not intending to revise the primary standards. In the proposed rulemaking the EPA, for the third time in 12 years, solicited comments on a short term standard to address peak sulfur dioxide emissions (Martineau & Novello, 2004). In a decision posted on May 22, 1996, the EPA finalized their decision not to revise the standard.

However, in the rationale, the agency stipulated that asthmatics could be affected by these short term exposure events which would result in pulmonary lung function decrements, but in a contradictory statement concluded that “the likelihood that an individual will be exposed . . . is very low when viewed from a national perspective” (USEPA, 2009a). Stated alternatively, a 5 minute peak exposure to a short term burst of sulfur dioxide does not pose a national health problem and therefore does not warrant revision or establishment of a new NAAQS (USEPA, 2009a).

The American Lung Association and the Environmental Defense Fund sued the EPA on the basis that it did not adequately explain its determination as to why a short term standard was not necessary. On January 30, 1998, the Court of Appeals for the District of Columbia sided with the plaintiffs and remanded the case to the EPA to more adequately explain its decision not to revise the NAAQS or address the plaintiffs concerns (In Re: American Lung Association Et Al Vs. USEPA, 1998). On May 15, 2006 EPA began the formal steps to review the air quality criteria for sulfur oxides and sulfur dioxide primary NAAQS (US EPA, 2006). The first document created in the review process, Integrated Review Plan for the Primary National Ambient Air Quality Standard for Sulfur Dioxide, was issued in draft in April 2007. Based on this plan the Agency stated it was only considering gaseous compounds in this review as it felt the review of the particulate matter standard, as well as various work with regional haze and visibility, would adequately address sulfate particles and secondary particulate (USEPA, 2009a).

The next phase of the review was the development of the Integrated Science Assessment for Oxides of Sulfur – Health Criteria (ISA). The final ISA was issued in September 2008 after multiple drafts and subsequent comments. From the ISA, the Risk and Exposure Assessment was developed and promulgated in August 2009 (USEPA, 2009a). These documents are critically important as they are the basis on which the EPA makes its statements. As discussed in the next section, the ISA and REA present significant evidence that a short term standard is warranted.

SO_2 Health Assessment Data – ISA and REA

Throughout the regulatory history of various standards for sulfur dioxide, the primary focus has been on sulfur dioxide's role in the chemistry of acid rain. From a health perspective, ambient air quality standards have focused on protecting the general population from the effects of a bolus dose of sulfur dioxide. As the toxicological effects of sulfur dioxide have been studied, it has been discovered that more sensitive segments of the population, particularly, asthmatics exist. Based on studies presented by the American Lung Association, these sensitive segments of the population can suffer decrements in lung function when exposed to sulfur dioxide concentrations far less than the ones which have no impacts on the general population. They can also begin suffering after a much shorter exposure time, as little as 5-10 minutes (USEPA, 2009b). This understanding of how sulfur dioxide impacts sensitive segments of the population was the impetus for the American Lung Association bringing suit, along with the Environmental Defense Fund, against the EPA to explain why no action was taken to develop a short term standard (In Re: American Lung Association Et Al Vs. USEPA, 1998). As mentioned earlier, the Washington DC Circuit Court of Appeals sided with the plaintiffs and remanded the EPA's actions back to the EPA for an explanation of why no action was taken regarding a short term sulfur dioxide standard. The EPA then convened its NAAQS review process whereas two documents which are the basis of setting the NAAQS are derived. The first is the Integrated Sciences Assessment and the second is the Risk Exposure Assessment. Based on the research cited in these documents, the EPA promulgated the short term NAAQS which is summarized in the following section (USEPA, 2010c).

The toxicological affects of acute sulfur dioxide exposure represent a vast opportunity for further research and discussion. However, for the purposes of this project, the scientific basis for proposal of the NAAQS is assumed to be well developed and accepted by the public as well as adequately reviewed by the scientific community. Therefore, the ISA and REA are mentioned only as sources of the data for the proposed NAAQS and will not be discussed nor explored in detail

Summary of Proposed Revision to Sulfur Dioxide NAAQS

In drafting a new short term standard based on the evidence presented to it in the previous section, the EPA has proposed changes from the current standard affecting the form, level, and averaging time. The indicator, that compound which is actually measured to determine compliance, remains sulfur dioxide. In considering the dramatic changes to the standard, the EPA has also proposed changes to the sulfur dioxide monitoring network which are necessary to properly assess attainment status across the country (USEPA, 2010c).

The form of a standard is defined as the "air quality statistic that is compared to the level of the standard to determine if an area meets the standard" (USEPA, 2009a). In the case of the revised standard, the EPA initially proposed two forms. The first would be based on the averaging the fourth highest annual 1 hour concentration with the previous two years, in effect, creating a rolling three year average of the 4th highest value. The second method is to utilize the 99th percentile daily value. In this form, the 99th percentile of each year is averaged with the previous two years and, just as with the 4th highest value form, compared to the standard to determine compliance. Both of these forms will yield the same value with a complete annual data set since the 99th percentile of 365 is equal to the 4th highest value. However, in cases where data is lost, discarded due to QA issues, or intermittent monitoring is performed, the two forms diverge. The point of divergence is at 82% data completeness.

At this point, the 99th percentile becomes the third highest annual value. (USEPA, 2009a) Upon receipt of comments and analysis of the data, the EPA chose to use the 3-year average of the 99th percentile of the annual distribution of daily maximum 1-hour average concentrations as the form for the revised NAAQS Final Rule promulgated on 6/10/2010 (USEPA, 2010a) .

The “level” of an air quality standard is that concentration level above which a locale is considered to be in non-attainment. In proposing this revision, the EPA did not set forth a discrete number, but rather, proposed a range from 50 to 100 ppb (USEPA, 2009a). As with the form, the EPA took public comments on the level. Upon examination of the comments and analysis of submitted arguments and data, the EPA selected 75 ppb in the final rule promulgated on 6/10/2010 (USEPA, 2010a). The current standard stipulates that the values are averaged over 24 hours and also annually, with each averaging time having its own discrete level. The revised standard uses a one hour averaging time.

In considering how to re-design the standard to protect the vulnerable portion of the population from short term exposures detrimental to their lung function as described earlier, the EPA evaluated several short term options. An averaging time less than one hour, e.g. a 10 or 15 minute standard, would require a massive amount of data handling which could become oppressively cumbersome to local air quality managers. An averaging time more than one hour may not adequately emphasize those

5-10 minutes spikes in ground-level concentration caused by brief source anomalies, such as startups, shutdowns, or rapid changes in meteorology. Therefore, the EPA has settled on a one hour averaging time (USEPA, 2010c). The one hour averaging time would continue to prevent sulfur dioxide concentrations from exceeding the 24 hours standard, additionally, there is little evidence that SO_2 represent a chronic health hazards. Therefore upon adoption of this standard in its final form, the EPA revoked both the 24 hour and annual standards, instead using single averaging time of one hour (USEPA, 2010c).

The indicator for this standard continues to be sulfur dioxide. Sulfur dioxide is a subset of the actual pollutant family known as “oxides of sulfur” or SO_x. From the inception of this standard the criteria pollutant classification is actually "oxides of sulfur." However, the standard has come to known as the "SO_2" or "sulfur dioxide standard." Sulfur dioxide is the species within the sulfur oxide family which is measured and used as a surrogate to determine the attainment status of the entire family of oxides of sulfur. This is because sulfur dioxide is found in the atmosphere at much greater concentrations than the other sulfur oxides, additionally sulfur dioxide is longer lived (USEPA, 2009a). Other species such as sulfur trioxide are either in particulate form and measured under the $PM_{2.5}$ standard or react very quickly once emitted in the atmosphere to form mists or particles making monitoring much more difficult for gaseous species of SO_3. Based on this, the EPA retains sulfur dioxide as the indicator species to represent the criteria pollutant group oxides of sulfur in the standard (USEPA, 2009a).

The EPA's proposal to alter the monitoring network does not directly impact the inputs to the model or outcomes of this study. However, it is important to mention the proposal, as the use of modeled results will become increasingly important to the demonstration of attainment.

In the proposed rule, the EPA used two different categories. One of these was based on a factor derived from the combination of population and sulfur dioxide emissions called the “Population Weighted Emission Index” or PWEI. The second category was based on that state’s contribution of the overall sulfur dioxide budget in the US and would be used to add additional random monitors through the state. The EPA sought comments on this approach in the proposed rulemaking, including any alternate suggestions for expansion of the monitoring network (USEPA, 2009a). In the final rule, the Agency kept the use of the PWEI, but deleted the factor based on the state's contribution to the overall sulfur dioxide budget (USEPA, 2010a).

The monitors required by the PWEI must be sited in the metropolitan or core based statistical area whose population was used for the calculation and are to be placed in those MSA or CBSA where the highest ground level concentration is to be expected. The PWEI requires two monitors for the Toledo CBSA, but can require up to 3 monitors based on the factor score (USEPA, 2009a). The agency describes the use of the monitors as the most effective manner in which to measure contributions from groups of smaller sources. That is because those sources are difficult to model, and areas where mobile sources or area sources are clustered or more prevalent. Modeling, on the other hand, is more efficient and less costly to assess compliance with the standard of medium and larger source as models tend to be able to predict emissions more accurately with those types of sources (USEPA, 2010a).

In lieu of solely using the dramatically expanded network of monitors in the proposed rule, the EPA has combined the use of a "refined dispersion modeling" with a slightly pared down expansion of the monitoring network (USEPA, 2010c). In the final rule, the agency committed to issuing further guidance on how to conduct said modeling addressing such issues as

- translating modeling results into a form appropriate for comparison the revised NAAQS
- identification and assess air quality impacts of SO_2 sources
- assessment of causation or contribution of a source to the violation of revised NAAQS (USEPA, 2010a).

The use of modeling becomes important in how the agency plans to classify attainment. Based on the final standard, a county whose monitors demonstrate a violation with the standard would be considered non-attainment, as is the case with other NAAQS. However, with this new standard, a county or CBSA can be designated as non-attainment based on modeled results also. Sites would need to demonstrate through appropriate, quality assured monitoring data and refined dispersion modeling that they are not violating the standard in order to be considered in attainment. Any area lacking either of these would be considered "unclassifiable" (USEPA, 2010c). As mentioned earlier, the EPA will be issuing guidance on how to properly execute the refined dispersion modeling for this standard. As of the writing of this paper, that guidance had yet to be issued. Without that guidance it is not possible to design this model to definitively determine attainment status. Additionally, it is unknown until the guidance is issued if EPA will use a new modeling protocol similar to what has been used in the recently proposed Clean Air Transport Rule or rely on AERMOD. This project used AERMOD as it is currently the EPA's regulatory model, but is designed for stationary sources (Turner & Schulze, 2007). Since most large sulfur dioxide sources are stationary it works well for a tool for assessing risk of non-attainment until said guidance is issued (Turner & Schulze, 2007).

The EPA has also recommended that modeling be used as the preferred siting tool for monitors required by the PWEI in order to ensure that they are capturing the anticipated maximum ground level concentration of sulfur dioxide. Therefore, the outcome of this study could be the basis for an expanded modeling study to determine the location for placement of the two monitors required to be located in the Toledo CBSA under the PWEI category. (USEPA, 2009a) Taking the results of this model and incorporating mobile source contributions, as well as greater detailed terrain and meteorological data, would refine the results further. This would make it easier to pinpoint those locations where the monitors should be placed.

Description of the Toledo Core Based Statistical Area (CBSA)

Toledo, Ohio is the industrial center of the Toledo Core Base Statistical Area and its surrounding suburbs and rural environs. Toledo has historically been known as an industrial area, sitting geographically between Detroit and Cleveland. It has suffered the same rise and decline as other “Rust Belt” cities surrounding the Great Lakes. While somewhat more diversified economically than Detroit, it is still tied heavily to the automotive industry and has suffered a sharp economic decline in recent years. The northeast suburb of Oregon, OH, contains what is known locally as the “Oregon Industrial Area”. This strip of land approximately 5 ½ miles long and one mile wide along the eastern edge of the Maumee River is home to the following major stationary sources of Sulfur Dioxide:

1.) Sunoco Oil Refinery
2.) BP-Husky Oil Refinery
3.) Bayshore Power Plant (Coal Fired)
4.) Marsulex Inc (Sulfuric Acid Plant)
5.) Libbey Glass

(USEPA, 2002)

While not located in the Oregon Industrial Area, approximately 5 miles to the west is the University of Toledo - Medical Center. The powerhouse uses coal as the primary fuel in its boilers were included (Ohio Environmental Protection Agency, 2009d).

Additionally, located approximately 6 miles due north of the Oregon Industrial Area is the JR Whiting (Coal Fired) Power Plant, also included in this study due to its close proximity. JR. Whiting, even though located in Michigan, is only 4 miles into Michigan and 6 miles to Oregon, OH, well within the ability to adversely affect the SO_2 ambient air concentration (Michigan Department of Environmental Quality, 2006).

Further to the north/northeast of Lucas County and the JR Whiting Power Plant, is the Monroe Power Plant in Monroe Michigan owned and operated by DTE Energy. Monroe is the 3rd largest coal fired power plant in the United States. The location of the Monroe Power Plant places it approximately 30 miles from the Toledo CBSA (Michigan Department of Environmental Quality, 2009). At this distance, AERMOD's ability to predict the impact of this source on receptors in Toledo and Lucas County begins to decrease (Turner & Schulze, 2007). However, Monroe is one of the largest sources of sulfur dioxide in the Country so it cannot simply be ignored therefore it was included in the initial screening run and, if the results are congruent with this hypothesis, it will be deleted from the more detailed base case and sensitivity model runs (US EPA, 2010b).

Several lime kilns are located in or very near the Toledo CBSA. Graymont Dolime is located in the far western reach of Ottawa County, which is part of the Toledo CBSA. The facility is approximately 10 miles from Oregon and 15 from the center of the Toledo CBSA (Ohio Environmental Protection Agency, 2010a). Martin Marrieta Magnesia Specialties is located approximately 2 miles outside of the Toledo CBSA in Sandusky County, but like the JR Whiting Power Plant, is sufficiently large enough and close enough to impact the study area (USEPA, 2002). Both of these kilns meet the screening requirements of this study in that they are major sources (> 100 TPY) of sulfur dioxide.

Other sources in a 50 mile radius that are significant sources of Sulfur Dioxide, but not included in this study include a Cement Kiln in Dundee, MI, approximate 30 miles to the northwest. While a significant source of sulfur dioxide in the past, production has been halted and the facility closed due to economic hardship (USEPA, 2002). It is unknown if this is a permanent shutdown or if the site will either be sold to another cement company or production started up at some future time.

Toledo's location at the mouth of the Maumee River on Lake Erie, makes it an important port location on the Great Lakes. According to the Port of Toledo's information, it is one of the busiest and most diverse ports in the area, easily boasting the largest land mass of any terminal in the Great Lakes (Toledo-Lucas County Port Authority, 2010). Depending on the type of freighter and its propulsion technology, large ships can represent major sources of sulfur dioxide while in port, traversing the Maumee River, or approaching the Port on Lake Erie (ICF International, 2007).

Tied into the marine traffic are four mainline railways – CSX, Norfolk and Southern, Canadian National, and Wheeling and Lake Erie. These mainline rail companies all maintain major switching yards in the Lucas County Area. While rail engines now use low sulfur diesel (<500 ppm), the near continuous operation of the engines in close proximity to other stationary sources contribute to the overall sulfur dioxide budget (US EPA, 2010c).

In addition to the rail lines, Toledo is crossed by three major interstate highways, Interstate 75 is a major North-South freeway traveled heavily by diesel powered tractor trailers. This road connects Canada to the industrial heartland and the southeastern United States. Interstate 80/90 traverses Toledo east to west and represents the main coast to coast freeway across the northern United States connecting San Francisco and the Pacific Northwest with New England. Since mobile source models are incredibly complex and are highly variable based on the price of fuel and economic activity, no attempt will be made to model the rail and highway traffic sources of sulfur dioxide (Turner & Schulze, 2007).

Summary and Review of Sources Selected for Modeling

The ideal model is one where every single source of sulfur dioxide is accounted for and each site has site specific meteorological data. To do so, would require a significant amount of resources well beyond the scope of this study. In determining which sources to include, a best professional judgment was made based on size and distance. The pool of potential sources are included below along with a brief background of their operations, summary of sulfur dioxide sources, and review of the available literature characterizing their emission profile. The actual data sources and methods used to characterize the source's model inputs are discussed in detail in Section 3.

Sunoco Oil Refinery.

The Sun Oil Company (“Sunoco”) operates a 160,000 barrel per calendar day capacity oil refinery in Oregon, Ohio (US Energy Information Administration, 2009). The site has undergone a recent expansion which has included the installation of several pieces of control equipment designed to reduce sulfur dioxide. While not yet reflected in the emission inventories, data extrapolations based on the permit limitations in the facility’s Title V Operating permit were used to estimate these emission reductions (Ohio Environmental Protection Agency, 2008).

The facility processes mainly sour domestic and Canadian crude (Sunoco Inc, 2010). Due to increasing regulation on the amount of sulfur in market fuels, refineries must remove this sulfur**.** Sour crudes from

Canada contain more sulfur and sulfur compounds. This increases the potential for sulfur to be released from a refinery in either a reduced form (hydrogen sulfide) or oxidized as sulfur dioxide depending on the process (Jones & Pujado, 2008). Therefore as mobile sources are emitting less and less sulfur compounds, there is a risk that the large stationary refining and processing sources have the potential to emit that sulfur dioxide further “upstream” in more concentrated doses (Jones & Pujado, 2008). Several projects designed to reduce Sulfur Dioxide emissions have recently been completed and, based on permit limitations, drastically cut emission from this source (Ohio Environmental Protection Agency, 2009b).

BP-Husky Refinery.

The BP-Husky Refinery represents a joint venture between BP and Husky Petroleum. This refinery located at the northern edge of the Oregon Industrial Area, has the capability to process approximately 125,000 barrels per calendar day (US Energy Information Administration, 2009). As with the Sunoco refinery, its feedstocks are primarily sour Canadian crudes. Because of the joint venture with Husky of Canada, who is a large producer of syncrude from the Athabasca Tar Sands, the amount of high sulfur sour crude is expected to increase, which will create more oxidized and reduced sulfur compounds for the refinery to manage (US Energy Information Administration, 2009). The BP-Husky Refinery is located adjacent to the First Energy Bayshore Power Plant and also to the

Marsulex Sulfuric Acid Facility (Ohio Environmental Protection Agency, 2009a).

First Energy Bayshore Power Plant.

First Energy's Bayshore Power Plant is a 500 MW coal and petroleum coke fired facility located near the mouth of the Maumee River (Ohio Environmental Protection Agency, 2009c). The facility has four boilers, three of which use pulverized coal and are uncontrolled for sulfur dioxide. One of the boilers is a newly reconstructed source which was designed to fire petroleum coke from the BP-Husky Refinery (USEPA, 2005a).

Petroleum Coke or "Petcoke" is the hard, coal like substance left over after the processing of crude oil. It has a high energy value and therefore is a good fuel, however, it also has a much higher sulfur content than coal (Jones & Pujado, 2008). Sulfur is present in various forms in coal (also with petcoke) however, during the combustion process, it is oxidized into predominantly sulfur dioxide. As part of the reconstruction, Bayshore utilized fluidized bed combustion instead of pulverized fuel combustion and also utilizes a dry scrubber. This results in much lower sulfur dioxide emissions versus an uncontrolled boiler (Ohio Environmental Protection Agency, 2009c).

Consumer's Energy JR Whiting Power Plant.

The JR Whiting Power Plant is located in Michigan approximately 4 miles across the state line. It is clearly visible from anywhere in the northern Toledo/Lucas county area and is only 6 miles from the Oregon Industrial area. Its three units produce a nominal 338 MW of electricity. It has no post-combustion controls for sulfur dioxide relying on low sulfur coal to reduce its sulfur dioxide emissions (Michigan Department of Environmental Quality, 2006).

Detroit Edison (DTE) Monroe Power Plant.

The Monroe Power Plant is located in Michigan approximately 30 miles north of Toledo. It is one of the largest power plants in North America, with four boilers generating enough steam for a gross electrical output of approximately 3.2 GW, an entire order of magnitude larger than the aforementioned Consumers Energy Whiting Facility's 338 MW. It is also one of the largest sources of sulfur dioxide in North America according to the 2005 National Emission Inventory (NEI)

Detroit Edison has commenced a major construction project where it is adding Wet Fluidized Gas Desulphurization Units (Wet Scrubbers) to its boilers. Two of the four units are now controlled and, based on data from DTE the other two will be controlled in the future. Since the screening model is a "snap shot", the initial model runs contain what is being emitting in the current EPA Data and Maps or the most recently populated National Emission Inventory (NEI). If it proves that the Monroe Power Plant does significantly impact the Toledo CBSA, future sensitivity runs will add "on the books" expansions or controls that are under construction, ordered as part of a USEPA Consent Decree, or will be necessary under future regulatory requirements (Michigan Department of Environmental Quality, 2009).

Marsulex Inc Sulfuric Acid Plant.

The Marsulex Sulfuric Acid Facility is located directly adjacent to the BP-Husky refinery and relies on the refinery for a portion of its feedstock as well as sending a significant part of its finished product to the refinery (Ohio Environmental Protection Agency, 2010b).

Petroleum refineries use sulfuric acid in their alkylation units (or “alky” unit). The acid acts as a catalyst in a reaction that increases the octane rating of the gasoline. While not consumed, the acid does become diluted and contaminated requiring regeneration. Additionally, through the operation of sulfur recovery units, refineries produce both hydrogen sulfide and elemental sulfur (Jones & Pujado, 2008).

Along with the contaminated sulfuric acid, the Marsulex plant combusts the elemental sulfur and hydrogen sulfide byproducts in one of two regeneration furnaces or “regen” furnaces. Supplemental natural gas and/or fuel oil are also consumed to create the necessary heat input for the oxidation of the sulfur and hydrogen sulfide and the decomposition of the sulfuric acid. Upon exit of the regen furnaces, the sulfur exists largely as sulfur dioxide. The sulfur dioxide then passes over converter beds consisting of vanadium pentoxide catalyst which assists in the addition of an oxygen to the sulfur dioxide creating sulfur trioxide. Sulfur trioxide rapidly combines with water (in the form of dilute sulfuric acid in an acid plant) to form sulfuric acid. However the process is not 100% efficient, so some of sulfur dioxide will pass through the system and exit through the exhaust gas stack (Ohio Environmental Protection Agency, 2010b).

Libbey Glass.

Toledo is also known as the “Glass City” having been a historic location for several glass and glass related industries. The glass industry has also felt the pressure of many “rust belt” manufacturing operations and has suffered a contraction of its size and number of facilities. However, the Libbey Corporation still operates a glass making facility across the Maumee River from the Oregon Industrial Area in the northern fringes of Toledo. There are also several other fiberglass manufacturing facilities in northwest Ohio, but due to the aforementioned selection criteria, do not qualify for this study.

The Libbey plant is described in publicly available literature (environmental permits, SEC Filings, etc.) as a “Glass Tableware Manufacturer”. Unlike the neighboring states of Indiana and Michigan, Ohio EPA Title V permits do not give a significant amount of detail nor are accompanied by “staff reports” which describe the site in general and the regulated processes in detail. From a general process description, large furnaces are used to process silica sand and recycled glass containing waste into raw, melted glass. Through the combustion of fuels which may contain sulfur and the melting of raw silica and recycled glass which can contain sulfur, sulfur dioxide is created (OhioEnvironmental Protection Agency, 2008).

UT Medical College.

The University of Toledo Medical College operates coal fired boilers on its campus for energy generation including the generation of steam. While the end use of the steam may be different, this source is substantially similar to any coal fired boiler, only on a smaller scale. Sulfur in the coal is oxidized and emitted as sulfur dioxide. The Title V permit does mention a sulfur dioxide control system, but not in significant detail to describe here (Ohio Environmental Protection Agency, 2009d).

Lime Kilns.

