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Modeled sulfur dioxide exposure from a proposed coal fired power plant, using geographic information systems and air dispersion modeling

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Modeled Sulfur Dioxide Exposure from a Proposed Coal Fired Power Plant, using Geographic Information Systems and Air Dispersion Modeling

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Thesis submitted to the College of Engineering and Mineral Resources at West Virginia
University in partial fulfillment of the requirements for the degree of

Master of Science

in

Safety Management

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Abstract

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Steven Jason Hutchens

This study models the contribution of sulfur dioxide (SO₂) from a proposed coal fired power plant (CFPP) above existing ambient levels. Most vulnerable to SO₂ exposure appear to be the elderly, young, and diseased, here identified as sensitive receptors (SR). Epidemiologic studies suggest 260µg/m³ as the lowest toxic threshold for SR exposure. It was hypothesized that added SO₂ concentrations to existing ambient levels at regional sensitive receptors, under worst case scenario, would not exceed 260µg/m³.

The methods used identify and quantify density locations of localized SR using geographic information systems. Modeled worst case air dispersion concentration exposure to localized SR was conducted using AERMOD. A kriged surface of 1145 modeled concentration points was generated to interpolate contour intervals of concentration contribution. Results show an increased exposure to 1.82µg/m³ SO₂, well within 260µg/m³. A higher density of young SR were observed than for the elderly and diseased.

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List of Acronyms

2D - 2 Dimensional
3D - 3 Dimensional
AERMAP - American Meteorological Society/Environmental Protection Regulatory
Terrain Preprocessor
AERMET - American Meteorological Society/Environmental Protection Regulatory
Meteorology Preprocessor
AERMOD - American Meteorological Society/Environmental Protection Regulatory Model
ANS - Autonomic Nervous System
ATSDR - Agency for Toxic Substance and Disease Registry
CAA - Clean Air Act
CAD - Computer Assisted Drafting
CFPP - Coal Fired Power Plant
CFR - Code of Federal Regulations
COPD - Chronic Obstructive Pulmonary Disease
DBF - Database File
DEM - Digital Elevation Model
ESRI - Environmental Research Institute
FAA - Federal Aviation Administration
FIPS - Federal Information Providing Service
GCS - Geographic Coordinate System
GEP - Good Engineering Practices
GIS - Geographic Information Systems
ISC - Industrial Source Complex Model
LIDAR - Light Detection and Ranging
NAAQS - National Ambient Air Quality Standards
NAD - North American Datum
NAMS - National Air Monitoring System
NO_x - Nitrous Oxides
PASDA - Pennsylvania Spatial Data Access
PBL - Planetary Boundary Layer
PSD - Prevention of Significant Deterioration
SBL - Stable Boundary Layer
SLAMS - State Local Air Monitoring System
SO₂ - Sulfur Dioxide
TRI - Toxic Release Inventory
UCS - User Coordinate System
US EPA - United States Environmental Protection Agency
USGS - United States Geological Survey
UTM - Universal Transverse Mercator
VOC - Volatile Organic Compounds
WCS - World Coordinate System

**List of Acronyms
(continued)**

WV DAQ - West Virginia Division of Air Quality
WV DEP - West Virginia Department of Environmental Protection
WV NRAC - West Virginia Natural Resources Analysis Center
WVU - West Virginia University
ZCTA - Zip Code Tabulation Area

Chapter One - Introduction

Today, there is an ongoing debate regarding the health effects of coal fired power plant (CFPP) emissions, especially on vulnerable populations of society, particularly the elderly, sick, and young. Sulfur Dioxide (SO_2) is a major pollutant of concern. Industrial smog occurs when carbon and oxygen come together to form carbon dioxide and carbon monoxide, or when sulfur compounds come together with oxygen, forming SO_2 . State air monitoring systems throughout the country are currently collecting and analyzing concentrations of SO_2 . SO_2 emissions are a result of fossil fuel combustion. The goal of this thesis was to estimate from GIS spatial analysis and dispersion modeling the contribution of SO_2 , from a proposed new coal-fired electricity generating plant under review for construction, to potential human exposure. This new plant is to be located near the Monongahela River valley in Monongalia County West Virginia. Two existing CFPP are currently located within the valley, in the same county along the same river.

This thesis hypothesizes that the added SO_2 concentration contribution from the new CFPP to existing ambient levels of SO_2 at regional sensitive receptors, under worst case scenario, will not exceed the provisional maximum ambient SO_2 concentration for this study, or other applicable air quality standards. The direct contribution of SO_2 from the proposed power plant to sensitive receptors, under worst case scenario, was analyzed through dispersion modeling and spatial analysis. Worst case scenario, is to be defined in this study, as the highest modeled 24 hour average pollutant contribution concentrations. In designing this research, it was assumed that through dispersion of its SO_2 concentrations under such circumstances, ambient air concentrations will show an increase of the pollutant at prioritized sensitive receptors, contributed by the new CFPP. A discussion of the provisional maximum ambient SO_2 concentration for this

study and air quality standards are to follow.

1.1 Problem Statement

Throughout the past decade, health concerns surrounding air pollution has increased. Evidence of such concerns has mounted, through extensive research conducted, both on small- and large-scale areas, by government, the private sector, and universities. Research on SO₂ has been shown to have respiratory impacts on all living organisms tested. Among humans, the elderly, sick, and young are of greatest concern because they are more vulnerable to health damage from industrial smog^{1,11,12,15,17,19,23,32,38}

The study area of this thesis, outward from the proposed CFPP to a 30 kilometer radius, includes the city of greater Morgantown. The enhanced SO₂ exposure modeled for the local air quality region was added to ambient monitored background concentrations for SO₂ (a criteria pollutant) for the same year.⁶² The local air quality region, including greater Morgantown, is currently within primary National Ambient Air Quality Standards (NAAQS) attainment for SO₂. The overall goal of this thesis was to assess the proposed new CFPP SO₂ contribution to exposure of sensitive populations in the area, seeing if these proposed emissions are likely to advance the study area into an un-healthy, non-attainment region for SO₂, as discussed in the following section. Therefore, I modeled the transport and dispersion of SO₂ emissions from the proposed CFPP to local prioritized sensitive receptor locations, which were identified using Geographic Information Systems (GIS).

The volume of spatial research regarding exposure of sensitive populations to air polluting sources is vastly expanding across the world^{10,11,38,43,45,51} showing a cause for concern. Like most of the Mid-Atlantic and Northeast regions of the United States, Morgantown and the surrounding

area are characteristically subjected to coal fired power plant (CFPP) emissions. Coal production and coal produced electricity are major industries in the region, producing emissions which are complex to model, due to the complex meteorology conditions associated with surrounding mountainous topology (as discussed below).

Compliance type modeling of regional air pollution, as defined by the Clean Air Act (CAA) and its regulations has been the only type of air dispersion modeling conducted within the region recently. There has been very limited air pollution modeling conducted on the surrounding region at West Virginia University or by other entities. For this reason, I decided that allowing the addition of another CFPP in the region warranted a review of its direct contribution to already existing air pollution concentrations, as well as review of sensitive population exposures in the area. Air dispersion modeling is continually evolving in technology and use, due to the increased pressure of concern for health threat from air pollution. Scientist's, epidemiologist's, air dispersion modelers, public health authorities, Geographic Information Systems (GIS) professionals, the federal government, and academic communities are all contributing to this body of research around the world^{1,11,12,20,22,24,41,63}.

Chapter Two - Overview of Literature

2.1 Health concerns surrounding SO₂

Sulfur dioxide is formed mostly during combustion of fossil fuels containing sulfur, but can form from other industrial processes as well. The literature contains substantial data, as evidence for the relationship between monitored ambient levels or experimentally defined exposure levels and associated health effects of sulfur dioxide. Recent monitoring and health studies have implicated that high concentrations of SO₂ aggravate lung and cardiovascular diseases, and may disrupt respiratory defenses and the nervous system.^{11,12,15,22,23,32,47,52} Evidence has also been published that SO₂, present at high enough concentrations, can disrupt the breathing of healthy individuals.^{11,17,33,42,45,47,54,55,60}

Clinical studies have demonstrated that in adolescents and senior citizens, susceptibility to SO₂ is determined primarily by respiratory health, not by age alone.⁷² The minimal risk level for sulfur dioxide, according to the Agency for Toxic Substances and Disease Registry (ATSDR) is 260 µg/m³.⁷² This is the lowest level at which increased bronchioconstriction of humans has been recognized in epidemiological studies and is set to be the provisionally maximum ambient air concentration of this study. Due to such literature evidence, the United States Environmental Protection Agency (EPA) and West Virginia Division Air Quality consider SO₂ a harmful pollutant to public health. Therefore EPA has promulgated an ambient primary standard for SO₂ to protect public health, as a criteria air pollutant NAAQS, requiring regular ambient monitoring by states.

Health problems associated with air pollution are not new information. The public health effects of air pollution have been a concern for quite some time.^{2,11,19,41,45,46,60} Citizens demands

for cleaner air and subsequent legislation began in the late 1940's when it became apparent that air pollution episodes were effecting public health. One such event occurred in October of 1948, within the same river valley as the proposed power plant being evaluated in this thesis. During late October of that year, a six day, increased air pollution episode in the Monongahela River Valley, in Donora, Pennsylvania, resulted in several deaths and thousands of residents suffering additional adverse health effects.⁴⁶ Around the same time period, other episodes were starting to be noticed throughout the world, gaining more attention from scientists and the public, stimulating the passage of new clean air legislation.¹⁷ Since then massive research has been devoted toward the association of air pollution with health deterioration.

Many laboratory animal and epidemiological studies have been conducted on the health effects of different criteria air pollutants, including sulfur dioxide. Scientists have emphasized the need to establish a biological plausible link between the health effects and air pollution, as described in many epidemiological reports.^{12,22,28,33,41,46,47,52,53,54,55,65} One animal study involved administration of sulfur dioxide by inhalation to healthy adult mice that resulted in oxidative damage to stomachs and intestines.²⁸ This study concluded that SO₂ can also be a toxic agent to stomach and intestines of mammals, in addition to its toxicity to the respiratory system.²⁸

Another recent study observed heart rate variability in non-exercising asthmatic adult humans undergoing SO₂ pollutant exposure.⁵⁴ This study found that the autonomic nervous system (ANS) may be influenced by SO₂ at concentrations frequently encountered during air pollution episodes.⁵⁴ The ANS is the part of nervous system that regulates vegetative organs of the body, such as the functions of heart, stomach, intestines, and other smooth muscle. ANS functions are reflexive and involuntary, controlling heart beat, blood pressure, iris in the eye,

urinary and gall bladders, among other tissues and organs. The research on effects of exposure of SO₂ on the ANS has recently expanded.^{22,54}

It is well established that SO₂ is a strong respiratory irritant to both humans and animals. SO₂ exposure has different consequences depending on the health and age of an individual human or animal, and on concentration and duration of exposure. Recent studies suggest larger concentrations of SO₂ create more severe health effects, a dose/response effect.^{28,47,52} Large concentrations of SO₂ are now thought to cause premature death in individuals with pre-existing heart and lung disease and also to aggravate asthma and other lung diseases in individuals of all ages. Research is showing that active asthmatics, the elderly, and very young are more susceptible to SO₂ because of pre-existing medical condition and weaker immune systems, as is the case with most other criteria pollutants.⁶² The human immune system deteriorates from aging, and may be further weakened by disease, improving the likelihood for infection. Immune systems in infants and young children are still developing. Exposing these infants and young children to SO₂ levels alone appear to intensify existing illness. A group of panel studies have been conducted on humans diagnosed with chronic obstructive pulmonary disease (COPD), which includes asthma, chronic bronchitis, bronchiectasis and emphysema.³³ During maximum SO₂ exposure in these studies, 4200 µg/m³ for 3 minutes, wheezing on the same day was observed, as well as at 24 hours and up to 48 hours later.³³

As one can see, evidence is very strong that adverse health consequences are clearly associated with the inhalation of sulfur dioxide environmental air pollution. As mentioned above, epidemiologic studies have drawn such association. The body of such causality studies continues to grow. Causality studies, in this context, are those in which human volunteers are the study and

control samples of the population, giving us more accurate insight towards the detrimental effects of particular exposure concentrations and durations on humans for a particular pollutant of concern. Causality studies give scientists a firmer estimate of risk to humans than those results extrapolated across species from studying rats and other laboratory animal models. Sufficient data are now available to support the need to assess public health risks associated with SO₂, among other criteria pollutants.

Various epidemiologic studies have been conducted internationally. In summary, such studies continue to find disproportionately high respiratory diseases in children in urban areas throughout the United States and in other countries.^{12,38} Epidemiologic studies involve drawing correlations between exposure estimates, air monitoring, biological samples, questionnaire responses, functional studies, and other, medical outcomes. In some types of epidemiologic study design, where possible, the effects on samples of exposed groups of individuals are compared with samples of unexposed groups.

2.2 Air Quality Standards on SO₂ attainment, and Air Quality of Surrounding Region

Recognition that high levels of air pollution induce or aggravate certain respiratory illnesses as well as strong lobbying of Congress by citizen's groups, led to the establishment of the Clean Air Act in 1970.^{19,62} The goal of the act was to set and achieve National Ambient Air Quality Standards (NAAQS). Primary versus secondary standards are discussed below. Later amendments to the Act required prevention of significant deterioration (PSD) of areas with pristine air quality and those populated non-pristine regions already in attainment with NAAQS. The CAA Amendments of 1977 established the requirement that US EPA designate maximum

PSD increments, classified per region, for all criteria pollutants. There are three PSD classifications. Class I areas include those regions with pristine air quality, like wilderness areas, and other national parks. Class II areas are non-pristine areas that are well within NAAQS attainment. Class III are those regions not in attainment with NAAQS and must strive for Class II advancement.

Currently the State of West Virginia, Department of Environmental Protection (DEP) Division of Air Quality (DAQ) monitors ambient air compliance in the air quality regions within the state to ensure NAAQS attainments are maintained. Using both continuous and periodic monitoring systems strategically located throughout the state, the air monitoring division of WV DAQ collects, analyzes and reports on air monitored concentrations; these data are available to the public. The US EPA requires each state to develop a State Implementation Plan (SIP), acceptable to the EPA, for attaining NAAQS compliance in non-attainment air quality regions and to maintain compliance. Currently the West Virginia State Implementation Plan (SIP) requirement for ambient air monitoring for criteria pollutants meets guidelines set forth by the EPA. As stated in 40 CFR 51.166,⁶ all SIP shall contain emission limitations and such other measures as may be necessary to prevent significant deterioration of air quality that is in attainment to NAAQS.

PSD increments for pollutants within attainment are established in the WV SIP in order to prevent existing ambient air pollution from deteriorating, by maintaining attainment levels of all NAAQS criteria pollutants, including SO₂. One PSD increment allotted for all contributing sources, including the proposed CFPP, is a maximum of 91 µg/m³ of SO₂ in an averaging period of 24 hours.⁵⁷ This is an amount that all regional air polluting facilities will be able to emit

without causing a significant deterioration in air quality which would further push the area significantly toward non-attainment, for that PSD increment. The last major PSD increment consuming source addition was the Beehurst Power Plant in Morgantown at the shore of the Monongahela River in 1989. This addition, together with all other increment consuming sources in 1988, modeled an increment consumption that nearly consumed the entire $91 \mu\text{g}/\text{m}^3$ of SO_2 in an averaging period of 24 hours, PSD increment.⁷⁰ This is addressed, in detail, in chapter 5.

Whereas the PSD increment allowed by the US EPA for all Class II regions is fitted at $91 \mu\text{g}/\text{m}^3$, the proportion of this increment actually used by regional sources, as 24-hour averages over a year, will vary from year to year. This work has assumed that the totality (or number) of all other contributing sources has not varied, with the naturally varying PSD increment consumption from year to year, in the time span since Beehurst Power Plant. Any contribution from the new CFPP source would be the only source potentially causing the region to exceed the allowed leftover PSD increment.

The PSD increment level of $91 \mu\text{g}/\text{m}^3$ of SO_2 in an averaging period of 24 hours is going to be the chosen air quality standard level for interpreting the exposure contribution modeled from the proposed CFPP in this thesis. Any contribution exposure levels modeled to exceed $91 \mu\text{g}/\text{m}^3$ in a 24 hour averaging period at spatially analyzed and prioritized sensitive receptors will be assumed to exceed the standard, therefore potentially creating levels harmful to human health. Relative to the usual range of emission rates from nearby CFPP sources, and other air polluting sources, this permitted PSD increment is huge, that is, very generous to regional air polluting businesses given today's Best Available Control Technologies (BACT). While development of the primary NAAQS is based on protecting human health and property (primary and secondary

pollutants), the PSD is based on what emission control is achievable, using BACT available at the time a PSD increment consumption is determined by the SIP modeling requirements and US EPA.

As described above, SO₂ aggravates lung and cardiovascular diseases, and may disrupt respiratory defenses and the autonomic nervous system. SO₂ is a criteria pollutant to which both primary and secondary NAAQS apply. The Clean Air Act mandates EPA to establish the more strict primary ambient air standards to protect public health, including the health of sensitive groups. A margin of safety that includes consideration of uncertainties in knowledge is also mandated, which leads to continual research and review of ambient air standards. In addition, the EPA must establish a secondary NAAQS for all criteria pollutants, including SO₂, which is a less strict, higher concentration, in order to protect property from damage (Table 2.1).

Below are tables from EPA and the PSD Permit Application for the proposed CFPP, indicating NAAQS standards and PSD Increment levels, of SO.^{57,60} These NAAQS values represent thresholds for non-attainment. Each CFPP and other air emitters within the state share the combined amount of on-site air releases, designated by the EPA and WV DAQ in increment levels for each site, as not to exceed the NAAQS threshold. Currently WV DEP models for compliance, all emission sources contributing to PSD increment levels.

Table 2.1 NAAQS for SO₂

Averaging Period	Standard Value	Standard Type
Annual Arithmetic Mean	80 µg/m ³	Primary
24-hour Average	365 µg/m ³	Primary
3-hour Average	1300 µg/m ³	Secondary

Table 2.2 PSD Increments Levels for SO₂ for All Class II Air Quality Regions

Averaging Period	PSD Increment
Annual Arithmetic Mean	20 µg/m ³
24-hour Average	91 µg/m ³
3-hour Average	521 µg/m ³

Given the population size and industries of northern West Virginia and the surrounding region, ambient air standard attainment is met for most of the year.^{2,25,37,64} The proposed study area, explained in more detail in the following chapter, is going to be within a 30 km radius of the proposed new stack location. This reaches far into Pennsylvania, and West Virginia. Beyond the proposed study area, the consensus from the literature is that coal fired power plants are one of the most significant SO₂ polluters within this Northern Appalachian region.^{2,11,59} It is important to note, that if industries in this region continue to grow, SO₂ ambient air standard attainment may be lost. Greater Morgantown is steadily growing and has recently been assigned metropolitan status by the US Census Bureau, based on the 2000 Census.

The study area is within one of the primary bituminous coal-producing regions of the U.S., so naturally all nearby electric power plants are fueled by bituminous coal, which is known to produce higher amounts of SO₂ than other grades of coal. The proposed power plant emissions could locally affect northern West Virginia and nearby states as well. As stated earlier, the proposed site is roughly 2 miles, straight line distance, south of the Pennsylvania state line and the prevailing wind for area ridge tops, where the proposed CFPP is to be constructed, are directed toward the east-northeast. It is important to note however, that prevailing wind direction changes inside valleys compared to surrounding ridge tops. Both states are currently meeting NAAQS

attainment for SO₂ withing the region.^{25,37,65}

For West Virginia and Pennsylvania, this area contains various air polluting industries.^{2,59} The Toxic Release Inventories (TRI) for various years, for each of these states, cite CFPPs as the largest stationary source contributors of on-site releases in pounds of SO₂ for air pollution. Allegheny Energy Inc., Fort Martin Power Station, Maidsville, West Virginia was third, on the top ten list of facilities, cited per pound of emissions, on the EPA TRI Fact Sheet for 2000 in West Virginia. The site location for the proposed plant is located on the hillside above Fort Martin, less than 2 miles straight line distance to the south-southwest. Four out of the top ten CFPP emitters in West Virginia, cited air pounds of SO₂ emissions per year, in this Fact Sheet are the counties within the proposed study area. Allegheny Energy Inc., Hatfield Power Station, Masontown, Pennsylvania, was third on the top ten facilities list for Pennsylvania.⁵⁹ Hatfield power plant is along the same Monongahela River valley as Fort Martin. Fort Martin is northwest in this valley but at an altitude substantially lower than the proposed CFPP location.

As discussed above, the surrounding region already contains a significant amount of CFPP emissions being emitted to local ambient air, which are among the largest CFPP emissions within each of these states. The State TRI's for this area cite some of the largest SO₂ emissions from other industry sectors as well.⁵⁹ Weather patterns, topological features, and changing seasons govern the dispersion of air pollution. Topological features can play a significant role in the dispersal CFPP emissions. Mountainous regions such as in this Appalachian area often prevent adequate dispersion of air pollution from industrial stack emissions. The established pollution situation, within the study area, in place prior to the construction of the proposed CFPP, could lead to further air pollution modeling research following this thesis.

2.3 Air Pollution Meteorology: Effects of Temperature Inversions and Wind Velocity on Pollutant Dispersion

As stated earlier, Donora, PA sits within a river valley that is in the proposed study region, where a severe upper air subsidence inversion associated with a stagnant high pressure system, together with low layer air radiation inversion episode caused 20 deaths and injured several thousand in October of 1948.^{13,21,42,46}

Microscale meteorology dictates weather behavior in the layer closest to the surface of the earth. Macroscale meteorology usually dictates weather in the atmospheric layers above the surface layer. An example of macroscale meteorology are those conditions covering large regions, like the huge stagnant prevailing high pressure system that extended over a greater portion of the entire eastern half of the United States during the Donora episode.⁴⁶ These high pressure systems normally produce sunny, dry warm days with calm winds. High pressure systems are those of a huge warming descending air mass, producing what is called an upper air subsidence inversion.

Within the descending high pressure system, air pressure increases with descent, causing the temperature of the upper air mass to increase as it subsides. This subsidence usually settles above a much smaller, cooler surface air mass (altitude where the two air masses meet). The normal decrease in temperature observed usually with an increase in altitude from the ground surface up, is interrupted, or inverted, thus the term subsidence inversion. The stable boundary layer between the smaller, cooler, lower air mass serves as a barrier to vertical dispersion of air pollution. Under such conditions, this stable boundary layer, preventing vertical dispersion of the plume, determines the plume mixing height.

Microscale meteorology refers to those conditions controlled by local factors, in shallow

layers of surface air, such as the radiative cooling of surface air, at night, sometimes referred to as nocturnal radiation inversion. Nocturnal radiation inversions can also produce fog if the shallow surface layer is more moist than the layer above and it cools to its established dew point (which was the case at Donora). The dew point is the temperature at which moisture in a given parcel of air will condense. Wind and increased air temperature serve to disperse fog. At Donora, daytime sunlight was not reaching the earth's surface due to fog formation, so the air directly above the surface, in the Monongahela River Valley, remained cool and foggy during those October days in 1948.⁴⁶ The high fog and pollutant concentration, together called smog, prevented the sun's radiating heat from penetrating to the valley floor, which would normally erode the surface layer radiation inversion during the day. As a result of calm winds and the decoupling meteorology conditions between these two air masses, the pollution concentrations in the valley increased to fatal levels.^{46,50}

When macroscale and Microscale meteorology are coupled, or in sync, conditions are such that vertical motion is induced in both layers and adequate vertical mixing and dispersion of pollutants occurs. Wind can also be an important driving factor of pollutant dispersion in both the upper air masses and surface air masses, when they are coupled. But in the case of Donora, winds were negligible as the two air mass systems remained stable and uncoupled.

This Donora episode helped motivate the clean air movement which led to the enactment of the original precursors of the Clean Air Act (CAA) in 1970. The Monongahela River valley generally has steep hills on both sides. During this episode, pollutant emissions to the air, that were normally dispersed by the prevailing westerly winds, became trapped within stagnant air.^{13,21,42,46} Air pollution episodes as strong as the one in Donora, October 1948, are encouraged

by meteorological processes discussed above, and even more complex processes not fully understood by scientists, both on large and small scales. Such weather episodes are a result of more complex macroscale and Microscale meteorological processes than what is fully understood by scientist's of upper air subsidence inversions and radiation inversions, within two different atmospheric layers.

As occurred in Denora, PA, radiation inversions in a river valley with industrial areas can result in extreme human exposure to toxic air pollutants. This thesis's study area, as well as most of Appalachia, experience radiation inversion episodes occurring throughout different times of the year depending on cloud cover and wind speed during the night.^{4,46,49,50} Episodes of extreme stagnate high pressure systems associated with a subsidence inversion occur more frequently during certain spring and fall months, in Appalachia valleys; April - June and September - October. See Figures1 and 2 below. The combination of theses two types of inversions, radiation and subsidence, occurring at the same time, become a problem in urban areas. Under inversion conditions, pollutants from industry can become trapped near the ground in urban areas, potentially harming those breathing that air, instead of dispersing out of the area due to natural wind current and vertical turbulent mixing.^{19,30,46} Human activities, releasing pollutants, including industry, cause the problem not the naturally occurring phenomena. The build up of air pollution to harmful levels depends on a number of factors including the specific local pollutants, the length of time of the inversion episode(s), and the location of people during an episode(s). Air inversions break up when either a strong, cooler, frontal system moves in to replace the stagnant high pressure system, or when the sun radiates through to the earth's surface or valley floor, heating the surface and surrounding layers of air causing them to rise. Cold air aloft then subsides

replacing the warm rising air that was acting as a lid, so that the air near the ground is no longer trapped.^{30,45,50}

Figure 1 : Stagnation Index for May 2000. This image depicts the percentage of days air stagnation occurred in West Virginia and surrounding states during that month, 2000.

Figure 2 : Stagnation Index for September 2000. This image depicts the percentage of days air stagnation occurred in West Virginia and surrounding states during that month, 2000.

Legend

The complexity of various types of atmospheric inversions has only been briefly discussed. Much is yet to be understood about the many variables required for accurately predicting extreme pollution episodes. EPA recognizes inversion trapped polluted air as unhealthy to breathe⁶⁰ and is currently funding research to model for inversion episodes in mountainous terrain in order to establish areas most susceptible to inversion pollution episodes.

Figures 1 and 2 show some maps provided by the National Oceanic Atmospheric Administration depicting percentage of days air stagnation occurs in West Virginia and surrounding regions during the months of May and September 2000. Stagnations are associated with slow moving high pressure systems with light winds in a stable lower atmosphere. Light winds and a stable lower atmosphere prevent to dispersion of pollutants. Maps of these same months are available from 1973 through 2002. Similar maps for radiation inversion and subsidence inversion frequencies have not been located.

As has been established, radiation inversions and air stagnation episodes play a major role in the failure of dispersion of air pollution. Such conditions were assumed in this thesis to be contributory to modeled worst case scenarios for human exposure. The geography and climatology of Morgantown meet criteria required for occurrence of both radiation caused thermal inversions and simultaneous upper air subsidence inversions associated with stagnations.

Another prime meteorological condition assumed in this thesis be contributory to modeled worst case scenarios for human exposure is extremely high wind velocity, inducing conditions know as stack tip or direction specific building downwash. Stack tip downwash is a result of a streamline of wind becoming interrupted by the stack and as a result, eddies (swirling motions of air) form in lee of stack, causing the plume to bend downward eliminating vertical

mixing and dispersion.¹⁹ Direction-specific building downwash occurs when a streamline of wind is interrupted by a building, or series of buildings, causing eddies to form on the lee side of the building(s), forming a wake which travels over the building, recirculating eddies on the lee side called the cavity.¹³ Emissions released at, or close to the same elevations of surrounding buildings can disperse into the wake and “lee” cavity of a building. In building downwash conditions, pollutant concentrations have the potential to become trapped and accumulate in the cavity on the lee side. If the condition persists, the accumulating pollutant mass on the lee side of the building will increase resulting in higher ground level concentrations in the cavity, called fumigation from source. These conditions, are of great concern and can be very dangerous to workers, or nearby sensitive receptor populations, of any facility emitting emissions through a source stack. A much higher stack can greatly reduce this likelihood of dangerous cavity fumigation.

2.4 Comparison of Air Dispersion Modeling Approaches

2.4.1 Introduction

Models are used in science to produce simplified pictures of reality. As is the case in air dispersion modeling, the advancement of knowledge surrounding the science and the respective theories being questioned or applied, often contain less features than those systems occurring in nature. Although it is much more complex, in simple terms, pollutants emitted into the air are mostly transported by wind and turbulence, becoming mixed with the ambient air over time. This mixing either increases or dilutes the emitted pollutant(s) concentration depending on the pre-existing concentration of pollutant(s) in the ambient air. Features accounted for in the most modern computer simulated models included emission rates, site characteristics, topology (terrain

elevation change), background concentrations, and available recorded weather data.

The preceding explanation of air pollution concentration modeling is a simplified introduction. Realistically modeling the transport of pollutants through the atmosphere is rather more complex. Many variables, not always necessarily available, need to be accounted for to accurately portray actual air pollution movement in the atmosphere. The mathematical calculations used to predict the transported concentrations of pollutants in today's latest models remain restrictive because of the tremendous meteorological effects operating on air pollutants that are yet to be completely understood. Instantaneous micro-meteorological effects, operating on pollutants continually change. Current technology is unable to account for these ever changing conditions, unless very costly detailed monitoring data can be recorded. The most common air pollution concentration modeling method for receptors near the source is described by a Gaussian distribution, which attempts to overcome the changing micro-meteorological conditions by averaging out the changes over time. Researchers, weather measuring instruments, and the mathematical computer simulations used to model the transport of air pollution concentrations are continually improving, as discussed in the following section of the thesis.

Model complexity varies, depending on the type of air pollution source(s) being modeled. Three most common types of sources include point sources, line sources and area sources. Point sources are identified as being industrial stacks, or chimneys, from chemical plants, other manufacturing plants, or a power plant, such as the proposed power plant being evaluated in this thesis. Examples of other sources, although not being evaluated in this thesis, include mobile source emissions (on- or off-roadway), and industrial storage or refuse pile emissions, often referred to in air pollution literature as line or area sources.^{14,16,19}

Three common types of air pollution concentration modeling found in literature, beginning from the simplest to the most complex, are fixed box-models, dispersion models, and multiple cell models.³¹ Each type of model becomes more detailed, accounting for more natural features and source types. The more natural features and sources accounted for in a model, the more digital data gathering, labor and computer power are needed to run the model. In return, however, models accounting for more natural features are more complex and are assumed to be more accurate with actual scenarios.

2.4.2 Fixed Box Models

As stated earlier, fixed box-models are over simplified and depict the most unrealistic concentration values. Applying a general balance equation, such models involve constructing a box over an entire city and calculating flows in and out of the box to obtain a concentration value inside the box ³¹. The sides of the box border both sides of the city, usually in the x direction, and are parallel with predominant wind direction. The city rests on the base/floor of the box while the top face of the box is established as the mixing height, in the z direction. Finally enclosing the system are the upwind and downwind faces adjacent to the parallel sides in the y direction, on both ends of the city.

Flows into a fixed-box model include emissions from the city through the base/floor, and wind from the upwind face of the box. Flows out of the box include emissions and upwind air currents added to the system through the upwind face. By subtracting the flows out from the flows in (a general balance equation) an average concentration above the city may be calculated. Values calculated using this method are extremely high, over exaggerating the ambient air pollution concentration within the box. The reason for this is because of the over simplified

assumptions made while constructing the model. As stated by Never, “several of the assumptions made using the fixed-box model are quit contrary to what is observed in nature.”³¹ Wind velocity and direction is assumed to be the same at all elevations in the box. In nature, wind velocity increases with an increase in elevation and continually changes direction at all elevations. Also, various types of emissions, from point and mobile sources, are combined into one uniform value for the city. Realistically, these emissions are emitted at different locations and elevations, initially subject to different surface micro-meteorology conditions (horizontal and vertical mixing parameters).

Complex micro- meteorology, effects the vertical and horizontal mixing of emissions at their sources, and are usually not taken into consideration in the fixed-box type of model. For example, wind velocity is often the only meteorological parameter considered in a fixed-box model. Temperature profile and atmospheric stability classifications, along with wind velocity and direction, are considered in other model designs, leading to more realistic calculated exposure values.

2.4.3 Multiple Cell Models

The most realistic model calculations can be obtained through multiple cell models, or an airshed model. As described by Never, ³¹these models consist of the airspace over an entire city or region divided into multiple cells, with each cell calculated separately from the others. These models contain uniform grid sizes, normally 2 to 5 km in the x and y direction, with half the stacked layers above the mixing height and the other half below, in the z direction. Flows, from all sources, in and out of each cell are calculated much like that in the preceding box model discussion. Each cell concentration calculated takes into account the different micro-

meteorological conditions, (temperature profile and stability, wind velocity, direction, etc.) that occurred throughout different times of the day within that particular cell. Light Detection and Ranging (LIDAR)¹ systems may be used to provide the type of weather data needed in each cell, measuring wind velocity, elevation, and chemical composition within.²⁹

Depending on the size of the city, these models may range anywhere from 100 to a 1000 or more cells. The chemical composition of each cell must be calculated, pollutant sources determined, and each cell's individual pollutant concentration summed, to receive total concentration per pollutant in multiple cell models. Given the size of data input into a multiple cell model, it requires large computer systems, expensive software, expensive weather measuring equipment, and many data collection and modeling hours. Currently, these models are only being used to model reactive atmospheric pollutants, such as conversion of Nitrous Oxide (NO_x) and Volatile Organic Compounds (VOC) to ground level O₃. Both NO_x and VOC serve as precursors to the formation of ground level ozone. These air pollutants, together with O₂, in the presence of high heat form ground level O₃ during summer months.

2.4.4 Plume Dispersion Models

Given current levels of air pollution concentration modeling technology, the most common modeling approach is through the dispersion, sometime referred to as the diffusion, model process. Throughout air pollution literature the word diffusion and dispersion are used interchangeably.^{31,35,63} Diffusion is often associated with molecular diffusion. Molecular diffusion is the mixing of substances through random molecular motion. Here, different substances are

¹LIDAR instruments transmit and receive electromagnetic radiation at high a frequency (ultraviolet, visible and infrared region of the electromagnetic spectrum). Different types of physical processes and chemical composition in the atmosphere are related to different types of light scattering. Choosing and evaluating for different types of scattering processes allows atmospheric composition, temperature, and wind to be measured.

mixed together as a result of each substance's molecules and ions being under constant random motion.²⁷ That simply is not the case with these types of air pollution concentration models. Molecular diffusion obviously occurs with emitted pollutants, however, it is not the principal mechanism described, and discussed below, by some of these types of models.³¹

Dispersion models attempt to calculate the average emission concentration flow directly from their source, using the well known Gaussian plume methods, or other Non-Gaussian plume methods.^{6,7} In this thesis, I used calculated results from the Gaussian plume method, only. Non-Gaussian plume methods include different probability functions, and are used to predict dispersion under atmospheric instability⁶. This thesis is only concerned with downwind dispersion of plume concentration during atmospheric stability (also extremely high wind velocities), in which the Gaussian model does have limited calculating abilities under such stable conditions (See Chapter 5), but is used by leading modeling software for such conditions. When such a stable air mass condition occurs, the likelihood of ground level plume concentration impact on receptors is the increased.

Gaussian models have been widely used to model the advection along the plume centerline and lateral and vertical diffusion of stack plumes.^{31,35,56,63} These models incorporate the Gaussian distribution curve at which time averaged atmospheric conditions are used to calculate diffusion as a normal distribution, in the y and z direction, of plume concentration from plume centerline. Because the Gaussian distribution equation (Figure 3) uses time-averaged atmospheric conditions, an instantaneous picture of the plume can not be calculated using this method. Rather the advection, or large scale linear motion along centerline, and progressive broadening of the plume with progressing distance from source, are calculated. The plume calculation is

superimposed over the natural snake-like twisting and turning observed in nature, as smoke is emitted and dispersed downwind from a stack.^{31,56} See Figure 4, taken from Turner's Workbook of Atmospheric Dispersion Estimates, below.

$$X = \frac{Q}{u} \cdot \frac{f}{\sigma_y \sqrt{2\pi}} \cdot \frac{g^1 + g^2}{\sigma_z \sqrt{2\pi}}$$

X = ground level pollutant concentration

u = wind speed

y = distance in horizontal direction

z = distance in vertical direction

H = effective stack height

Q = mass emitted per unit time

σ_y = standard deviation of plume pollutant concentration
in y (horizontal) direction

σ_z = standard deviation of plume pollutant concentration
in z (vertical) direction

$$f = \exp\left[-y^2 / (2\sigma_y^2)\right]$$

$$g^1 = \exp\left[-(z - H)^2 / (2\sigma_z^2)\right]$$

$$g^2 = \exp\left[-(z + H)^2 / (2\sigma_z^2)\right]$$

Figure 3: Gaussian plume distribution equation. Gaussian models incorporate the Gaussian distribution curve at which time averaged atmospheric conditions are used to calculate diffusion as a normal distribution, in the y and z direction, of plume concentration from plume centerline.

Source: Workbook of Atmospheric Dispersion Estimate

Figure 4: Gaussian plume distribution 3 dimensional coordinate system. Because the Gaussian distribution equation (Figure 3) uses time-averaged atmospheric conditions, an instantaneous picture of the plume can not be calculated. The advection, or large scale linear motion along centerline, and progressive broadening of the plume with progressing distance from source, is what is calculated.

Source: Workbook of Atmospheric Dispersion Estimate

As stated by D.B. Turner,⁵⁶ the Gaussian distribution equation uses relatively simple calculations requiring only two diffusive dispersion parameters, σ_z and σ_y , to identify the variation of pollutant concentrations away from the center of the plume; where σ 's represent standard deviations under normal distribution of pollutant concentration at different atmospheric conditions. Dispersion coefficients (σ_z and σ_y) representing variances from centerline plume concentration, for each atmospheric stability category, have been established from experimental research conducted by Pasquill and Gillford,³⁵ and correlated with work conducted by Turner,⁵⁶ for use in the Gaussian plume distribution equation from the Eulerian viewpoint. Stability categories have been developed to represent various atmospheric conditions. The different stability categories, developed by Pasquill and Gillford are listed in Table 2.3.⁵⁶ Dispersion coefficients, extrapolated for distances greater than 1 km, in the form of plots of $\log \sigma_y$ and $\log \sigma_z$ versus $\log x$ are represented in Figures 5 - 6, and were taken from Turners "Workbook of Atmospheric Dispersion Estimates".^{31,35,56} The two dispersion parameters and stability categories like those discussed above, together with other variables listed in Figure 3 above, are required by the Gaussian plume distribution equation to calculate from source, the downwind concentration of emissions, away from plume centerline, at receptor locations.

Table 2.3 Pasquill and Gillford (PG) Stability Categories

	Day	Day (Incoming solar radiation)	Day	Night	Night
Surface wind speed at 10m (m/sec)	strong	moderate	slight	Thinly overcast or > 4/8 cloud cover	Clear or < 3/8 cloud cover
< 2	A	A - B	B	-----	-----
2 - 3	A - B	B	C	E	F
3 - 5	B	B - C	C	D	E
5 - 6	C	C - D	D	D	D
> 6	C	D	D	D	D

Source: Workbook of Atmospheric Dispersion Estimate

Figure 5: Horizontal dispersion coefficients for PG stability categories. See Table 2.3. Dispersion coefficients (σ_y) representing variances from centerline plume concentration, for each atmospheric stability category.

Source: Workbook of Atmospheric Dispersion Estimate

Figure 6 : Vertical dispersion coefficients for PG stability categories. See Table 2.3. Dispersion coefficients (σ_z) representing variances from centerline plume concentration, for each atmospheric stability category.

Source: Workbook of Atmospheric Dispersion Estimates

As stated earlier, the calculated concentration, at a fixed downwind distance X , represents the Eulerian viewpoint.³¹ The Lagrangian viewpoint is another form (or derivative) of the Gaussian plume distribution, that may be used to calculate plume concentrations at point X within the middle of the moving puff of plume as apposed to a fixed point represented by X .³¹ This thesis is evaluating the Gaussian distribution equation from the Eulerian viewpoint only, using a polar coordinate grid system within the computer simulated air dispersion model.⁶ In the model, downwind distance X is represented by multiple radii/radius intersections with incremental ring distances from source on a polar grid, as well as other manually added prioritized sensitive receptor points, used in running the computer simulated dispersion model. Therefore, various plume concentrations, can be calculated as caused by wind changes, moving in different directions, and impacting different elevations.

2.4.4.1 Effect of Atmospheric Stability on Plume

Current modeling software use the same Gaussian plume distribution equation discussed above to calculate different directed plume concentrations under stable atmospheric conditions, however they have the ability to recognize more atmospheric conditions than what is listed in Pasquill and Gillford table. Using recorded weather soundings extracted for use within its own software, computer simulated models develop and use more sophisticated (or in-depth) stability categories and dispersion coefficients, derived from more comprehensive meteorological data.⁷ Other variables listed with Gaussian plume distribution equation, Figure 3, and for terrain elevation, are entered into the model run as well.

2.4.4.2 Modeling in Complex Terrain

Where plume computations are conducted, during stable conditions, for locations of complex terrain, computer simulated models use the dividing streamline approach, demonstrated in laboratory experiments conducted by Synder.^{7,48} This theoretical concept assumes that a dividing layer forms during stable conditions in which air flow in the upper layer rises over the terrain while air flow in the lower layer remains horizontal, deflecting, or splitting to flow around high obstacles. During unstable conditions, such a dividing stream line disappears, and all flows rise up and over the elevated terrain.⁴⁸ Detailed wind and turbulence data, and vertical profiles of temperature, are needed for computer models to construct the elevation of dividing stream lines.^{44,48} Depending on the elevation of the plume, it will either go over a hill or be forced to go around the hill (often up or down the valley if the plume is emitted within the valley). Higher stacks can prevent plumes from becoming embedded under dividing stream lines, forcing plume movement over the hill rather than laterally around the hill.

2.4.4.3 United States Compliance Modeling

Understanding current levels of technology and labor intensities involved with accurately predicting air pollution transport and mixing in the atmosphere, EPA establishes preferred/chosen computer simulating models for compliance use. Different computer simulated models are required for different types of sources being modeled. EPA's preferred models are continually reviewed as science and technology surrounding air pollution modeling software advances. The fixed box models are overly simplified and rarely used for compliance evaluation. Given the current level of computer technology and atmospheric science, multiple cell models are extremely labor intensive, but are increasing in use for reactive atmospheric pollutants.³¹ For many years the

preferred dispersion model for a continuous steady-state point source has been the Industrial Source Complex (ISC). AERMOD, another dispersion model was used in this thesis, and is currently under EPA review for becoming the preferred continuous steady-state model for compliance. A more in depth discussion of AERMOD is to follow in Chapter 3.

Both AERMOD and ISC are dispersion models that use the Gaussian plume distribution equation when modeling under stable atmospheric conditions. AERMOD however comprises the latest in Planetary Boundary Layer (PBL) parameterization, accounting for technological advancements ISC otherwise does not possess. The goal of EPA regulatory concentration models is to design or improve modeling capabilities as the science and technology surrounding air pollution modeling advances. Table 2.4, adapted from one of EPA's detailed comparison reviews of AERMOD and ISC, compares and contrasts some of the major differences between ISC and AERMOD capabilities.⁴⁰

Table 2.4 Comparison of AERMOD and ISC Compliance Plume Models

ISC	AERMOD
Only wind speed is profiled using profiling meteorological data	AERMOD creates profiles of wind, temperature, and turbulence, using all available measurement levels of meteorological data
Stack-top meteorological variables for all downwind distances	Meteorological variables measured throughout the plume depth (averaged from plume centerline; changes with downwind distance)
Gaussian treatment in horizontal and vertical	Gaussian treatment in horizontal and in vertical for stable conditions; non-Gaussian probability density function in vertical for unstable conditions
Interpolates mixing height based upon maximum afternoon mixing height	Interpolates convective and mechanical mixing heights and their fluctuations throughout the day

Source: Comparison of Regulatory Design Concentration Modeling

AERMOD obviously incorporates advancements in air dispersion modeling technology. As stated earlier, the more variables that can be accounted for in a model, the more accurate portrayal of real world conditions. AERMOD has become the chosen model for this thesis due to its availability and advancements in technology. It is important to note, however, that both ISC and AERMOD use the same Gaussian treatment under stable atmospheric conditions, which as stated earlier, may contribute to modeled worst case scenario in this thesis.