The use of coal as the primary fuel in the lime kilns is the process which emits the sulfur dioxide (Ohio Environmental Protection Agency, 2010a) (Ohio Environmental Protection Agency, 2003). The Graymont and Martin Marietta Facilities are both lime kilns producing lime for agricultural use, manufacturing commercial products, and for use in industrial processes. Each facility uses coal as the primary fuel in its kilns, which oxidizes the sulfur to sulfur dioxide as part of the combustion process. The Martin Marietta facility is the larger of the two facilities, but is located slightly further away geographically (Ohio Environmental Protection Agency, 2003; Ohio Environmental Protection Agency, 2010a). Another kiln was located farther to the south and east in Sandusky County, but no emission data could be located via publicly available sources without the use of a FOIA request. It is also nearly 30 miles from the Toledo CBSA. But assuming its emissions are nearly the same as the two other lime kilns, its emission is probably as much as two orders of magnitude lower than Monroe's. Therefore, it is much less likely to have an impact on the Toledo CBSA. However, it may have localized impacts combined with the Martin Marrietta facility in Sandusky County.

The Graymont facility utilizes a combined stack for its entire combustion operation. However, the Martin Marietta facility has several kilns of different sizes. Based on publicly available information it is unknown if there are any differences except size of these kilns. There is some grouping of the kilns into stacks, but there still exists three separate stacks (Ohio Environmental Protection Agency, 2010a) (Ohio Environmental Protection Agency, 2003).

Johns Manville.

The Johns Manville Site located in Waterville, Ohio is a relatively small emitter of sulfur dioxide in relationship to this study. While meeting the threshold according to the 2002 US EPA Air Data database (USEPA 2002), it truly is a marginal inclusion. The site manufactures fiberglass products such as insulation. Little publically available data was located which detailed the processes generating sulfur dioxide.

Composite Marine Freighter.

The Port of Toledo is one of the larger ports of operation on the Great Lakes. It ships everything from coal for nearby power plants to taconite pellets for Midwestern steel mills, to the various agricultural crops from the Midwestern farms (Toledo-Lucas County Port Authority, 2010). Hauling this freight are large (sometimes as much as 1000 feet in length) Lake Freighters or “Lakers”. Very rarely, the port is visited by ocean going freighters or “Salties”. These ships are usually smaller in length in order to fit through the Welland Canal.

Most of these ships are powered by medium speed diesel engines using Low Sulfur Diesel (<500 ppm) (ICF International, 2007). However, 20% of the Lakers are powered by steam turbines which generate their steam from oil fired boilers (Cree, Weakley, Bake, & O'Hearn, 2009). A common fuel is called “Bunker C” or Heavy Fuel Oil (HFO). Bunker fuel contains significant amounts of sulfur, as much as 40,000-50,000 ppm. These ships represent a significant global source of sulfur dioxide whether in port or on the open sea lanes (Streets, Carmichael, & Arndt, 1998).

The difficulty in modeling these ships is that they are technically mobile sources which AERMOD is not designed to model. However, their mooring locations are discrete and only 7 miles of the Maumee River is navigable, nearly all of this occurring in and around the study area. Additionally, since 20% of the fleet is powered by these engines, there exists a one in five average chance that a ship in a Great Lakes Port is burning Bunker Fuel (Cree et al., 2009).

Another disadvantage of the steam powered Lakers, is that the main boiler is often needed to power the ancillary equipment while in port, whereas newer diesel powered ships often have smaller auxiliary engines to power cranes, conveyors, generators, etc… Therefore a bunker fueled ship must fire its main boiler nearly the entire time, whereas the diesel power ships can shut down its large engines (Bawal, 2009). However, not all ships visit each and every port randomly. What is not known is exactly which ships visit at any given time and which one never visit. But using what is known, is that over a long averaging period, the likelihood of the Port of Toledo being visited by one of the steam power Lakers (“Steamers”) is sufficiently high that any study would fall short not to include some SO_2 emissions from the marine shipping industry (Jalkanen, 2009).

One particular steam-powered freighter, American Valor, owned and operated as part of the American Steamship Company (ASC), uses Toledo as her home port. She mainly hauls taconite pellets to the Port and Coal from the Port. This is mainly done by using the Torco docks at the mouth of the Maumee River (Bawal, 2009). The Torco Docks are also used by several other large freighters and therefore make an excellent point for use as the location of the composite marine freighter (Toledo-Lucas County Port Authority, 2010).

Since specific emission data is not publicly available for an individual freighter, this study uses published emission factors developed by ICF International under contract with the EPA (ICF International, 2007). The emission calculations for the freighter are shown in Chapter

Three, but are essentially based on a "gram per kilowatt-hour" output model. The size of the American Valor's turbines are known, 7500 horsepower, this will be converted to watts and scaled using the emission factors (Bawal, 2009). Since emission factors are based on an "average" they likely do not reflect the exact emission profile of the American Valor, instead, they represent an average of the steamer based fleet. The American Valor does represent the median sized steamer based on steam turbine output, therefore, the use of the American Valor as the basis for the composite freighter works well for this study.

Since a freighter spends most of the time in the Maumee River moored and either loading or unloading it acts as a stationary source and its emission contribution to the ambient air should be accurately calculated using this method. The composite freighter is entered into the model as a stationary source operating 8760 hours per year, which dramatically overestimates the annual contribution. However, this study is attempting to determine whether or not there is a risk that Lucas County would trigger non-attainment under the newly proposed NAAQS for Sulfur Dioxide, which is determined on an hourly basis, not an annual mass loading. In reality a steamer may not be in port on those days when the meteorological conditions are at their “worst” or most likely to create low dispersion. Additionally, a steamer may be in port when one or more of the larger sources are not running to capacity or possibly in an outage situation. The Port of Toledo sees the most traffic in the late summer and early fall when grains are being shipped with the highest frequency (Toledo-Lucas County Port Authority, 2010). The fall is when most refineries and power plants take their planned maintenance outages. However, if the study demonstrates that a sufficiently high risk of non-attainment exists, then local air quality officials can work with the operators of these vessels to develop correction or avoidance strategies to minimize their impact. The map below shows the likely ports on the Maumee River and also where the TORCO docks are located. The red dots along the river represent port facilities, which demonstrate the number of sites where a freighter could dock.

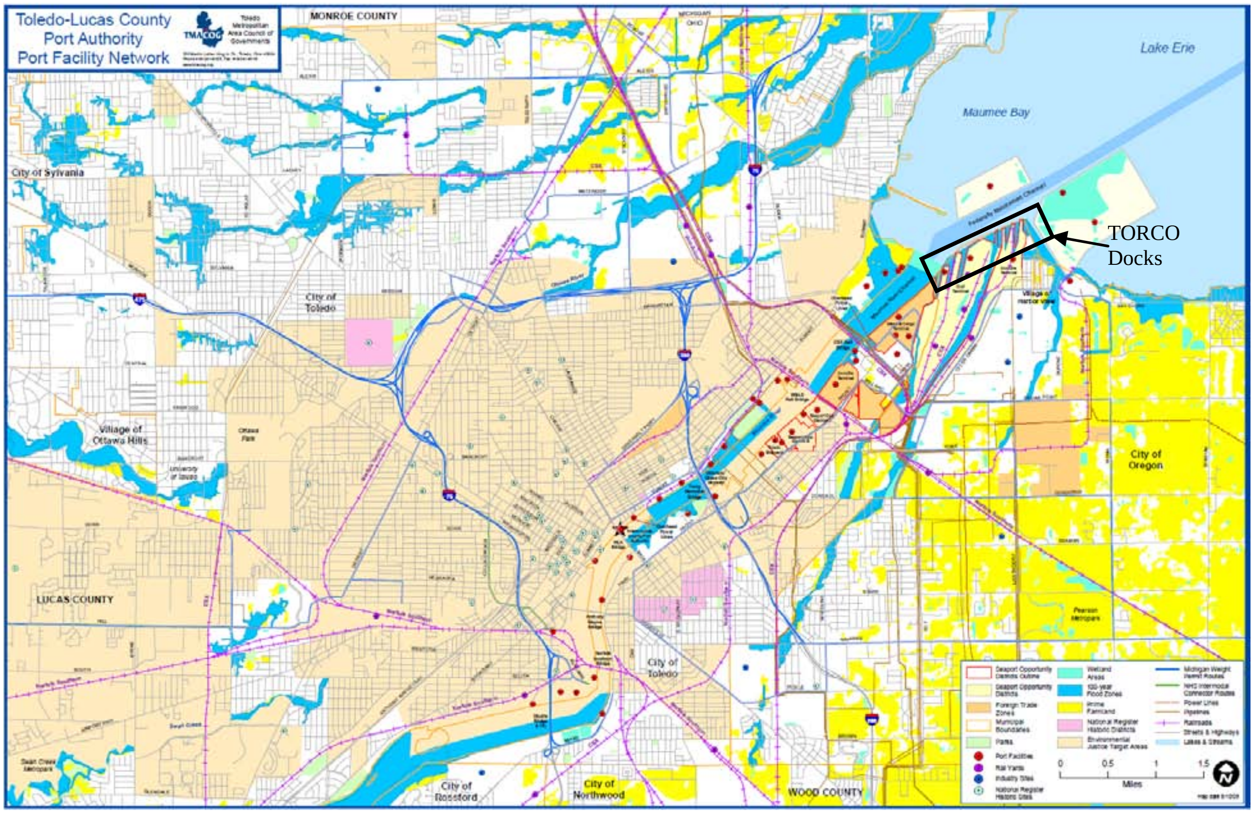


Figure 2.1. Location of TORCO Dock Facilities (Toledo-Lucas County Port Authority, 2010)

The sources mentioned represent a significant concentration of sulfur dioxide emissions in Lucas County Ohio. Their proximity to each other would seem to exacerbate the risk of inadequate dispersion to avoid. The map below graphically demonstrates where these sources are located in the Lucas County/Greater Toledo Area.

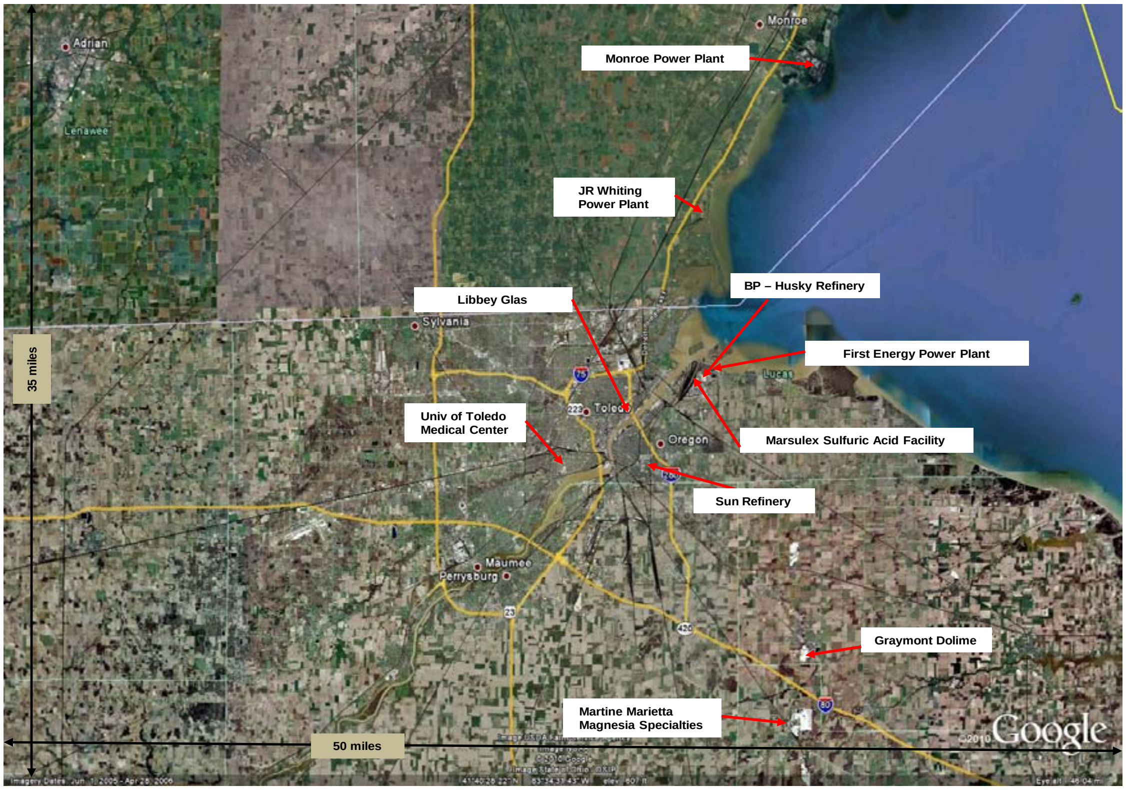


Figure 2. Map of Source Facilities (Google, 2010)

Dispersion Modeling

In order to determine and/or estimate ambient air quality concentrations of a pollutant, only two methods are available: ambient air monitoring and dispersion modeling.

Individual source contributions are generally well known by various publicly available databases such as the Acid Rain Program, Title V annual emission reports, national emission inventory, etc. However, simply summing the source contributions does not necessarily give a solid estimate of whether or not a geographical area will meet the NAAQS. Meteorological factors and terrain dramatically impact how pollutants disperse from the source and ultimately how they impact the ambient air concentration (Turner & Schulze, 2007). Intuitively, a location with many sources of a pollutant has a higher risk of non-attainment that pollutant than one with fewer, however, knowledge of source contributions alone are insufficient to determine the ambient air concentration.

Ambient air quality monitoring is and has been the most accurate method of determining concentrations in the atmosphere; however, monitoring is a “lagging” indicator, meaning time must elapse in order to determine the impact of source contributions. In the case of the sulfur dioxide standard, it is based on the three year average of the 99th percentile of annual distribution of daily maximum 1-hour average concentrations (USEPA, 2010a). Therefore a minimum of three years of monitoring data would be required. During this lag time from the date of the regulatory proposal to the first available data report, critical time could be lost by regulators, local planners, and sources which could be used to implement measures to increase a locale’s chances of reaching attainment. Although not of consequence to this study, it is also possible to use monitoring for the prediction of ambient air quality impacts of a source yet to be built (in the case of a new proposed major stationary source or major modification) (Turner & Schulze, 2007).

Additionally, the deployment of a monitoring network robust enough to measure ambient air quality in any one given location is very expensive to install and operate. This cost is multiplied by the need to measure hundreds of locations (Turner & Schulze, 2007). If a monitoring network is already in place and measuring the pollutant concentration per the method dictated in the NAAQS, historical data can be utilized to predict future attainment as long as the source impacts are static (no growth or contraction).

An example would be the ozone monitoring network in our country In the case of the Sulfur Dioxide monitoring network, it is neither robust enough in terms of the number and location of air quality monitors to predict on a large scale the attainment status in much of the United States (USEPA, 2009a). This is primarily due to the fact that the sulfur dioxide standard has been untouched since its original promulgation forty years ago. Since all but seven of the 3,140 counties in this country are in attainment status with the current sulfur dioxide NAAQs, many state and local air quality managers have discontinued monitoring for sulfur dioxide for some time as a cost mitigation measure as there was little risk for lapsing into non-attainment.

This dropoff in sulfur dioxide monitoring locations and data has been especially rapid in the last 10 years as ozone and particulate standards have received much of the regulatory emphasis. With limited budgets, state and local air quality planners and managers have eliminated many sulfur dioxide monitoring sites as they expand the ozone and particulate monitoring network (USEPA, 2009a).

As mentioned earlier, the Toledo MSA does not have a sulfur dioxide monitor. The three closest monitors are 70-100 miles away in the Detroit, MI; Cleveland, OH, and Lima, OH areas. Due to distance, these monitors provide limited useful data for Toledo (USEPA, 2002). Given this information, a method of estimating or predicting ambient air quality concentrations is needed.

Building off of military dispersion models dating back to the use of chemical weapons in World War I and radionuclide diffusion research following the advent of atomic weapons and nuclear power plants, atmospheric scientists have developed various iterations of mathematical models that can, with a reasonable amount of accuracy, predict the dispersion of chemicals in the atmosphere (Turner & Schulze, 2007). Models have been created to simulate mobile source impact, toxic releases, odor, chronic risk assessment as well as dispersion from stationary sources.

There are two types of stationary source dispersion models: Eulerian and Langrangian. Eulerian models calculate the plume concentrations as a discrete point or receptor on an underlying surface. Lagrangian models consider a point in the moving plume and calculate concentration. Lagrangian models are also called “puff models” (Turner & Schulze, 2007).

Historically, the USEPA has utilized Eulerian models, such as ISC and AERMOD. Simplicity and widespread understanding are the primary reasons for that choice. Lagrangian models such as CALPUFF do have some advantages over Eulerian models, primarily in their accuracy in predicting impacts at a greater distance, but are more complex, perform more calculations, and subsequently, take a higher degree of computing power (Caputo, Giménez, & Schlamp, 2003).

Chapter 3, Methods and Materials

Introduction

The goal of this study is the use of the AERMOD model and analyze source characterization data to assess the risk of non-attainment for the Toledo, Ohio Core Based Statistical Area by analyzing the output plots of the modeled domain.

The AERMOD model is an open-ware FORTRAN executable tool provided for free by the EPA. Without significant prior experience in using FORTRAN command line programs, it is very cumbersome to use for the average air quality / atmospheric scientist (Turner & Schulze, 2007). Several third party companies have developed a graphical user interface (GUI), very similar to a Windows® program, which allows for a more intuitive use of the model. After investigating the two more well known providers, Breeze Software's version of AERMOD was selected. Breeze Software, a division of Trinity Consultants, also has several training and implementation courses available for the use of this software which were utilized (Caputo et al., 2003). A copyright release from Breeze to use their program and its outputs in this research project and also to publish these results is included in Appendix A. Breeze incorporates terrain and meteorological pre-processors into their program as well as a post file analysis program called 3D-Analyst which allows for creation of various dispersion maps and also the ability to download the result data to Google Earth (Trinity Consultants, 2010c).

The AERMOD model is not a long range model, having the best accuracy with sources that are less than 50 KM from any given point (approximately 30 miles) (Turner & Schulze, 2007). Therefore only those sources within 50 km/30Mi of Toledo and Oregon were considered. To determine which sources of sulfur dioxide meet these criteria, the EPA *AirData* database tool was used. This web page allows a user to query sources at a state level based on pollutant emitted. The data was from calendar year 2002, while the emission numbers from this data is too dated for use in the model, it does provide a screening tool to quickly list those sources of sulfur dioxide (USEPA, 2002). The threshold selected for inclusion in the model was the definition of a major source under the Title V permit program. For criteria pollutants such as sulfur dioxide, that is 100 tons per year on a facility wide basis (Martineau & Novello, 2004).

To successfully utilize the BREEZE AERMOD program, the model inputs must be properly developed. This includes the following tasks:

1.) Develop emission source characterization data
2.) Acquire and pre-process terrain data
3.) Acquire and pre-process meteorological (met) data

Once these steps are completed and the resultant data and files are loaded into BREEZE, the AERMOD model can be executed. Following successful execution, post and plot files are generated. These files are analyzed in BREEZE's 3D Analyst program and are mapped in Google

Earth for visual examination of the ambient air concentration gradient (Trinity Consultants, 2010b).

Purpose of Model Runs

In designing the modeling protocol, several model iterations were run. Each model run provided data designed to address specific questions. They are described in the following sections:

1.) Screening/Scoping Run: The initial iteration of the model included all sources discussed and their most recent publicly available emission characterization data. The resultant plot answered the following questions:

- Did the Monroe Power Plant have a significant enough impact on the Toledo CBSA, essentially did it "cause or contribute" to non-attainment or maintenance problems? The USEPA is currently using 1% of the NAAQS as the "significance level" in the Clean Air Transport Rule (US EPA, 2010c) for PM 2.5 and Ozone. That same guideline was used in this study. Therefore, if the Monroe Power Plant output files demonstrated an impact above 7.5 ppb in the Toledo CBSA, it would be included in the Base Case.
- Was there any significant concentration of SO_2 near the Waterville, OH location of Johns Manville? If so, re-evaluate the decision to omit that source.

- Is the geographical extent of the modeling domain sufficient to determine non-attainment risk?

2.) Base Case: The base case includes those sources in or immediately adjacent to the Toledo CBSA. Base Case also included the most recent 5 years of met data available. The post and plot file outcomes of these model runs allows for an analysis of the risk of non-attainment for the Toledo CBSA based on publicly available data as of January 1, 2011.

3.) Year 2015 "on the books" controls: If the base case demonstrates risk of non-attainment in the Toledo CBSA, each site will be examined individually and determine, through publicly available means, if there are any "on the books" controls yet to be installed. "On the books" controls is defined in this study to mean an add on pollution control required by a regulatory action and is yet to be built or is under construction such that significant capital has been invested. Such actions include consent decrees, new regulatory programs, or instances where a firm contract has been signed and construction has commenced. Since years (five or more) can elapse between the issuing of a contract and tie-in of a control system on a large facility such as a power plant, a county can accumulate enough monitoring data to push it into non-attainment before said control system can have an effect. Once in non-attainment, the regulatory hurdle is raised for demonstrating compliance with the standard, so even in the long run if the results are still the same, it is better to avoid non-attainment if possible. If the Toledo CBSA does present significant risk of non-attainment, and this iteration demonstrates that risk is significantly mitigated, then accelerating the installation of these controls is a good idea for the SIP.

4.) Year 2015 "anticipated" + "on the books" controls: In addition to model run #3, the potential effect of two major regulatory initiatives involving the power plants will be analyzed for impacts to the sources. Since those facilities are the three largest contributors of sulfur dioxide, regulatory initiatives aimed at those facilities will have a more significant final impact (Vallero, 2008).

There are two such initiatives currently in varying stages of implementation by the EPA. The first is the Clean Air Transport Rule or CATR. It is in the proposed stage and will require reductions beyond the Clean Air Interstate Rule in both sulfur dioxide and nitrous oxides to address long range transport of precursors to fine particulate (PM2.5) and ozone. CATR is a cap and trade program, so controls are not required on each and every facility as fleet averaging and allowance purchases are possible to allow larger units to over-comply and smaller units where the cost to control is higher, to continue with a lower level of control (US EPA, 2010c).

The second potential rule is the Electric Generating Rule Maximum Achievable Control Technology Standard (EGU MACT). This rule has yet to be proposed, but the EPA is under court order to propose it by March and finalize it by November of 2011. The rule will not target sulfur dioxide directly, but rather the suite of Hazardous Air Pollutants or "HAPS". A subset of these HAPs is acid gases including sulfuric acid mists and hydrogen chloride. These pollutants are controlled in the exact same manner as sulfur dioxide, with the use of wet or dry scrubbers (US EPA, 2010a).

The biggest impact of this rule is, unlike CATR, is that compliance with a MACT standard is required on a unit-by-unit basis. Therefore each of the power plants would be required to be "fully scrubbed" (Belden, 2001). Without a proposed rule, the level of control cannot be calculated, however for the purposes of this study, 80% limitation will be used for the power plants not already controlled by model run #3. This represents the low end of control efficiency for modern scrubbing equipment and therefore should provide a conservative estimate (Davis, Buonicore, & et al, 2000).

Based on the scoping run, it was decided to eliminate the Johns Manville site from the initial round of modeling. This site is located 17 miles away from the center of the Oregon Industrial Area in addition, this site barely qualifies as a major source, permitted for 113 tons per year. Recent emission inventories show that the site has been emitting somewhat less than 100 tons per year on average. In comparison to the coal fired power plants in the study emitting 7-10K tons per year, the effect on the model output is therefore minimal. The distance, while acceptable for use in AERMOD, requires the expansion of the input maps in the Graphical User Interface of BREEZE AERMOD to the point where the zooming for accuracy becomes burdensome. Coupled with minimal publically available information on the source, it was assumed to be assimilated into background with the mobile sources and small stationary sources and thus a part of the sensitivity analysis.

Development of Emission Characterization Data for Model

The Breeze AERMOD program requires specific data to properly calculate atmospheric dispersion and estimate ambient air concentrations. For the model runs in this study, the following inputs were needed for each source:

1.) Latitude/Longitude in Universal Trans Mercator (UTM) format
2.) Base elevation in meters above sea level
3.) Emission rate in grams per second
4.) Stack height in meters
5.) Stack temperature in Kelvin
6.) Stack gas velocity in meters per second
7.) Stack diameter in meters

This emissions data for use as inputs into the model were all obtained using publicly available sources. Electric utility steam generating units (EUSGU's) must report emissions as well as other monitoring data quarterly to the Clean Air Market's Division (CAMD) of the EPA on a quarterly basis. CAMD makes this data available on its "Data and Maps" web page. This searchable database tool allows any user to query data such as mass emissions, load, controls, monitoring, location, etc… It is updated each day with data received the day before. Current year data and previous year data in the first 6 months of the following year is considered “preliminary” until it passes certain quality assurance tests. This tool is as close to real time data as is possible, particularly when considering it is publicly available.