2.5 Geographic Information Systems Applicability

The use of Geographic Information Systems (GIS) to solve environmental problems is increasing rapidly.³⁴ GIS is an information system that is designed to work with digitized data referenced by spatial or geographic coordinates.⁶¹ GIS has also been referred to as a collection or system of computer hardware, software, geographic data and personnel expertise integrated to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information.⁵¹ The power of GIS lies in the production of its visual images, and spatial analysis of them, as compared to any other computer based information system. GIS allows various types of maps, all with different surfaces and features, to be laid over one another in layers to produce a preferred map of interest. It allows one to visualize such spatial information changes in air pollution concentrations, land cover, population density, watershed and stream location, road and building location, elevation, and many other sets of data, by statistically analyzing the geographically referenced spatial data, layered over one another, to produce a map. These maps may undergo further manipulation, to help one understand a particular environmental problem. Today, GIS is used by a wide range of disciplines and

entities. Government agencies, private industry, and universities all use GIS to understand relationships that cause and solve spatial problems in our natural environment.

Recent developments of GIS have provided environmental epidemiologist's with new tools to study associations between environmental exposures and disease.¹¹ Various geographically referenced data, including population census data, are being spatially analyzed through GIS by different public health and environmental pollution researchers . A particular focus area of this thesis is the geographical point locations of sensitive receptor populations to the proposed stack. GIS spatial analysis application allows for the identification of the real world point locations of sensitive receptor populations at certain straight line distances from the proposed stack, to modeled air pollution concentration from the stack. Such concentrations represent pollution that could contribute to health effects discussed in section 2.1, at locations identified using GIS techniques.

GIS spatial analysis application to sensitive receptor point locations, alone, cannot determine public environmental health threats associated with the one proposed CFPP air pollution source. Therefore, so air dispersion modeling was pursued as well. GIS spatial analysis does, however, provide unique additional information for this study. One literature study involved evaluating the magnitude of outdoor exposure to particulate matter potentially experienced by the population of Mexico City.¹⁰ Circero-Fernandez used GIS software, to link population groups in Mexico City to particulate matter concentrations that exceeded air quality standards during certain days throughout a period of one year. Other studies have included pollution exposure to minority or otherwise underprivileged individuals and populations.^{5,10,43}

Rushton⁴³ stated that “recent advances in the analysis of disease maps (produced using

GIS) have been influenced by and benefitted from the adoption of new practices for georeferencing health data and new ways of linking such data geographically to potential sources of environmental exposures, the locations of health resources and the geodemographic characteristics of populations.

Another GIS technique applied in this thesis was kriging, a geostatistical method. As defined in Using ArcGIS Geostatistical Analyst book, “kriging a statistical interpolation method that uses data from a single data type to predict values of that same data type at unsampled locations.” Geostatistics is actually a much broader term to include kriging, spatial statistics common to geography and geology, as well as other mathematical interpolation techniques known as deterministic technique.⁶⁹ See chapter 3, section 3.3.3 for a more detailed discussion on kriging and geostatistical analysis.

Precipitation measurements and predictions, groundwater hydrology, oil exploration or spills, water and air pollution all use geostatistics, to create and illustrate their boundary location or phenomenon. More current applications of kriging air pollution include those on monitored concentrations of air pollution. Such programs include analysis of ozone concentrations in California (EPA monitoring), and studies of particulate pollution in British Columbia and hydrogen sulfide in Nebraska.^{67,68,69} Under all three cases, kriging was used to interpolate exposure estimates, producing prediction maps, using monitoring data from strategically georeferenced locations. In this study, I conducted the same type of exposure estimates, not from monitored concentration data, but rather from calculated concentration estimates determined from air dispersion modeling.

This thesis combines GIS spatial analysis application, resembling studies discussed

above, with air dispersion modeling to geographically identify at point locations of sensitive population groups to concentration contributions of air pollution from the proposed CFPP source. After the air dispersion modeling, further analysis was conducted, using GIS geostatistical analysis to produce prediction maps of exposure to the entire study area (30km radius), including those sensitive population locations.

Chapter Three - Methods

The previous chapter makes it clear that modeling the exposure of air pollution from a single source involve large amounts of many different types of digital data, including weather, demographic, geographic, and mechanical data. This data stems from an array of different sciences and techniques that must be linked together, in organized fashion, in order to attempt to model and graphically present that which might be occurring in nature. For example, the study area is defined to be a 30 kilometer radius surrounding the proposed CFPP stack. Although it is expected that, under worst case scenario, the lateral distribution of the CFPP emissions will not disperse that far, the software modeling distance (discussed below) is validated up to a 50 kilometer radius of the stack. It is most accurate up to 30 kilometers ⁷ which is the distance chosen for this study. The region within the 30 kilometer radius is mostly deciduous forest, with urban areas scattered intermittently throughout the entire study area. The Monongahela and Cheat Rivers are the lowest elevations in the area. Moderate to rolling hills are to the west, while higher mountains predominate eastward, southeast of the proposed stack, starting with the Chestnut Ridge anticline. Emission rates from the proposed CFPP, in combination with certain local climate situations, locations of sensitive populations, and the geologic topography of the area could present an environmental public health threat. This thesis quantifies this possible threat.

This chapter is intended to lay out the sources of data, projections, software used and how the data was compiled, organized and used for GIS, AutoCAD and air dispersion modeling. Many organizations contributed the needed data for either GIS application, AutoCAD, dispersion modeling, or for all three.

3.1 Sources of Data

Where possible, proposed CFPP emissions, meteorological, and sensitive receptors was for the year 2000, or as close to that as possible. This information was provided by various federal and state departments, universities, non-profit organizations, as well as a private company. Organizations providing data and information include the West Virginia (WV) Division of Air Quality (DAQ), West Virginia University (WVU) Natural Resource Analysis Center (NRAC), GenPower LLC of Newton, MA, US Geological Survey, Pennsylvania Spatial Data Access (PASDA), the Yellow Pages, and WV Geographical Information System (GIS) Technical Center at West Virginia University, US Environmental Protection Agency, US Census Bureau, and Trinity Consultants. I used this information together with various software and devices, and resources made available through books and courses taken here at West Virginia University as well as training in air pollutant dispersion modeling received from Trinity Consultants. A more in - depth discussion is to follow in this chapter. See Appendix A for a brief discussion of the types of data used and the organizations previously mentioned.

3.1.1 Geographic Information System (GIS) Data

In order to use GIS, to run the models, proper digitized tabular, and georeferenced spatial data were needed and collected from various data sources. See Appendix A for the data resource locations and sites. Tabular data were then organized into spreadsheet formats using Microsoft Excel 2002². Some of these files were then transformed, within Excel, to Database III files, with extension DBF, to be used by the GIS software. GIS applications were conducted using ArcGIS

²Microsoft excel is a standard spreadsheet software program allowing users to organize and analyze data in tabular form.

8.3 by ESRI³, which only recognizes spreadsheet files with data-base file (DBF) extensions.

The scale of the georeferenced spatial data and maps were determined next. The scale is the ratio of distance on a map to it's corresponding real world distance. The established scale for this study ranged from 1:24k meters to 1:100k meters. The various data sources listed above provided maps at different scales, therefore analysis was only as good as the worst or smallest scale, i.e. 1:100k. An important factor in determining the proper scale for maps created in this thesis was the chosen resolution size of the study area. Resolution, as it pertains to this study, was the ability to see the difference, or discriminate on the study area maps, between locations on the earth's surface at a set aerial distance. For example, one point location represents an area that may contain more than one sensitive receptors, but receives the same calculated SO₂ concentration, to be discussed in section 3.3.3. Maps produced on a county-wide scale, as apposed to state-wide, were portrayed at 1:24k meter resolution. The majority of data was collected at a scale of 1:24k.

3.1.2 Proposed Coal Fired Power Plant (CFPP) Data

Data on the proposed CFPP was provided through GenPower, LLC's PSD permit application that was reviewed by West Virginia Department of Air Quality. The Clean Air Act and it's respective NAAQS and PSD criteria, require both dispersion modeling of proposed emissions to be modeled to prove a prevention of significant deterioration of air quality as well as an emissions inventory to be kept by the proposed CFPP facility, once built and operating. Dispersion modeling, required for applying for a permit to operate, within PSD criteria, was not

³“ESRI is the largest research and development organization dedicated to GIS development software. ESRI's ArcGIS is a scalable system for geographic data creation, management, integration, analysis, and dissemination for every organization, from an individual to a globally distributed network of people.”²⁶

the goal of this thesis. Rather, the goal was to model contribution exposure to sensitive receptors during worst case scenario - using as the air quality PSD standard for this study, 24 hour SO₂ PSD Increment allotted by the US EPA. Source (stack) data parameters obtained for the proposed CFPP include emissions, all listed in Table 3.1, were: georeferenced coordinates of the stack, internal stack diameter at stack mouth, stack emission temperature, exit velocity, and stack height (above grade). WV DAQ also provided digitized engineering drawings of the proposed CFPP site plan. This CFPP information was organized and manipulated into various different types of spreadsheets, and compatible software files, to fit GIS import requirements, an AutoCAD drawing of the site in UTM projection, and for import into the dispersion model.

Table 3.1 Longview PC Boiler (main) Location and Stack Parameters

Coordinates	Stack Height	Emission Temperature	Emission Rate	Stack internal diameter	Exit velocity	Elevation
Longitude: 79 Deg 57 Min 23 Sec Latitude: 39 Deg 42 Min 21 Sec	168.9 m = 554 ft	56.85 °C = 135 °F	13.866 g/s	5.94m = 19.5ft	26m/s = 86fps	~335.28 m = 1100ft

3.1.3 Air Dispersion Modeling Data

Ground level pollution concentrations are controlled by the weather and surface roughness of the surrounding topology. As discussed in the previous chapter, wind direction and speed (transport distance), vertical mixing and turbulence are the main meteorological elements that determine plume dispersion. The boundary layer that the plume height rises to is its mixing height. Atmosphere stability and mixing height are a function of atmospheric turbulence. During

upper air inversions, the thermal stratification between layers in the atmosphere resists vertical movement of a plume. Depending on plume momentum on emissions, concentrations, and buoyancy, plumes can sometimes penetrate these inversions. Although based on the same thermal stratification concept, the mixing height during a radiation inversion is often the height of the mountains on either side of the valley, or is, sometimes, the level of the bottom layer of an upper air subsidence inversion. The combination of these two inversion conditions was discussed in chapter 2. Surface roughness, in units of length, is determined by topographical features such as buildings and vegetation. Both the height and spacing between surface roughness features effect wind turbulence and thus vertical mixing of the plume. Below is Table 3.2, showing surface roughness length for surface type categories.³²

Table 3.2 Surface Roughness Categories and Length (m)

Urban	1.0 - 3.0
Deciduous Forest	2.2
Coniferous Forest	1.3
Cultivated land (summer)	0.2
Cultivated land (winter)	0.1
Grassland (summer)	0.1
Grassland (winter)	0.001
Water	0.001

Atmospheric Dispersion Modeling Compliance Guide, 1999

The USGS provides nationwide land cover maps from their “National Map Viewer” website. Land cover maps provided by USGS, were used to establish the predominant surface roughness of the study area, to be used in the air dispersion model. See Figure 7.

Figure 7: Land Cover Map. The land cover map and legend was used to identify major surface roughness categories and lengths (m) within the study area. Table 7 lists surface roughness categories and lengths (m) used by the air dispersion model. Surface roughness of surrounding topology induce wind turbulence which in return effects vertical mixing of ground level pollution, discussed in chapter 2. Deciduous forest was the chosen predominant land cover there by the surface roughness category chosen for use in the air dispersion model.

Three different types of meteorological data needed for the air dispersion model meteorological preprocessor, AERMET⁴, include National Weather Service (NWS) hourly surface observations, NWS upper air soundings, and on-site measurements. NWS hourly surface observations and upper air soundings are ultimately retrieved from the National Climatic Data Center (NCDC) of the National Oceanic Atmospheric Administration (NOAA) in compact formats and extracted to usable formats by AERMET. Local meteorological towers, measuring wind (speed and direction) and temperature, provide on-site data for AERMET. Trinity Consultants, designer of a AERMET with their “Breeze” Graphical User Interface (GUI), organized meteorological data formats for us to run these models. Trinity is located in Houston, Texas.

Elevation data were converted from the US Geological Survey ordinance survey format to digital elevation model (DEM), using the program crlf.exe to the format necessary for the AERMAP⁵ terrain preprocessor module of the Breeze AERMOD Suite of dispersion modeling applications. Data are identified by unique "quads," each quad consisting of a rectangle, one degree latitude by one degree longitude. Each quad is subdivided into 64 equal squares, each 7.5 minutes a side, as follows. Each quad is divided into 8 columns, each 7.5 minutes wide, sequentially numbered 1 through 8 from the SE toward the SW corner of the quad. Each quad is

⁴AERMET is the meteorological preprocessor for the AERMOD. Input data can come from surface meteorological observations, hourly cloud cover observations, and twice-a-day upper air observations. Output includes surface meteorological observation parameters and vertical profiles of several atmospheric parameters.

⁵AERMAP is a terrain preprocessor used to simplify and standardize the input of terrain data for use in AERMOD. Input data includes receptor terrain elevation data. It may be in the form of digital terrain data, available from the U.S. Geological Survey. Output for each receptor includes, location and height scale, which are elevations that are then used for the computation of air flow around hills.

also divided into 8 rows, each 7.5 minutes high, sequentially lettered a through h from the SE to the NE corners of the quad. Each square within the quad is then uniquely identified by a column number and a row letter. The quads to be used by AERMOD must be "stitched" together, so the program sees them as a continuous array of digital elevation measurements. The lateral resolution of these measurements, at the latitude of Morgantown is about + or - 30 meters in both N-S and E-W directions.

Background concentrations of existing air pollution are monitored by WV DAQ and the US EPA, as required by NAAQS, through State and Local Air Monitoring Stations (SLAMS) and National Air Monitoring Stations (NAMS) strategically scattered throughout the nation.^{2,64} This recorded background concentration of air pollution data is public information, and is made available through EPA's AirData web-site at www.epa.gov/air/data/geosel.html. The study area SO₂ concentrations for the year 2000 were obtained from AirData and are presented in a simplified format, in Table 3.3 below. These SO₂ concentrations are assumed to be representative concentrations of existing SO₂, contributed from all air pollution sources in the region as well as from farther west, moving eastward into the study area with the movement of weather patterns. Modeled SO₂ concentrations from the proposed CFPP were to be added to monitored SO₂ concentrations reported by WV DAQ and EPA. This gives a generalized estimate of what the highest SO₂ concentration would have been if the proposed CFPP had been constructed and running for the year 2000. As mentioned, year 2000 emissions and weather have been used in order to correspond to US Census data on population and sensitive receptor distribution across the study area.

Table 3.3 Monitored SO₂ (µg/m³) for 2000

24-Hour Values				
1st Max	Number of Site Monitors	Site Location	County	State
0.723	1	Knapp Hall, WVU, Morgantown	Monongalia Co	WV
0.542	1	Morgantown Airport Us 119&Airport Blvd.	Monongalia Co	WV
0.747	1	WVU Law School, Morgantown	Monongalia Co	WV
0.277	1	4.8 Km SE Of Holbrook	Greene Co	PA

3.2 Projections

When gathering geographic data from different sources, the projection of the data must be the same to be able to graphically present the data, layered together, in the form of maps. All data and maps in this thesis are georeferenced in the spherical geographic coordinate system (GCS) as opposed to the two-dimensional cartesian coordinate system. These locations are then projected into UTM flat dimensional cartesian coordinate system, as explained below. The theory behind GCS projections enables for a more precise determination of real world point locations. The GCS uses latitude/longitude lines to locate points lined across the x and y axes grided over the entire, approximately spherical, surface of the earth. The angles of these lines are measured from the center of the earth to a location on the earth's surface resulting in rad or degree units with the equator being zero degrees latitude (x-axis) and the prime meridian (through Greenwich, England) being zero degrees longitude (y-axis). Although more accurate than the cartesian coordinate system, a coordinate system such as this results in spherical surface curved maps which need to be projected back to a flat map in order to be analyzed on paper or in

GIS by ESRI, AutoCAD by Autodesk⁶, or AERMOD by Trinity. Projecting a map converts a curved map to a flat surface while somewhat holding coordinate grid accuracy.

Map projections are important when analyzing smaller, more local geographical areas. Since the poles are somewhat flattened and the equatorial region expanded due to the centrifugal effect, the earth's surface is not precisely spherical. Therefore, for greater accuracy, an ellipsoid correction, or datum, is used for projecting a quasi-spheroid surface into a flat surface map. The converted quasi-sphere of the earth is called a geoid. Some of the more common projections used in the region of the U.S. are NAD83 and NAD27. NAD83 is the projection chosen for this thesis. It is an Earth-centered datum, using the Geodetic Reference System 1980 (GRS 80) ellipsoid and its reference point is the center of the earth. NAD27 uses the Geodetic Reference System but its reference point is on the surface of the earth.^{36,39} Using recent measurements with modern geodetic, gravimetric, astrodynamic, and astronomic instruments, the GRS 80 ellipsoid has proven to best fit the worldwide geoid.^{36,39} A lot of GIS Data is either NAD27 or NAD83, and these projections onto a flat, two-dimensional sphere, are only slightly different. Having all the data and maps produced in this thesis in the same projection is very important. The position of a point based between these two different datums will result in a deviation between what should be the same location on the earth's surface, meaning that the georeferenced points will not match.

Also, it is important to point out that a difference in coordinate system terminology sometimes exists between civil and environmental engineers, and other scientists that work strictly with geographic data. Most engineers, that make use of AutoCAD software technology and

⁶Autodesk is a software and digital content company. They offer business solutions through technology products and services. AutoCAD is a registered trademark of Autodesk.

various surveying technology for use in their project design, are familiar with what is referred to as the user coordinate system (UCS). They often use the simple X and Y coordinate system, with the 0,0 (X,Y) located in the lower left hand corner of their grid for project designs. AutoCAD does however contain another coordinate system design option, referred to as the world coordinate system (WCS), which is more compatible for use with other geographic data. The WCS is a spherical coordinate system that has been projected back to a flat surface for use in AutoCAD. The WCS enable engineers to design projects directly over real world coordinate points, like that of the GCS. This option, however, requires engineers to conform to, recognize and work with much larger X,Y figures than what is otherwise used in AutoCAD, when designing over the simplified UCS.

3.3 Software Application and Methods

The following section gives detailed description of software and methods used to identify sensitive population exposure to SO₂ contributions from the proposed CFPP under worst case weather scenarios. GIS applications were approached first, using ArcGIS 8.3. This established the identification, locations of, and number of categorized sensitive receptor populations which are located within the study area, centered at the proposed CFPP location. After the GIS work was completed, AutoCAD applications were focused on next. Here, I constructed a digital drawing compatible for use in the air dispersion modeling software using the site plan drawings of the proposed CFPP provided by WV DAQ. Air dispersion modeling was conducted last, using some of the results obtained from the previous software applications. Breeze AERMOD Pro Prime version 4.0.13 was used for air dispersion modeling.

3.3.1 Method 1, Sensitive Receptors

I have separated sensitive receptors into two classes. GIS was used to establish the category and location of institutional sensitive receptors surrounding the proposed site plan, out to a radius of 30km. The first class of sensitive receptors are comprised of sites containing people of limited mobility, here represented by nursing homes, and hospitals. The second class of sensitive receptors are those where large numbers of people congregate intermittently, so that a serious air pollution episode affecting such a site could have catastrophic consequences. For this thesis, child day care facilities and grade schools will represent the second class of sensitive receptors. As previously mentioned, the elderly, sick and young are the especially vulnerable sectors of the population. A similar study could, however, add more categories of sensitive receptors, in each of these two classes. For example, shopping malls, stadiums and churches may be added for areas where a number of people gather intermittently, while prisons, and homes for the disabled may added for those of limited mobility. Based on the literature review and discussion of SO₂ health effects, it was decided that these aforementioned categories of sensitive receptors lack the population size and frequency of visits of those categories used as representative of these two classes in this thesis, which are most especially vulnerable to air pollution episodes.

GIS analysis with mapping was conducted using ArcGIS 8.3, from the Environmental Systems and Research Institute (ESRI). Yellowpages.com, and the US Census Bureau's Zip Code Tabulation Area (ZCTA) map files from TIGER geographic database provided a way to gather a representative sample of the institutional sensitive receptors within the study area. The Bureau provides access to these GIS friendly ZCTA files. Such ZCTA files were used in this study to

develop a Zip Code Boundary Map (Figure 8 below) of the study area, per county, to be used in conjunction with the Yellowpages.com search per classification per zip code of sensitive receptors. ZCTA was developed by the US Census Bureau to overcome difficulties in precisely defining the land area covered by each ZIP Code when tabulating census data.⁵⁸ Addresses and name of the sensitive receptors, returned from the Yellowpages.com searches, were matched with the georeferenced populated place points.

Figure 8: US Census Bureau's Zip Code Tabulation Area (ZCTA) Map. The ZCTA map of the study area was used to match georeferenced populated place points with names and addresses from Yellowpages.com sensitive receptor search. A Yellowpages.com sensitive receptor search was conducted per zip code, per county. See appendix B for a complete list of Yellowpages.com search results discussed in chapter 4.

Extensions to ArcGIS are included within the 8.3 version are Spatial Analyst, such as StreetMap USA, ArcPress, 3D Analyst, Ecological Management Decision Support, Extension, and Geostatistical Analyst. These essential tools within the software enable users to question, analyze, discover, visualize, navigate, and solve spatial problems. The ArcGIS extensions used in this thesis was the Spatial Analyst and Geostatistical Analyst. The Spatial Analyst was used to measure distances from the proposed coal fired power plant to regional prioritized sensitive receptors.

Using the Spatial Analyst extension allows spatial analysis of data being studied in ArcGIS. You can provide answers to simple spatial questions, such as "How far is this location to another?" or "What direction is this location facing?", or more complex spatial questions, like "Where is the best location to build a new building?" or "What is the least-cost path from point A to B?"²⁶ Least cost path refers to the travel path with the fewest obstacles (fewest impedances) to movement from one location to another - helpful in locations with irregular topography. A large part of this thesis was to identify the straight line distances from the proposed source stack to prioritized sensitive receptor locations.

Calculating the distance of sensitive receptors from the new stack's location was done using the analysis mask and raster calculator tools within the Spatial Analyst extension. The analysis mask was used, establishing georeferenced boundaries, among other features, to the new map layer being created. The raster calculator was used next to statistically analyze spatial data inputs, producing a continuous interpolated map surface that can be used to visualize, analyze, and answer spatial questions. In this distance to stack calculation, a new color-coded radial distance surface layer from source stack was produced, depicting distance, moving away from

stack. Each color of the new surface layer theoretically corresponds to a given distance, changing as you get further away from a stack or sensitive receptor location, as shown when overlaying the two different map layers.

ArcGIS extension tools were crucial software for fulfilling the goals of this thesis. Developing maps using the techniques discussed above enabled the creation and overlay of various map layers, allowing me to determine city/community/area containing sensitive receptors, and the stack to straight line distances to those city/community/area containing sensitive receptors. For example, I was able to produce map layers of populated place at 5 km radius increments, out to a maximum of 30 km, from the distance to stack map calculation. This broke the volume of populated place containing sensitive receptors, into annular segments, minimizing the volume to be evaluated and presented at any one time. Real world coordinates of each city/community/area with sensitive receptors were also established using GIS tabular data. That, combined with sensitive receptors location per 5 km increment level, facilitated identification of sensitive receptors, in the receptor grid designed later for use in air dispersion modeling. A more detailed description of the receptor grid design is to follow in section 3.3.3.

3.3.2 Method 2, Site Plan

The AutoCAD application in this type of study is smaller than use of GIS and air dispersion modeling, but is crucial to improving the quality of air dispersion modeling. Local site characteristics, especially height and width of stacks and buildings, of any CFPP have the ability to greatly effect plume dispersal. A 2 dimensional (2D) AutoCAD drawing, file extension DXF, of the proposed stack and building(s) provided in feet, had to be re-created in meters and imported for use in the air dispersion modeling software.

This study is only concerned with ground level concentration impacts outside of the proposed CFPP boundaries. Stack-tip and direction-specific building downwash are only briefly discussed above because of the relatively smaller residential population density that would be directly surrounding the proposed CFPP. However, because of the possibility, and the magnitude of the impact outside plant boundaries being so great, if it were to occur, such conditions warrant an evaluation within the air dispersion modeling process.

AutoCAD is the leading software used by engineers and architects to construct digital drawings of their design projects. AutoCAD is a computer program that may be used to manipulate CAD drawings of buildings, bridges, roads, among other engineering drawings. AutoCAD was only to be used in this thesis for proposed site plan drawings, to be used in AERMOD for modeling. Many engineering disciplines make use of this software, including civil, environmental, mechanical, as well as others. Architects find AutoCAD a great resource when designing buildings. This study made use of AutoCAD, to construct a 2D drawing of the proposed plant.

Four different buildings, the main stack, and the site boundary were digitally drawn, using the proposed site plan provided by WV DAQ. The file provided to me by WV DAQ was rather detailed, and of unfamiliar coordinates. It contained more information than necessary for air dispersion modeling, however features of interest were readily extractable. Plant coordinates, discussed above, appeared to be in the WCS, but did not match that of any coordinates found in West Virginia. As mentioned earlier, real world coordinates are often irrelevant during the first steps of drawing a project design. Coordinates may be repositioned in AutoCAD, to real world coordinates, anytime throughout the process. To do this, a unit conversion may be required, if

the project design was originally drawn from a grid in Imperial (or English) units, as apposed to Metric. Geographic projections discussed in section 3.2 are all measured in Metric units, and as it turns out, the file provided to me by WV DAQ was in Imperial units. A unit conversion was required in order to import the correct type of .DBF file and run the air dispersion model. The 2D drawing, developed for use in the model was drawn in feet and needed to be converted to meters. This was done in AutoCAD by re-setting the drawing to the UCS, re-scaling the drawing, converting the grid size to meters, and re-setting the drawing to the correct world coordinates.

A 3 dimensional (3D) drawing file could not be imported into the air dispersion model. Only the 2D drawing needs to be imported into AERMOD plus data on the heights of the stack and individual buildings. 3D capabilities do exist in AutoCAD, however, the air dispersion modeling software reserves the right to add the third dimension (height) from the 2D. This is due to it's direction specific building and stack tip downwash algorithms, and the importing of terrain elevations. Importing elevation data allows for the additional heights of building and stack features, above grade, to be considered in the modeling. Constructing the third dimension in the air dispersion model, decreases the quantity of input data required from the modeler, by adding these important terrain elevations and site characteristics to the model all at once. Doing so correctly, empowers the model to incorporate possible building and stack tip downwash incidents, during any model run.

3.3.3 Method 3, Concentration Exposure Modeling

The transport and dispersion of SO₂ from the proposed CFPP was modeled in this study using the U.S. EPA model AERMOD, accessed through the graphical user interface (GUI), Breeze version of AERMOD from Trinity Consultants. Breeze AERMOD makes use of various

weather conditions, plume rise (emission momentum and buoyancy induced dispersion), stack-tip downwash, direction-specific building downwash, buoyancy-induced and lateral dispersion. Special non-gaussian methods are used by AERMOD, constructing a convective boundary layer (CBL), when modeling under atmospheric instability. This goal of this thesis is to model downwind dispersion under worst case scenario. For this study then, AERMOD uses the more basic Gaussian method discussed in chapter 2, when modeling under stable boundary layer (SBL) conditions. Upon completion of air dispersion modeling, calculated concentration estimates were used to produce concentration maps further depicting calculated contribution exposure of the entire study area (30km radius).

Again, factors most likely to influence dispersion include plume contents and concentration, hourly wind velocity and direction, location and height (above grade) of the stack relevant to site characteristics, stack exit velocity of emissions determining emission momentum, topology and surface roughness (such as effects of vegetation, and water bodies), and internal diameter of the stack at its outlet. AERMOD can account for all these factors, combining the equations for continuous plume mass flow with diffusion Gaussian dispersion in the y (lateral) direction and z (vertical) direction from plume centerline.

AERMIC (American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee), introduced this state-of-the-art modeling concept into the EPA's air quality models. As described, AERMOD requires the concurrent use of a meteorological preprocessor and terrain preprocessor, respectively U.S. EPA models AERMET and AERMAP used here in the Breeze GUI version. As stated earlier, it is validated up to a radius of 50 km from the source stack, although greatest accuracy is probably limited to a radius

of 30 km, which defines the study area of interest in this thesis.

AERMOD can model an unlimited number of point sources (stacks), source groups, receptors, regularly spaced receptor grids, and short- and long-term averages, and can store up to 200 pollutant emission rates in a modeling project. AERMOD is the second, updated, major U.S. EPA model (following ISC), for dispersion from industrial source points, flares, lines, areas, or volumes which can accommodate irregular terrain (ISC accommodates irregular terrain as well), as is necessary in Appalachia. AERMOD can model ambient concentrations due to emissions, separately, by hour of day, month, and season, seasonal and hourly combined, and pre-processed meteorological data.⁶ An unlimited amount of receptor concentrations can be calculated at all elevations in one model run.

Picking the correct averaging times to run in AERMOD was crucial. Designing a modeling scenario that would incorporate AERMOD's maximum capabilities becomes very labor intensive for the modeler(s) (often more than one modeler is necessary), maximizing computer memory capabilities, as well.

Air dispersion modeling conducted for this thesis was rather simple compared to what AERMOD is capable of modeling. However, the goal here was to review model results under stable atmospheric conditions. The air dispersion modeling steps, roughly followed, are listed in below:

1. Stack coordinate location, height (above grade), exit velocity, emission rate, internal diameter, and exit temperature were entered.
2. Imported the .dxf drawing of the proposed site plan, converting buildings to 3D, and adding discrete receptors along the plant boundary.
3. Designed the polar grid receptor, and entered discrete receptors at real world coordinates established by GIS within the receptor grid.

4. Imported weather data for the 2000, extracted for use by AERMET.
5. Imported terrain elevation data, extracted for use by AERMAP.
6. Run Building Downwash Profile Input Program (BPIP) establishing dimensions necessary to model direction-specific building downwash.
7. Run model for desired time frame, and averaging periods

These same steps were roughly followed in consecutive model runs. Selected features discussed throughout this chapter were entered into the model and runs, first for the entire year for 2000, and for consecutive model runs.

This study is much less complex, mostly due to much simpler source parameters (than full model capability) and computer RAM and speed limitations. This modeling scenario, incorporates the worst 24 hour average modeled emission concentrations at receptor locations from the proposed CFPP main stack emissions, for the year 2000. These modeled contributions were then added to monitored background concentrations for the same year. The combined concentrations were then compared to the provisional maximum ambient SO₂ concentration for this study, as well as the US EPA PSD 91µg/m³ 24 hour averaging standard.

Higher concentrations are theoretically calculated when stable atmospheric conditions occurred, and those are the days on which I have focused. The first model run, for the entire year for 2000, was conducted to establish which day the highest modeled plume concentrations occurred. The output file of this modeling software is programed to list the coordinate locations and date of maximum concentrations, per averaging period chosen. I chose to have the model list the locations and date of the 25 maximum high concentrations at a 24 hour averaging period in the first model run. I then broke subsequent model runs down into the top five highest 24 average

concentration dates modeled, running the same model run criteria for all 5 dates, for the year 2000. After modeling the 5 subsequent days, and for the entire year, a detailed evaluation of results on high concentration modeled days was conducted. The location of populated places with sensitive receptors, relative to high concentration locations modeled, were key variables evaluated.

Geostatistical analyst, has the ability to interpolate a continuous surface using calculated concentration points taken throughout a particular area of interest, selecting one method within a range of mathematical and statistical functions for interpolation. In this thesis the georeferenced location of calculated concentration contributions, obtained from the air dispersion modeling, served as SO₂ sample concentration contribution points to be interpolated over the study area. Calculated concentration contribution point data were examined for normality of distribution. A normal QQ Plot of these 1145 data points, for each of the 5 modeled worst case (highest SO₂ concentration) days were generated. The normal QQ Plots for these 5 days showed the modeling data to be close to normally distributed.

Arc GIS's Geostatistical Analyst extension allows the use of some of the most widely used deterministic and geostatistical interpolation methods. Inverse Distance Weighted (IDW) is a deterministic interpolation method that uses basic mathematical functions to interpolate a surface by placing a weighted value to calculated concentration points, fitting planes to the calculated concentration points. First to third order global polynomial functions may be used to interpolate various types of surfaces. These families of mathematical formulas are used to account for influential trends, over time and distance, within a set of calculated concentration points. Examples of trends include slope or wind as was the case in this study. The closer the calculated concentration

points to one another, the more heavily those calculated concentration points are weighed. Points spread farther apart are weighed less, resulting in a lower weighted sample value. A disadvantage of IDW is its tendency to exclude extreme outlying calculated concentration points from influencing in the interpolation. for example assuming that extreme outliers have insignificant relationships to those located close to one another.

Kriging is a geostatistical method. Calculated concentration points are not only weighted based on distance between one another but also weighted based on their overall spatial arrangement. All calculated concentration points within a data set were used for predicting values between known calculated concentration points. The distances, between all known value points, are statistically analyzed. The kriging method uses mathematical and statistical methods to interpolate its surface. Here, spatial autocorrelation between sample points are quantified, meaning closer sample points are assumed to be more alike than the points spread farther apart.⁶⁹ Through ordinary kriging, calculated SO₂ contribution concentration estimates were used to interpolate concentration contributions for the entire study area of 30 km radius from stack.

Spatial autocorrelation evaluates the statistical relationship among measured concentration values.⁶⁹ The quantification of such relationships are calculated using the semivariogram plot, a tool available in Geostatistical Analyst. In the semivariogram, trends within the calculated concentration values may be explored, and a prediction model fitted with some measure of certainty or accuracy.⁶⁹

Wind direction was the trend analyzed for in this study. Trend analysis of dispersion modeled SO₂ concentration point values indicated directionality corresponding to prevailing wind direction, as independently verified by the annual windrose for the site, for the year 2000, from meteorological monitoring stations. Therefore, it was judged unnecessary to temporarily remove

the trend, for analysis of residuals indicating variance in the data.

Cross validation of calculated concentration values to predicted values provides the measure of certainty or accuracy. One by one, for each of the 1145 calculated SO₂ concentrations at specific locations, the Geostatistical Analyst sequentially removes a known calculated concentration value, predicts a value for that exact location, compares the two values, and calculates statistical prediction errors based on the differences between the two values for each of these 1145 locations. For a model to provide accurate predictions, the mean prediction error should be close to 0, the root-mean-square standardized prediction error should be close to 1, and the root-mean-square prediction error should be small if predictions are close the calculated SO₂ concentration contribution at each of these 1145 locations.⁶⁹

Chapter 4 - Results

This chapter is divided into the following sections: 1) results of the GIS spatial analysis, 2) site plan drawing of the CFPP as a foundation for direction specific building downwash, 3) results of the air dispersion modeling of SO₂ concentration contributions from the subject CFPP, 4) SO₂ concentration contributions summed with the background monitored concentrations. It is to be understood that the term concentration, used throughout this chapter, is referring to SO₂ concentrations in $\mu\text{g}/\text{m}^3$. Various maps, figures and tables are used to address the key results. Appendix A - C serve to fully document details of key results below.

4.1 GIS Spatial Analysis

In order to conduct spatial analysis of categorized sensitive receptor populations to the proposed CFPP emissions, their spatial density and locations within the study area first needed to be identified. This was completed searching Yellowpages.com per category of sensitive receptor for each zip code in the study area, and comparing search results to the populated places database file (DBF). All sensitive receptor locations were identified and mapped, see Figure 9 and Table 4.1 below, by matching the tabular data of each sensitive receptor's local addresses, obtained from Yellowpages.com searches, to the corresponding populated places point DBF table, provided by WV NRAC. The nationwide populated places data (both map and DBF table) was cropped to match 30 km radius study area (see 30km radius results below under straight line distance calculation). Using Microsoft excel, each category of sensitive receptor used was placed in separate spreadsheets, per county. Columns of the spreadsheet include the name column from the populated places DBF table, as well as address information provided by Yellowpages.com. Table 4.2 below, is a spreadsheet

example of tabular data matched between Yellowpages.com address results and the populated places DBF. See Appendix B for the complete list of Yellowpages.com results and populated places DBF name column matches. Where Yellowpages.com did not provide a street address, this cell in the table has been left blank. This matching was used to eliminate from the study area, those populated places that did not have any categorized sensitive receptors identified within them.

Figure 9: 51 populated places with sensitive receptor categories, out 30 km from source stack. There were 51 populated places identified with having one or more of the sensitive receptor categories. See Table 4.1 for corresponding names and numbers of populated places containing sensitive receptor categories.

Table 4.1 Names of Populated Places Containing Sensitive Receptor Categories Used

NUMBER	NAME
1	Baker Ridge
2	Braewick Woods
3	Canyon
4	Fairmor
5	Hilderbrand
6	Hopecrest
7	Morgantown
8	National
9	Osage
10	Ragtown
11	Richard
12	Riverside
13	Sabraton
14	South Hills
15	South Park
16	Star City
17	Sturgisson
18	Suncrest
19	Sunset Beach
20	The Flatts
21	The Mileground
22	West Sabraton
23	Westover
24	Wiles Hill
25	Barrackville
26	Chesapeake
27	Fairmont
28	Fairview
29	Palatine
30	Rivesville
31	Arthurdale
32	Bruceton Mills
33	Masontown
34	Reedsville
35	Carmichaels
36	Jefferson
37	Mapletown
38	Mount Morris
39	Rices Landing
40	Waynesburg
41	Fairchance
42	Hopwood
43	Masontown

44	McClellandtown
45	New Salem
46	Point Breeze
47	Point Marion
48	Republic
49	Smithfield
50	South Uniontown
51	Uniontown

Table 4.2 Example Tabular Data Matched between Yellowpages.com and the Populated Places DBF Table, Year 2000

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
BRAEWICK WOODS	MORGANTOWN HOSPICE	989 MAPLE DR	MORGANTOWN	WV	26505
SUNCREST	TENDER LOVING CARE HOME CARE	3280 UNIVERSITY AVE	MORGANTOWN	WV	26505
THE FLATTS	THE MADISON	445 VAN VOORHIS RD	MORGANTOWN	WV	26505

After establishing the density and location of sensitive receptor within populated place of the study area, spatial analysis of those point locations to the proposed CFPP main stack was conducted. This was done using the straight line distance calculation with ArcGIS 8.3 Spatial Analyst extension, previously discussed. Using the Spatial Analyst raster calculator, the radius, extending from the proposed CFPP out to 30km was calculated, then divided into separate 5km increments. The 5km increments were arbitrarily chosen to improve the evaluating ability of sensitive receptors within the entire 30km radius. To date, I have not located in the literature any data that suggests maximum or minimum radial increment levels to be established out from CFPP stacks and facilities. Figure 10 shows the distance to stack radial calculation and respective counties and states with in the study area.

Figure 10: Increment of annular distance to stack calculation. It shows the distance to stack radial calculation and respective counties and states within the study area. The radius, extending from the proposed CFPP out to 30km was calculated using spatial analysis tools in GIS software. It was arbitrarily divided into separate 5km increments to improve the evaluating ability of sensitive receptors within the entire 30km radius. This annular distance calculation was used to identify straight line distances of populated places containing sensitive receptor categories.

Figure 11 below shows those populated places within 0-5km radius of the proposed stack. Table 4.3 is the DBF table associated with Figure 11. At this point, the DBF locations associated with the populated place shapefiles having sensitive receptors, were upgraded with spatial density information on sensitive receptors, and could be presented in conjunction with the various figures of incremental distance to stack. The particular DBF table below identifies that Baker Ridge has 1 child day care facility, and Braewick Woods has 1 hospital, 1 nursing home, 1 school, and 2 child day care facilities. Each point in the DBF table correlates to actual coordinate points (UTM; easting and northing), with FIPS number. The Federal Information Processing Standards (FIPS) number is the federal government coding system for identifying geographic locations. This particular code identifies location by state and county level and was provided in the populated places DBF. The first two numbers signify which state while the last three numbers signify a county within the state. Figures of populated places at 5-10km, 10-15km, 15-20km, 20-25km, 25-30km and their associated DBF attribute names follow in Figures 12 - 19, and Tables 4.4 - 4.8. In order to clearly read the names of all populated places at 25-30km radius, nine different figures were developed for presentation.

Figure 11: Counties and locations of sensitive receptor categories used within distance to stack calculation of 0 - 5 km. Bakers Ridge and Braewick Woods are the only two populated places containing sensitive receptor categories within 0 - 5 km from the proposed stack. There is a hospital, nursing home, school, and 3 child day care facilities identified within this distance from the proposed stack. Table 4.3, page 78, identifies which populated place contains these sensitive receptors.

Figure 12: Counties and locations of sensitive receptor categories used within distance to stack calculation of 5 - 10 km. Greater Morgantown, WV and neighboring populated places containing sensitive receptor categories are within 5 - 10 km from the proposed stack. Point Marion, PA is also within 5 - 10 km from the proposed stack. There are two hospitals, 2 nursing homes, 25 schools, and 17 child day care facilities identified within this distance from the proposed stack. Table 4.4, page 78, identifies which populated place contains what sensitive receptor category.

Figure 13: Counties and locations of sensitive receptor categories used within distance to stack calculation of 10 - 15 km. Hilderbrand and Richard, WV, and Mount Morris and Mapletown, PA are the populated places containing sensitive receptor categories within 10 - 15 km from the proposed stack. There are 4 schools, and 2 child day care facilities identified within this distance from the proposed stack. Table 4.5, page 78, identifies which populated place contains what sensitive receptor category.

Figure 14: Counties and locations of sensitive receptor categories used within distance to stack calculation of 15 - 20 km. National and Sturgis, WV and Smithfield and Masontown, PA populated places containing sensitive receptor categories are within 15 - 20 km from the proposed stack. There are two 4 schools, and 4 child day care facilities identified within this distance from the proposed stack. Table 4.6, page 79, identifies which populated place contains what sensitive receptor category.

Figure 15: Counties and locations of sensitive receptor categories used within distance to stack calculation of 20 - 25 km. Rivesville and Masontown, WV, and Fairchance, McClellandtown, and Carmichaels, PA are the populated places containing sensitive receptor categories within 20 - 25 km from the proposed stack. There is a hospital, 5 schools, and 5 child day care facilities identified within this distance from the proposed stack. Table 4.7, page 79, identifies which populated place contains what sensitive receptor category.

Figure 16: Southwest Counties and locations of sensitive receptor categories used within distance to stack calculation of 25 - 30 km. This figure identifies Ragtown, Fairview and Fairmont, WV (and neighboring communities) as the populated places containing sensitive receptor categories within 25 - 30 km from the proposed stack. This is southwest from the proposed stack. There are 10 hospitals, 4 nursing homes, 35 schools, and 33 child day care facilities identified within this distance from the proposed stack; more than what is depicted in this figure. Table 4.8, page 79, identifies which populated place contains what sensitive receptor category.