The mass emissions were used from this database for the JR Whiting power plant, Bayshore Power Plant and the Monroe Power Plant. Mass emissions were converted to an emission rate using another EPA publicly available source, the National Emission Inventory. Unlike the CAMD database, this is only updated every 3 years on average, the last publicly available inventory accessible on 1/1/2011 (the cutoff for this project) was for 2005 . However, this database includes all necessary data needed for modeling including emission rate, stack height, stack coordinates, stack temperature, and mass flow rate. The entire inventory is 1.3 GB and includes all permitted sources of criteria pollutants in the USA and its territories.

This data was far too cumbersome to use for this study, instead, the database was downloaded in Microsoft Access and sorted for Ohio and Michigan. Then, it was again sorted for Lucas, Ottawa, and Sandusky counties in Ohio and Monroe County in Michigan. All other sources were deleted *en masse*. Then, the sources for this study were located in the much smaller data set and copied to Microsoft Excel. Once in Excel, all data for criteria pollutants other than Sulfur Dioxide were deleted. Some sources, such as the oil refineries, had hundreds of point sources – many with *de minimis* sulfur dioxide emissions, representing the myriad of processes within the refinery. To determine which process units to include at the facilities, only those processes within a source that emit more than 10 tons per year in the facility were used. For example, at the Sunoco Refinery, only two process units emit more than 10 tons per year of sulfur dioxide but the site contained dozens of much smaller process units which emitted lesser amounts, some under 1 ton per year. These sites are unlikely to impact anything beyond the fence line and therefore to prevent the model from becoming overly complex without any meaningful benefit, they were omitted (Turner & Schulze, 2007).

What was left were the source facilities and their respective process units which account for the significant sulfur dioxide emissions in the study area. For the three coal fired power plants, the mass emissions from the CAMD Database is compared to the NEI mass emissions, if the two data sources differ dramatically, then the more recent CAMD Data from the EPA Data and Maps is used. The stack data was obtained from the NEI. For the other sites, the 2005 data was used verbatim, except where noted that more current data exists, such as a Permit to Install new equipment (e.g. Sunoco Refinery). The Table 3-1 lists these inputs for each facility and source at the facility if more than one exists (e.g. each boiler at a power plant). The detailed discussions and calculations follow the table for each site except the composite marine freighter which is discussed separately.

Table 3

Model Inputs - Screening and Base Case

Source Name	Unit / Process Name	UTM Zone	UTM Northing	UTM Easting	Base Elevation (m)	Emission Rate (gr/sec)
Bayshore Power Plant	Combined Stack 1	17	297122.9	4618514.64	176	322.13
Source Name	Unit / Process Name	UTM Zone	UTM Northing	UTM Easting	Base Elevation (m)	Emission Rate (gr/sec)
Bayshore Power Plant	Boiler 6	17	297049.31	4618412.1	176	76.74
Whiting Power Plant	Boiler 1	17	296539.55	4629573.27	175	105
Whiting Power Plant	Boiler 2	17	296539.55	4629573.27	175	105
Whiting Power Plant	Boiler 3	17	296539.55	4629573.27	175	105
Monroe Power Plant	Unit 1 & 2 Combined Stack	17	305506.75	4640346.5	175	1500.89
Monroe Power Plant	Unit 3 & 4 Combined Stack	17	305371.88	4640211.7	175	32.3
UT Medical College	Combined Stack	17	282957.83	4610861.98	187	6.12
Marsulex	A plant	17	295412.22	4617328.97	178	10.57
Marsulex	B plant	17	295463.76	4617328.97	178	5.33
Libbey Glass	P003 "B" Furnace	17	290530.90	4616240.77	182	1.64
Libbey Glass	P005 "D" Furnace	17	290488.29	4616246.44	182	1.41
Libbey Glass	P006 "E" Furnace	17	290492.48	4616239.25	182	0.79
Libbey Glass	P007 "G" Furnace	17	290433.50	4616291.9	182	1.19
Libbey Glass	P022 "F" Furnace	17	290500.87	4616233.17	182	1.81
BP Husky Refinery	FCCU	17	295745.99	4616993.3	178	24.64
BP Husky Refinery	SRU 1	17	295467.47	4617094.3	178	1.03
BP Husky Refinery	SRU 2 & 3	17	295472.60	4617015.8	178	0.29
Sun Oil Co	FCCU	17	291583.48	4612104.81	184	39.8153

Refinery	WGS					
Sun Oil Co Refinery	P012 SRU	17	291337.70	4612022.39	185	29.08
Graymont Dolime	Comb Kiln Stack	17	303949.07	4598122.4	189	23.23
Martin Marietta	P010,13, 14	17	302382.9	4592561.1	198	12.43
Martin Marietta	P015 Lime Kiln	17	302350.5	4593343.98	192	16.16
Martin Marietta	P019 Lime Kiln	17	302411.88	4593343.98	192	28.57
Source Name	Unit / Process Name	Stack Height (m)	Stack Temp (K)	Stack Gas Velocity (m/s)	Stack Diameter (meters)	Stack Flow (m3/sec)
Bayshore Power Plant	Combined Stack 1	158.19	340		7.01	954.75
Source Name	Unit / Process Name	Stack Height (m)	Stack Temp (K)	Stack Gas Velocity (m/s)	Stack Diameter (meters)	Stack Flow (m3/sec)
Bayshore Power Plant	Boiler 6	91.44	423.71		3.65	259.10
Whiting Power Plant	Boiler 1	90	414		3.51	174.15
Whiting Power Plant	Boiler 2	90	414		3.51	174.15
Whiting Power Plant	Boiler 3	90	414		3.51	174.15
Monroe Power Plant	Unit 1 & 2 Combined Stack	245	405		8.53	2232
Monroe Power Plant	Unit 3 & 4 Combined Stack	176	330		9.14	2232
UT Medical College	Combined Stack	45.72	394		1.22	24.72
Marsulex	A plant	36.57	349.82		1.20	13.922
Marsulex	B plant	36.57	349.82		1.20	7.787
Libbey Glass	P003 "B" Furnace	32.31	547.0		1.22	6.1
Libbey Glass	P005 "D" Furnace	18.29	505		0.76	5.46
Libbey Glass	P006 "E" Furnace	18.29	505		0.76	4.72
Libbey Glass	P007 "G" Furnace	32.31	547.0		1.76	12.32
Libbey Glass	P022 "F" Furnace	18.29	505		0.76	4.72
BP Husky Refinery	FCCU	76.2	480		3.35	117.99
BP Husky Refinery	SRU 1	69.49	810.93		1.07	15.06
BP Husky Refinery	SRU 2 & 3	53.34	922.04		1.52	30.58
Sun Oil Co	FCCU	76.2	325	20	3.81	

Refinery	WGS					
Sun Oil Co Refinery	P012 SRU	45.72	779.82		1.09	82.59
Graymont Dolime	Comb Kiln Stack	45.72	298.15		1.52	23.05
Martin Marietta	P010,13, 14	15.54	449.82		0.61	10.85
Martin Marietta	P015 Lime Kiln	28.96	616.48		1.59	34.64
Martin Marietta	P019 Lime Kiln	28.96	449.82		2.19	58.99

Source Specific Emission Characterization Data and Calculations

Bayshore Power Plant.

The Bayshore Power Plant was characterized by using the EPA's Data and Maps report tool, data from the 2005 National Emission Inventory, and the facility Title V Operating Permit. Both EPA sources are publicly available on its website and the Title V Operating Permit is available on the Ohio EPA website. To obtain the location coordinates, the address of the facility was obtained from the operating permit and entered into Google Earth. For base elevation, the cursor location was placed at the bottom of the stack, taking care to account for parallax and shadowing. The elevation was then copied into the table. These two techniques were repeated for each source. Stack heights were copied directly from the most 2005 National Emission Inventory and converted to meters.

In the case of Bayshore Power Plant, all of the boilers except B006, the petcoke fired circulating fluidized bed boiler, were combined into one stack (Ohio Environmental Protection Agency, 2009c). For Bayshore

Power Plant, that means that it will have two model objects, the combined stack exhausting three boilers and the stack for B006. For the combined stack emission rate, the mass emissions from each unit in the combined stack was queried in the EPA Data and Maps tool and summed. This mass was then divided by the hours of operation to obtain a “pounds per hour” rate which was subsequently converted to grams per second as required by the BREEZE AERMOD model. Since operations vary with outage schedules, maintenance, and other factors, the most accurate way to reflect the emission rate is by looking across the most recent 3-5 years. With Bayshore, this was evident as 2009 was approximately 30% lower emissions than previous years. One of boilers was operated less than 3000 hours, indicating an operational anomaly. (US EPA, 2010b) Therefore, data was used from previous years where the variation from year to year was minimal. See Appendix E, Calculation 1 for detail.

No boiler runs for 8760 hours per year and both the NEI and the CAMD Data and Maps does list hours of operation, however, in a combined stack scenario, in all likelihood one of the three units are operational and exhausting gases. Since the average is across all units for the entire year, the 8760 is used. Stack height, temperature, diameter, and flow rate were all taken directly from the 2005 NEI and converted into the appropriate SI units. For the B006 process unit, the NEI data was converted into the appropriate SI units and used without any further modification. Stack velocity, even though its listed as an input, is only used if the stack diameter and mass flow rate are not available. In all cases except for the Sunoco Fluid Catalytic Cracking Unit (FCCU) Wet Gas Scrubber (WGS), the velocity is NOT used.

J. R. Whiting Power Plant.

The coordinates, base elevation, and stack height, temperature, diameter, and mass flow were obtained in exactly the same manner as with the Bayshore Power Plant.

The J R Whiting Power Plant does differ somewhat from the Bayshore Facility in that each boiler exhausts through its own dedicated stack (Michigan Department of Environmental Quality, 2006). The Whiting facility's boilers historically have very similar emissions across all three units, varying as little as 1% in some years. Additionally, the highest emitting boiler does change based mainly on operational hours (US EPA, 2010b). That is expected to continue through the foreseeable future. Therefore, the highest emission rate of the three boilers was used across all three units. This technique is justified in that it represents a conservative estimate of future emissions since the variation in Whiting's past operations appear to be random based on dispatch and maintenance outages (US EPA, 2010b).

Monroe Power Plant.

Monroe Power Plant utilizes a combined stack for Units 1 and 2. Units 3 and 4 are vented through individual flues in a single stack (US EPA, 2010b). For the purposes of the study, it was be treated as a single discharge point given the proximity of the flues to each other. This simplifies the model and requires fewer computations for completion without materially impacting model accuracy or precision. The coordinates and base elevation for both stacks were obtained in the same manner as the previous sources. Stack height, temperature, diameter, and mass flow for the Units 1 and 2 stack were taken directly from the 2005 NEI. The masses from each unit were combined with the listed exit gas flow rate to determine a combined emission rate in the same manner that was used for Bayshore Power Plant. Significant differences exist between the 2005 NEI data and the USEPA CAMD Data and Maps tool, therefore 2009 data from the Data and Maps is used to determine emission rate. See Appendix E, Calculation 2 for detail.

Properly characterizing the emissions from Units 3 and 4, where a wet flue gas desulphurization unit has recently commenced operation, required extrapolation steps beyond what was performed for the other coal power plants. Looking at the EPA CAMD Data and Maps for 2009, the emissions are still in the 25,000 tons per year range, except for Unit 4, where it is 10,000 tons. The operating times are all similar, so it appears that the Unit 4 scrubber was started some time later in 2009, but is still not fully reflected in the emission data (US EPA, 2010b). The annual sulfur dioxide data is considered "preliminary" until year end data quality assurance review are performed early in the following year. Therefore, the use of 2010 data does present risks that it could be amended prior to the quality assurance finalization (US EPA, 2010b). However, use of the 2005 NEI Data or the 2009 CAMD Data would radically overestimate the emissions from these two extremely large process units by several orders of magnitude, introducing a much larger error than would be by the use of preliminary CAMD Data. Therefore, the 2010 data was used for the calculation of the emission rate, see Appendix E, Calculation 3 for detail. The stack height and diameter were taken directly from the Title V Renewable Operating Permit, which was recently renewed in 2009. The new stacks for the scrubbers are specifically described in the renewable operating permit, giving the height and diameter (Michigan Department of Environmental Quality, 2009). What could not be located in any publicly available sources, were the exit gas temperature and stack flow rate for units 3 and 4. For the purposes of this study, stack gas flow rate was held the same as prior to the tie in of the scrubber. The units rating as not changed, meaning that the same/similar coal throughput is likely to exist. The same amount of stoichiometric air would be required to support good combustion as the modifications are to the exit gas pathway, not the boiler or fuel supply. However, the gas pathway has been lengthened and more "obstructions" in the form of they control equipment will increase pressure drop in the system. Therefore new fans are likely to be installed to overcome the pressure drop and may change the exit gas mass flow rate to some extent (Davis et al., 2000). For the purposes of this screening study, that change is deemed negligible. As for stack gas temperature, literature was consulted to determine an average or general exit gas temperature from a wet scrubber. The sources of literature generally gave a range of temperatures, therefore the midpoint was utilized (Davis et al., 2000).

The balance of the facilities are not electric generating units and thus the EPA CAMD Data and Maps tool cannot be used in determining emission rate.

University of Toledo Medical College.

In consulting the Title V Operating Permit and the 2005 NEI, the sulfur dioxide emitting process units exhaust through a common stack. Therefore the 2005 NEI data was used without alteration, only converting to the required metric units (Ohio Environmental Protection Agency, 2009d; USEPA, 2005a). The coordinate and base elevation data was obtained in the same manner as the previous sources.

Marsulex.

Based on the site’s Title V Renewable Operating Permit, the source's two sulfur dioxide emitting process units each exhaust through an individual stack (Ohio Environmental Protection Agency, 2010b). Based on Ohio EPA's air permit inventory, there have been no PTI's issued that would indicate a change from the last Title V permit or from the data available in the 2005 NEI (Ohio Environmental Protection Agency, 2010b). However, a consent decree does exist requiring future installation of control equipment.

As discussed in the modeling protocol section, this data will be included in the 2015 "on the books" control model run if required (Guzman, Lang, & Edwards, William J. et al..., 2009). Therefore the 2005 NEI data will be used for the emission rates and stack characteristics following conversion to the required metric units. The location coordinates and stack base elevation were obtained in the same manner as the previous sources.

Libbey Glass.

The Libbey Glass facility has over 117 entries into the 2005 NEI, therefore the narrowing criteria discussed earlier was of increased importance at this facility (USEPA, 2010b). All entries consisting of criteria pollutants other than sulfur dioxide were deleted. In addition, any process unit with an annual emission mass of less than 10 tons was omitted. What remained was five process units listed as "furnaces" designated "B", "D", "E", "G", and "F" in the Operating Permit exhausting through individual stacks (OhioEnvironmental Protection Agency, 2008). No active or recent permits to install existed which would indicate any process change to these source that have been implemented since the last NEI. There were no consent decrees or other sources of data available to indicate that the 2005 NEI was outdated, therefore the emission rate and stack characterization from the inventory was used without modification following conversion to the appropriate metric units. As with all previous sources, determination of the coordinates and base elevation utilized Google Earth.

BP Husky.

Refineries present both point and diffuse "area" sources of oxidized sulfur compounds. Additionally, a refinery by its nature possesses many process units that emit various criteria and hazardous air pollutants (Jones & Pujado, 2008). This is reflected by both refineries in this study, each possessing nearly 500 separate entries into the 2005 NEI. The narrowing criteria were applied to both to allow for a more manageable modeling exercise. For the BP-Husky Refinery, that left three emission points listed in the 2005 NEI, P007, P009, and P037 (USEPA, 2005a). According to the Renewable Operating Permit, those designations correspond with the Fluid Catalytic Cracking Unit (FCCU), #1 Sulfur Recovery Unit (SRU), and the #2/#3 SRU respectively (Ohio Environmental Protection Agency, 2009a).

No permits to install could be located which would indicate any significant changes in these process units or emission points from the 2005 NEI Data, additionally, no consent decrees or enforcement/compliance orders could be located indicating any action which would affect the emissions from these units. Therefore, the 2005 NEI Data will be used to for the emission characterization and stack parameters. The coordinate and stack base elevation data of each emission point was obtained in the same manner as previous sources.

Sun Oil Company (SUNOCO) Refinery.

The SUNOCO Refinery performed a major modification to its operations following a lengthy turnaround in the fall of 2009. During this time several major sources of sulfur dioxide were impacted. A wet gas scrubber (WGS) was installed which captured the exhaust gas from the FCCU and dramatically reduced the overall sulfur dioxide emissions from this refinery (Ohio Environmental Protection Agency, 2008). Since this project was completed in late 2009, the 2005 NEI Data is invalid and cannot be used. Also no CAMD Data and Maps tool exists for refineries; therefore an alternate method of extrapolation was needed to determine the emission profile of the new process unit.

Only a handful of WGS units exist at refineries in the US, with most being installed in the past few years (Hamon Research-Cottrell, 2010). A permit to install a WGS with modeling input data was located for a similar sized refinery in Delaware City, DE (Delaware DNREC, 2004). The FCCU capacity for the Delaware City site was listed at 87,000 barrels per day with the Sunoco Refinery at 79,000 barrels per day. However, the Delaware City location processes lower sulfur crude than the Sunoco Refinery, therefore the higher throughput is offset by the lower sulfur content (US EPA, 2008). Based on this data, the use of the Delaware City emission characterization data is an acceptable surrogate for the SUNOCO Data.

A request has been submitted to the Ohio EPA for the same data for the SUNOCO Refinery, but no information has been received. The imagery date for the SUNOCO site in Google Earth is shown to be March 1, 2006, well before construction of the WGS at the Sunoco refinery (Google Inc, 2009). In order to determine the location of the WGS Stack for coordinate entry and for base elevation, the location was approximated based on visiting the location and assessing the approximate real-life location in relationship to structures present in the 2006 image.

A second process unit emission point also was also present in addition to the FCCU WGS. Narrowing the 2005 NEI results in "P012" as meeting the criteria for use in this study (USEPA, 2005a). The Title V Operating permit indicates P012 is the Sulfur Recovery Unit. No Permit to Install or enforcement/compliance documents exist to indicate any change in the SRU since the 2005 NEI, therefore the emission characterization data and stack parameters were used from the 2005 NEI following conversion to the appropriate metric units. The stack coordinates and base location were determined in the same manner using Google Earth as the balance of the study sources.

Graymont Dolime.

The Title V Operating Permit for this location states that the three kilns are routed through the same control device for particulate matter (Ohio Environmental Protection Agency, 2010a). Additionally, the 2005 NEI indicates a combined stack for the three kilns at this source. No

Permit to Install or enforcement/compliance documents exist to indicate any change in the operations since the 2005 NEI, therefore the emission characterization data and stack parameters were used from the 2005 NEI following conversion to the appropriate metric units. The stack coordinates and base location were determined in the same manner using Google Earth as the balance of the study sources.

Martin Marietta Magnesia Specialties.

This facility has three emission points of sulfur dioxide meeting the study's narrowing criteria based on the 2005 NEI (USEPA, 2005a). The Title V Operating Permit indicates that the first emission point is a combined stack for three of the facility's kilns. Two other kilns located on site are connected to respective individual stacks (Ohio Environmental Protection Agency, 2003).

No Permit to Install or enforcement/compliance documents exist to indicate any change in the operations since the 2005 NEI, therefore the emission characterization data and stack parameters were used from the 2005 NEI following conversion to the appropriate metric units. The stack coordinates and base location were determined in the same manner using Google Earth as the balance of the study sources.

Composite Marine Freighter.

The mooring location of the Composite Marine Freighter is based on the current ore unloading area of the TORCO Docks near the mouth of the Maumee River. The coordinates were obtained by using Google Earth in the same manner as the stationary sources. Base Elevation was also obtained from Google Earth, however, the elevation was taken from several points off shore. Google Earth averages elevation based on the discrete points of reference. If a location is between those discreet points, it is averaged. To accurately record the surface elevation of Lake Erie, reference points off shore would be reflecting the actual flat surface of the Lake.

Stack height also presents an issue, as a loaded lake freighter would be sitting much lower than one unloaded prior to ballasting. As the unloading occurs, the freighter slowly rises in the water until it is completely unloaded. Then, if no return freight is to be loaded, ballast tanks are flooded for stability and the boat sinks back to a stable freeboard, but not as low as fully loaded. The vessel then sails to the next port (Bawal, 2009). Since elevation would be changing during the unloading, an "average" or estimate a freighter's stack height was used. Since this is a "composite" freighter, the stack height from used in the 2002 Commercial Marine Port [Emission] Inventory Development was used (ICF International, 2007). In order to properly characterize the emission data from the composite freighter, the emission factors from the ICF-EPA Inventory Development Document was used.

Initially, fuel consumption factors are used to determine the amount of fuel consumed by the average vessel based on the type of propulsion system. For "steamers" or steam turbines, that is 305 grams of fuel per kilowatt hour. This is known referred to as the "Brake Specific Fuel Consumption" (ICF International, 2007). The SO_2 emission factor determination is then based on the following formula:

SO_2 EF = BSFC*2*0.97753*Fuel Sulfur Fraction (Equation 3.1)

In this equation, BSFC = 305, 2 = molecular weight multiplier (SO_2 is 2 times heavier than elemental sulfur), 0.97753 = conversion factor of fuel sulfur to sulfur dioxide (represents 97.753% conversion), Fuel Sulfur Fraction = percent of sulfur in fuel in decimal form (ICF International, 2007). For the composite freighter in this study, 7700 horsepower is used, which is the rated capacity of the American Valor. The American Valor represents an "average" sized steam turbine powered freighter on the Great Lakes and also calls Toledo her home port (Bawal, 2009). 7700 horsepower converts to 5741.8 kilowatts. Therefore, the BSFC for the composite freighter is:

305 gr/kWh * 5741.8 kW = 1,751,249 g/hr at 100% load (Equation 3.2)

Fuel sulfur fraction varies depending on the type of fuel utilized. Bunker "C" fuel oil can range as high as 5% or 50,000 ppm, compared to 500 ppm for "off-road" diesel use and 15 ppm for "on-road" diesel use (USEPA, 2005b). The ICF study uses residual oil as the benchmark for steam turbine power, indicating an average of 2.7% sulfur fraction in areas outside of the West Coast of the US (ICF International, 2007). Therefore 0.027 will be used as the fuel sulfur fraction in the emission factor calculation. See Appendix E, Calculation 4 for the specific calculations.

To determine stack flow, the amount of air necessary to stoichimetrically oxidize the fuel must be determined. According to the Boiler Operators Handbook, 14.1 pounds air is required to burn 1 pound of #4 residual oil (Heselton, 2005). Slightly less is required for #6 or Bunker "C" oil. See Appendix E, Calculation 5 for the specific calculations to determine air stack flow. Since most boilers operate at approximately 12% excess air, the final stack flow used in the model will be 1.33 (from Appendix e, Calculation 5) * 1.12 = 1.49 cubic meters per second (Heselton, 2005). Literature was also consulted for stack temperature, with an average stack temperature of 533.2 common for this type of boiler operation (Heselton, 2005). The stack diameter of this composite freighter will be set at 1m. Stack configurations may vary widely, with many vessels possessing two stacks, at it is common for the turbine to be fed by two boilers, however, for modeling simplicity, a single emission point of 1m will be used (Bawal, 2009).

Meteorological Data Inputs

Once the emission characterization data was developed, the next step was to develop the model ready meteorological data inputs or “met data”. For most regulatory modeling exercises, five consecutive years of met data are used to determine the ambient air impact. While that increases results for an hourly model to nearly 45,000 data points, that method was used for this study (Turner & Schulze, 2007). For Breeze’s AERMOD program, two met data files are necessary, a surface file and a profile file (Trinity Consultants, 2010b). Surface data is developed from meteorological observations at either on-site met stations or at a nearby weather station, usually an airport. The raw surface data files are text format listings of the readings and generally include the following data:

- Date
- Time
- Station Type
- Sky Conditions
- Visibility
- Weather Type
- Dry Bulb Temp
- Wet Bulb Temp
- Dew Point Temp
- Relative Humidity
- Wind Speed
- Wind Direction
- Wind Gusts
- Station Pressure
- Pressure Tendency
- Net 3 Hr change in Pressure
- Report Type
- Precipitation

- Altimeter

(National Oceanic and Atmospheric Association, 2009).

Profile data are readings taken more regionally by weather balloons which list various readings in lower atmosphere. These are known as “radiosonde” readings. The readings are generally taken early in the morning and late in the evening when the atmospheric turbulence is at its lowest. These readings determine the planetary boundary layer or PBL. The PBL has a tremendous impact on how pollutants disperse locally and regionally (Turner & Schulze, 2007). A typical raw radiosonde file contains the following raw data:

- Temperature
- relative humidity
- atmospheric pressure
- wind

(National Oceanic and Atmospheric Association, 2009).

The raw surface files can be obtained from varying sources, many which charge a fee to obtain this data. The modeling group at the Ohio EPA was first contacted provided 5 years worth of model ready data for no charge. However, this data was over 20 years old. While acceptable to the OEPA, better data quality options do exist which were utilized. The National Oceanic and Atmospheric Association National Climatic Data Center (NCDC) sells the raw surface files for a specific station and includes any date range that the user specifies as long as the station has been in operation during that time. The raw data is then processed by AERMET into model ready data, which is the method used for this study. However, there are several different formats of the data available and only a select few are compatible with AERMET, the TD3505, full achieve format is the newer format provided by the NCDC and what was selected for this study (Trinity Consultants, 2010b). NOAA also maintains a record of upper air radiosonde files for free use on a separate website. For each year modeled, a profile and surface file are needed; therefore the same date ranges for the upper air/profile data set will be input as the surface/land based observations (Trinity Consultants, 2010b).

This raw data must be reduced into “model ready” format by a program known as a pre-processor. For AERMOD, that preprocessor is known as AERMET. Each year is processed separately to produce a .sfc and .pfl for a discrete year. These files are loaded into AERMOD and are used along with the emission data and terrain data to determine dispersion (Trinity Consultants, 2010a).

Terrain Data

The third piece of the model puzzle is the terrain data as the surrounding landforms can greatly impact the dispersion of pollutants form a source (Turner & Schulze, 2007). The AERMOD model incorporates the effects of terrain such as mountains and land use characteristics on how pollutants disperse through the modeled domain (Turner & Schulze, 2007). Raw terrain data in the form of elevation points are fed into another pre-processor called AERMAP as part of the BREEZE AERMOD Program (Trinity Consultants, 2010c). This program creates an input file used by AERMOD in calculating the ground level.

The raw terrain data used for this study was obtained from the United States Geological Survey's National Map Seamless Server. This tool allows user-defined elevation data to be downloaded in a GeoTIFF format. Resolution can be selected from 1/9 arc second to 1 arc second and the geographical area is determined by a "drag and drop" tool. Once downloaded, the raw elevation data is processed into a model ready input file (United States Geological Survey, 2010). An approximate 30 x 50 mile area was selected encompassing all the model sources as well as surrounding area.

Certain parts of southern Wood County and far western Fulton County (part of the Toledo Core Based Statistical Area) were omitted from the terrain plots to ensure model efficiency in run times and data analyzed. The larger the area selected, the larger the model output files become and the slower the model runs. If the results from the screening run demonstrate the need to encompass a larger area, a larger raw data set will be downloaded and input into AERMAP.

Model Execution

Once all input data has been collected and pre-processed, if necessary, the entry of data and execution of the model runs is an intuitive process with the BREEZE Version of the AERMOD software. In addition to the project specific data discussed in the earlier sections that requires development, there are also a few minor structural or control selections that are also require in order to obtain valid model results. These items will be briefly discussed here, but Appendix B contains the step by step screen shots of the data entry and control selections for this project.

1.) Define Projection - In this step, the UTM datum and zone are selected (Trinity Consultants, 2010c).

2.) Project Control - Here, a user defined title is entered, the AERMOD executable is selected and pollutant specific information can be selected. In addition, customizable options allowing for "flagpole" receptors, urban boundary layer effects, and multi-year files for PM10 analysis are available here, where were not used for this project (Trinity Consultants, 2010c).

3.) Import Base Map - A base map can be imported at this step. It is not required, but assists in assuring proper model object placement and interpreting results. The maps can be imported as a shape file (.shp), a drawing file (.dwg/.dwx) or in a portable document format (.pdf). For this study, a .pdf was created using Google Earth and encompassing all modeled sources and a majority of the Toledo CBSA (Trinity Consultants, 2010c).

4.) Source Data Entry - The data from Table 3.1 is entered here. There are multiple options available for data entry. The two most popular options are importing a table and manual entry using the entry tool. For this project, the manual entry method was used. As an option, sources can also be grouped. For this study, the emission units at a source facility were grouped allowing for the analysis of each source facility's contribution individually in addition to a group including all sources for the total concentration impacts (Trinity Consultants, 2010c).

5.) Receptor Generation and Data - Receptors can also be generated in multiple ways. For the screening run, the gridded receptor tool was utilized. For the following runs, a table import of receptors was used as the same receptor spacing was used for the three additional runs (Trinity Consultants, 2010c).

6.) AERMOD includes options for entering non-emitting model objects such as buildings or other structures that may impact dispersion. Additionally, a tool known as "BPIP" which analyzes building downwash effects is also available. No buildings or structures were entered into this model other than the stacks or emission points and no building downwash analysis was performed (Trinity Consultants, 2010c). This becomes important with low elevation emission points, area sources, line sources, etc... However, all of the sources in this study were combustion sources with moderate to tall stack heights making the emission points higher than most surrounding structures, minimizing downwash effects (Turner & Schulze, 2007).

Entering the structures and performing the BPIP analysis may potentially increase accuracy somewhat, but to do so would require an analysis of hundreds of buildings and other structures such as highway overpasses, water towers, storage silos, etc... in the Toledo CBSA and surrounding areas and entry into the model (Canepa, 2004). This is far beyond the scope of this project and is more suited for a single site permitting analysis versus a regional dispersion model. Such analysis would require computing resources beyond what is available for this study.

7.) Terrain Data - as discussed in the Terrain section, the pre-processor AERMAP is utilized to process raw GEOTIFF terrain files for importation into the model (Trinity Consultants, 2010c).

8.) Assignment of Meteorology - Also discussed in its respective section above.

9.) Output Options - The final step prior to execution is selecting the output options. There are a myriad of options available in the BREEZE program, but essentially, the user is selecting the aggregation and averaging periods. This study is analyzing hourly concentration, so the model is set to calculate hourly concentrations. Post and Plot files are also selected based on the source groupings and/or the entire model input.

10.) Finally, the model is executed (Trinity Consultants, 2010a).

BREEZE Provides a graphical representation of this data flow, which is very useful in following the progression of the model construction:

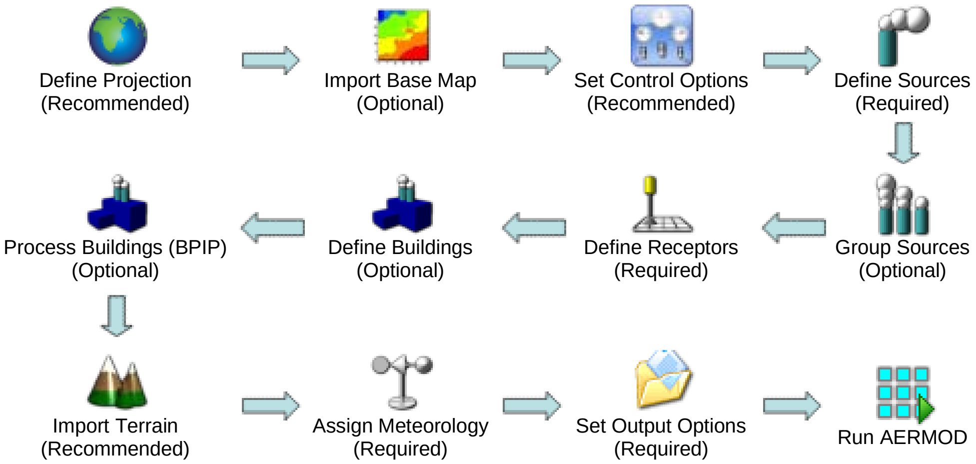


Figure 3.1. Graphical flow of model execution (Trinity Consultants, 2010c)

Analysis of results

Once model results are generated, the post and plot files are imported into BREEZE's 3D Analyst. This program contains several tools to generate visual plots of the data to determine concentration gradients as well as an export tool to enter the data into Google Earth. Additionally, raw concentration data from the receptors will be loaded into Microsoft Excel for use in determining the fourth high and performing statistical analysis of data quality. Other options available in 3D Analyst will not be utilized. These tools mainly allow for advanced graphics utilization and exportation to other formats. For this project those are not necessary (Trinity Consultants, 2009).

Chapter 4 Results

Screening Model

The screening model run was successfully completed with the 1988 met data. Due to the volume of data generated in a model run, in excess of 5000-6000 pages, the raw outputs are not included in this report. The plot of all sources demonstrates significant concentrations of sulfur dioxide near and in excess of the 75 ppb in the modeling domain:

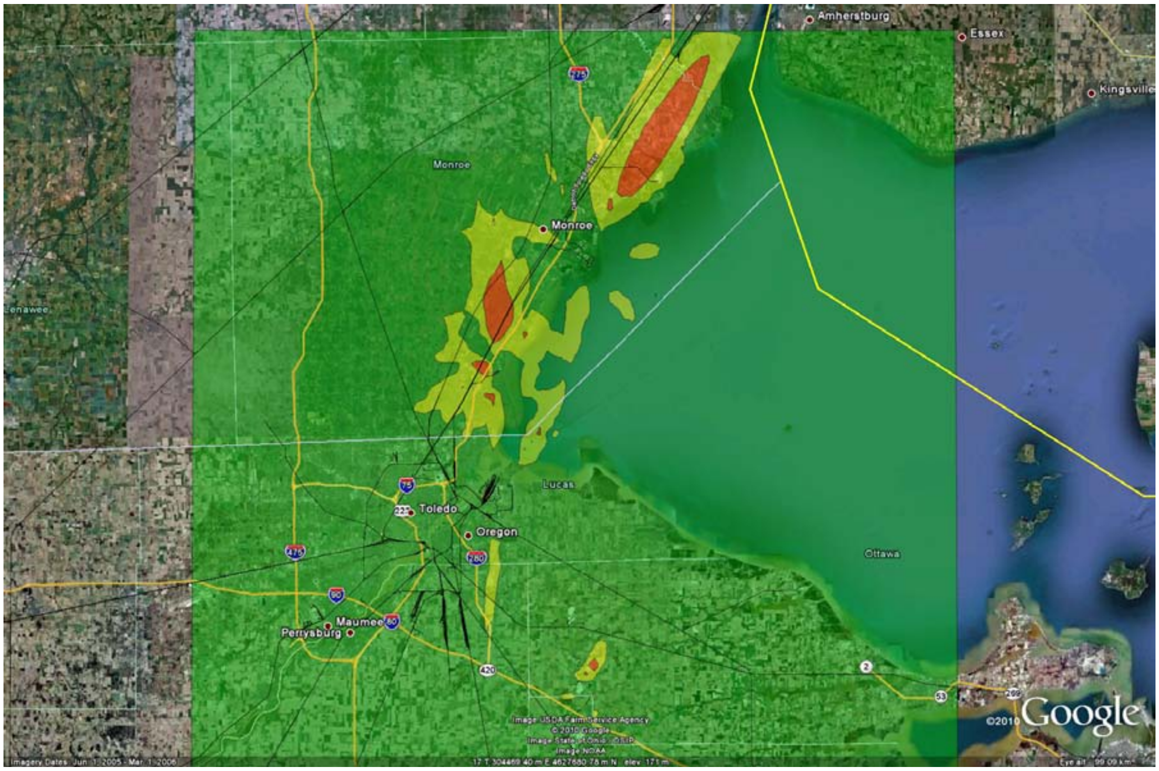


Figure 4.1 Screening model run - All sources, 1st highs (Trinity Consultants, 2010a)

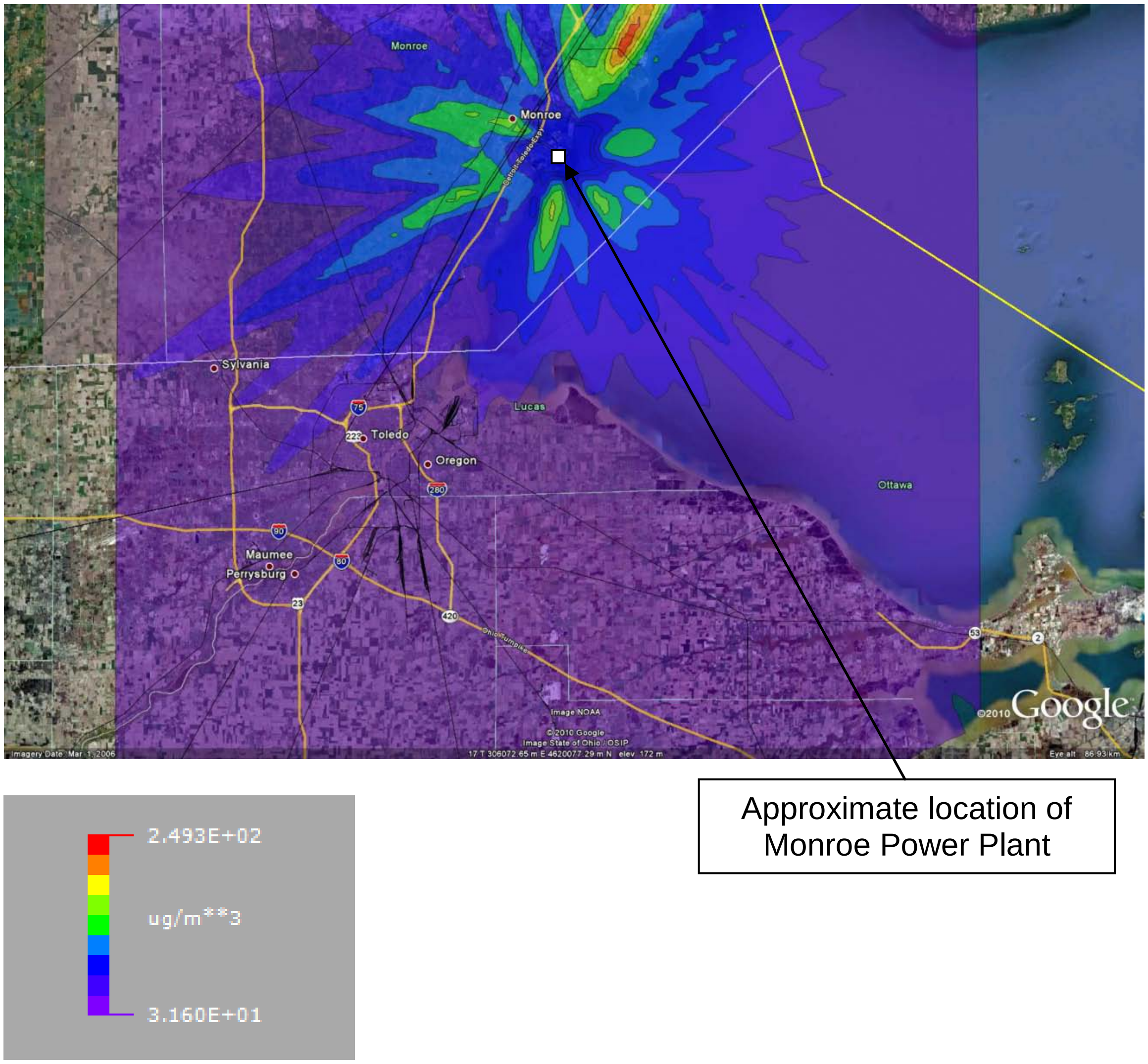
The green shaded area represents those concentrations between 12 ppb (lowest modeled concentration in the modeling domain) and 64 ppb. This range also encompasses the entire modeled domain. The yellow shaded areas represent concentrations between 65 and 85 ppb, while red shaded areas represent concentrations in excess of 86 ppb.

Since discrepancies can and do exist between monitored and modeled concentration, any receptor in the 65-85 range is deemed to be a moderate risk, however, any receptor calculated at 86 ppb or above is deemed to be a high risk, if not certainty, of attainment issues. No background sulfur dioxide was included in this study because the EPA has not yet issued guidance on how to account for background. Therefore all modeled values represent the absolute minimum values and when background is added, they will likely increase. That is why a site that is 65 ppm is still in a moderate risk and anything over 86 ppm has a near certainty of being in non-attainment. While the screening run is not designed to assess the risk, it provides a snap shot of where the model may indicate high concentrations. As detailed in Section 3, this run was designed to answer the following questions:

1. Does the Monroe Power Plant have a significant enough impact on the Toledo CBSA, essentially does it "cause or contribute" to non-attainment or maintenance problems? The USEPA is currently using 1% of the NAAQS as the "significance level" in the Clean Air Transport Rule (US EPA, 2010c) for PM 2.5 and Ozone. In keeping with that convention, I will utilize this guideline. Therefore, if the Monroe Power Plant output files demonstrate an impact above 0.75 ppb in the Toledo CBSA. it will be included in the Base Case.

2. Is there any significant concentration of SO_2 near the Waterville, OH location of Johns Manville? If so, re-evaluate the decision to omit that source.
3. Is the geographical extent of the modeling domain sufficient to determine non-attainment risk?

Isolating the Monroe Power Plant's modeled emissions, the following plot is generated:



Approximate location of Monroe Power Plant

Figure 4.2. Screening Model - Monroe Power Plant, 1st highs (Trinity Consultants, 2010a)

As shown, the output scale is shows in micrograms per cubic meter, converting to parts per billion (units of the SO_2 Standard), the minimum value reported in the geographic extent of generated receptors and terrain data yields 12.1 ppb:

ppb = (24.45 x 31.6 ug/m^3) / 64.06 grams/mol = 12.1 ppb (Equation 4.1)

In Equation 4.1, 31.6 ug/m^3 is the concentration and 65.06 represents the molecular weight of sulfur dioxide. Using the same criteria that the EPA uses in the Clean Air Transport Rule that any source in another state that contributes 1% or more to non-attainment or maintenance problems in a downwind state is deemed to have an impact, the Monroe Power Plant clearly meets this criteria as the purple covering the modeled portion of the county demonstrates receptors with at least 12.1 ppb sulfur dioxide (US EPA, 2010c). As the plot also shows the heaviest plume generally travels in a northeastern direction toward Detroit, MI, however, certain meteorological conditions do allow for the plume to impact the Toledo area. Therefore, the answer to question #1 is "yes", the Monroe Power Plant impacts attainment in the Toledo CBSA according to the 1% contribution criterion used in the Clean Air Transport Rule and thus will be considered in the base and sensitivity cases.

The second issue to clarify by the screening model is whether the Johns Manville site in Waterville, OH should be included in the base and sensitivity case model runs. Looking at a close up of the Waterville, OH and Johns Manville Plant area from Figure 4.1, with the receptors and calculated concentrations at those points, the average concentration in micrograms per cubic meter is ranges from 55 ug/m3 on the low end to as high as 100 ug/m3 in the immediate vicinity of the Johns Manville facility. This corresponds to 21.0 ppb to 38.2 ppb, approximately half of the standard. No attainment issues exist even directly on top of the plant. While Monroe was included with a lower concentration in certain areas, the total mass of SO_2 transported into the Toledo CBSA that is attributed to Monroe is significantly higher than the Johns Manville facility.

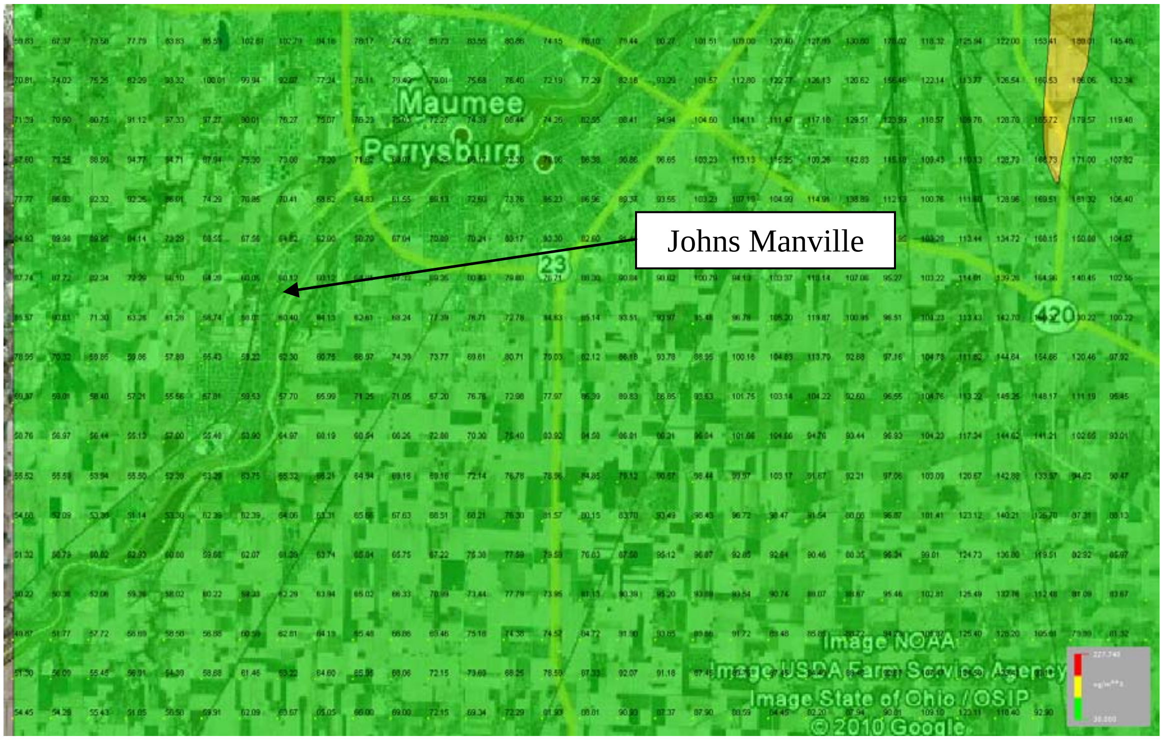


Figure 4.3. Screening Run - Waterville OH enlargement demonstrating little to no impact of Johns Manville facility (Trinity Consultants, 2010a)

It is unlikely a relatively small source (in terms of this study) with actual emissions just under 100 tons per year, could cause the ambient air concentrations to reach non-attainment levels by itself. However, could it, combine with nearby sources and cause issues? The nearest sources is

8 miles away, the University of Toledo Medical Center, and is also a relatively small source for this study, but is still approximately twice as large as Johns Manville in terms of sulfur dioxide emissions. No receptors in the nearby area between these two facilities are close to the SO_2 standard and the larger sources in the study are approximately 12 miles away. However, based on the windrose, a graphical representation summarizing the dominant wind direction, rarely is the plume from the larger sources pushed in toward Waterville and Johns Manville, indicating that Johns Manville itself would be required to cause non-attainment.