Figure 17: Southeast Counties and locations of sensitive receptor categories used within distance to stack calculation of 25 - 30 km. This figure identifies Arthurddale, Reedsville and Bruceton Mills, WV as the populated places containing sensitive receptor categories within 25 - 30 km from the proposed stack. This is southeast from the proposed stack. There are 10 hospitals, 4 nursing homes, 35 schools, and 33 child day care facilities identified within this distance from the proposed stack; more than what is depicted in this figure. Table 4.8, page 79, identifies which populated place contains what sensitive receptor category.

Figure 18: Northeast Counties and locations of sensitive receptor categories used within distance to stack calculation of 25 - 30 km. This figure identifies Uniontown, PA (and neighboring communities) as the populated places containing sensitive receptor categories within 25 - 30 km from the proposed stack. This is northeast from the proposed stack. There are 10 hospitals, 4 nursing homes, 35 schools, and 33 child day care facilities identified within this distance from the proposed stack; more than what is depicted in this figure. Table 4.8, page 79, identifies which populated place contains what sensitive receptor category.

Figure 19: Northwest Counties and locations of sensitive receptor categories used within distance to stack calculation of 25 - 30 km. This figure identifies Waynesburg, Jefferson, and Rices Landing, PA as the populated places containing sensitive receptor categories within 25 - 30 km from the proposed stack. This is northwest from the proposed stack. There are 10 hospitals, 4 nursing homes, 35 schools, and 33 child day care facilities identified within this distance from the proposed stack; more than what is depicted in this figure. Table 4.8, page 79, identifies which populated place contains what sensitive receptor category.

**Table 4.3 DBF Table: Sensitive Receptors at Populated Areas, Distance to Stack
Calculation - 0 - 5 km**

NAME	HOSPITALS	NURSING HOMES	SCHOOLS	CHILD DAY CARE	EASTING	NORTHING	FIPS
Baker Ridge	0	0	0	1	590168.10	4392253.90	54061
Braewick Woods	1	1	1	2	589384.60	4390817.50	54061

**Table 4.4 DBF Table: Sensitive Receptors at Populated Areas, Distance to Stack Calculation
- 5 - 10 km**

NAME	HOSPITALS	NURSING HOMES	SCHOOLS	CHILD DAY CARE	EASTING	NORTHING	FIPS
Canyon	0	0	0	1	595130.10	4392645.60	54061
Fairmor	0	0	0	1	587034.20	4387422.50	54061
Hopecrest	0	0	3	2	589223.60	4386070.40	54061
Morgantown	0	0	4	4	589574.20	4387161.10	54061
Osage	0	0	2	0	585055.70	4390433.20	54061
Riverside	0	0	2	1	587788.30	4388137.40	54061
Sabraton	0	0	2	0	591911.40	4387167.20	54061
South Hills	0	0	2	0	590892.70	4386100.10	54061
South Park	0	0	2	1	589728.60	4386100.10	54061
Star City	0	0	0	2	586915.10	4390386.70	54061
Suncrest	0	1	3	1	587933.80	4390029.20	54061
Sunset Beach	0	0	2	0	598023.40	4392794.10	54061
The Flatts	2	1	0	1	588903.90	4389738.10	54061
The Mileground	0	0	0	2	591717.40	4388671.00	54061
West Sabraton	0	0	0	1	592088.40	4385809.00	54061
Westover	0	0	1	0	588370.30	4387797.80	54061
Wiles Hill	0	0	1	0	589631.50	4388768.00	54061
Point Marion	0	0	1	0	594336.80	4399439.70	42051

**Table 4.5 DBF Table: Sensitive Receptors at Populated Areas, Distance to Stack Calculation
- 10 - 15 km**

NAME	HOSPITALS	NURSING HOMES	SCHOOLS	CHILD DAY CARE	EASTING	NORTHING	FIPS
Hilderbrand	0	0	0	1	586068.40	4382798.30	54061
Richard	0	0	0	1	593900.20	4384693.30	54061
Mapletown	0	0	2	0	590310.70	4406570.30	42059
Mount Morris	0	0	2	0	579784.50	4398566.50	42059

**Table 4.6 DBF Table: Sensitive Receptors at Populated Areas, Distance to Stack Calculation
- 15 - 20 km**

NAME	HOSPITALS	NURSING HOME	SCHOOLS	CHILD DAY CARE	EASTING	NORTHING	FIPS
National	0	0	2	0	582679.50	4381980.30	54061
Sturgisson	0	0	0	1	597101.70	4382219.40	54061
Masontown	0	0	1	1	594045.70	4411372.60	42051
Smithfield	0	0	1	2	602049.50	4406570.30	42051

**Table 4.7 DBF Table: Sensitive Receptors at Populated Areas, Distance to Stack Calculation
- 20 - 25 km**

NAME	HOSPITALS	NURSING HOMES	SCHOOLS	CHILD DAY CARE	EASTING	NORTHING	FIPS
Rivesville	0	0	1	1	575855.40	4375961.90	54049
Masontown	0	0	1	1	603165.20	4378872.40	54077
Carmichaels	0	0	1	3	587691.20	4416853.90	42059
Fairchance	1	0	1	0	606560.70	4409092.70	42051
McClellandtown	0	0	1	0	596762.20	4415838.30	42051

**Table 4.8 DBF Table: Sensitive Receptors at Populated Areas, Distance to Stack Calculation
-25 - 30 km**

NAME	HOSPITALS	NURSING HOMES	SCHOOLS	CHILD DAY CARE	EASTING	NORTHING	FIPS
Ragtown	0	0	0	1	562877.10	4388989.40	54061
Barrackville	0	0	2	0	571538.20	4373003.00	54049
Chesapeake	0	0	1	0	572799.40	4373439.50	54049
Fairmont	3	1	10	10	573672.50	4370965.60	54049
Fairview	0	0	1	0	564553.10	4382801.50	54049
Palatine	0	0	1	1	574109.10	4370383.60	54049
Arthurdale	0	0	1	0	601806.90	4372420.90	54077
Bruceton Mills	0	0	1	1	616504.80	4390805.30	54077
Reedsville	1	0	0	2	603310.70	4374167.20	54077
Jefferson	0	0	1	1	580318.10	4420443.50	42059
Rices Landing	0	0	0	1	585750.90	4422189.80	42059
Waynesburg	1	1	5	5	570082.90	4416708.40	42059
Hopwood	0	0	0	1	610974.90	4414962.10	42051
New Salem	0	0	1	0	599430.10	4420006.90	42051
Point Breeze	0	0	2	1	613497.30	4405988.20	42051
Republic	0	0	1	0	595937.50	4424227.10	42051
South Uniontown	1	0	2	1	607094.30	4416659.90	42051
Uniontown	4	2	6	8	609713.70	4417484.50	42051

Upon completing the identification and spatial analysis, 51 populated place points have been which contain sensitive receptor categories used. Their densities and distance to stack were depicted and listed in the figures and tables above. A total of 76 schools, 64 child day care facilities, 7 nursing homes and 8 hospitals are associated with the populated places mapped within the 30km radius. Appendix C provides a complete list of facilities, per type of categorized sensitive receptor. Each table in Appendix C is divided into 7 columns: distance to stack range (km), populated place, name of sensitive receptor, state, FIPS, and county. Rows are divided into the 5km increment level sections, counting the number of that particular type of sensitive receptor within that increment level.

4.2 Plot Plan Drawing Results for Potential Building Downwash

The layout of the proposed CFPP boundary and building profiles are very important when modeling the dispersion of on-site emissions off-site. As stated earlier, the direct impact of building downwash concentrations on neighboring surrounding communities, does sometimes occur. This is why I chose to construct a 2D digital drawing, Figure 20 below, of the proposed CFPP plot plan as a foundation for use in the air dispersion modeling software for modeling potential direction specific building downwash effects. Another drawing depicts building and stack dimensions, and their relative location to one another. See Figure 21 below. Both drawings were derived from the CFPP proposed plot plan provided by WV DAQ.

Figure 20: 2 dimensional drawing of proposed coal fired power plant plot plan. This digital drawing was used in the air dispersion modeling software for modeling potential direction specific building downwash effects discussed in chapter 2. The air dispersion modeling software only imports 2D digital drawings. The dimensions of each building and the stack (See figure below) is added to the 2D drawing in the air dispersion model.

Figure 21: Plot plan dimensions of proposed coal fired power plant plot plan. This drawing depicts building and stack dimensions, and their relative location to one another. There are five different buildings. The dimensions of each building were added to the 2D drawing in the air dispersion model.

To date, the proposed site is going to have 6 different building tiers. The simple 2D drawing above was drawn in the world coordinate system (WCS), over the proposed plot plan real world coordinates, as discussed sections 3.2 and 3.3.2 respectively. Drawing it in such a manner enables it to be imported and read by the air dispersion modeling software. The Bag House is 39.37 meters wide x 57.26 meters long x 25.9 meters tall. Boiler Tier # 1 is 39.37 meters wide x 65.05 meters long x 52.1 meters high. Boiler Tier #3 is 37.58 meters wide x 46.53 meters long x 78.3 meters high. Boiler Tier #2 is 21.47 meters wide x 57.26 meters long x 58.5 meters high. The Turbine Hall is 23.26 meters wide x 75.16 meters long x 30.4 meters high. The stack, as listed in Table 3.1, is 168.9 meters high with an internal stack exit diameter of 5.94 meters. The 3 dimensional profile, however, not depicted in the figures above, is what contributes to downwash effects. Calculation and evaluation of the third dimension contributions to direction specific building downwash takes place in AERMOD, as stated in Method 2. The results of 3D modeling, within AERMOD is below (Figure 22). This does not show wake, or cavity, for each direction per particular day 24 hour average. Figure 22 does however point out visually the relative sizes and locations of proposed stack and buildings withing the site plan, from an elevated vantage point, from south of the site, looking north. From this viewing direction, building downwash would conceivably occur on the east or south side of the buildings.

Figure 22: 3 dimensional modeling in the air dispersion modeling software, AERMOD. 3 dimensional profile, not depicted in the figures above, is what contributes to downwash effects discussed in chapter 2. Calculation and evaluation of the third dimension takes place in air dispersion modeling software, and is depicted here.

Unfortunately, neither dimensions nor the building themselves can be labeled by the 3D view in AERMOD. Buildings and dimensions may be distinguished using Figure 21 above.

4.3 Concentration Exposure Modeling Results

Modeled concentration results, and concentration contour map results, with populated places included, are listed below. It was decided that modeling would be conducted for the maximum 24 hour averages, for the entire year of 2000. Choosing to model at this averaging period, matched that of the same averaging period for monitored background concentrations, that were provided to us by the EPA. Table 4.9 shows the highest 25 maximum 24 hour averaging concentrations, their real world coordinates in UTM (meters), and the dates they occurred, modeled for the year 2000. This table was extracted from the, extremely large, model run output file, and organized into an Excel

spreadsheet to facilitate evaluation.

Table 4.9 25 Maximum, 24 Hour Averaging Concentrations ($\mu\text{g}/\text{m}^3$) Contributions, for 2000

RANK	CONC	DATE	XCOOR	YCOOR
1	1.07346	June 11, 2000	590763.31	4396379.00
2	0.99433	June 19, 2000	588951.25	4394219.50
3	0.98795	June 16, 2000	590428.50	4396778.00
4	0.97003	June 11, 2000	590330.31	4396129.00
5	0.95395	July 23, 2000	588951.25	4394219.50
6	0.92331	June 19, 2000	588780.25	4393749.50
7	0.88237	June 11, 2000	591196.38	4396629.00
8	0.86932	July 23, 2000	588780.25	4393749.50
9	0.86635	May 31, 2000	590428.50	4396778.00
10	0.84513	May 12, 2000	590763.31	4396379.00
11	0.82696	July 23, 2000	589122.25	4394689.50
12	0.81994	June 16, 2000	590749.88	4397161.00
13	0.81748	July 25, 2000	587987.06	4395889.50
14	0.81437	May 12, 2000	590428.50	4396778.00
15	0.80741	May 31, 2000	590107.06	4396395.00
16	0.79782	May 8, 2000	590763.31	4396379.00
17	0.79255	June 21, 2000	590428.50	4396778.00
18	0.77657	May 8, 2000	590330.31	4396129.00
19	0.76232	May 18, 2000	590428.50	4396778.00
20	0.76187	May 12, 2000	590749.88	4397161.00
21	0.74810	June 25, 2000	590428.50	4396778.00
22	0.73689	May 30, 2000	588165.25	4396379.00
23	0.73676	May 15, 2000	590428.50	4396778.00
24	0.72924	May 12, 2000	591196.38	4396629.00
25	0.72848	July 25, 2000	588165.25	4396379.00

The above table was used to assess in more detail the top five modeled highest concentration dates for the entire year. The highest modeled 24 hour average concentration date, at $1.073 \mu\text{g}/\text{m}^3$, occurred on June 11, 2000. The second highest modeled concentration date, at $0.994 \mu\text{g}/\text{m}^3$, occurred on June 19. The third highest modeled concentration date, at $0.987 \mu\text{g}/\text{m}^3$, occurred on June 16. The fourth highest modeled concentration date, at $0.953 \mu\text{g}/\text{m}^3$, occurred on July 23. The

fifth highest modeled concentration date, at $0.866 \mu\text{g}/\text{m}^3$, occurred on May 31. Each of these dates were chosen for individual modeling, and creation of contour map, in order to represent the 5 worst 24 hour averaging conditions for that year. A contour map of the first model run would only represent an annual average concentration, not worst conditions. Such a map would depict lower concentrations than what is of concern in this study.

The individual 24 hour model run of June 11, 2000, again modeled the same highest concentration value and it's location for that day, as the preceding annual model run. The same thing happened for the four other dates. For presentation purposes, only the top 25 modeled average 24 hour concentrations for each 24 hour period are listed in Table 4.10 - 4.14. UTM easting (X COOR) and northing (Y COORD) in meters, Zone 17 North. Latitude is here measured westward from zero meridian at Greenwich, England, which would make these Latitudes negative; however, by convention, in the Western Hemisphere, these are written as positive values of meters, as in this table.

**Table 4.10 Top 25, 24 Hour Concentration ($\mu\text{g}/\text{m}^3$)
Contributions for June 11, 2000**

RANK	CONC	XCOOR	YCOOR
1	1.07346	590763.31	4396379.00
2	0.97003	590330.31	4396129.00
3	0.88237	591196.38	4396629.00
4	0.69305	590449.12	4395802.50
5	0.69279	591629.38	4396879.00
6	0.65419	590941.50	4395889.50
7	0.55408	591433.94	4395976.50
8	0.50955	590428.50	4396778.00
9	0.49644	592062.38	4397129.00
10	0.46710	590749.88	4397161.00
11	0.42773	592495.38	4397379.00
12	0.37882	591926.31	4396063.00
13	0.36992	591071.25	4397544.00
14	0.33462	592928.38	4397629.00
15	0.31271	590107.06	4396395.00
16	0.30200	592418.75	4396150.00
17	0.29857	591392.69	4397927.00
18	0.27711	593361.44	4397879.00
19	0.26124	592911.12	4396237.00
20	0.24557	591714.06	4398310.00
21	0.23900	593794.44	4398129.00
22	0.20872	594227.44	4398379.00
23	0.20835	593403.50	4396323.50
24	0.19939	592035.44	4398693.00
25	0.18393	594660.44	4398629.00

**Table 4.11 Top 25, 24 Hour Concentration ($\mu\text{g}/\text{m}^3$)
Contributions for June 19, 2000**

RANK	CONC	XCOOR	YCOOR
1	0.99433	588951.25	4394219.50
2	0.92331	588780.25	4393749.50
3	0.72689	588609.25	4393280.00
4	0.70224	589122.25	4394689.50
5	0.57393	588438.25	4392810.00
6	0.49761	588267.25	4392340.00
7	0.44256	588096.25	4391870.00
8	0.40031	587925.19	4391400.50
9	0.36149	587754.19	4390930.50
10	0.34376	587933.81	4390029.00
11	0.33476	587583.19	4390460.50
12	0.33416	588500.12	4394480.00
13	0.31103	587412.19	4389991.00
14	0.30965	588178.75	4394097.00
15	0.29289	587241.19	4389521.00
16	0.27507	587070.19	4389051.00
17	0.27182	587788.31	4388137.50
18	0.26784	587034.19	4387422.50
19	0.25459	586899.12	4388581.50
20	0.25170	586915.12	4390386.50
21	0.24737	587857.31	4393714.00
22	0.24259	586728.12	4388111.50
23	0.23244	586557.12	4387641.50
24	0.22921	589464.31	4394129.00
25	0.22696	586386.12	4387172.00

**Table 4.12 Top 25, 24 Hour Concentration ($\mu\text{g}/\text{m}^3$)
Contributions for June 16, 2000**

RANK	CONC	XCOOR	YCOOR
1	0.98795	590428.50	4396778.00
2	0.81994	590749.88	4397161.00
3	0.69709	590107.06	4396395.00
4	0.62887	591071.25	4397544.00
5	0.49976	591392.69	4397927.00
6	0.41037	591714.06	4398310.00
7	0.40261	590763.31	4396379.00
8	0.34867	592035.44	4398693.00
9	0.33054	589977.31	4397038.50
10	0.32987	590330.31	4396129.00
11	0.31894	591196.38	4396629.00
12	0.29583	592356.81	4399076.00
13	0.29096	589806.31	4396568.50
14	0.28339	590148.31	4397508.50
15	0.25327	592678.25	4399459.00
16	0.24450	591629.38	4396879.00
17	0.22440	590319.38	4397978.00
18	0.22229	592999.62	4399842.00
19	0.18299	593321.00	4400225.50
20	0.17312	592062.38	4397129.00
21	0.16957	590490.38	4398448.00
22	0.16797	593642.44	4400608.50
23	0.15833	593963.81	4400991.50
24	0.14918	592495.38	4397379.00
25	0.14454	594285.19	4401374.50

**Table 4.13 Top 25, 24 Hour Concentration ($\mu\text{g}/\text{m}^3$)
Contributions for July 23, 2000**

RANK	CONC	XCOOR	YCOOR
1	0.95395	588951.25	4394219.50
2	0.86932	588780.25	4393749.50
3	0.82696	589122.25	4394689.50
4	0.69965	588609.25	4393280.00
5	0.56952	588438.25	4392810.00
6	0.50257	588267.25	4392340.00
7	0.47804	589464.31	4394129.00
8	0.44730	588096.25	4391870.00
9	0.42466	589464.31	4393629.00
10	0.42455	589464.31	4394629.00
11	0.40386	587925.19	4391400.50
12	0.38696	588500.12	4394480.00
13	0.36354	587754.19	4390930.50
14	0.35663	588178.75	4394097.00
15	0.33446	587583.19	4390460.50
16	0.33311	588821.50	4394863.00
17	0.33275	587933.81	4390029.00
18	0.31393	589464.31	4393129.00
19	0.30910	587412.19	4389991.00
20	0.29009	587857.31	4393714.00
21	0.28971	587241.19	4389521.00
22	0.28745	589464.31	4392629.00
23	0.27081	587070.19	4389051.00
24	0.26553	586915.12	4390386.50
25	0.26022	589464.31	4392129.00

Table 4.14 Top 25, 24 Hour Concentration ($\mu\text{g}/\text{m}^3$) Contributions for May, 31 2000

RANK	CONC	XCOOR	YCOOR
1	0.86635	590428.50	4396778.00
2	0.80741	590107.06	4396395.00
3	0.68635	589806.31	4396568.50
4	0.68594	590749.88	4397161.00
5	0.61240	589977.31	4397038.50
6	0.51792	591071.25	4397544.00
7	0.51316	590148.31	4397508.50
8	0.40937	590319.38	4397978.00
9	0.40732	591392.69	4397927.00
10	0.39117	590763.31	4396379.00
11	0.37211	590330.31	4396129.00
12	0.33214	591714.06	4398310.00
13	0.31934	590490.38	4398448.00
14	0.30903	591196.38	4396629.00
15	0.27463	592035.44	4398693.00
16	0.25962	590661.38	4398918.00
17	0.23631	591629.38	4396879.00
18	0.23620	592356.81	4399076.00
19	0.21528	589785.69	4396012.00
20	0.21379	590832.38	4399388.00
21	0.20283	592678.25	4399459.00
22	0.18445	591003.38	4399857.50
23	0.17871	592999.62	4399842.00
24	0.17027	589635.31	4396099.00
25	0.16653	592062.38	4397129.00

Analyzing Table 4.9 above, June 11 is the highest 24 hour average concentration day modeled. Provided EPA monitored background concentrations, Table 3.3, only lists the highest monitored 24 hour average concentration from the only four monitors within the study area. By combining, June 11 modeled concentration contribution to the highest monitored background concentration out of the four area monitors for the year 2000, ambient background concentration can be estimated at being $1.82 \mu\text{g}/\text{m}^3$. That is far below $260 \mu\text{g}/\text{m}^3$, the provisional maximum ambient SO_2 concentration of this study. Comparing this same estimation to the allotted PSD increment consumption of $91 \mu\text{g}/\text{m}^3$ 24 hour averaging standard, only 2 % is being consumed when

using modeling techniques applied in this thesis. The WV DAQ modeling has estimated that 17% (15.5 $\mu\text{g}/\text{m}^3$) of the PSD increment consumption of 91 $\mu\text{g}/\text{m}^3$ 24 hour averaging standard will be consumed using different modeling techniques.⁵⁷ WV DAQ summed all modeled contributing sources, creating a higher overall consumption of the PSD increment, by combining both nearby source contributions, using AERMOD, and distant sources, using CALPUFF models. The last historical PSD incremental modeling conducted of this area (PSD permit application to construct Beechurst Power Plant), by WV DAQ in 1988, estimated that 99.5% (90.5 $\mu\text{g}/\text{m}^3$) of the PSD increment consumption of 91 $\mu\text{g}/\text{m}^3$ 24 hour averaging standard would be consumed.⁷⁰ See chapter 5 for a discussion of the differences between the PSD increment consumption of 91 $\mu\text{g}/\text{m}^3$ 24 hour averaging standard estimates modeled by WV DAQ in 1988, and the recently modeled estimates by WV DAQ in 2003, and the proposed CFPP contribution estimates modeled in this thesis.

Contour maps provide a means to present large quantities of spatial information in a condensed, easy to understand format. The output files for each modeled day are over 500 pages in length; each complete list is a significant amount of useful spatial information. The complete list of polar grid coordinate point and populated place concentrations from each model run output file was used to produce contour maps, using GIS Kriging methods discussed in Method 3, for each of the 5 days modeled. Calculated populated place concentrations and contour maps of each day modeled are presented in the tables 4.15- 4.19 and Figures 23- 27 below.

**Tables 4.15 June 11, 2000 Populated Place Concentration
Contribution Calculations ($\mu\text{g}/\text{m}^3$)**

RANK	POPULATED PLACE	CONC	XCORD	YCOORD
1	Point Marion	0.15286	594336.80	4399439.70
2	Smithfield	0.03859	602049.50	4406570.30
3	Fairchance	0.03252	606560.70	4409092.70
4	Point Breeze	0.02760	613497.30	4405988.20
5	Hopwood	0.02203	610974.90	4414962.10
6	Uniontown	0.01649	609713.70	4417484.50
7	South Uniontown	0.01547	607094.30	4416659.90
8	New Salem	0.00766	599430.10	4420006.90
9	Baker Ridge	0.00544	590168.10	4392253.90
10	McClellandtown	0.00511	596762.20	4415838.30
11	Barrackville	0.00495	571538.20	4373003.00
12	Chesapeake	0.00304	572799.40	4373439.50
13	Masontown	0.00299	594045.70	4411372.60
14	Suncrest	0.00223	587933.80	4390029.20
15	Star City	0.00218	586915.10	4390386.70
16	The Flatts	0.00215	588903.90	4389738.10
17	Osage	0.00198	585055.70	4390433.20
18	Canyon	0.00189	595130.10	4392645.60
19	Wiles Hill	0.00166	589631.50	4388768.00
20	The Mileground	0.00140	591717.40	4388671.00
21	Rivesville	0.00139	575855.40	4375961.90
22	Riverside	0.00137	587788.30	4388137.40
23	Westover	0.00133	588370.30	4387797.80
24	Sunset Beach	0.00128	598023.40	4392794.10
25	Morgantown	0.00119	589574.20	4387161.10
26	Fairmor	0.00118	587034.20	4387422.50
27	Sabraton	0.00113	591911.40	4387167.20
28	Hopecrest	0.00101	589223.60	4386070.40

29	South Park	0.00101	589728.60	4386100.10
30	South Hills	0.00100	590892.70	4386100.10
31	West Sabraton	0.00092	592088.40	4385809.00
32	Mount Morris	0.00092	579784.50	4398566.50
33	Mapletown	0.00089	590310.70	4406570.30
34	Richard	0.00077	593900.20	4384693.30
35	Hilderbrand	0.00067	586068.40	4382798.30
36	Fairmont	0.00066	573672.50	4370965.60
37	Republic	0.00065	595937.50	4424227.10
38	National	0.00060	582679.50	4381980.30
39	Bruceton Mills	0.00056	616504.80	4390805.30
40	Masontown	0.00054	603165.20	4378872.40
41	Sturgis	0.00053	597101.70	4382219.40
42	Reedsville	0.00053	603310.70	4374167.20
43	Palatine	0.00050	574109.10	4370383.60
44	Carmichaels	0.00049	587691.20	4416853.90
45	Arthurdale	0.00047	601806.90	4372420.90
46	Fairview	0.00045	564553.10	4382801.50
47	Ragtown	0.00044	562877.10	4388989.40
48	Jefferson	0.00044	580318.10	4420443.50
49	Rices Landing	0.00043	585750.90	4422189.80
50	Waynesburg	0.00043	570082.90	4416708.40
51	Braewick Woods	0.00000	589384.60	4390817.50

**Tables 4.16 June 19, 2000 Populated Place Concentration
Contribution Calculations ($\mu\text{g}/\text{m}^3$)**

RANK	POPULATED PLACE	CONC	XCOORD	YCOORD
1	Suncrest	0.36398	587933.80	4390029.20
2	Riverside	0.28781	587788.30	4388137.40
3	Fairmor	0.28359	587034.20	4387422.50
4	Star City	0.26650	586915.10	4390386.70
5	Westover	0.23425	588370.30	4387797.80
6	Hilderbrand	0.23321	586068.40	4382798.30
7	The Flatts	0.21021	588903.90	4389738.10
8	Braewick Woods	0.12964	589384.60	4390817.50
9	Hopecrest	0.11593	589223.60	4386070.40
10	National	0.10667	582679.50	4381980.30
11	Wiles Hill	0.08152	589631.50	4388768.00
12	Morgantown	0.07955	589574.20	4387161.10
13	Osage	0.07647	585055.70	4390433.20
14	South Park	0.07192	589728.60	4386100.10
15	Palatine	0.03332	574109.10	4370383.60
16	Rivesville	0.03133	575855.40	4375961.90
17	Fairmont	0.03004	573672.50	4370965.60
18	Chesapeake	0.02333	572799.40	4373439.50
19	Barrackville	0.02076	571538.20	4373003.00
20	South Hills	0.01376	590892.70	4386100.10
21	Baker Ridge	0.01261	590168.10	4392253.90
22	Canyon	0.00254	595130.10	4392645.60
23	Point Marion	0.00251	594336.80	4399439.70
24	West Sabraton	0.00245	592088.40	4385809.00
25	Sabraton	0.00233	591911.40	4387167.20
26	The Mileground	0.00222	591717.40	4388671.00
27	Sunset Beach	0.00194	598023.40	4392794.10
28	Mount Morris	0.00182	579784.50	4398566.50
29	Richard	0.00177	593900.20	4384693.30

30	Mapletown	0.00177	590310.70	4406570.30
31	Smithfield	0.00152	602049.50	4406570.30
32	Masontown	0.00151	594045.70	4411372.60
33	Fairview	0.00137	564553.10	4382801.50
34	McClellandtown	0.00136	596762.20	4415838.30
35	Fairchance	0.00134	606560.70	4409092.70
36	Carmichaels	0.00133	587691.20	4416853.90
37	Sturgis	0.00127	597101.70	4382219.40
38	New Salem	0.00124	599430.10	4420006.90
39	Ragtown	0.00121	562877.10	4388989.40
40	South Uniontown	0.00121	607094.30	4416659.90
41	Jefferson	0.00120	580318.10	4420443.50
42	Hopwood	0.00119	610974.90	4414962.10
43	Rices Landing	0.00117	585750.90	4422189.80
44	Waynesburg	0.00117	570082.90	4416708.40
45	Republic	0.00116	595937.50	4424227.10
46	Uniontown	0.00116	609713.70	4417484.50
47	Masontown	0.00103	603165.20	4378872.40
48	Bruceton Mills	0.00097	616504.80	4390805.30
49	Reedsville	0.00096	603310.70	4374167.20
50	Arthurdale	0.00095	601806.90	4372420.90
51	Point Breeze	0.00086	613497.30	4405988.20

**Tables 4.17 July 23, 2000 Populated Place Concentration
Contribution Calculations ($\mu\text{g}/\text{m}^3$)**

RANK	POPULATED PLACES	CONC	XCOORD	YCOORD
1	Suncrest	0.35232	587933.80	4390029.20
2	Star City	0.28115	586915.10	4390386.70
3	Riverside	0.26066	587788.30	4388137.40
4	Fairmor	0.25712	587034.20	4387422.50
5	The Flatts	0.24112	588903.90	4389738.10
6	Westover	0.21725	588370.30	4387797.80
7	Braewick Woods	0.21036	589384.60	4390817.50
8	Hilderbrand	0.18336	586068.40	4382798.30
9	National	0.12357	582679.50	4381980.30
10	Osage	0.12176	585055.70	4390433.20
11	Wiles Hill	0.11184	589631.50	4388768.00
12	Hopecrest	0.11087	589223.60	4386070.40
13	Morgantown	0.09511	589574.20	4387161.10
14	South Park	0.07765	589728.60	4386100.10
15	Baker Ridge	0.06173	590168.10	4392253.90
16	Palatine	0.05968	574109.10	4370383.60
17	Rivesville	0.05774	575855.40	4375961.90
18	Fairmont	0.05586	573672.50	4370965.60
19	Chesapeake	0.04707	572799.40	4373439.50
20	Barrackville	0.04372	571538.20	4373003.00
21	South Hills	0.02681	590892.70	4386100.10
22	Sabraton	0.00791	591911.40	4387167.20
23	West Sabraton	0.00789	592088.40	4385809.00
24	The Mileground	0.00677	591717.40	4388671.00
25	Canyon	0.00430	595130.10	4392645.60
26	Point Marion	0.00422	594336.80	4399439.70
27	Fairview	0.00371	564553.10	4382801.50
28	Sunset Beach	0.00347	598023.40	4392794.10

29	Richard	0.00345	593900.20	4384693.30
30	Mount Morris	0.00327	579784.50	4398566.50
31	Mapletown	0.00318	590310.70	4406570.30
32	Masontown	0.00260	594045.70	4411372.60
33	Smithfield	0.00260	602049.50	4406570.30
34	McClellandtown	0.00228	596762.20	4415838.30
35	Sturgis	0.00226	597101.70	4382219.40
36	Fairchance	0.00225	606560.70	4409092.70
37	Carmichaels	0.00224	587691.20	4416853.90
38	New Salem	0.00203	599430.10	4420006.90
39	Ragtown	0.00199	562877.10	4388989.40
40	South Uniontown	0.00199	607094.30	4416659.90
41	Jefferson	0.00197	580318.10	4420443.50
42	Hopwood	0.00194	610974.90	4414962.10
43	Rices Landing	0.00193	585750.90	4422189.80
44	Waynesburg	0.00192	570082.90	4416708.40
45	Republic	0.00190	595937.50	4424227.10
46	Uniontown	0.00190	609713.70	4417484.50
47	Masontown	0.00183	603165.20	4378872.40
48	Reedsville	0.00170	603310.70	4374167.20
49	Arthurdale	0.00166	601806.90	4372420.90
50	Bruceton Mills	0.00164	616504.80	4390805.30
51	Point Breeze	0.00160	613497.30	4405988.20

**Tables 4.18 June 16, 2000 Populated Place Concentration
Contribution Calculations ($\mu\text{g}/\text{m}^3$)**

RANK	POPULATED PLACE	CONC	XCOORD	YCOORD
1	Point Marion	0.13792	594336.80	4399439.70
2	New Salem	0.06292	599430.10	4420006.90
3	McClellandtown	0.05634	596762.20	4415838.30
4	Smithfield	0.04797	602049.50	4406570.30
5	Masontown	0.04181	594045.70	4411372.60
6	South Uniontown	0.03205	607094.30	4416659.90
7	Fairchance	0.02990	606560.70	4409092.70
8	Uniontown	0.02818	609713.70	4417484.50
9	Hopwood	0.02565	610974.90	4414962.10
10	Republic	0.02215	595937.50	4424227.10
11	Mapletown	0.01718	590310.70	4406570.30
12	Baker Ridge	0.00327	590168.10	4392253.90
13	Point Breeze	0.00257	613497.30	4405988.20
14	Braewick Woods	0.00195	589384.60	4390817.50
15	Suncrest	0.00146	587933.80	4390029.20
16	Star City	0.00141	586915.10	4390386.70
17	The Flatts	0.00141	588903.90	4389738.10
18	Canyon	0.00126	595130.10	4392645.60
19	Wiles Hill	0.00117	589631.50	4388768.00
20	Osage	0.00114	585055.70	4390433.20
21	Carmichaels	0.00101	587691.20	4416853.90
22	The Mileground	0.00100	591717.40	4388671.00
23	Riverside	0.00098	587788.30	4388137.40
24	Westover	0.00096	588370.30	4387797.80
25	Fairmor	0.00089	587034.20	4387422.50
26	Morgantown	0.00088	589574.20	4387161.10
27	Sabraton	0.00085	591911.40	4387167.20
28	Sunset Beach	0.00082	598023.40	4392794.10
29	South Hills	0.00081	590892.70	4386100.10

30	Hopecrest	0.00080	589223.60	4386070.40
31	South Park	0.00080	589728.60	4386100.10
32	West Sabraton	0.00073	592088.40	4385809.00
33	Mount Morris	0.00073	579784.50	4398566.50
34	Richard	0.00066	593900.20	4384693.30
35	Hilderbrand	0.00057	586068.40	4382798.30
36	National	0.00053	582679.50	4381980.30
37	Rices Landing	0.00045	585750.90	4422189.80
38	Sturgisson	0.00042	597101.70	4382219.40
39	Rivesville	0.00040	575855.40	4375961.90
40	Masontown	0.00040	603165.20	4378872.40
41	Ragtown	0.00039	562877.10	4388989.40
42	Fairview	0.00039	564553.10	4382801.50
43	Reedsville	0.00039	603310.70	4374167.20
44	Jefferson	0.00039	580318.10	4420443.50
45	Waynesburg	0.00038	570082.90	4416708.40
46	Chesapeake	0.00037	572799.40	4373439.50
47	Fairmont	0.00037	573672.50	4370965.60
48	Barrackville	0.00036	571538.20	4373003.00
49	Palatine	0.00036	574109.10	4370383.60
50	Arthurdale	0.00035	601806.90	4372420.90
51	Bruceton Mills	0.00031	616504.80	4390805.30

**Tables 4.19 May 31, 2000 Populated Place Concentration
Contribution Calculations ($\mu\text{g}/\text{m}^3$)**

RANK	POPULATED PLACE	CONC	XCOORD	YCOORD
1	Point Marion	0.09380	594336.80	4399439.70
2	New Salem	0.05280	599430.10	4420006.90
3	McClellandtown	0.04243	596762.20	4415838.30
4	Smithfield	0.03768	602049.50	4406570.30
5	South Uniontown	0.03457	607094.30	4416659.90
6	Masontown	0.02954	594045.70	4411372.60
7	Uniontown	0.02751	609713.70	4417484.50
8	Jefferson	0.02692	580318.10	4420443.50
9	Fairchance	0.02458	606560.70	4409092.70
10	Hopwood	0.02305	610974.90	4414962.10
11	Republic	0.01163	595937.50	4424227.10
12	Point Breeze	0.00808	613497.30	4405988.20
13	Rices Landing	0.00686	585750.90	4422189.80
14	Mapletown	0.00607	590310.70	4406570.30
15	Baker Ridge	0.00599	590168.10	4392253.90
16	Suncrest	0.00467	587933.80	4390029.20
17	Carmichaels	0.00366	587691.20	4416853.90
18	Star City	0.00272	586915.10	4390386.70
19	The Flatts	0.00271	588903.90	4389738.10
20	Canyon	0.00244	595130.10	4392645.60
21	Osage	0.00225	585055.70	4390433.20
22	Wiles Hill	0.00224	589631.50	4388768.00
23	The Mileground	0.00198	591717.40	4388671.00
24	Riverside	0.00196	587788.30	4388137.40
25	Westover	0.00192	588370.30	4387797.80
26	Fairmor	0.00179	587034.20	4387422.50
27	Morgantown	0.00179	589574.20	4387161.10
28	Sabraton	0.00174	591911.40	4387167.20
29	Sunset Beach	0.00169	598023.40	4392794.10

30	Hopecrest	0.00163	589223.60	4386070.40
31	South Hills	0.00163	590892.70	4386100.10
32	South Park	0.00163	589728.60	4386100.10
33	West Sabraton	0.00153	592088.40	4385809.00
34	Mount Morris	0.00153	579784.50	4398566.50
35	Richard	0.00139	593900.20	4384693.30
36	Hilderbrand	0.00125	586068.40	4382798.30
37	National	0.00115	582679.50	4381980.30
38	Waynesburg	0.00108	570082.90	4416708.40
39	Sturgis	0.00103	597101.70	4382219.40
40	Masontown	0.00088	603165.20	4378872.40
41	Rivesville	0.00087	575855.40	4375961.90
42	Ragtown	0.00085	562877.10	4388989.40
43	Fairview	0.00084	564553.10	4382801.50
44	Chesapeake	0.00082	572799.40	4373439.50
45	Fairmont	0.00081	573672.50	4370965.60
46	Reedsville	0.00081	603310.70	4374167.20
47	Barrackville	0.00080	571538.20	4373003.00
48	Palatine	0.00080	574109.10	4370383.60
49	Arthurdale	0.00079	601806.90	4372420.90
50	Bruceton Mills	0.00075	616504.80	4390805.30
51	Braewick Woods	0.00001	589384.60	4390817.50

Figure 23: June 11, 2000 concentration contours from kriging ($\mu\text{g}/\text{m}^3$) - highest 24 hour average values. June 11, 2000 was the highest concentration contribution day modeled from the proposed coal fired power plant. The highest 24 hour average concentration for June 11, 2000 was $1.07 \mu\text{g}/\text{m}^3$. It occurred northeast of the proposed stack on the West Virginia, Pennsylvania border. Point Marion, PA has the highest concentration contribution, at $0.15 \mu\text{g}/\text{m}^3$ modeled that day. A majority of the contribution concentration moved toward the northeast on June 11, 2000. See chapter 5 for further discussion on kriging concentration predictions beyond the 30 km radius study area .

Figure 24: June 19, 2000 concentration contours from kriging ($\mu\text{g}/\text{m}^3$) - highest 24 hour average values. June 19, 2000 was the second highest concentration contribution day modeled from the proposed coal fired power plant. The highest 24 hour average concentration for June 19, 2000 was $1.05 \mu\text{g}/\text{m}^3$. It occurred almost directly south of the proposed stack, northwest of Bakers Ridge. Suncrest, WV has the highest concentration contribution, at $0.36 \mu\text{g}/\text{m}^3$ modeled that day. A majority of the contribution concentration moved toward the southwest on June 19, 2000. See chapter 5 for further discussion on kriging concentration predictions beyond the 30 km radius study area .

Figure 25: July 23, 2000 concentration contours from kriging ($\mu\text{g}/\text{m}^3$) - highest 24 hour average values. June 23, 2000 was the third highest concentration contribution day modeled from the proposed coal fired power plant. The highest 24 hour average concentration for June 23, 2000 was $0.101 \mu\text{g}/\text{m}^3$. It occurred southwest of the proposed stack, northwest of Bakers Ridge, WV. Suncrest, WV has the highest concentration contribution, at $0.35 \mu\text{g}/\text{m}^3$ modeled that day. A majority of the contribution concentration moved toward the southwest on June 23, 2000. See chapter 5 for further discussion on kriging concentration predictions beyond the 30 km radius study area .

Figure 26 : June 16, 2000 concentration contours from kriging ($\mu\text{g}/\text{m}^3$) - highest 24 hour average values. June 16, 2000 was the fourth highest concentration contribution day modeled from the proposed coal fired power plant. The highest 24 hour average concentration for June 16, 2000 was $0.99 \mu\text{g}/\text{m}^3$. It occurred northeast of the proposed stack, southwest of Point Marion, PA. Point Marion, PA has the highest concentration contribution, at $0.14 \mu\text{g}/\text{m}^3$ modeled that day. A majority of the contribution concentration moved toward the northeast on June 16, 2000. See chapter 5 for further discussion on kriging concentration predictions beyond the 30 km radius study area .

Figure 27 : May 31, 2000 concentration contours from kriging ($\mu\text{g}/\text{m}^3$) - highest 24 hour average values. May 31, 2000 was the fifth highest concentration contribution day modeled from the proposed coal fired power plant. The highest 24 hour average concentration for May 31, 2000 was $0.92 \mu\text{g}/\text{m}^3$. It occurred northeast of the proposed stack, southwest of Point Marion, PA. Point Marion, PA has the highest concentration contribution, at $0.09 \mu\text{g}/\text{m}^3$ modeled that day. A majority of the contribution concentration moved toward the northeast on May 31, 2000. See chapter 5 for further discussion on kriging concentration predictions beyond the 30 km radius study area .

By analyzing the contour maps above and concentration calculations for each populated place, concentration contributions of the proposed CFPP can be estimated for each five days modeled. The highest modeled concentration contribution coordinate point on June 11 is $1.07\mu\text{g}/\text{m}^3$. Populated places closest to this point, as well as other high modeled concentration contribution coordinate points, would assume to be exposed to a concentration represented by the contour interval level in which it is located, using these modeling methods. For example, modeled results (Figure 23, page 95) show that Point Marion was exposed to a 24 hour average concentration contribution of $0.15\mu\text{g}/\text{m}^3$ (Table 4.15, page 90) on June 11 and is within the 0.067630 - 0.170042 concentration contour interval. The highest calculated concentration of $1.07\mu\text{g}/\text{m}^3$ was calculated a few meters south west of Point Marion. Point Marion and Suncrest alternated at being the highest populated place concentration contribution for each day modeled, falling in higher ranges of interpolated contour levels. On June 16, a concentration of $0.36\mu\text{g}/\text{m}^3$ at Suncrest was the worst 24 hour average contribution condition modeled for any populated place, of any of the five days modeled using these methods. Similar types of analysis can be conducted on all five contour maps for each day.

The measure of certainty or accuracy of the interpolated concentration contour interval maps are listed in tables 4.20 - 4.24 below. The prediction error value are pretty close to zero. The root-mean-square standardized prediction error is as it should be, close to 1, and the root-mean-square prediction error is pretty small. The spatial relationships of each calculated concentration value, for each day modeled, was explored in the semivariogram and fitted to a model receiving the best prediction error scores from the cross validation analysis conducted in the Geostatistical Analyst.