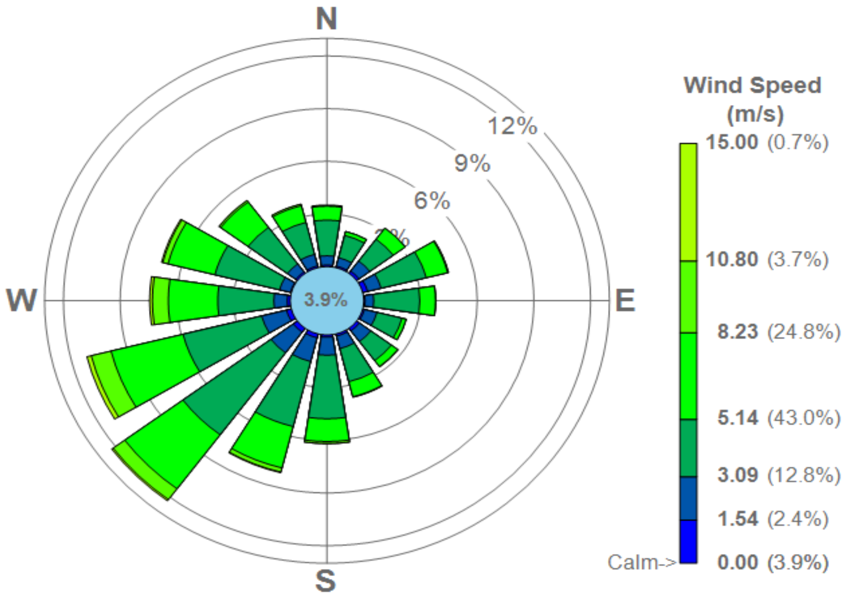


Figure 4.4. 1998 Met Data Windrose (Trinity Consultants, 2010b)

The "arms" of the windrose represent the direction the wind is coming from, and their length symbolizes the intensity of the wind speed (Turner & Schulze, 2007). Therefore, at the Toledo Express Airport, the dominant wind direction is from the southwest. Winds from the northeast occur less than 9% of the time and are generally light in nature. This does not favor high concentrations from other sources being transported to the Waterville area. Consequently as a small source, the high winds that dominate the area from the southwest would likely cause a "dilution" effect of this source's emissions. At the very least, significant depletion would likely occur before atmospheric transport could cause an interaction with the larger sources to the north and northeast or the kilns directly to the east approximately 20 miles away (Rama Krishna et al., 2005).

The conclusion from the screening model run is that the size of the Johns Manville facility and its distant location from larger sources present a very low risk of causing or contributing to non-attainment and it will not be considered in the base case and any control cases.

The final issue to address with the screening model is to determine whether or not the modeling domain is sufficient to analyze the ambient air impacts of the sources and determine if significant risk exists for non-attainment. Looking again at Figure 4.1, and the associated output data no yellow or red indications are near the edge of the modeling domain in the Toledo CBSA. North of the Monroe facility, the modeling domain cuts off a portion of the plume, however, this study is not assessing Monroe County; therefore extending the range to encompass that portion of the plume would just result in unnecessary calculations for a geographical domain out of the study scope. The green areas represent concentrations above 12 ppb as that is the lowest modeled concentration in the domain.

Areas that are un-shaded do not necessarily represent a "zero" concentration, but are outside of the processed terrain data and as such, no receptors are placed there.

The model calculates concentration at discrete points on the ground surface, called receptors. The more receptors, the more calculations and thus the longer the time required to run the model. While large scale regulatory models may look for the depletion point (zero concentration), that is outside the scope of the model (Turner & Schulze, 2007).

With the concentrations on the edge of the model in the Toledo CBSA well below the standard and also on a definitive downward trend, further expansion of the modeling domain is unnecessary. Sulfur dioxide is direct pollutant, meaning that it is measured or modeled as it is emitted, whereas ozone and a fraction of PM 2.5 are secondary pollutants, meaning they are formed from other pollutants. Therefore, we would expect that the highest concentrations of SO_2 to be in the immediate vicinity of the facility and deplete as it moves away (Vallero, 2008). Dispersion effects of high flow rates at the stack may not necessarily place the highest concentration directly over the stack, but the expectation is the highest concentration would be nearby. This also means we would not expect a detached pool of higher concentration at some far away point downwind. With secondary pollutants that require some type of photochemical or physical reaction in the atmosphere, such an event may occur, and therefore would need to look at a wider modeling domain. (Turner & Schulze, 2007). Based on the screening level outputs the modeling domain appears sufficient to adequately assess attainment in the Toledo CBSA and further expansion to encompass southern and western fringes of the CBSA where no source exists is unnecessary.

Base Case Model Run

The Base Case Model Run consists of five separate runs of the model, each for one year of met data encompassing 2006-2010. Due to computing resource limitations, the entire five years were not entered as one run. In the Base Case, the study now concentrates on determining the attainment risk based on the standard.

During the screening run, the study just took one year of met data and looked at the single first high given. However, the revised standard stipulates attainment is determined by the three year average of the 99th percentile. Also as discussed earlier the proposed revisions included consideration of both the three year average of the fourth highest and also the three year average of the 99th percentile. If, in a calendar year, at least 83% of total potential readings are statistically valid and quality assured, then the two methods yield the same results (USEPA, 2009a). Using a model, the completeness of the data set is based on the met data. All five met data years utilized (2006-2010) are complete with 8760 hours or are "filled" by NOAA prior to distribution using appropriate data substitution routines. That data is assumed to be complete and valid.

Therefore each model run will provide 8760 concentration readings, one for each hour, for each of the 5625 receptors. The average of the fourth highest over three years will be identical to the 99th percentile. The data is analyzed in two methods, first the graphical plots of the 4th highest concentration was examined. Each output plot follows for graphical representation of the data in temporal order. Since this study is based on modeling, a complete set of 8760 data points for each receptor was available, one for each hour in a year, the form is of no consequence. However, the form can have a dramatic impact once the monitoring network is deployed and monitoring begins. One can assume that with any large scale expansion of a monitoring network, maintenance and reliability issues will be prevalent which may impact monitor data availability, completeness, and quality. Therefore the final form will be of great importance to state and local air quality regulatory planners and scientists. With the use of the percentile form in the final rule, missing data can cause a locale to use higher monitored values in its comparison to the revised NAAQS.

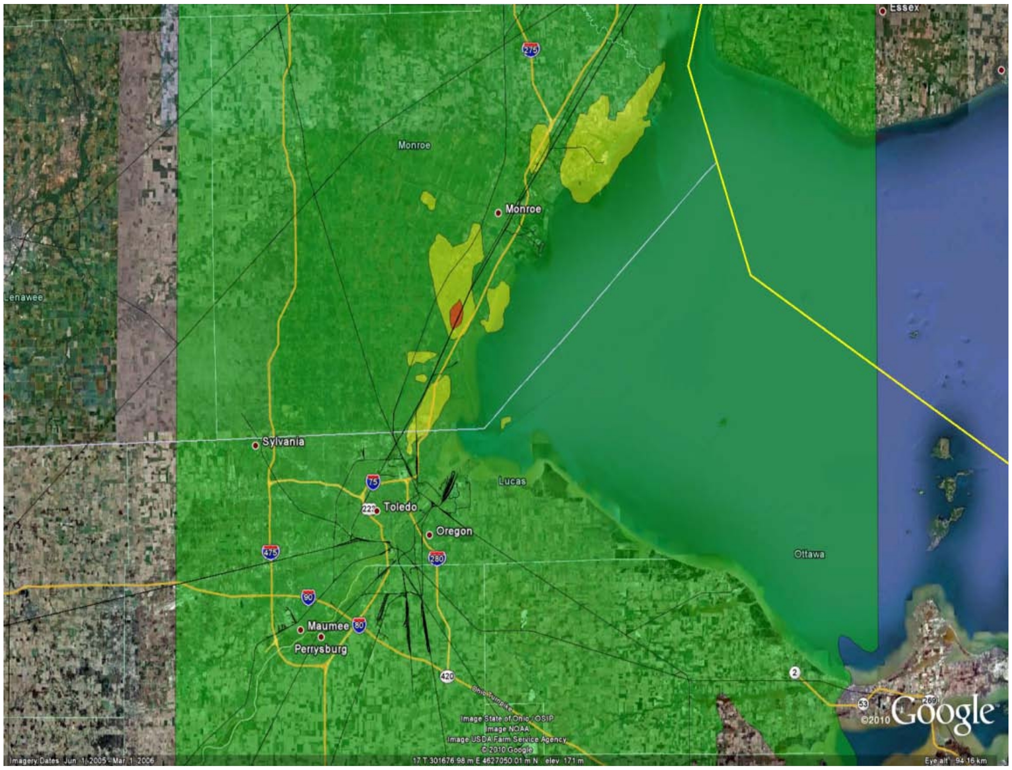


Figure 4.5a Temporal Progression of Base Case Runs Year 1 (Trinity Consultants, 2010a).

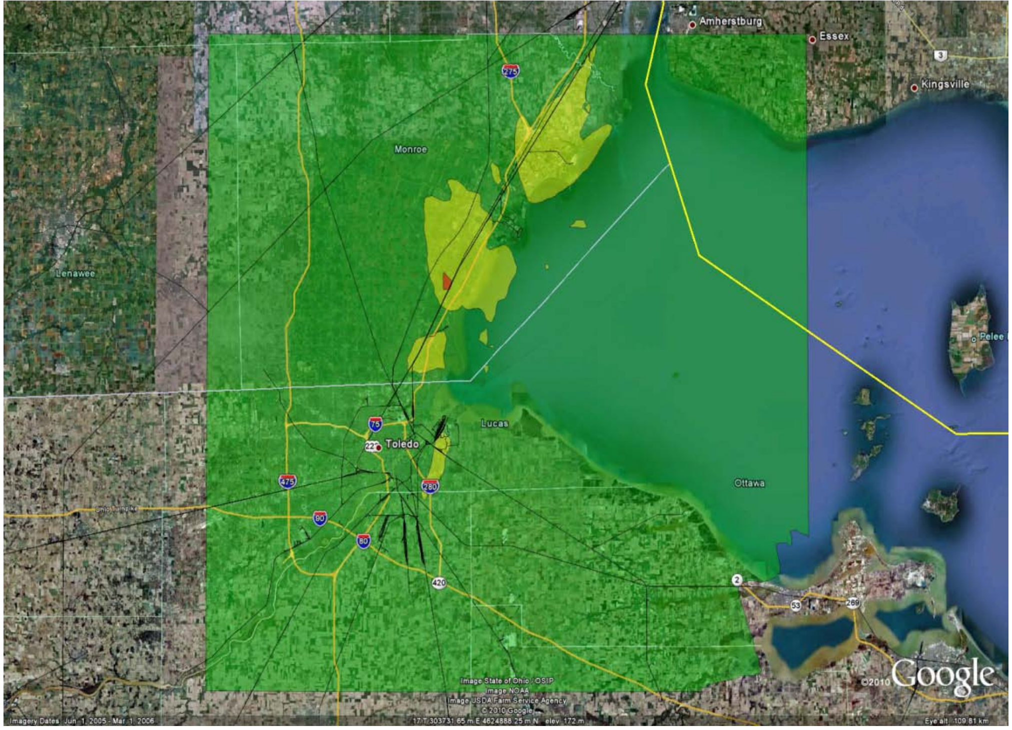


Figure 4.5b Temporal Progression of Base Case Runs Year 2 (Trinity Consultants, 2010a).

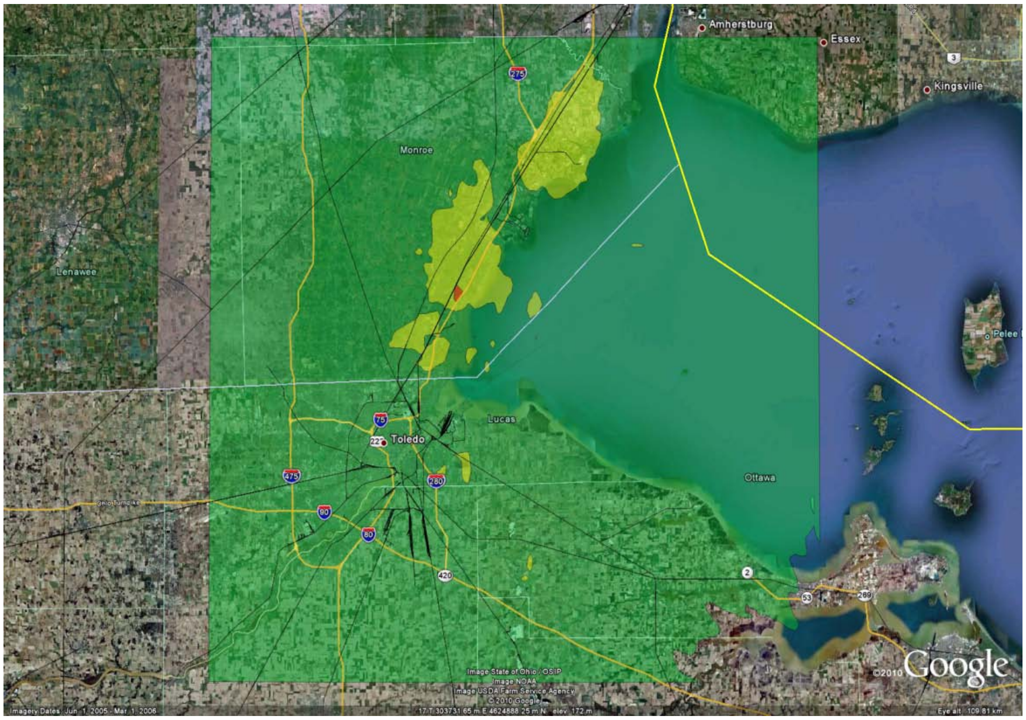


Figure 4.5c Temporal Progression of Base Case Runs Year 3 (Trinity Consultants, 2010a).

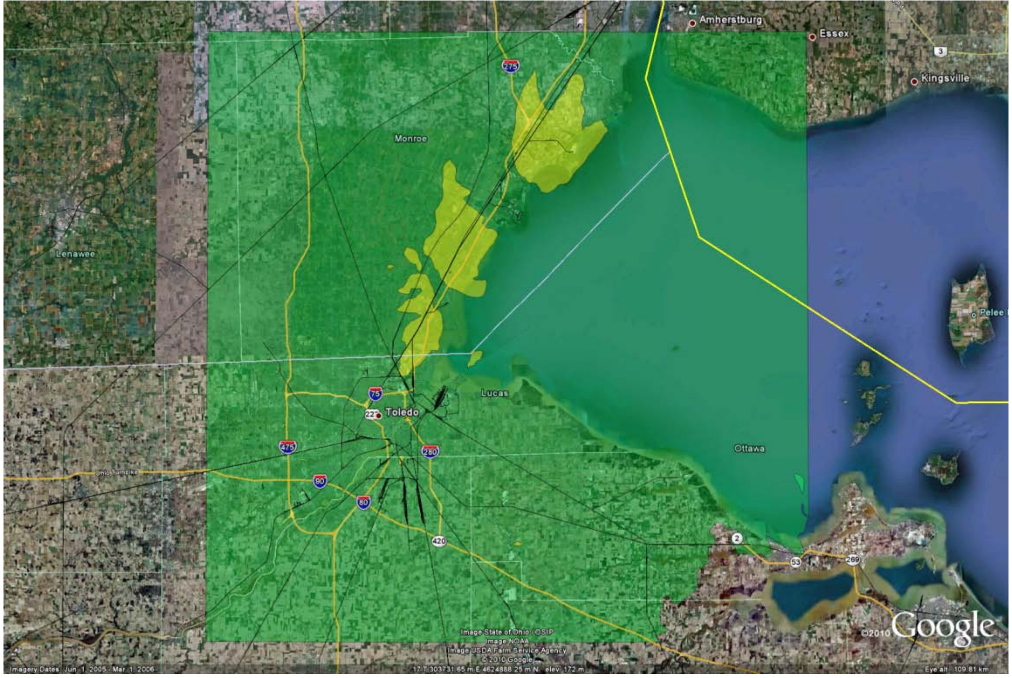


Figure 4.5d Temporal Progression of Base Case Runs Year 4 (Trinity Consultants, 2010a).

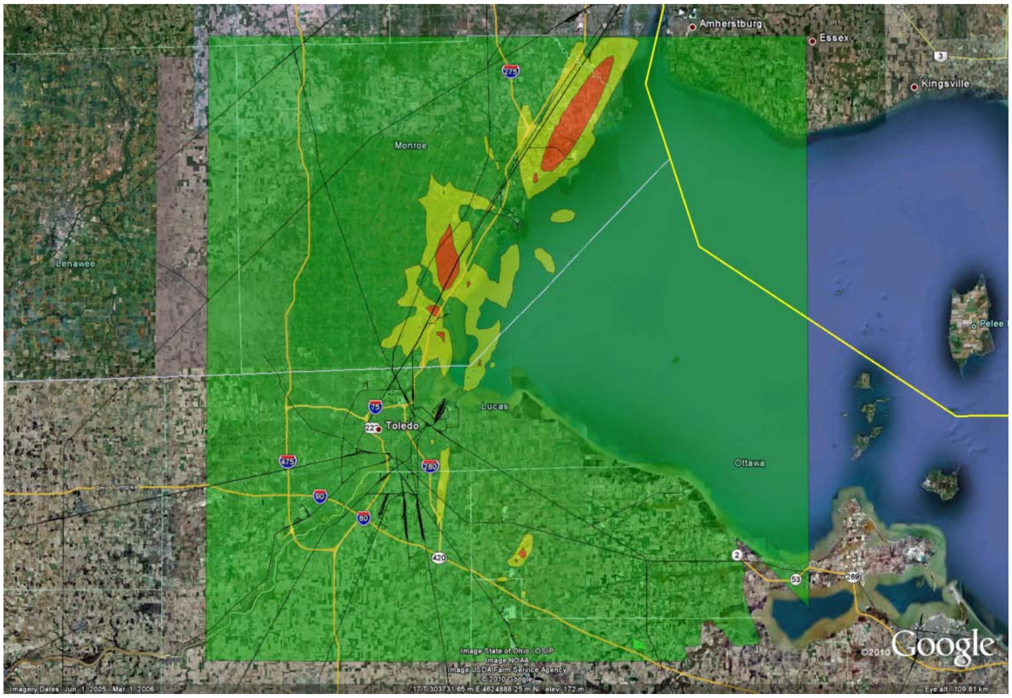


Figure 4.5e Temporal Progression of Base Case Runs Year 5 (Trinity Consultants, 2010a).

The same scales were used in the Base Case as were utilized in the screening run:

Minimum modeled concentration to 64 ppb = green

65 ppb - 84 ppb = yellow

85 ppb and higher = red

Again, no background is included in this study as the EPA has yet to issue guidance on how to account for background. No monitor exists in the vicinity nor in the region that isn't heavily impacted by a source of SO_2, (US EPA 2011) which would not represent background. Therefore values within 10% of the standard are represented as moderate risk. Depending on the background level EPA requires in a State Implementation Plan, the "moderate" risk window may need to be lowered even further toward 50 ppb.

In comparison to Figure 4.1, utilizing the 4th highest versus the 1st highest in the screening run significantly reduces the extent of the "red" and "yellow" geographical areas. Again, the standard is based on the 99th percentile versus the 4th high, but those two values are identical with a data set that is at least 82% complete. If the valid readings in monitored data or the available valid met data in a modeling run is 82% or below, the 99th percentile becomes the 3rd highest and so on as the valid data completeness is reduced. Intuitively, as the concentration closes in on the 1st high, seen in the screening runs, the locale becomes "penalized" for invalid or missing data (USEPA, 2009a).

Using Google Earth, below, all 5 years are plotted together as a layer picture, meaning, each year is “painted” on the other, which demonstrates any discrepancies in year to year concentrations.

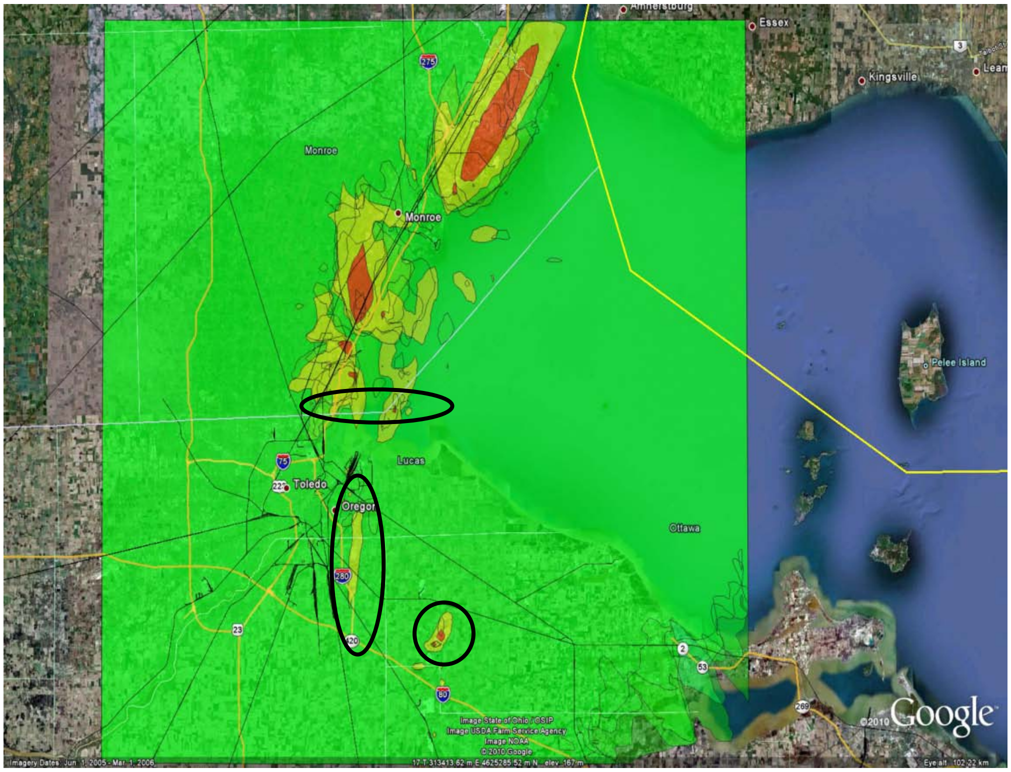


Figure 4.6. Combined Concentration Plot with circled areas denoting *Locations in the Toledo CBSA where excedances of the NAAQS are likely* (Trinity Consultants, 2010a)

As evidenced by the plot above, there are three areas where non-attainment risk exists in the Toledo CBSA. The first is directly along the State Line with Michigan, extending slightly out into Lake Erie near Turtle Island and turning south to the mouth of the Maumee River. The second extends in a narrow band directly south from the Oregon Industrial Area toward I-80/90 Interstate Highway. And the third is in the far southeastern corner of the CBSA, near the lime kilns, again also near I-80/90. Two smaller "yellow" pools lie just south of the "kiln pool", but are in a county excluded from the Toledo CBSA, therefore are outside of the scope of this study. There is a significant geographical extent of modeled ambient air concentrations above the standard just along and north of the State Line with Michigan. How accurately AERMOD depicts the exact location of this high concentration versus what is monitored in real-world assessments will be critically important in determining how much and to what extent of the Toledo CBSA will have attainment issues.

The graphical plots provide an easy visual assessment of the data, however, the output tables provide a more accurate, albeit more tedious, analysis of risk of non-attainment. Each year of the outputs of the 4th highest were loaded into a Microsoft Excel spreadsheet on a receptor by receptor basis. Those receptors in Monroe County, MI were deleted since the study is not assessing Monroe County. Additionally, since a significant portion of Ottawa County, OH is over Lake Erie and the border is irregular a portion of those receptors were also deleted. Water bodies technically could be classified as non-attainment, but monitors are not usually put on buoys. Additionally, the portion deleted, generally north and to the far east of Toledo, is shaded "green" and shows little effect of the modeled sources. A formula was then entered averaging three successive years of concentration for each data point in the following manner:

1.) 2006-2008

2.) 2007-2009

3.) 2008-2010

Any one of these three year rolling averages above our "red" criteria signified a strong probability of non-attainment with the 75 ppb 1-hour standard. Any one of the averages in the "yellow" range indicates risk of non-attainment for that receptor. The number of receptors in each range were summed and expressed as a percentage. One receptor in excess of the standard may not necessarily represent a high risk, although as discussed earlier, the EPA has yet to issue the guidance on how to perform the enhanced dispersion modeling for attainment. For this study the receptors above 85 ppm, the "red" range are expressed as a high probability percent and the yellow + red are expressed as the total modeled receptors in risk of non-attainment. Due to the size of the spreadsheet, it is not included here, only the summary of the results.

1.) 2006-2008: During this three year period, an average of 0.84% of the 2972 receptors in the approximate Toledo CBSA were in the "yellow" range, none were in the "red" range. Year 3 or 2008 appears to be an outlier that affects each of the averaging periods; in that one year, only 0.13% of the receptors were in the yellow range with none in the red range. It is unknown why this anomaly exists, but the only variable from year to year is meteorological data, therefore, it must be associated with a high level of very efficient dispersion or transport out of the modeling domain. While percentages between 0.1 and 1% appear to be small, considering the geographical extent of the modeling domain and the highly localized nature of the pollutant and its sources, having 30 receptors demonstrating attainment issues (roughly 1%) is significant.