Table 4.20 June 11, 2000 Cross Validation Results

Mean	0.0003901
Root-Mean-Square	0.01006
Root-Mean-Square	0.9268
Sandardized	

Table 4.21 June 19, 2000 Cross Validation Results

Mean	0.0001272
Root-Mean-Square	0.01663
Root-Mean-Square	0.7953
Sandardized	

Table 4.22 July 23, 2000 Cross Validation Results

Mean	0.0003133
Root-Mean-Square	0.01573
Root-Mean-Square	0.8913
Sandardized	

Table 4.23 June 16, 2000 Cross Validation Results

Mean	0.0003362
Root-Mean-Square	0.02372
Root-Mean-Square	0.841
Sandardized	

Table 4.24 May 31, 2000 Cross Validation Results

Mean	0.0001152
Root-Mean-Square	0.01311
Root-Mean-Square	0.8935
Sandardized	

It is of interest that for 2 of these 5 highest concentration contribution days, June 19 and July 23, 2000, the bulk of downwind exposure was toward the Greater Morgantown area, where the highest density of sensitive receptor categories were located (Figure 9), and that this general direction of dispersion is opposite that of prevailing wind direction for the study area. Figure 28 are the 2000 Windrows for Morgantown. As depicted in the figure, the majority of the wind was from the South-South-West, at velocities ranging from <1.54 m/s up to 8.23 m/s. The wind direction for June 19 and July 23, 2000 were nearly opposite.

Figure 28: Morgantown, West Virginia windrose for the year 2000. The majority of the wind was from the South-South-West, at velocities ranging from <1.54 m/s up to 8.23 m/s. See Figures 23, 26 and 27. The wind direction for June 19 and July 23, 2000 were nearly opposite. See Figures 24 and 25.

As it turns out, none of the modeled runs for the top five contribution days for the entire year of 2000, were as a result of direction specific building downwash. All of the highest calculated concentration contributions, for each modeled day, were off-site of the proposed CFPP. This may be contributed to two slightly different but related assumptions. One, is that the direction specific wind velocity, conducive to what would be necessary for building downwash to occur on the proposed CFPP site, never occurred on those days. The other assumption is that GEP height was consequently high enough to eliminate such direction specific building downwash within general area of the proposed site, as one would expect when implementing GEP practices.

Chapter 5 - Discussion and Summary

Elderly, young and diseased populations, those most vulnerable to increased pollution emissions, are an integral part of our nations communities. Steadily rising industrial, economic, and population growth, resulting increasing air pollution, may episodically present serious public and environmental health threats those most vulnerable groups, as well as to the general population. Recognition of such issues has led private researchers, the government, and universities to conduct extensive research, looking for correlations between pollution levels to public and environmental health. This thesis was only concerned with an increased sulfur dioxide (SO₂) contribution from a proposed new coal fired power plant (CFPP). The study area of Greater Morgantown, WV, is comprised of diverse industry, including coal mining, coal fired electricity production, the chemical and other manufacturing industries, governmental research facilities, and universities. Any substantial regional increase in pollution emissions, including that of SO₂, has the potential to increase ambient pollution levels in this area. This was the rationale for a study of possible changes in exposure of these sensitive sub-populations.

Using Geographic Information Systems (GIS) technology, together with air pollutant dispersion modeling technology, within a particular study area, I have analyzed the potential for increased SO₂ exposure to these local vulnerable groups. The goal of this thesis was to model, using these two technologies, the contribution of SO₂ from a proposed new coal-fired electricity generating plant, which is now under review for construction permitting, to the potential for human exposure. Year 2000 emissions and weather data were used to be compatible with the decennial US Census data. Two distinct major objectives to accomplishing this goal included: 1) categorizing types of population locations that may contain people most vulnerable to increased ambient levels of

SO₂; 2) modeling the worst case downwind dispersion of proposed SO₂ contributions from this plant, added to monitored background ambient levels of SO₂, toward those locations established in the first objective. The modeled increase in SO₂ was then compared to the provisional maximum ambient air concentration as well as the 24 hour average 91 µg/m³ PSD increment level. This chapter discusses the results using the methodologies described in chapter 3 and that were used to accomplish the major objectives. Discussion of some of the limitations to using the GIS and air dispersion modeling concepts that have been presented here, are reviewed as well in this chapter.

5.1 Summary of Categorized Sensitive Receptors Locations

GIS analysis was conducted in this study to quantify the density of established sensitive receptor categories within a set distance of a proposed air pollution source. The results of the sensitive receptor category location density analysis quantitatively identifies schools as being the most spatially dense of categorized sensitive receptor groups within the study area, followed by progressively less dense day care, hospitals/medical centers, and nursing home facilities. See Figure 29. Out of the two different classes of categorized sensitive receptor types, those which have populations congregating intermittently appear to be more dense than those which contain populations of limited mobility.

Figure 29: Sensitive receptor categories within 30km of stack. The figure depicts the density of established sensitive receptor categories within the entire study area. There are 76 schools, 64 day care facilities, 13 hospitals, and 7 nursing homes.

It reasonable to expect that the most vulnerable sensitive receptor category, to local increased SO₂ contributions, are the sensitive receptor categories with limited mobility, as seen by this type of analysis - due to longer time of a modeled exposure per 24 hours. This suggests that the most dense of sensitive receptor categories in this study area, may be the less vulnerable of the two categories, when considering spatial density only. We do not have data on the residential locations of the children in these day care or school facilities, so we cannot state with greater accuracy whether the overall exposure is less or greater than that of less mobile people in custodial facilities.

Another key factor of sensitive receptor category vulnerability is that of straight line distance to the proposed stack. Since the proposed CFPP is on a mountain ridge and proposes a very high stack, straight line plume dispersion was considered more likely in spite of the irregular topography. I conducted a straight line distance calculation, using GIS Spatial Analyst. It was assumed that

those closer to the stack may be more heavily exposed and, therefore, more vulnerable than those farther away from the proposed source stack during weather conditions likely to impede dispersion. Discussion of modeled worst case episodes are to follow in the next section.

By comparing the density of sensitive receptor categories to their distances from the proposed stack, vulnerability to those sensitive groups discussed above may be addressed. Figure 30 presents the bimodal density of sensitive receptor category types at the increasing distances from the proposed stack. Over half, of both the most dense and less dense sensitive receptor category types, appear to be the farthest away from the proposed stack, therefore may be the least vulnerable to increased SO₂ contributions. Note that the Greater Morgantown area occurs within the second highest dense distance increment, 5 - 10 km away from the proposed stack. Also at least one of each type of categorized sensitive receptor is located within 0 - 5 km of the proposed increasing SO₂ contributing source, while the less dense collections are located toward the middle of the range of distances modeled.

Figure 30: Density of sensitive receptors within distance to stack range. The highest dense area is the Greater Uniontown, PA. The second highest dense area is Greater Morgantown, WV. The least dense area is between Morgantown, WV and Uniontown, PA.

Geographically identifying locations and densities of categorized sensitive receptors to the proposed increased SO₂ contributing source contributed to fulfilling one objective for this thesis.

This method can be applied to any type of population vulnerability, to any pollution source, on any type of population group. John Boettner's method to assess population vulnerability to air pollution used some of these methods. His thesis, from the same laboratory as this one, is accessible on the Internet at <http://etd.wvu.edu/>.

In my judgement, future research extending to different types of categorized sensitive and non-sensitive receptor type populations exposed to air pollution, or proposed increases to air pollution is justifiable. Although beyond the scope of this thesis, location and density data on, these and other categories of sensitive receptors within the Greater Morgantown area now exists and can be used to assess vulnerability to other air pollution sources within the area.

5.2 Summary and Discussion of Worst Case Modeled SO₂ Contribution Exposure

The second objective of this thesis was to model worst case downwind exposure, from the proposed CFPP stack, of SO₂ emissions for each day of the year 2000, and to add this plant contribution to the highest 24 - hour average monitored ambient background concentration for the same year. Air dispersion modeling and kriging of modeled calculated concentration points of the proposed CFPP contribution provided a way to analyze directional patterns of plume dispersion under highest modeled concentration days for that year. It was assumed that increasing SO₂ pollution concentration can correlate to an increased public and environmental health threat. It is here argued that claiming a potential environmental public health threat for the proposed CFPP emissions is supported by modeling the movement of the highest SO₂ concentration contributions, comparing them to the provisional maximum ambient air concentration recommended in this thesis, and to the 24 hour averaging PSD increment limit established by the EPA.

As expected, the highest modeled 24 - hour concentration contributions were relatively close in distance to proposed stack, but outside of the proposed CFPP property parameter (Figures 23 - 27). The highest worst case daily modeled concentration contribution for the entire year of 2000 was 1.82 µg/m³. This value is far below the established provisional maximum ambient air concentration recommended in this thesis of 260 µg/m³, established for this study; the minimum risk level established by the Agency for Toxic Substances and Disease Registry (ATSDR). By adding this highest modeled concentration value to the highest monitored 24 hour average ambient background concentration for the year 2000, the allotted 24 hour averaging SO₂ Prevention of Significant Deterioration (PSD) increment consumption of 91 µg/m³ is consumed at 2%. See Figure 31. The

highest SO₂ monitored ambient background concentration value was chosen to represent a worst case ambient background concentration for the year 2000. This value represents all other SO₂ air polluting sources in this air quality region, and was also added to the other four (second to fifth) highest days of 24 - hour average contributions modeled. All sources, including the proposed CFPP, contribute to levels that fell below the established provisional maximum ambient air concentration. They also share the consumption of the 24 hour average PSD increment of 91 µg/m³.

Figure 31 : Modeled increment consumption of prevention of significant deterioration (PSD), 91 µg/m³ 24 hour averaging standard. Worst case proposed stack 24 hour average of 1.07 µg/m³ was added to worst case monitored background 24 hour average concentration of 0.75 µg/m³, totaling 1.82 µg/m³. 2% of 91 µg/m³ averaging standard was consumed using modeling methods in this thesis.

Modeled values from this study did not exceed the provisional maximum ambient air concentration if the proposed CFPP were to be constructed and operated consistent with the current West Virginia Department of Air Quality (WV DAQ) draft permit. The body of epidemiological studies used for establishing the provisional maximum ambient air concentration in this study is growing. Extensive bodies of research coupled with public concern could conceivably lead to stricter air quality standards (National Ambient Air Quality Standard or NAAQS, PSD increment standards). The modeled worst case exposure also shows very little deterioration in ambient SO₂ air quality. However, this value marginally represents the expected PSD increment consumption and is discussed under the following discussion of limitations section. In the past, PSD modeled values of this incremental consumption, within this air quality region, have been conducted by other entities. Modeling values vary, as discussed in the following section.

Even though modeled concentration values fell below the provisional maximum ambient air concentration and estimated PSD increment consumption was extremely low, using this modeling technique, a directional influence to contribution of the 5 highest days modeled for the year 2000 was discovered. Directional changes in modeled SO₂ concentration contributions, can be viewed in the results presented in Results, chapter 4. The contour concentration maps for these five highest contribution days show the majority of the highest SO₂ concentration contribution dispersing towards a north-north-east or south-south-west (toward Greater Morgantown) direction. Directional influence may be attributed to the vector wind directional velocity per day modeled. The SO₂ contribution modeling results indicate Point Marion (Fayette Co., PA) and Suncrest (Monongalia Co., WV) as being the most vulnerable populated places. Point Marion was the highest populated place concentration, for 3 out of the 5 (at 60%) highest days modeled. Suncrest, a

subdivision of Morgantown, WV, was the highest populated place concentration, for 2 out of the 5 (at 40%) highest days modeled.

Point Marion and Suncrest share concentration contour intervals with other populated places modeled. Other populated places, neighboring either of the two locations, have high concentrations modeled as well. Overall, it was determined that those exposed, closest to the stack, under worst case scenario, are more exposed to higher SO₂ contributions from the proposed CFPP. Sensitive receptor populations farther away, although exposed, were modeled as being less exposed than those closer to the stack.

As discussed in chapter 2, inhalation is the primary route of SO₂ exposure. Susceptibility of sensitive populations to SO₂, within the modeled exposed locations above is also likely to be influenced by genetic make-up, age, health and nutritional status, as well as the potential for exposure to other toxic pollutants.⁷¹ Elderly adults with preexisting respiratory and cardiovascular conditions appear to be more susceptible to increased respiratory illness following SO₂ exposure than elderly populations lacking such conditions. The young appear to be more susceptible during the structural developing and maturing stages of their organ structure and functions.⁷¹ The young also breathe more air per body weight than adults and exercise more, leading to an increased potential for SO₂ inhalation exposure.

Out of all the concerned sensitive populations addressed in this study, exercising mild asthmatics are recognized as the most sensitive receptor of humans to SO₂ exposure. A human volunteer study of asthmatics exhibited the lowest threshold for bronchconstriction, which is the basis for the current ATSDR toxicological profile for SO₂ recommended Minimum Risk Level (MRL) of 260 µg/m³. That MRL concentration is the lower provisional maximum ambient

concentration recommended in this thesis.⁷¹ This research is further supported by the finding of dose-response among such volunteers.

Beginning before birth and up through childhood, pre-teen, and teenage years, the human body goes through different developmental stages of structure and function. Susceptibility to SO₂ and other xenobiotics may vary with developmental stage.⁷¹ Xenobiotics are foreign chemicals that can cause changes, often adverse, in biological systems. Children often display pharmacokinetics and metabolism different from adults. For example, enzymes that have the ability to activate a parent compound to its toxic form may only be present during certain developmental stages.⁷¹ One enzyme may be important: sulfite oxidase. On exposure of SO₂ gas to the moist nasal mucosa, SO₂ is converted to a mixture of sulfite, bisulfite and hydrogen ions. Sulfites are then oxidized to sulfates by sulfite oxidase. Rats show differences in sulfite oxidase activity with age.⁷¹ Sulfite oxidase activity, lower than that of the adult, may cause increased susceptibility to oxidative damage due to an increased presence of the sulfur trioxide radical intermediate. In animals, the lower the sulfite oxidase activity, the greater the susceptibility to mortality from intratracheally introduced bisulfite.⁷¹ Other examples include a more permeable immature blood-brain barrier and different excretion rates in the infant. Also, the newborn has a lower glomerular filtration rate than adults and has not developed efficient tubular secretion and resorption rates.⁷¹

The most important characteristic of children, making them more susceptible to SO₂ exposure may be their more active lifestyles. Children exercise more frequently, increasing their breathing rate, enhancing their potential for increased SO₂ exposure. However, this may be counterbalanced by less developed alveoli in infants resulting in a proportionally smaller gas exchange surface area per body weight from adults. Urban and industrialized area air levels tend to

have higher SO₂ levels. Non-Caucasian US populations have higher asthma mortality than Caucasians. Prevalence of asthma in the US is highest in African American children of ages 8 to 11. Increased SO₂ susceptibility is therefore expected in urban asthmatic minority children.⁷¹

In summary, children are different in behaviors, biological growth and maturity, making them more susceptible to increased inhalation exposure to SO₂ than adults. Epidemiological studies show that the associated impacts of increased levels of SO₂ in adults and the elderly appear to be due to pre-existing medical conditions, such as COPD. Regardless of the potential threshold concentration for a particular sensitive population's susceptibilities to SO₂, the modeled SO₂ concentration contribution from the proposed CFPP does show a potential for increased exposure at a range of sensitive receptor locations.

5.3 Discussion of Limitations

This section briefly addresses the limitations with the methods used to identify any SO₂ contribution exposure, as a potential public and environmental health threat from the proposed CFPP. First the limitations of using GIS applications and data use will be addressed. Secondly, I will discuss limitations of the methods used to model worst case SO₂ concentrations. Air dispersion modeling calculations, and geostatistical kriging methods used to map calculated concentration contribution surface contours, are reasonable yet somewhat limited estimates.

5.3.1 Categorized Sensitive Receptor Location Identification

The results of any GIS application is as accurate as the spatial data acquired, manipulated, and layered to produce desired visual images. It is important to acquire GIS data from reliable sources, reviewing the associated metadata provided upon receiving the data. Metadata may be

referred to as background data on the data, validating its credibility. For example, good metadata will include the year assembled, from what sources, and who assembled it. Sources for all the GIS data used in this thesis are listed in Appendix A. All metadata for the GIS data used, were reviewed for use in this thesis.

Sensitive receptor density information, zip code area, and land cover used in the GIS spatial analysis are dynamic. Data such as this can change over time with population growth. Ideally, having all the sampled spatial and population data for the same year would improve the accuracy of spatial analysis; however that is not always feasible. Where feasible, all data were within, or close to as possible to, the year 2000. This provided an optimally realistic insight into actual conditions for that year. The two sets of spatial analysis data farthest from 2000 were use of 1990 land cover data and 2003 Yellowpages.com. 1990 land cover was the United States Geological Survey's (USGS) latest land cover data on the proposed study area available at the time of analysis. Information provided by Yellowpages.com on each sensitive receptor category evaluated could be an under - or over - estimation. Identification and location of some sensitive receptor facilities from Yellowpages.com may or may not be accurate today. I do not have any data indicating the frequency with which Yellowpages.com updates their listings. For example, search returns on categorized sensitive receptor facilities constructed since 2000, or renovated for other uses, may not be accurately represented by Yellowpages.com listing. For example, the Madison Nursing Home building in Morgantown, WV, was transformed into a West Virginia University (WVU) dormitory since 2000.

The annular incremental distance to stack calculation maps, also, does not consider topology. That is the maps depict straight line distances from the source stack to populated places containing sensitive receptors, without considering the rolling hills to the west and higher mountains to the

east.. As a result, some distortion between the actual real world straight line distance to the source stack and calculated distances, may exist. However, this type of distance calculation was chosen due to the height of the source stack being very high compared to surrounding elevations and populated places containing one or more of the sensitive receptors. It was assumed that the proposed height of the source stack would disperse SO₂ concentrations more or less in a straight line.

5.3.2 Modeled Worst Case SO₂ Exposure

Modeling is, by nature, an intentional simplification of actual conditions. The size and scope of a particular model, data use, terrain, among numerous other factors, all contribute complex variables difficult to model using current scientific knowledge and technology. So modeled results are reasonable quantitative estimates of reality. I elected, in this case, to model the likely worst case scenario for contributions to regional SO₂ population exposure.

The procedure of adding worst case background monitored concentrations to modeled worst case contribution concentrations from the proposed CFPP, evaluating levels possibly exceeding a provisional maximum ambient air concentration as well as to estimate a PSD consumption, has limitations. To date, the body of epidemiological research on the health effects of SO₂ have not been used to establish a more permanent toxicity level. The PSD incremental consumption predicted using the methods of this thesis differ greatly from other modeled results. The Gaussian dispersion theory used in the air dispersion modeling software has limited validity, when modeling under low wind speed conditions or within areas with drastically changing weather conditions occurring over short distances. Also, the quality of the weather data used in the air dispersion model per averaging time period, also contains technical limitations. Surface weather data is collected hourly across the year. Upper air data, tending to change less, is usually measured twice a day. Further, the three SO₂

monitoring sites active in 2000 in Morgantown, WV, were at different elevations. Among these three measurements, the highest monitored 24 - hour average value was used. We would have expected this highest value to occur at the lowest elevation monitor at Knapp Hall, in the Monongahela River Valley, but the highest value actually occurred at the WVU Law School, on a small mountain ridge, 45 meters higher. Also, stack parameters used in these models may be changed at direction of WV DAQ, US Environmental Protection Agency (EPA), or the US Federal Aviation Administration (US FAA), requiring these model contribution calculations to be redone. All these situations are addressed in detail in the following section.

5.3.2.1 Modeled Provisional Maximum Ambient Air Concentration and PSD

Consumption Limitations

There are only four SO₂ monitoring sites located throughout the study area. Three in Monongalia county, West Virginia, and the other in Greene county, Pennsylvania. All three monitoring sites in Monongalia county are within the Greater Morgantown area. Two are located at roughly 305 meters (1000 feet) elevation above sea level, while the other is located within the Monongahela River valley at roughly 260 meters (850 feet) elevation. Out of the four monitoring sites, the highest recorded 24 hour average SO₂ concentration, added together with modeled concentration contributions, was used to simulate worst case conditions. A ratio of 1:1145, single monitored concentration point to 1145 calculated concentration points was used in this procedure. The quantity of one monitoring point value to 1145 calculated contribution concentrations is quite a disproportion. Modeled concentration calculations from the proposed CFPP, far exceed those observations made at one monitoring site, here interpreted to represent all SO₂ contribution from other (existing) sources.

The highest annual 24 - hour average concentration monitored was $0.747 \mu\text{g}/\text{m}^3$. The second highest, in the valley, at WVU Knapp Hall was $0.723 \mu\text{g}/\text{m}^3$, slightly lower, and would give results close to my analysis based on the first highest. Third through fifth highest concentrations for that year were not available for monitored results.

The considerable gap between the much lower highest monitored concentration value and the modeled concentration contribution estimates may account for the value being below the provisional maximum ambient air concentration. A single monitored ambient background concentration point, used to represent existing SO_2 concentrations extending across the study area, does not accurately represent ambient SO_2 concentrations across the entire region. Ambient background concentrations of pollutants, at any particular time, fluctuate across changing land mass. Existing ambient concentrations could have been higher or lower, at different locations throughout the study area, than the concentration recorded at one monitoring station.

The same inadequate representation of existing SO_2 monitored background concentrations may be attributed to low PSD incremental consumption results. Other SO_2 PSD incremental consumption modeling, by the WV DAQ, conducted on both this proposed CFPP, and the last CFPP addition (Beechurst Power Plant), to this region's air quality, included modeling worst case SO_2 concentration contributions from all contributing CFPP and other industrial sources. Highest monitored ambient background concentrations were not used to interpret the results of such modeling. The WV DAQ method will more accurately estimate the cumulative worst case ambient level and PSD consumption due to a variety of sources, each modeled at worst case conditions. However, my results are probably closer to the actual exposure to be expected if the proposed CFPP goes into operation (looking at worst case contribution for only one source)

The WV DAQ is currently responsible for modeling PSD incremental consumption. There is a large difference between PSD modeling results, conducted in 1988, prior to the construction of the Beechurst Power Station, to that conducted in 2003 for the construction of the new proposed CFPP. Modeling by the WV DAQ, or what was referred to then as the West Virginia Air Pollution Control Commission prior to issuing the permit for construction of the Beechurst Power Plant, showed an incremental consumption of $90.5 \mu\text{g}/\text{m}^3$ (i.e., a, or almost complete consumption at 99.5% of the allotted $91 \mu\text{g}/\text{m}^3$ PSD standard in a 24 hour averaging period). See Figure 32. Today, WV DAQ is modeling the same PSD standard consumption for all existing sources, plus the proposed CFPP, at $15.5 \mu\text{g}/\text{m}^3$ (17%). See Figure 33. These are not comparable estimates for what might otherwise be expected. PSD consumption values are fluid, meaning they change annually, although the PSD SO_2 standard of $91 \mu\text{g}/\text{m}^3$ for this air quality region remains unchanged. The differences between the two modeled values, although beyond the scope of this thesis, may be attributed to advancements in modeling and emission control technology or changes in regional air polluting source emission contributions, for example due to source plant closures.