2.) 2007-2009: During this period, the average drops to 0.72 % of the receptors were in yellow range non-attainment readings, none were in red. Again, the 2008 outlier numbers dominate the average, bolstered by a slightly lower 2009 number.

3.) 2008-2010: As much as 2008 appears to be an outlier on the low end, 2010 appears to be an outlier on the high end. 3.6% of the receptors were in yellow + red non-attainment and, during 2010, "red" range non-attainment readings show up with 0.37% exceeding the 85 ppb threshold. This drives up the three year average to 1.48% of the readings in the "yellow + red" range and 0.12% of the readings in that three year period in the red range, again, driven exclusively by the 2010 data.

If the 2008 and 2010 data are excluded, the 2006, 2007, and 2009 years all average to 1.03% of the receptors in non-attainment range with a standard deviation of 0.00305. Including all five years produces a standard deviation of 0.01326, a much less effective fit of the data. Based on this, one could assert that given the base case emissions and "average" met data, in any give year 1% of the receptors will demonstrate 4th highest ambient air concentrations readings close to or in excess of the standard. Since no EPA criteria exist yet to compare these percentages to the assessment of risk is based on best professional judgment and not regulatory criteria.

2015 "*On-the-Books*" controls

In the 2015 On the Books (OTB) control run, those sources with either controls in progress of construction or those announced as part of a federally enforceable consent decree were estimated or calculate per the decree requirements. The Monroe Power Plant currently has two units fully scrubbed for sulfur dioxide, but Detroit Edison has announced that the two uncontrolled units will also have wet scrubbers installed and operating in the next few years, therefore for this run, the two uncontrolled units were given emission rates identical to the currently controlled units. Since the controls have not been constructed, this was deemed the best way to estimate controls.

The second facility with controls that will be in place is the Marsulex Sulfuric Acid Facility.   The EPA enforcement website has an announcement of a consent decree which includes this facility as well as other related plants across the county. The decree requires a scrubber with "95% removal efficiency" (Guzman et al., 2009). No other publicly available information about the planned controls were listed, therefore the Base Case emission rate was reduced by 95%, with all other parameters including stack flow rates, location, heights, and temperatures being held constant. If the scrubber is a wet scrubber, it is likely the temperature will be lower than the current stack exhaust, but again, no design parameters were found. Therefore this method is the best available estimate.

The final change for the 2015 OTB, was Bayshore Power Plant. The Bayshore Facility is owned and operated by First Energy Inc. Recent press releases as well as an official Securities and Exchange Commission 10-K quarterly submission state that due to lower demand and higher costs at older, smaller power plants such as Bayshore, they are curtailing operations. The 10-K announced full shutdowns at other FirstEnergy plants, but the Bayshore facility will only be curtailed seasonally at some point in the future. During the spring and fall, the boilers feeding the combined stack will not operated. However, "Boiler 6" which is controlled for sulfur dioxide and utilizes petcoke from the nearby BP refinery will operate normally year round. Boiler 6 also utilizes a separate stack, so not stack parameter modifications (e.g. reduced flow) were necessary (FIRSTENERGY Corp, 2010).

In the model, emissions from the combined stack were "shut off" during the spring and fall. While this type of control may have limited effect on a 1-hr standard because normal hourly emission rates will occur for at least 6 months of the year, it is still included to improve accuracy of the predicted condition in 2015.   Since both 2015 cases are snapshots of ambient air concentration looking at various control scenarios, they were ran similar to the screening run, utilizing one year of met data. However, the 4th highs were calculated for graphical analysis. The 2015 OTB plot also utilizes the same "green", "yellow", and "red" ranges.

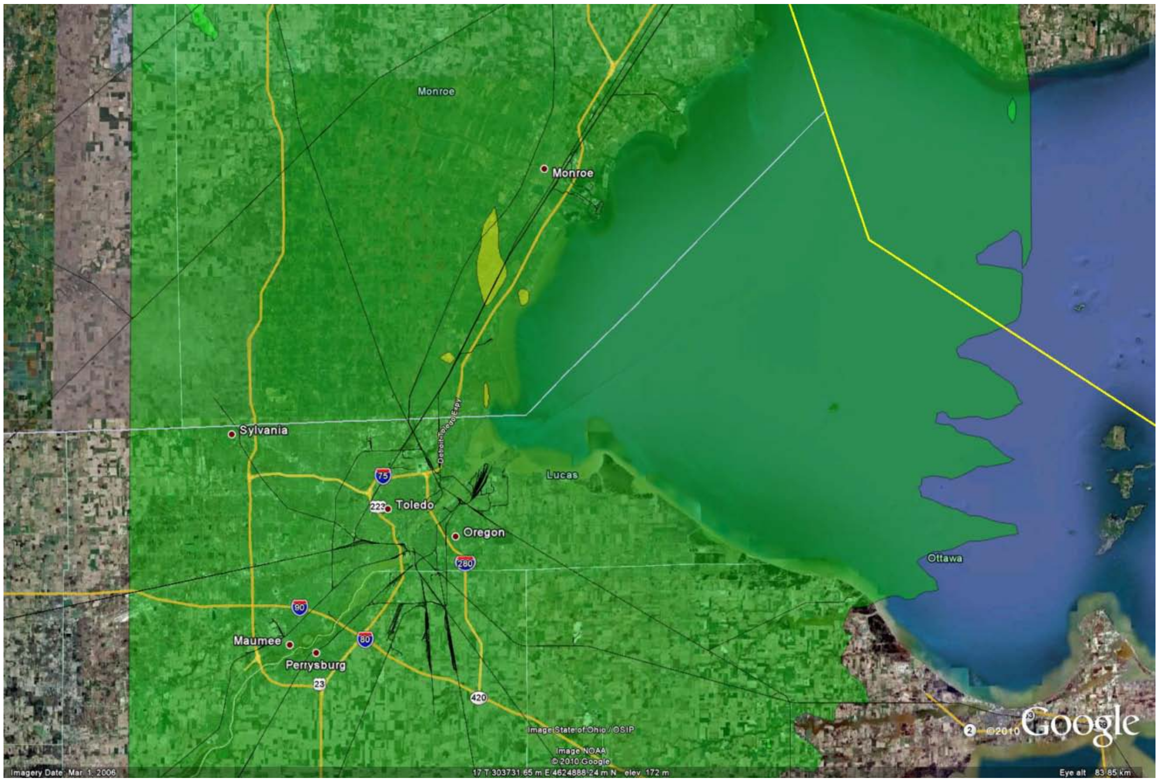


Figure 4.7. 2015 On the books controls - 4th highs (Trinity Consultants, 2010a)

While some "yellow" range concentration pools exist 5-10 miles north into Michigan, the geographical extent is far reduced from the earlier plots. Additionally, we start to see some significant depletion toward the eastern edge of the modeling domain. No yellow or red range concentrations exist in the Toledo CBSA in this case.

2015 OTB + Reasonably anticipated regulatory controls

In this sensitivity case, the 2015 OTB controls are combined with those which may reasonably be anticipated in the future based on regulatory initiatives. Since sulfur dioxide is often associated with coal combustion, many of the regulatory initiatives involve the three coal fired power plants in the study. In this case, as discussed in Section 3, the

EGU MACT is considered to drive controls on the power plants on or about 2015. The EGU MACT has yet to be proposed but will likely include the need for sulfur dioxide scrubbing for compliance with acid gas emission rates (US EPA, 2010a).

For this run, the 2015 OTB controls are combined with 80% controls on the JR Whiting and Bayshore Power Plants. Since the Monroe Power Plant is already 50% scrubbed today and the balance of the facility was captured in the 2015 OTB run, no alterations were made for this case. Scrubbers usually have a much better control efficiency than 80%, however, that is usually considered the bottom end of potential controls (Davis et al., 2000). So as not to overestimate any effect of probable future controls, the bottom end of the range was used.

Since both 2015 cases are snapshots of ambient air concentration looking at various control scenarios, they were ran similar to the screening run, utilizing one year of met data. However, the 1st and 4th highs were calculated for graphical analysis. The 2015 OTB plot also utilizes the same "green", "yellow", and "red" ranges.

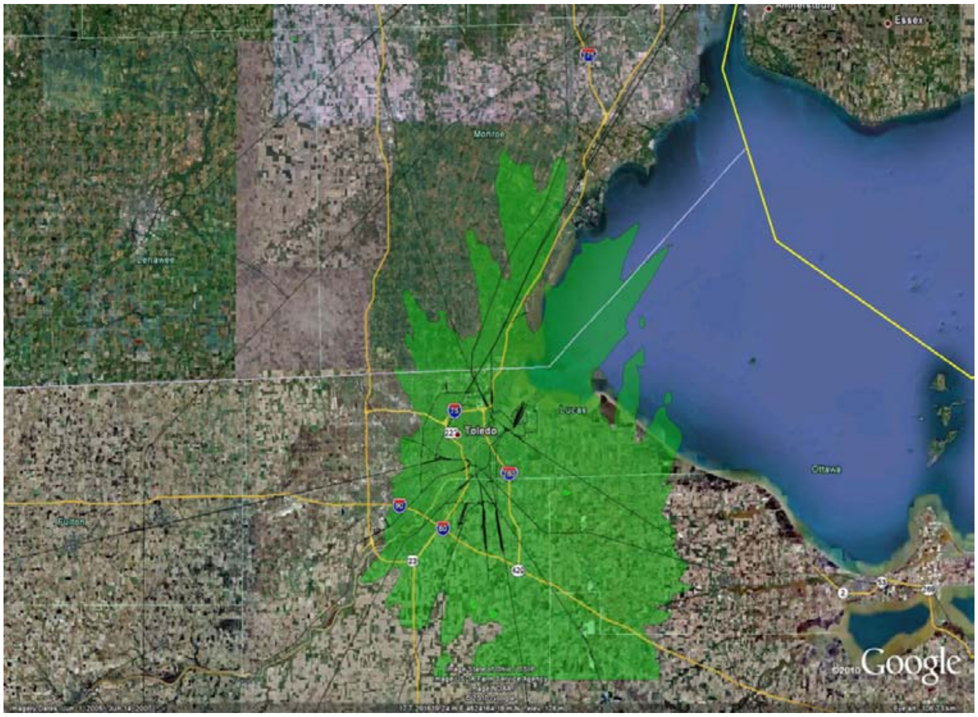


Figure 4.8. 2015 OTB + Reasonably anticipated controls - 4th high (Trinity Consultants, 2010a)

Here, any cautionary ranges of ambient air concentration have completely disappeared based on the 4th highest average. In fact the large geographical areas in Michigan between the JR Whiting and Monroe Power Plants where both red and yellow ranges existed have also largely disappeared. Even when considering the 1st high concentration, only a small area around the lime kilns show any risk of nearing or exceeding the standard:

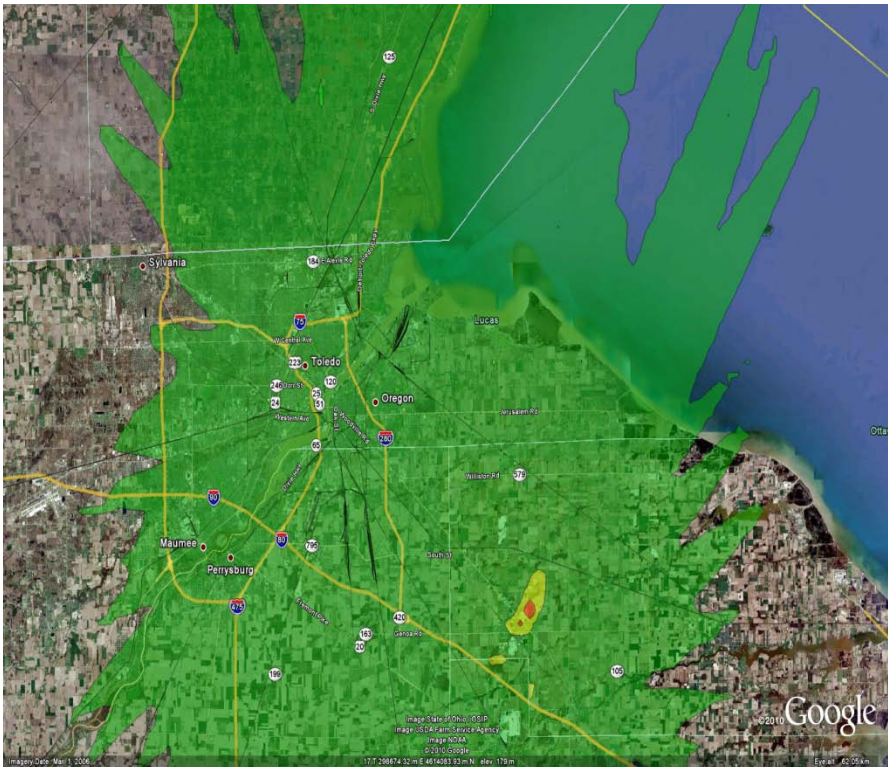


Figure 4.9. 2015 OTB + Reasonably anticipated controls - 1st high (Trinity Consultants, 2010a)

These two sensitivity cases strongly point to the conclusion that, while risk of non-attainment does exist in the Toledo CBSA, due to regulatory programs already on the books, non-attainment may be short-lived and self-remedying.

Other initiatives, such as an emphasis program on petroleum refineries, were generally referenced in literature, but no specific requirements or regulatory programs could be located in publicly available sources which would lead one to believe that controls were imminent in the next 4 years on the balance of the sources. Therefore no further control scenarios were analyzed.

Chapter 5 Conclusions and Recommendations for Further Study

The recently revised sulfur dioxide National Ambient Air Quality Standard presents significant challenges to certain industrialized areas which have long been in attainment with the old standard. The old standard was the original NAAQS for sulfur dioxide and had enjoyed such thorough compliance across the country that many monitoring stations no longer measured sulfur dioxide. Because of the lack of monitored data, the expense of new monitors, and the short time allotment for attainment designations, the EPA will make extensive use of modeling, such as the methodology proposed here, to determine attainment in many areas across the Country. Using the Toledo, Ohio Core Based Statistical Area as the focus of this case study provided many varied types of sources of sulfur dioxide in an area which lacked a sulfur dioxide monitor. The EPA has not yet issued its guidance on how to use modeling for assessing attainment, however designations are due in to the EPA in the summer of 2011, making studies such as this critical to accurately determine how a CBSA or County will be classified. Said classification has significant impact on investment and costs of living and doing business in the geographical area.

Conclusions

Based on the results of the study the Toledo CBSA currently has a high probability of non-attainment with the proposed 1-hour sulfur dioxide standard. A better analysis of these results will be possible upon the issuance of the promised EPA Guidance regarding the use of "enhanced dispersion modeling" in non-attainment determinations. If substantive changes are required to the modeling protocol, the inputs at the very least will serve as a base for the enhanced technique. However, even with the risk of non-attainment, the remedies may already be in place. Due to the fact that the highest mass emitters of sulfur dioxide are generally complex and large facilities, controls are relatively expensive in total dollars and can take several years to install, progress can take time. However, in taking snapshot looks at the effect of announced and probable controls on a subset of the 25 modeled emission points, there is a distinct downward trend in the sulfur dioxide ambient air concentration, with the “2015 OTB + reasonably anticipated control scenario” demonstrating a high likelihood of attainment. But, again, the future sensitivity cases contain many assumptions and estimates that would need to be confirmed by local air planners and regulatory officials before any certainty can be placed in that conclusion.

Two anomalies did arise in the modeling results. The first was regarding the actual impact of steam powered lake freighters. The way the model was constructed, a steamer was placed in Port running at a reduced load day and night for all seasons except the winter. This was done due to the limitations of AERMOD in accounting for mobile source emissions and also due to the difficulty randomizing when a vessel would be in Port versus conditions amenable to non-attainment. One would assume this would overestimate the impact of the freighter, but even so and with the extremely high content of sulfur in Bunker C fuel oil, the freighter had very limited impact in the study as evidenced by this 4th high plot from Year 4, showing a low concentration and limited geographical extent of a sulfur dioxide plume:

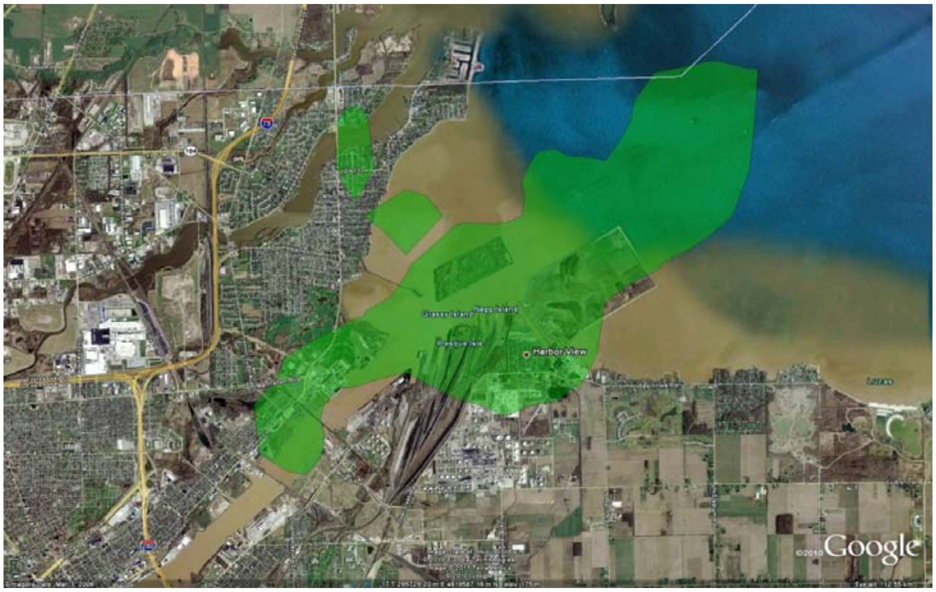


Figure 5.1) Effect of composite freighter, 4th highs (Trinity Consultants, 2010a)

Further analysis should assess the accuracy of his conclusion. The original hypothesis anticipated a significant impact from this source. The original hypothesis was also anticipating the bulk of the attainment issues in the Toledo CBSA to be in and near the Oregon Industrial Area. While this was true, a second significant area of non-attainment risk exists in the southeastern portion of the CBSA due to the numerous lime kilns in the area. There was little data available on these sources, but they do represent an area of non-attainment risk and do deserve further research.

Recommendations for further study

A study such as this which relies on several assumptions and estimates provides a number of offshoot research opportunities to analyze the detailed inputs to this project. The impact of each type of related sources, if not each emission unit, could be further analyzed in more detail to determine the individual impacts and what operations and controls may be used. This could then be repeated over any number of locales where a significant concentration of industrial sources emitting sulfur dioxide may exist. Based on that, the following subjects for further study would prove useful in improving the body of knowledge of this field and, since it is a current and important regulatory development, the information would be highly relevant to a myriad of stakeholders and interested parties.

- This study looked solely at the impact of the large stationary local sources of sulfur dioxide and assumed that long-range transport of sulfur dioxide as well as natural background was negligible. Depending on the extent of non-attainment that is officially modeled or measured and attributable to local sources, this may prove true at first, however, as local sources are controlled, regional transport and natural background become more important. The use of transport models such as CALPUFF to assess transport from other areas would prove useful here. In addition, understanding how the EPA will calculate and/or model background in its guidance will be critical to future studies.

- One limitation to the accuracy of data on which the conclusions were made was the availability of current emission data. By law, the power plants report emission data quarterly and all of it is publically available (US EPA, 2010b). However, many assumptions and manipulating calculations were required on some other sources due to a dearth of current emission data. In most cases, the 2005 NEI was used for the basis of the emission data. Locating, calculating, or obtaining through measurement, more recent data that reflects the economic downturn since 2008 may itself represent a control that could not be assessed here. Updating this model with said data as well as a quality assessment of its procurement methods would improve the confidence in the risk assessment of non-attainment.
- An important next step is to assess smaller and more diffuse sources such as oil-fired generators used as back-up power, non-road engines used in heavy equipment, and a better understanding of the use of switching engines at the many rail terminals in the CBSA. These sources may individually prove to be small, but their combined impact is unknown.
- A method to combine the results of the stationary modeling and the mobile sources of sulfur dioxide from the numerous rail lines and interstate highways that traverse the Toledo CBSA also will provide more accuracy to conclusions. It is unknown as to the cumulative

impact mobile sources will have on SO_2 emissions in a regional assessment such as this. With recent regulations lowering “over the road” diesel to 15 ppm, the contribution of tractor trailer traffic, while not de-minims has definitely decreased in importance (USEPA, 2005b), but still needs to be accounted.

- A more detailed assessment of the marine vessel impact on sulfur dioxide is required. The modeling results here show that impact is less than substantive. Traffic studies and as well as emission profiles of the sizes and individual types of vessels entering and exiting the Maumee River is really necessary to further the understanding of that impact. In certain portions of the Indian Ocean, shipping can account for 75% of the sulfur dioxide present (Streets et al., 1998). While seeing less traffic, there is a strong reason to believe an impact on Great Lakes air quality should still be present.
- The impacts of the lime kilns in the south eastern portion of the CBSA were not expected to be as significant as the modeling demonstrated. A more detailed analysis of those sources as well as a quality assessment of the emission data used is necessary to determine if those impacts would actually be monitored by an ambient air quality monitoring station. The kilns use coal as a fuel in the kilns, but not to any degree similar to the power plants modeled, yet their localized impacts were nearly as significant

when adjusted for facility size. Whether this was due to poor dispersion or some other issue should be explored.

- Finally, if detailed engineering is available with planned and under construction controls or permit application data based on such is currently being considered, the utilization of that data for to assess the conclusion that the non-attainment in the local area is "self-remedying" would be of interest to the stakeholders of this issue and would provide significant research opportunities as well.

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APPENDIX A

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Trinity Consultants
Offices nationwide n trinityconsultants.com

April 15, 2010

Arizona State University
Attention: Greg Myers
8330 Sycamore Woods Lane
Holland Ohio 43528

Re: BREEZE Software & Data
Permission to use Copyrighted Material

Mr. Myers:

BREEZE Software has received your request for permission to use the copyrighted BREEZE Software and its outs in your Graduate School Thesis Project at Arizona State University.

By issuance of this letter, BREEZE Software will grant and allow you permission to use the BREEZE AERMOD Pro Plus, BREEZE AERMET Pro and BREEZE 3D Analyst software for the basis of your project.

BREEZE Software also understands your intent to publish your thesis in a yet-to-be determined professional journal(s) and also to present your findings of your research at various symposia and/or conferences. BREEZE Software expects that you will reference and cite our products in your academic research.

We thank you for your request and also for the continued use of our software.

Sincerely,

Mr. Vale Reyna
BREEZE Software
Customer Care Coordinator

vr/cc

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Please do not request that we interpret whether your use of Content is a fair use. Google cannot tell you if your use of Content from our products would be a fair use or would be considered fair dealing; these are legal analyses that depend on all of the specific facts of your proposed use. We suggest you speak with an attorney if you have questions regarding fair use of copyrighted works.

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Below is a demonstration on where to find attribution in Earth and Maps.

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- If a TV use, show in context with any chyrons, lower-thirds, network bugs, or other on-screen graphics that will appear at the same time
- If a film use, describe or demonstrate the precise use and clarify whether the imagery will be shown full-screen or as part of a scene (such as on a computer screen)
- If another use, such as public display, photograph or mock up the scene so we can be assured that attribution will be reasonably apparent to the audience

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- My Maps, which you can use to add lines, shapes, and points to any map view
- Maps with search results (example) or a search result "info bubble" (example)
- Driving/walking/transit directions

Earth

- Views of hilly terrain
- 3D buildings
- Paths and polygons

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Tracing. You may not use Google Maps or Google Earth as the basis for tracing your own maps or other geographic content.

FAQs

How do I report an inaccuracy or request a change in Google Maps or imagery?
Please do not report these matters through the permissions process. In the US, you may use the Report a Problem link at the bottom-left of the map view (watch this video for instructions). If your country is editable through Map Maker, you may make the changes yourself. For other countries, submit your request through the Fix an Error form where it will be evaluated by the appropriate teams. If your concern relates to privacy in Street View, please visit the Street View microsite.

I'm interested in a co-marketing opportunity with Google, or I've done something cool with Google Maps or Earth that I'd like to share. Whom should I contact?
Please contact us through the Geo Permissions form. While we cannot accommodate all inquiries, we are interested to hear from you. If you have created a KML layer you may upload it to our KML Gallery.

Can you sign an agreement or letter indicating that I have permission to use your imagery?
We are unable to sign any letter or contract specifying that your project or use has our explicit permission. The only exception is when you arrange for a content license from us.

Would you please give me permission to show your content without attribution, or put the attribution at the end of my book/movie/TV show?
Without exception, we require attribution when Content is shown. Please scroll up to the "Attribution Requirements" section for full details. If you are unwilling to meet our attribution requirements, please contact our data provider(s) directly to inquire about purchasing the rights to the content directly.

I'd like to publicize the work I've created using Content from Google Earth and Maps. Can I send out a press release?
Google is pretty conservative when it comes to press releases. Please do not release any publicity materials that refer to Google, Google Earth or Google Maps unless you have prior written approval from us.

Can Google provide me with high-resolution screenshots?
If you need to export high-resolution imagery from Google Earth, you may want to purchase Google Earth Pro, but please keep in mind the restrictions on uses of aerial and satellite imagery. Unfortunately, we are not able to provide high-resolution versions of our map tiles.

I've found what I believe to be an improper use of Google maps or satellite imagery. Should I let you know?
Yes, please, through our Geo Permissions form.

I'm having trouble with Google Maps or Google Earth. Can I contact you?
For technical questions, please refer to our online help center for Google Maps and Google Earth.

I need to contact one of your data providers. Can you please provide their contact information?
Unfortunately, we cannot. May we recommend a Google search?

What if my question isn't answered above?
If your questions are not addressed in the permissions guidelines for Google Maps and Google Earth as mentioned on this page, please contact Geo Permissions. Due to the large volume of incoming requests, please allow to two to three weeks for a response.

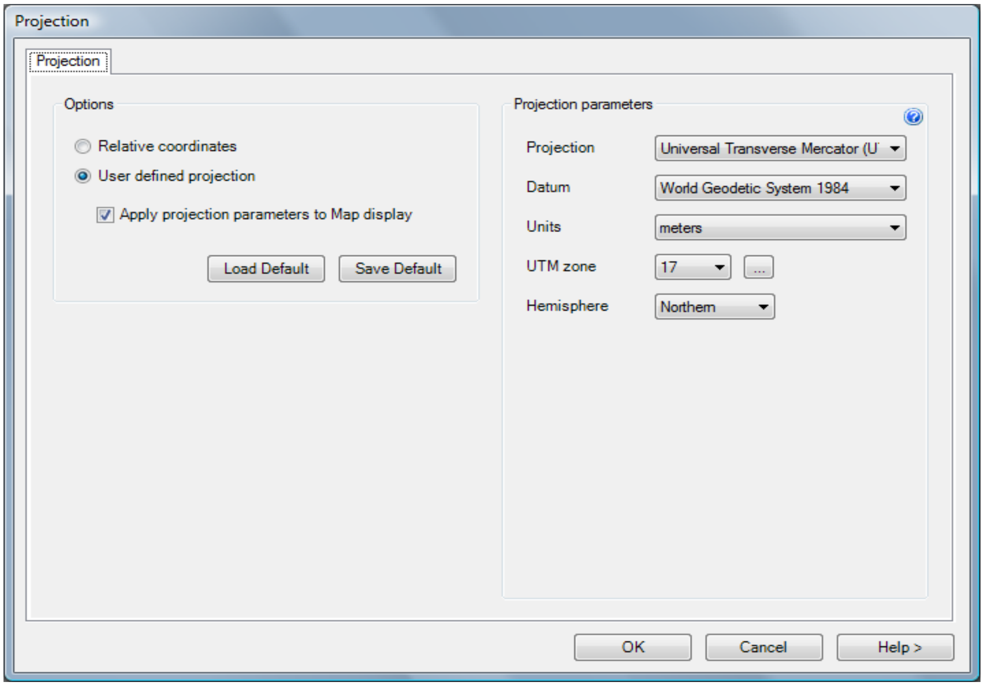
(Google Inc, 2009)

APPENDIX B

MODEL INPUT SCREEN CAPTURES

Appendix B contains screen captures of the input steps to the Breeze AERMOD model used for the project. They were taken from the entry of the screening model data. These screen images are the basic manner in which data was entered into the model program. Other manipulations described in the body of the project as well as others which are not described but are used to check accuracy of entered data, allow for easier visualization of the project model objects and inputs, and personal options which an individual user may choose as a preferences. These steps do not affect model results and as such have been omitted from discussion.

1.) Setting the Projection:



Options

○ Relative coordinates

● User defined projection

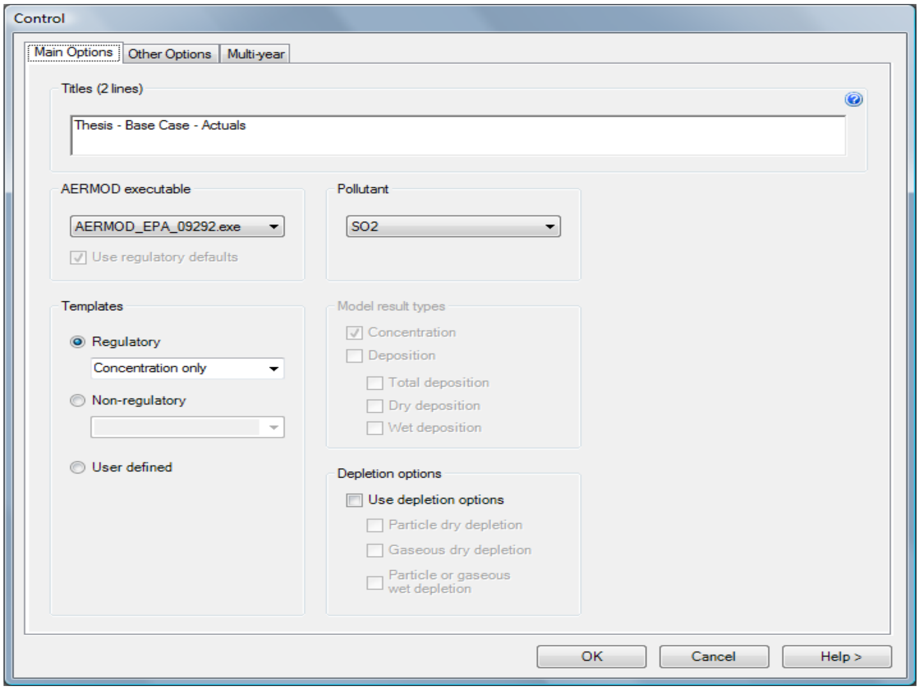
☑ Apply projection parameters to Map display

Projection parameters

Projection	Universal Transverse Mercator (U
Datum	World Geodetic System 1984
Units	meters
UTM zone	17
Hemisphere	Northern

(Trinity Consultants, 2010c)

2.) Selection of Control Options:



Titles (2 lines): Thesis - Base Case - Actuals

AERMOD executable: AERMOD_EPA_09292.exe

☑ Use regulatory defaults

Pollutant: SO2

Templates:
- ● Regulatory: Concentration only
- ○ Non-regulatory
- ○ User defined

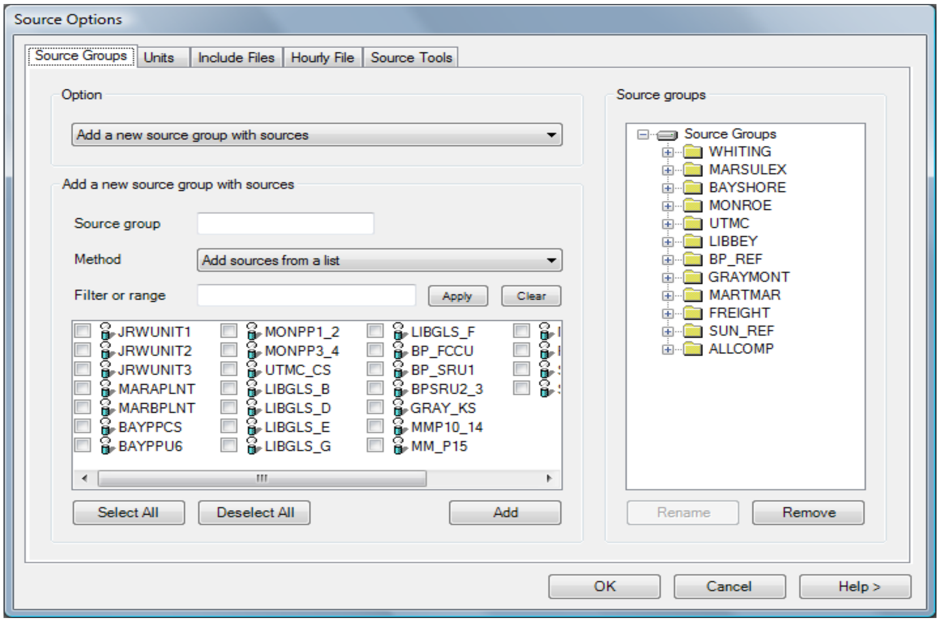
Model result types:
- ☑ Concentration
- ☐ Deposition
  - ☐ Total deposition
  - ☐ Dry deposition
  - ☐ Wet deposition

Depletion options:
- ☐ Use depletion options
  - ☐ Particle dry depletion
  - ☐ Gaseous dry depletion
  - ☐ Particle or gaseous wet depletion

(Trinity Consultants, 2010c)

The second tab - Other Options and the third tab - Multiyear were not utilized.

3.) Source Options:



Option: Add a new source group with sources

Add a new source group with sources

Source group:

Method: Add sources from a list

Filter or range:

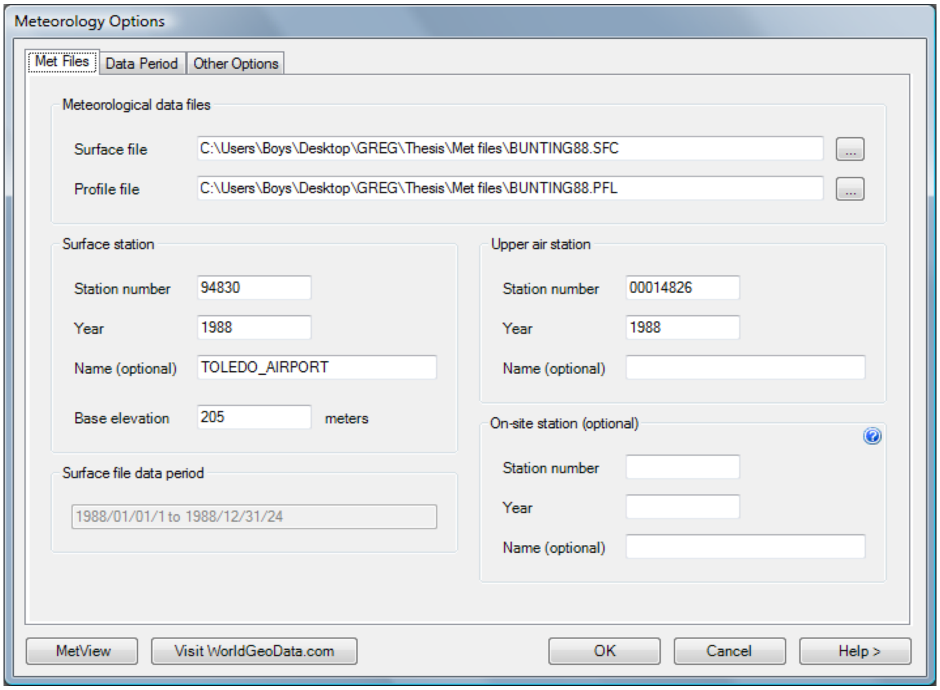
☐ JRWUNIT1	☐ MONPP1_2	☐ LIBGLS_F
☐ JRWUNIT2	☐ MONPP3_4	☐ BP_FCCU
☐ JRWUNIT3	☐ UTMC_CS	☐ BP_SRU1
☐ MARAPLNT	☐ LIBGLS_B	☐ BPSRU2_3
☐ MARBPLNT	☐ LIBGLS_D	☐ GRAY_KS
☐ BAYPPCS	☐ LIBGLS_E	☐ MMP10_14
☐ BAYPPU6	☐ LIBGLS_G	☐ MM_P15

Source groups:
- Source Groups
  - WHITING
  - MARSULEX
  - BAYSHORE
  - MONROE
  - UTMC
  - LIBBEY
  - BP_REF
  - GRAYMONT
  - MARTMAR
  - FREIGHT
  - SUN_REF
  - ALLCOMP

(Trinity Consultants, 2010c)

Source groupings were identified using this option, no other tabs were used.

4.) Meteorology Options:



Meteorological data files

Surface file: C:\Users\Boys\Desktop\GREG\Thesis\Met files\BUNTING88.SFC

Profile file: C:\Users\Boys\Desktop\GREG\Thesis\Met files\BUNTING88.PFL

Surface station

Station number: 94830

Year: 1988

Name (optional): TOLEDO_AIRPORT

Base elevation: 205 meters

Upper air station

Station number: 00014826

Year: 1988

Name (optional):

On-site station (optional)

Station number:

Year:

Name (optional):

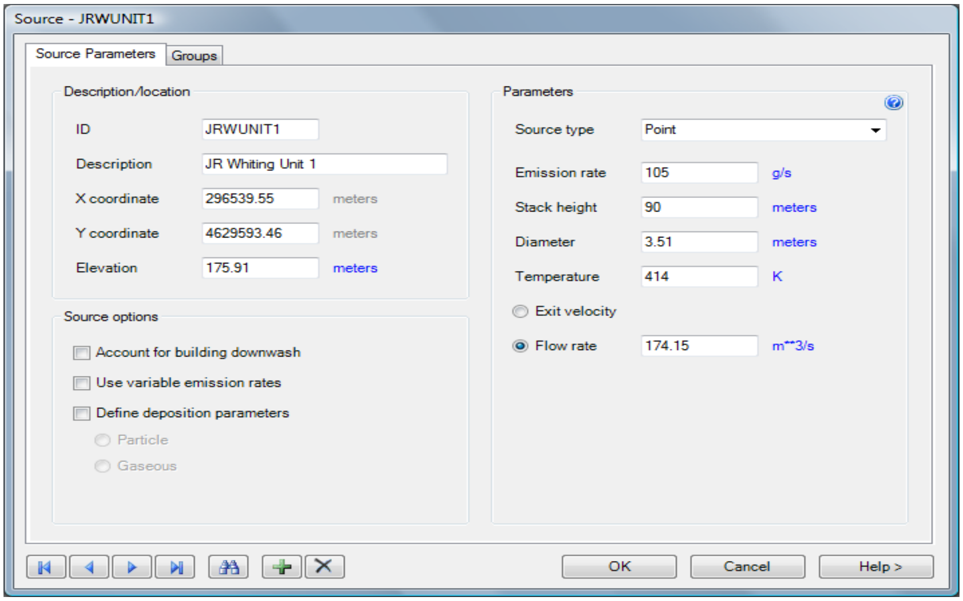
Surface file data period

1988/01/01/1 to 1988/12/31/24

(Trinity Consultants, 2010c)

Data period was left as default or all available hours, no other options were selected.

5.) Source Emission Unit Parameters:



Description/location

ID JRWUNIT1
Description JR Whiting Unit 1
X coordinate 296539.55 meters
Y coordinate 4629593.46 meters
Elevation 175.91 meters

Source options

☐ Account for building downwash
☐ Use variable emission rates
☐ Define deposition parameters
○ Particle
○ Gaseous

Parameters

Source type Point
Emission rate 105 g/s
Stack height 90 meters
Diameter 3.51 meters
Temperature 414 K
○ Exit velocity
● Flow rate 174.15 m**3/s

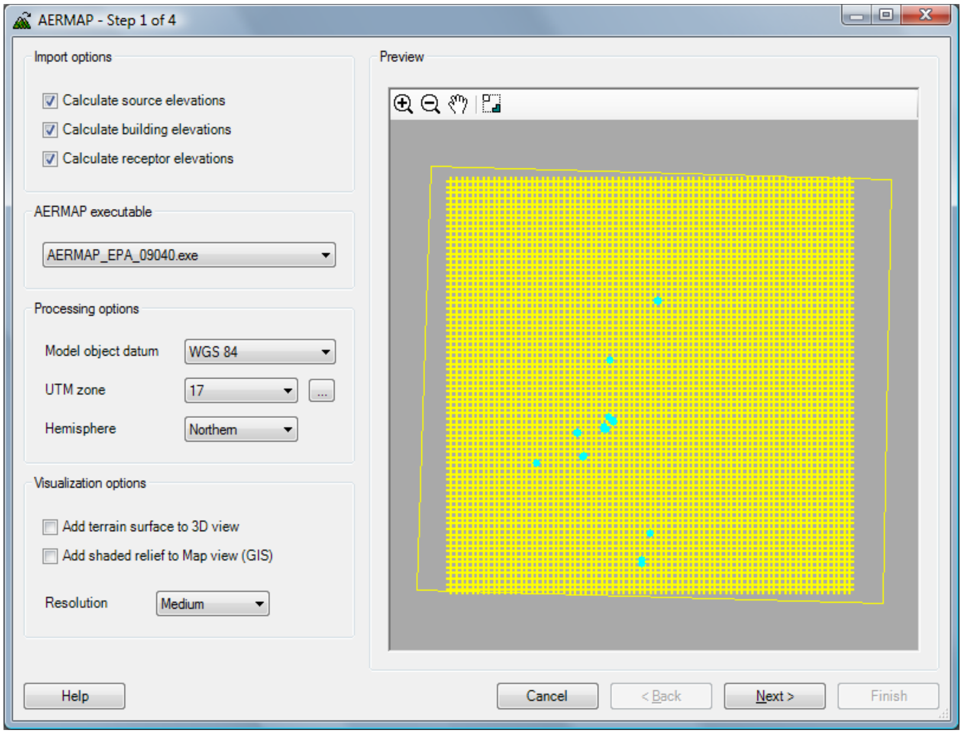
(Trinity Consultants, 2010c)

Only the first source emission unit, Consumers Energy, J R Whiting Unit 1 is depicted here as an example. However, the balance of the sources were entered using the same screen and, but their respective data was taken from Table 3.1.

4.) Receptors - The setting of receptors involved using a drag and drop tool in the program and is not conducive to screen captures. Receptors can also be directly imported via table or manually entered, but neither of those options were utilized by this project and will not be depicted here.

5.) AERMAP and Terrain Data

Entry of the terrain data and running the AERMAP utility is a four step process, each of which will be shown in the next four captures:



Import options

☑ Calculate source elevations
☑ Calculate building elevations
☑ Calculate receptor elevations

AERMAP executable: AERMAP_EPA_09040.exe

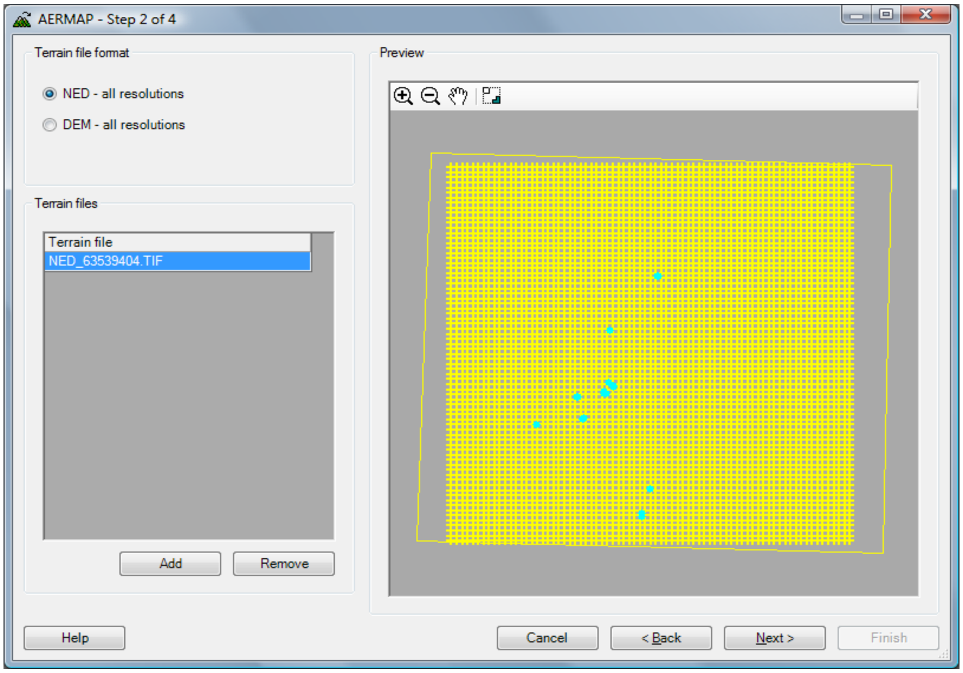
Processing options

Model object datum: WGS 84
UTM zone: 17
Hemisphere: Northern

Visualization options

☐ Add terrain surface to 3D view
☐ Add shaded relief to Map view (GIS)

Resolution: Medium



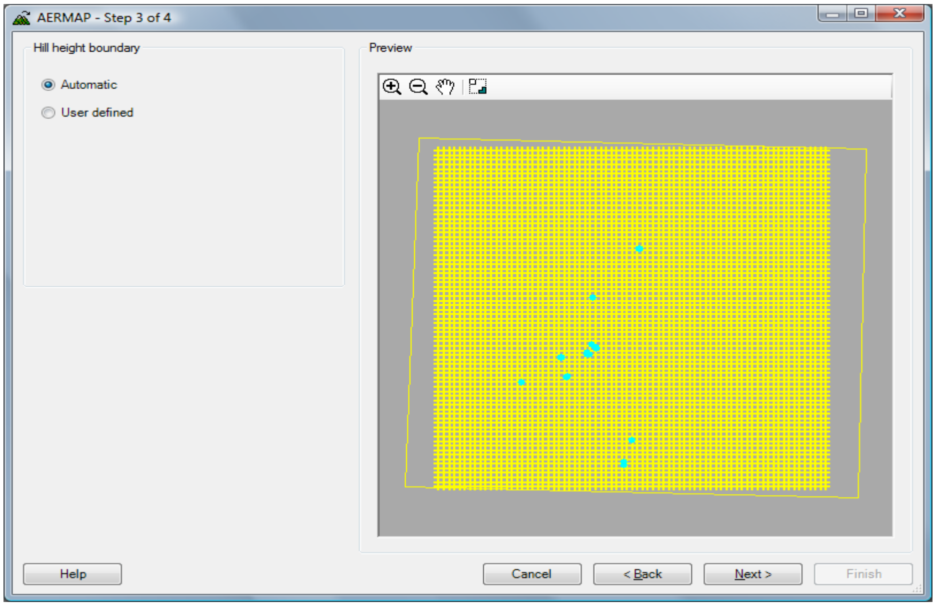
Terrain file format

● NED - all resolutions
○ DEM - all resolutions

Terrain files

Terrain file
NED_63539404.TIF

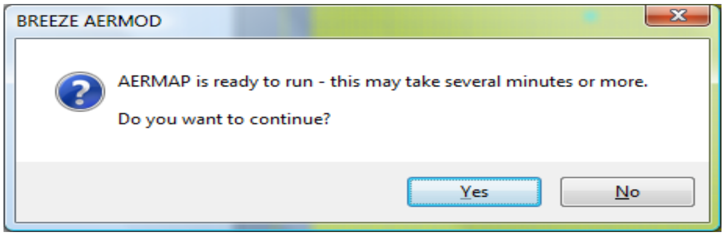
The NED_65339404.TIF file was obtained the USGS as described in Chapter 3.



AERMAP - Step 3 of 4

Hill height boundary

● Automatic
○ User defined



BREEZE AERMOD

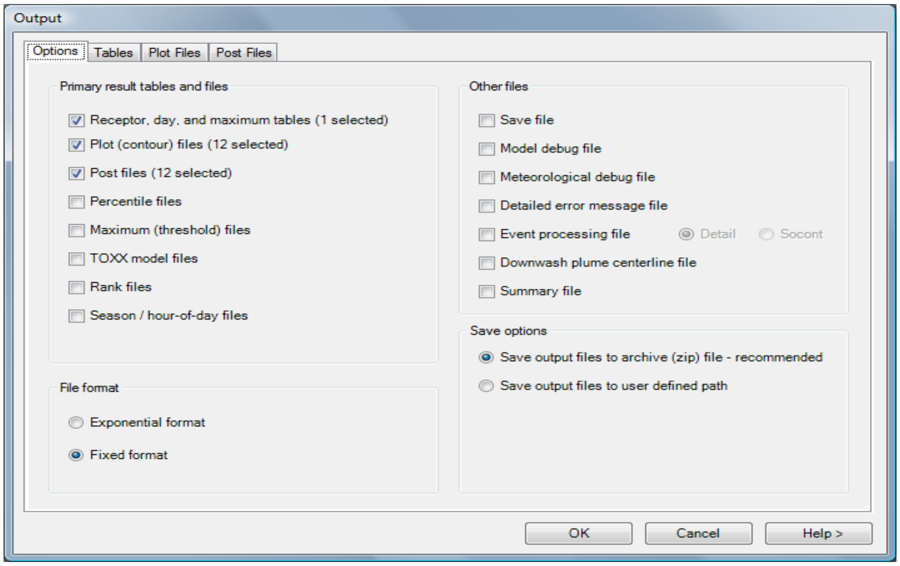
AERMAP is ready to run - this may take several minutes or more.

Do you want to continue?

(Trinity Consultants, 2010c)

6.) Output Options

There are four screens to select output options, they are shown next:



Output

Primary result tables and files

☑ Receptor, day, and maximum tables (1 selected)
☑ Plot (contour) files (12 selected)
☑ Post files (12 selected)
☐ Percentile files
☐ Maximum (threshold) files
☐ TOXX model files
☐ Rank files
☐ Season / hour-of-day files

File format

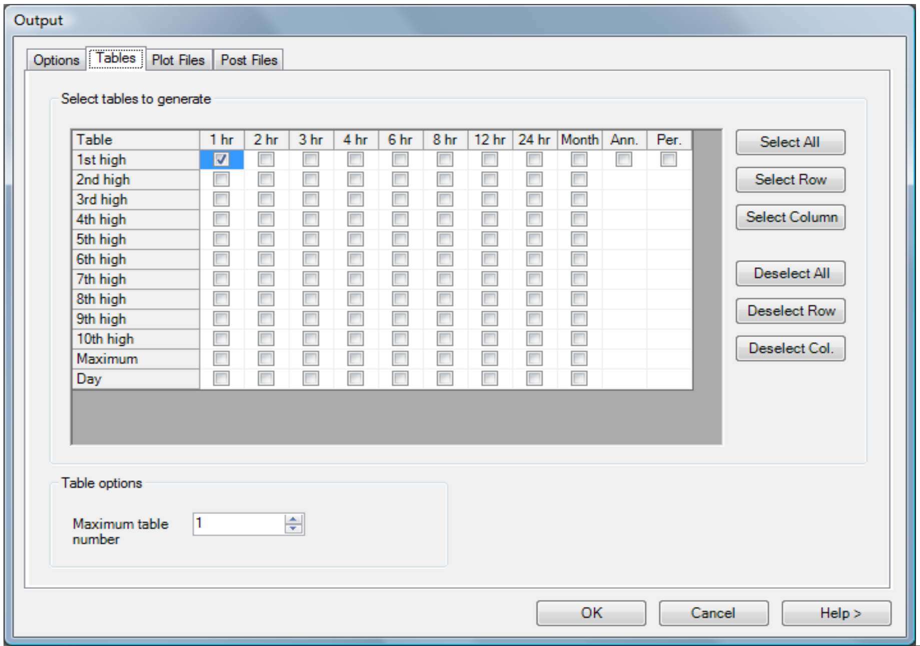
○ Exponential format
● Fixed format

Other files

☐ Save file
☐ Model debug file
☐ Meteorological debug file
☐ Detailed error message file
☐ Event processing file ● Detail ○ Socont
☐ Downwash plume centerline file
☐ Summary file

Save options

● Save output files to archive (zip) file - recommended
○ Save output files to user defined path

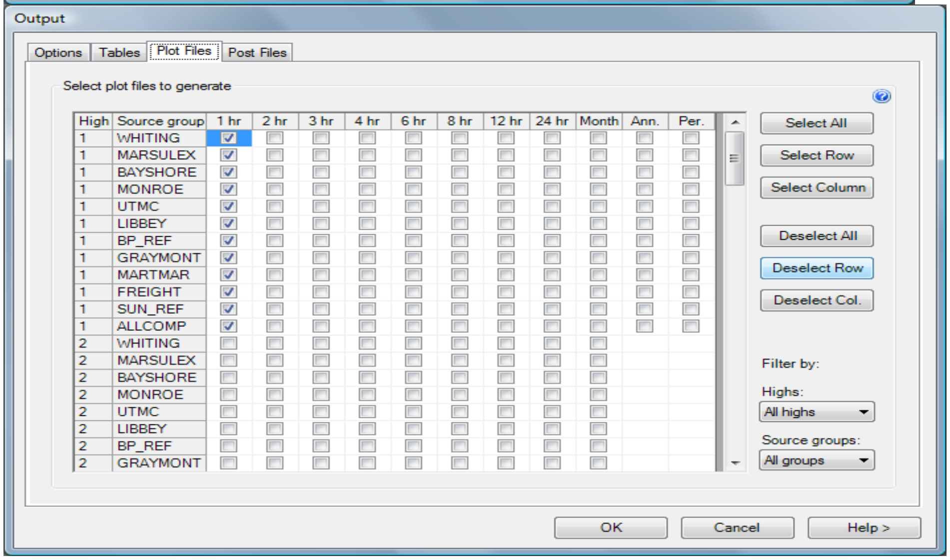


Select tables to generate

Table	1 hr	2 hr	3 hr	4 hr	6 hr	8 hr	12 hr	24 hr	Month	Ann.	Per.
1st high	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
2nd high	☐	☐	☐	☐	☐	☐	☐	☐	☐		
3rd high	☐	☐	☐	☐	☐	☐	☐	☐	☐		
4th high	☐	☐	☐	☐	☐	☐	☐	☐	☐		
5th high	☐	☐	☐	☐	☐	☐	☐	☐	☐		
6th high	☐	☐	☐	☐	☐	☐	☐	☐	☐		
7th high	☐	☐	☐	☐	☐	☐	☐	☐	☐		
8th high	☐	☐	☐	☐	☐	☐	☐	☐	☐		
9th high	☐	☐	☐	☐	☐	☐	☐	☐	☐		
10th high	☐	☐	☐	☐	☐	☐	☐	☐	☐		
Maximum	☐	☐	☐	☐	☐	☐	☐	☐	☐		
Day	☐	☐	☐	☐	☐	☐	☐	☐	☐		

Table options

Maximum table number: 1



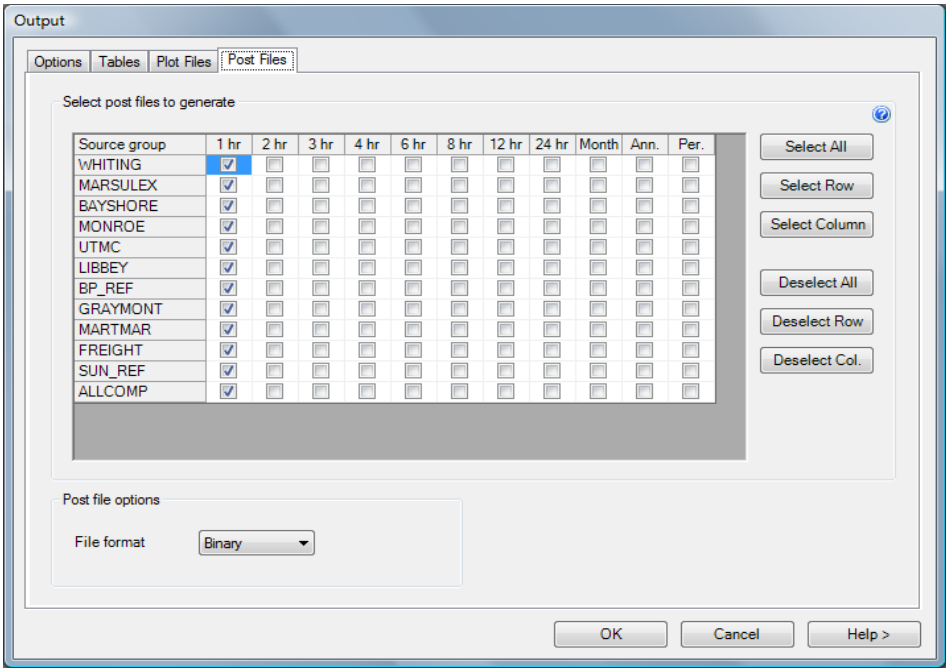
Select plot files to generate

High	Source group	1 hr	2 hr	3 hr	4 hr	6 hr	8 hr	12 hr	24 hr	Month	Ann.	Per.
1	WHITING	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
1	MARSULEX	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
1	BAYSHORE	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
1	MONROE	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
1	UTMC	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
1	LIBBEY	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
1	BP_REF	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
1	GRAYMONT	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
1	MARTMAR	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
1	FREIGHT	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
1	SUN_REF	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
1	ALLCOMP	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
2	WHITING	☐	☐	☐	☐	☐	☐	☐	☐	☐		
2	MARSULEX	☐	☐	☐	☐	☐	☐	☐	☐	☐		
2	BAYSHORE	☐	☐	☐	☐	☐	☐	☐	☐	☐		
2	MONROE	☐	☐	☐	☐	☐	☐	☐	☐	☐		
2	UTMC	☐	☐	☐	☐	☐	☐	☐	☐	☐		
2	LIBBEY	☐	☐	☐	☐	☐	☐	☐	☐	☐		
2	BP_REF	☐	☐	☐	☐	☐	☐	☐	☐	☐		
2	GRAYMONT	☐	☐	☐	☐	☐	☐	☐	☐	☐		

Filter by:

Highs: All highs

Source groups: All groups



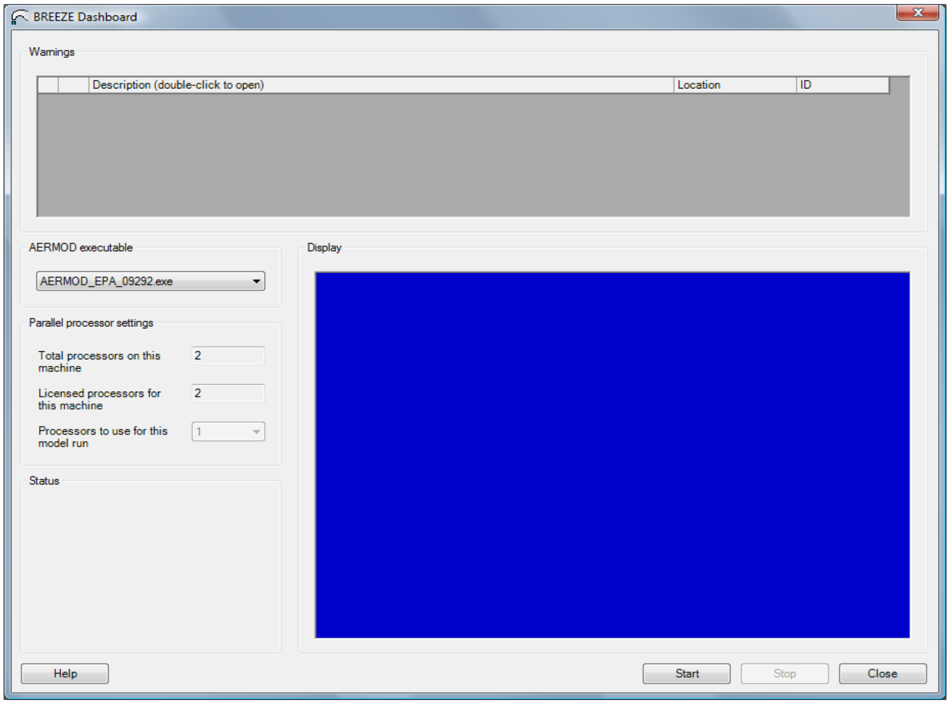
Source group	1 hr	2 hr	3 hr	4 hr	6 hr	8 hr	12 hr	24 hr	Month	Ann.	Per.
WHITING	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
MARSULEX	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
BAYSHORE	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
MONROE	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
UTMC	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
LIBBEY	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
BP_REF	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
GRAYMONT	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
MARTMAR	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
FREIGHT	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SUN_REF	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ALLCOMP	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Post file options

File format: Binary

(Trinity Consultants, 2010c)

7.) Model Execution



AERMOD executable: AERMOD_EPA_09292.exe

Parallel processor settings

Total processors on this machine: 2

Licensed processors for this machine: 2

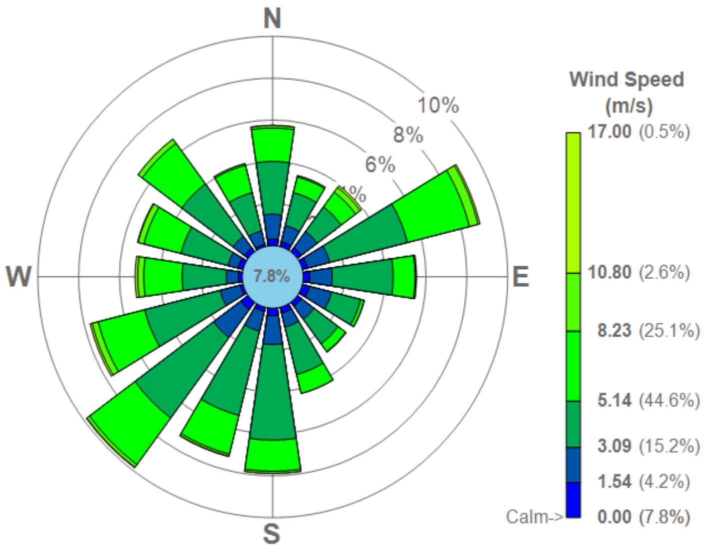
Processors to use for this model run: 1

(Trinity Consultants, 2010c)

APPENDIX C

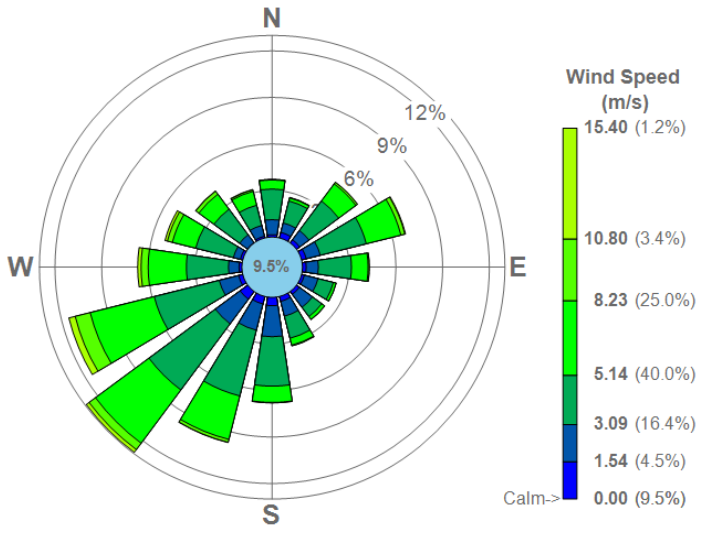
BASE CASE METEORLOGICAL WINDROSES

Year 1:



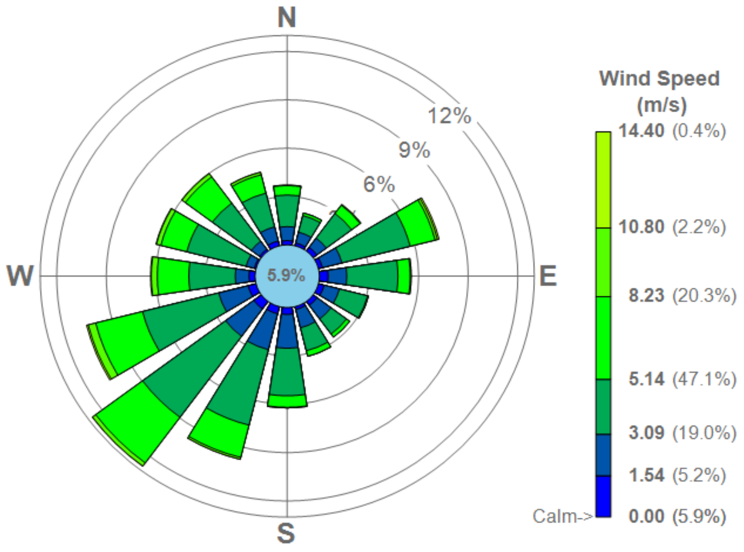
(Trinity Consultants, 2010b)

Year 2:



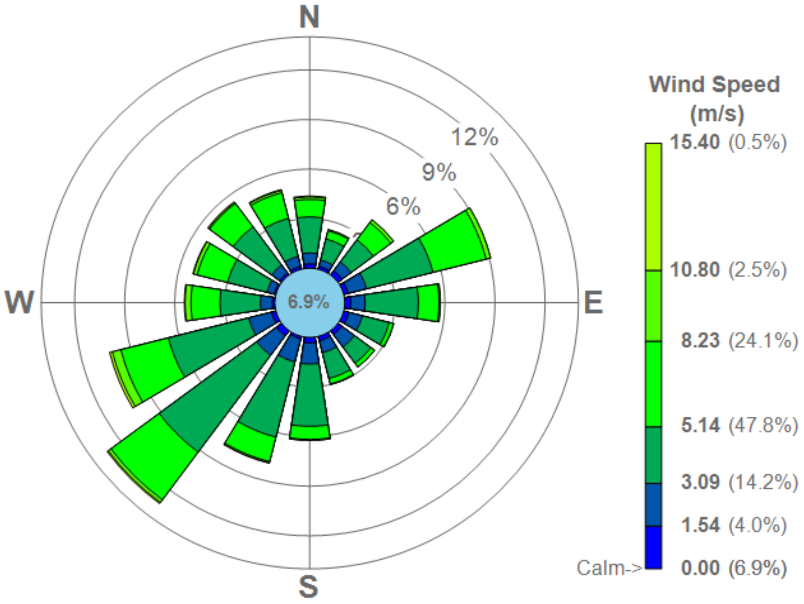
(Trinity Consultants, 2010b)

Year 3:



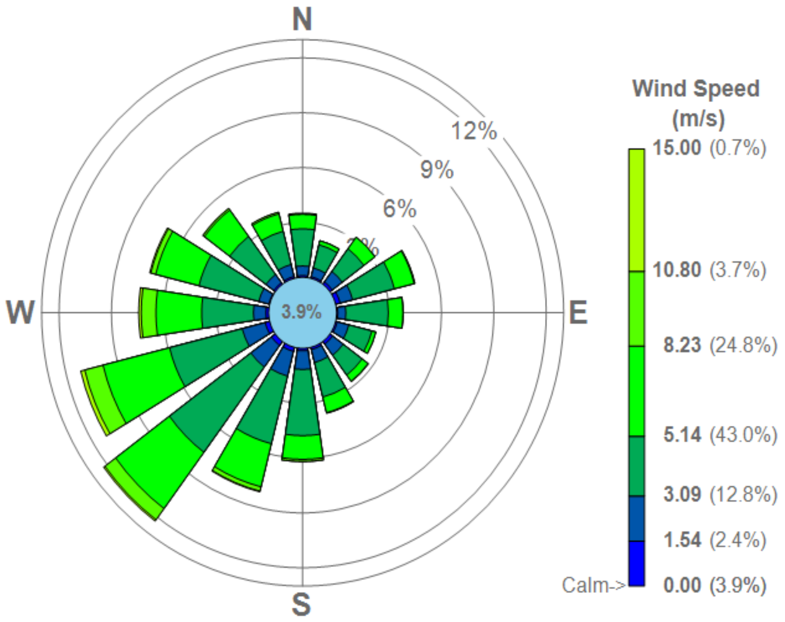
(Trinity Consultants, 2010b)

Year 4:



(Trinity Consultants, 2010b)

Year 5:



(Trinity Consultants, 2010b)

APPENDIX D

COMMONLY USED ACRONYMS

AERMOD: American Meteorological Society Environmental Protection Agency Regulatory Model

CAA: Clean Air Act

CAMD: Clean Air Markets Division (EPA)

CAAA: Clean Air Act Amendments

CASAC: Clean Air Science Advisory Council

CATR: Clean Air Transport Rule

CBSA: Core Based Statistical Area

CFR: Code of Federal Regulation

CMAQ: Community Multiscale Air Quality model

EGU MACT: Electric Generating Unit Maximum Achievable Control Technology Standard

EPA: Environmental Protection Agency

GW: Gigawatts

ISA: Integrated Sciences Assessment

ISC: Industrial Source Complex model

MW: Megawatts

NAAQS: National Ambient Air Quality Standard

NCDC: National Climatic Data Center

NEI: National Emission Inventory

NSR: New Source Review

NOx: Oxides of Nitrogen

NOAA: National Oceanic and Atmospheric Administration

$PM_{2.5}$: Particulate Matter less than 2.5 microns

PM_{10}: Particulate Matter less than 10 microns

ppb: Parts per billion

ppm: Parts per million

PWEI: Population Weighted Emission Index

REA: Risk Exposure Assessment

SIP: State Implementation Plan

SO2: Sulfur Dioxide

USC: United States Code

USGS: United State Geological Survey

UTM: Universal Trans Mercator

VOC: Volatile Organic Compound

WEPCO: Wisconsin Electric Power Company

WGS: Wet Gas Scrubbers

APPENDIX E

CALCULATIONS

Calculation 1)

B002: 3028.2 Tons per year
B003: 2897.9 Tons per year
B004: 5271.9 Tons per year
Total: 11198 Tons per year

(11198 Tons per year * 2000 Pounds/Ton) = 22396000 pounds per year

22396000 pounds per year / 8760 hours per year = 2556.62 pound/hour

2556.62 pounds per hour = 322.13 grams per second

Calculation 2)

Unit 1 Mass emissions: 24946.7 Tons per year
Unit 2 Mass emissions: 27230.1 Tons per year
Total: 52176 Tons Per year

52176 Tons per year * 2000 pounds per ton = 104352000 pounds per year

104352000 pounds per year / 8760 hours per year = 11912 pounds/hour

11912 pounds per hour = 1500.89 grams per second.

Calculation 3)

2010 First Quarter:
Unit 3 mass: 139.0 Tons   Operating time: 1989 hours
Unit 4 mass: 134.7 Tons   Operating time: 2054 hours

2010 Second Quarter:
Unit 3 mass: 149 Tons   Operating time: 2087 hours
Unit 4 mass: 126 Tons   Operating time: 2006 hours

2010 Third Quarter:
Unit 3 mass: 110.7 Tons   Operating time: 2039 hours
Unit 4 mass: 134.7 Tons   Operating time: 2202 hours

Totals through the end of the third quarter
Unit 3 mass: 398.0   Operating time: 6115
Unit 4 mass: 395.4   Operating time: 6262

Since this data was accessed prior to the end of the fourth quarter, no valid data exists for that quarter.

Unit 3 emission rate: (398.0 tons*2000 pounds/ton) / 6115 hours of operation = 130.0 pounds per hour

Unit 4 emission rate: (395.4 tons*2000 pounds/ton) / 6262 hours of operation = 126.3 pounds per hour

Unit 3 emission rate in gr/sec: 16.4 grams/second
Unit 4 emission rate in gr/sec: 15.9 grams/second

Combined emission rate = 32.3 grams per second

Calculation 4)

SO_2 EF = 1751249*2*0.97753*0.027 = 92442.52 grams/hr of SO_2

Converting to grams per second 92442.52 gr/hr * 1hr/3600 sec

= 25.67 grams per second at 100% load

= 6.42 grams per second at 25% load (representing loading, unloading, hotelling, and maneuvering)

Calculation 5)

BSFC = 1751249 grams of fuel per hour (from equation 3.2, p. 79)

1751249 grams of fuel per hr = 3860.8 pounds of fuel per hour

3860.8 lbs/hr of fuel * 14.1 lbs of air/lb of fuel = 54437.3 lb/hr of air

54437.3 lbs of air per hour = 6859.0 grams per second

Reduced load (to 25%) = 1714.8 grams per second

1 gram of air = 0.775 L of air - based on density of air

1714.8 of air per second = 1329.0 L per second

1L = 0.001 cubic meters per second

1329.0 L/second = 1.33 cubic meters per second at 0% excess air