Figure 32 : Modeled increment consumption of prevention of significant deterioration (PSD), $91 \mu\text{g}/\text{m}^3$ 24 hour averaging standard by West Virginia Air Pollution Control Commission prior to issuing the permit for construction of the Beechurst Power Plant in 1988. Model results, then, showed an incremental consumption of $90.5 \mu\text{g}/\text{m}^3$. This was almost complete consumption at 99.5% of the allotted $91 \mu\text{g}/\text{m}^3$ PSD standard in a 24 hour averaging period.

Figure 33: Modeled increment consumption of prevention of significant deterioration (PSD), $91 \mu\text{g}/\text{m}^3$ 24 hour averaging standard by West Virginia Department of Air Quality prior to issuing the permit for construction of the proposed CFPP in 2003. The $91 \mu\text{g}/\text{m}^3$ PSD standard in a 24 hour averaging period was modeled by WV DAQ at $15.5 \mu\text{g}/\text{m}^3$, or 17% consumption.

5.3.2.2 Gaussian Distribution Equation Limitations

The Gaussian distribution equation relies on a “steady state” assumption and relatively higher wind speeds for accuracy in plume concentration calculations. The steady state assumption assumes that meteorology conditions (temperature profile and wind speed) between source emission and down wind receptor are spatially uniform and do not change. This is quite opposite of what is usually observed in nature. Also the Gaussian distribution equation can breakdown during low wind speed, or calm conditions, due to the inverse relationship between calculated ambient concentration and wind speed.^{31,63} Figure 34, shows the relationship of concentration predictions calculated over a range of common wind speeds. The lower the wind speed, the greater the concentration rapidly

increases towards infinity, so that the results of calculated plume concentrations are no longer valid. Such limitations prevent the Gaussian distribution equation from modeling concentrations during atmospheric stagnation episodes or that of radiation inversions, conditions proven to induce dangerously high levels of ambient air pollution concentrations.

Figure 34: Inverse relationship between wind speed and SO₂ calculated concentrations. Shows the relationship of concentration predictions calculated over a range of common wind speeds. The lower the wind speed, the greater the concentration rapidly increases towards infinity, making the results of calculated plume concentrations no longer valid. Concentrations approach unrealistic values.

Out of the 8784 hours of wind data recorded for the year 2000, 3350 were calm hours. That suggests that 38% of the year could not be modeled using the Gaussian distribution type model applied in this thesis.

5.3.2.3 Potential Stack Parameter Limitations

Depending on the outcome of the proposed CFPP's PSD permit application, for emission of SO₂ and other criteria pollutants, the proposed stack parameters (Table 3.1, page 41) may have to be altered to meet the West Virginia State Implementation Plan (SIP) monitoring and Environmental Protection Agency (EPA) requirements. Any alteration in stack parameters would directly effect the modeled results of this study. Alterations to stack parameters required by the SIP or any other federal agency may alter air dispersion modeled results, as well. For example, the proposed stack height may be a potential obstruction to air traffic, as designated by the Federal Aviation Administration (FAA). If this turns out to be the case, stack height may have to be decreased, altering this thesis model results as well as that of WV DAQ. Any future changes to stack parameters will limit current model results.

5.3.2.4 Kriging Interpolation Limitations

As a reminder, the simpler contour map created by the dispersion model uses inverse distance weighted for plume concentration contour mapping. Inverse distance means that interpolated concentrations of only the nearest data points are used to interpolate. Kriging is a more powerful process which takes into account all 1145 calculated concentration points to interpolate between calculated point concentrations which is, therefore, more accurate. Kriging predicts concentrations beyond the 30 km radius, but I cannot defend its spatial extrapolations beyond the study area, because I have no modeled concentrations to compare to the kriged extrapolations beyond the study area of 30km radius.

Chapter 6 - Conclusions

Historically, the air quality resulting from existing coal fired power plant (CFPP) emissions and the addition of new regional CFPP have been debated within Northern West Virginia. There are potential environmental and public health consequences associated with inhalation of sulfur dioxide (SO₂) from CFPP emissions. The proposed study area is steadily growing in economic activity and population. As such, it may be facing the need for serious pollution abatement. If pollution becomes too great, industrial economic growth could be forced to stop, due to enforcement of abatement regulations. Conclusion 1: A decision as to what type of economic growth would be best may be needed by the surrounding communities.

A growing economy and population surely has its positive outcomes; however, it may have negative impacts as well. Residents of this part of West Virginia, and potentially impacted border states, have a right to know the dangers associated with increased CFPP emissions and whether these are likely to affect local health. In this thesis, a sample of the literature on the possible public and environmental health threats associated with increased levels of SO₂ exposure was reviewed. Conclusion 2: This study's modeling results show that the establishment of the proposed new CFPP within the region would have an insignificant impact on ambient SO₂ concentrations. Conclusions on the possible public and environmental health threats associated with increased levels of other National Ambient Air Quality Standards (NAAQS) criteria pollutants were not reviewed in this study. However, the same methods used to model SO₂ exposure in this study area may very well be used to individually model for ambient exposure to each of the NAAQS criteria pollutants.

By comparing Geographic Information Systems (GIS) spatial analysis to the air dispersion models produced using American Meteorological Society/Environmental Protection Agency

Regulatory Model (AERMOD), a series of maps were developed showing the spatial relationship of categorized sensitive receptors to the downwind dispersion of the pollutant concentrations from the proposed stack. This information could be used by the state to make important public and environmental health decisions. Use of such maps can give authorities an idea of the public health threats associated with SO₂ pollution in northern West Virginia and southwestern Pennsylvania, particularly in the urban area of greater Morgantown, which has recently been reclassified as a metropolitan area. Conclusion 3: Maps of sensitive (SR) spatial density together with modeled pollutant concentrations at SR are useful tools for public health and air quality decision making.

Furthermore, the results from modeling the dispersion of this criteria pollutant can be used to modify state air monitoring systems. Such modifications might include relocating the air monitoring systems in order to increase monitoring efficiency: to increase the number of pollutants monitored per station; to increase monitoring of more industrial, higher traffic areas; or to increase the number of air monitoring sites, in order to better measure compliance with air quality standards. Monitoring various criteria pollutants has been ongoing, and should continue throughout the study area. Future modeling of all the air polluting sources, in addition to that conducted by the state government, would be beneficial and could serve as reason to upgrade the ambient monitoring of all air pollution sources within the region. Conclusion 4: Regional compliance air monitoring could be expanded. Conclusion 5: Dispersion modeling can help decision making in upgrading monitoring systems.

This thesis demonstrates the spatial density of communities containing a sample of SR and modeled the worst case concentration contribution of SO₂ to the ambient SO₂ concentration within a 30 kilometer radius from the proposed stack. A kriged continuous concentration surface interpolation of this proposed CFPP SO₂ contributions was developed for the 5 worst case

distributions days in 2000. Conclusion 6: Based on a review of a sample of key epidemiologic studies and reviews, it is concluded that the primary 24 hour averaging NAAQS for SO₂ should be lowered, in order to protect the SR in exposed populations, from 365µg/m³ to 260µg/m³.

Chapter 7 - Recommendations

The complexity of modeling air pollution concentrations within the atmosphere has been discussed in this study. Complex meteorological conditions, different types of pollutant behavior in the atmosphere, and all other variables effecting pollutant concentration are not easily modeled given current levels of atmospheric science and technology and modeler(s) labor intensity. For this reason only one pollutant was chosen for modeling the addition of a proposed coal fired power plant (CFPP) to existing concentrations within the vicinity of Greater Morgantown, WV. There is a need for a clearer picture of regional meteorology that can affect air quality.

Results of this study can open the door to further air quality research within the Greater Morgantown area. Research beyond air dispersion modeling is certainly warranted. Current National Ambient Air Quality Standards (NAAQS), as well as other air quality standards, rely on research beyond that conducted in this thesis for promulgating current standards. Potential research areas include a better understanding of local micro-meteorological conditions, increased ambient air pollution monitoring or other sources of air pollution such as traffic, and local epidemiological studies on the health effects of existing concentrations of air pollution. Such information may subsequently lead to changes in air quality standards, which will improve air quality in the region. This chapter briefly addresses some of these potential research topics. Recommendation 1: Further research is warranted.

It is recommended that a provisional safe standard for sensitive receptors be established. Primary NAAQS are intended to protect public health, however epidemiological studies reveal SO₂ standards are too high for protecting individuals most susceptible to air pollution. Currently, the primary SO₂ NAAQS for a 24 hour averaging period is 365 µg/m³. The provisional maximum

ambient SO₂ concentration in this study, based on the Agency of Toxic Substances and Disease Registry (ATSDR), establishes a minimum risk level for SO₂, at 260 µg/m³. Changes in lung function have been noticed in asthmatics at this concentration, which is 105 µg/m³ less than the current 24 hour averaging NAAQS for SO₂. ATSDR establishes minimum risk levels of toxicity for various substances, reviewing substantial epidemiological studies that have been conducted on that particular substance. Established minimum toxicity levels are based on significant bodies of epidemiological research. A comparison between other primary NAAQS pollutants and their associated established minimum risk levels of toxicity by ATSDR for each pollutant is certainly justifiable. Recommendation 2: The primary 24 hour NAAQS for SO₂ should be lowered to 260 µg/m³.

Another important criteria pollutant of concern is particulate matter (PM). Given the current traffic conditions, existing regional CFPP, other industry, and local weather patterns, a strong need for researching potential PM exposure is suggested. In West Virginia the population in the northern part of the state has been growing due to steady growth of new businesses, university facilities and government research facilities. This is particularly true within Monongalia County, which contains Morgantown. The area is mountainous, limiting appropriate sites for roadways. As a result, traffic congestion has become a big problem. Pollution concentrations, mainly ambient particulate matter resulting from this traffic congestion, are likely to be a cause for concern. Further, with the steady area growth in population, Monongalia County and the surrounding region has seen an increasing demand for electric power. Consequently, the electric generating capacity has also had to keep expanding to meet rising demands. This area is within one of the primary coal-producing areas of the U.S., so naturally all nearby electric power plants are fueled by coal. Coal combustion for power

generation is a major source of PM. Monitoring and modeling should be conducted not only of PM₁₀ but also on PM_{2.5}, which studies have shown is responsible for most of the health effects from inhalation of PM.⁴¹ Recommendation 3: NAAQS for other criteria pollutants should be reviewed again and perhaps revised to reflect research since they promulgated, particularly for PM, to include PM_{2.5}.

CFPP are known to produce higher amounts of air pollutants than other forms of electric generation. There are 4 ambient air quality monitors, previously addressed in greater detail in chapter 5, established throughout this thesis study area. These monitors have been strategically placed to monitor for NAAQS compliance. The ability of these monitors to adequately monitor for ambient concentrations accurately remains inconclusive. Given the current population growth and traffic density, the number of monitors, as well as their locations, may need to be reevaluated. To do so, all regional and distant air pollution sources need to be evaluated in great detail. Also, since air quality monitors lack the ability to distinguish between air pollution sources, increasing the number of monitors used, strategically located across ridge tops and valley floors, a more accurate insight as to the most significant polluters may be provided. Recommendation 4: Local monitoring for criteria pollutant ambient concentrations should be expanded to include more valley floor sites, particularly along inhabited areas containing congested traffic corridors.

In order to obtain more accurate insight, an increase in monitoring local micro-meteorological conditions within the river valley is needed. With the growing population, increasing traffic density, numerous CFPP and other industry, there is a need for greater understanding on the effects of regional nocturnal radiation inversion frequency (see chapter 2) within the Monongahela River Valley. Currently, stagnation periods, or slow moving high pressure systems, gives some

insight as to the frequency of potential air pollution episodes. However, these stagnation maps are large scale, constituting areas within West Virginia and surrounding states. As discussed in chapter 2, local weather conditions are often different and change more frequently on smaller scales. Before that of large scale weather conditions, local weather conditions effect the immediate dispersion of air pollution.

National Weather Service (NWS) hourly temperature and wind speed data are also available, however at altitudes above the valley. Hourly temperature and wind speed within the Monongahela River Valley, often theoretically different than that on the valley ridge tops, are currently not being monitored by NWS. Collecting hourly temperature and wind speed data both within the valley and at valley ridge tops is recommended, in order to provide frequency of nocturnal radiation inversions within the river valley.

Valley inversion data could be used to produce maps for analyzing frequency and strength of air pollution episodes in conjunction with stagnation maps. The effects of nocturnal radiation inversions on the dispersion of air pollution have been recognized since the 1950's. Air pollution concentrations could be exceeding susceptible public health levels and established air quality standards within major industrial and urban areas located in river valleys across the United States. This thesis work suggests that a determination of public health impacts and air quality standards compliance within this type of topology would improve by introducing considerably more valley weather data, as well as using methods similar to those used in this study but modeling on a much smaller geographic scale. Recommendation 5: Ongoing local surface meteorological monitoring should be expanded to be more representative of industrial and traffic corridor areas in valley floors.

Modeling the impact of a new regional CFPP only addresses a portion of the current air quality situation within Northern West Virginia. Local government and development authorities, within the study area of this thesis, are currently pushing economic growth that could result in significant impacts to public health and compliance with air quality standards. Air quality does not necessarily have to be sacrificed for economic growth. A broad-based community decision is needed as to the type and rate of economic growth desired within the surrounding region. Current rates of growth are straining local transportation infrastructure and possibly increasing the need for more electricity. In order to truly understand the effects of air pollution on public health and possibly promulgate more protective air quality standards, the body of air quality research needs to expand.

Recommendation 6: Development of a mechanism to meaningfully involve the public is recommended in regional planning and in defining the degree and type of growth that is optimal for the region, including the issuance of commercial permits.

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Appendix

Appendix A - GIS Data Used

Provided Data Sets:

Data Layer	Source	Scale	File Type
1990 County Boundaries (WV and PA)	WV GIS Technical Center and PASDA	1:100k	Shape-file
2000 USGS GNIS Populated Places	NRAC	N/A	Shape- and Database-file
2000 U. S. Zip Code Tabulation Area	US Census Bureau	1:100k	Shape-file
1990 U.S Land Cover	USGS National Map Viewer	1:50k	ArcInfo Grid

Created Data Sets:

Data Layer	Source	Scale	File Type
1990 Study Area County Boundaries	WV GIS Technical Center and PASDA	1:24k	Shape-file
2000 Study Area Populated Places with Sensitive Receptors	NRAC	1:24k	Shape- and Database-file
2000 U.S. Zip Code Tabulation Area of Study Area	US Census Bureau	1:50k	Shape-file
30 Kilometer Distance to Stack Calculation	Spatial Analyst Raster Calculator	1:24k	ArcInfo Grid
Contribution Concentration Contours	Geostatistical Analyst	1:24k	ArcInfo Grid

*NOTE: All GIS data was projected to North American Datum 1983 UTM zone 17 for this thesis.

The Technical Center is a division of the Department of Geology and Geography at West Virginia University that provides technical support services to support the development and operation of GIS in West Virginia. PASDA is sponsored by Pennsylvania State University, the Pennsylvania Geospatial Information Council, and the Pennsylvania Department of Environmental Protection. The Pennsylvania Geospatial Information Council, consisting of state-wide associations and nonprofit organizations, facilitate the sharing of geospatial data, cooperatively, across different agency jurisdictions.

Yellowpages.com provided the name of each category of sensitive receptor within each city/community/area, searchable per zip code area within the study area. Zip code boundaries within each county studied, were obtained from the US Census Bureau's Zipcode Tabulation Area database via their website. The community/town/city names provided by Yellowpages.com were matched with those names found in a nationwide points shapefile of cities, towns, townships, community areas, and subdivisions, provided by Michael Strager and the WV Natural Resources Analysis (WV NRAC).

Metadata are data about quality of data, including such information as where the data came from, who collected it and where. County shapefile boundaries and their respective metadata were downloaded from two WVU resource websites, the WVU NRAC, in the Davis College of Agricultural, Forestry and Consumer Sciences, from the WVU GIS Technology Center, run by the Department of Geography and Geology in the Eberley College of Arts and Sciences, and from Pennsylvania Spatial Data Access compiled by Pennsylvania State University.

**Appendix B - Complete List: Yellowpages Sensitive Receptor Category Matched to Populated Places Table
Schools, Monongalia Co. WV**

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
BRAEWICK WOODS	CHRISTIAN SCHOOLS INCORPORATED	1189 PINEVIEW DR	MORGANTOWN	WV	26505
HOPECRESRT	AREA SCHOOLS MONANGALIA COUNTY	661 GREENBAG RD	MORGANTOWN	WV	26508
HOPECRESRT	MORGANTOWN SCHOOL	109 WILSON AVE	MORGANTOWN	WV	26501
HOPECRESRT	MORGANTOWN SCHOOL	263 PRAIRIE AVE	MORGANTOWN	WV	26501
MORGANTOWN	MORGANTOWN SCHOOL	475 BAIRD ST	MORGANTOWN	WV	26505
MORGANTOWN	PRESSLEY RIDGE SCHOOLS OF W V MORGANTOWN SITE	1431 UNIVERSITY AVE	MORGANTOWN	WV	26505
MORGANTOWN	SCHOOLS CLAY BATTELLE HIGH & JR HIGH BLACKSVILLE	13 S HIGH ST	MORGANTOWN	WV	26501
MORGANTOWN	UNIVERSITY HIGH SCHOOL	991 PRICE ST	MORGANTOWN	WV	26505
NATIONAL	AREA SCHOOLS MONANGALIA COUNTY	1702 RIVER RD	MORGANTOWN	WV	26501
NATIONAL	AREA SCHOOLS MONANGALIA COUNTY	670 RIVER RD	MORGANTOWN	WV	26501
OSAGE	ADVENTURE HIGH SCHOOL		MORGANTOWN	WV	26501
OSAGE	MORGANTOWN SCHOOL		OSAGE	WV	26543
RIVERSIDE	MORGANTOWN SCHOOL	417 HOLLAND AVE	MORGANTOWN	WV	26501
RIVERSIDE	MORGANTOWN SCHOOL	403 SCHLEY ST	MORGANTOWN	WV	26501
SABRATON	TRINITY HIGH SCHOOL	30 HARNER RUN RD	MORGANTOWN	WV	26508
SABRATON	AREA SCHOOLS MONANGALIA COUNTY	1837 LISTRAVIA AVE	MORGANTOWN	WV	26505
SOUTHHILLS	MORGANTOWN SCHOOL	533 BROCKWAY AVE	MORGANTOWN	WV	26501
SOUTHHILLS	SCHOOLS WAITMAN BARBE ELEMENTARY	109 WILSON AVE	MORGANTOWN	WV	26501

SOUTHPARK	MORGANTOWN SCHOOL	500 E PARKWAY DR	MORGANTOWN	WV	26501
SOUTHPARK	MORGANTOWN CHRISTIAN ACADEMY	64 GREENBAG RD	MORGANTOWN	WV	26501
SUNCREST	AREA SCHOOLS MONANGALIA COUNTY	360 BALDWIN ST	MORGANTOWN	WV	26505
SUNCREST	AREA SCHOOLS MONANGALIA COUNTY	523 JUNIOR AVE	MORGANTOWN	WV	26505
SUNCREST	ADVENTIST CHRISTIAN SCHOOL FOR NCENTRAL W VA	437 DRUMMOND ST	MORGANTOWN	WV	26505
SUNSET BEACH	AREA SCHOOLS MONANGALIA COUNTY	160 CROSBY RD	MORGANTOWN	WV	26508
SUNSET BEACH	SHAFFRON PETE & DONNA	3135 N GREYSTONE DR	MORGANTOWN	WV	26508
WESTOVER	MORGANTOWN SCHOOL	200 W PARK AVE	MORGANTOWN	WV	26501
WILES HILL	MORGANTOWN SCHOOL	287 EUREKA DR	MORGANTOWN	WV	26505

Child Day Care Facilities, Monongalia Co. WV

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
BAKER RIDGE	CONTINUOUS LEARNING CENTER	201 BAKERS RIDGE RD	MORGANTOWN	WV	26508
BRAEWICK WOODS	LIFE CARE LEARNING CENTER	99 J D ANDERSON DR	MORGANTOWN	WV	26505
BRAEWICK WOODS	CHYLEENS 2S & 3S DAYCARE LLC	116 ELLEN LN	MORGANTOWN	WV	26505
CANYON	CHOICE CHILDRENS CENTERS LLC	246 LAKESIDE DR	MORGANTOWN	WV	26508
FAIRMOR	SHEPHERDS CARE	6 EDWIN ST	MORGANTOWN	WV	26501
FAIRMOR	BUNDLES OF JOY	16 COMMERCE DR	MORGANTOWN	WV	26501
HILDERBRAND	CHILD DEVELOPMENT RESOURCE	1045 RIVER RD	MORGANTOWN	WV	26501

HOPECREST	CHILD CARE RESOURCE CENTER	235 S HIGH ST	MORGANTOWN	WV	26501
HOPECREST	KINDER HAUS CHILD CARE CENTER	129 GREENBAG RD	MORGANTOWN	WV	26501
MORGANTOWN	HEAD START		MORGANTOWN	WV	26501
MORGANTOWN	HIGH STREETS A PLUS LEARNING CENTER	54 HIGH ST	MORGANTOWN	WV	26505
MORGANTOWN	KLINGBERG CENTER FOR CHILD DEVELOPMENT		MORGANTOWN	WV	26501
MORGANTOWN	PRESBYTERIAN CHILD DEVELOPMENT CENTER		MORGANTOWN	WV	26501
RAGTOWN	COUNTRY ANGEL DAY CARE	224 DUNKARD VALLEY BLVD	CORE	WV	26529
RICHARD	SMALL WONDERS CHILD CARE SERVICE	3174 EARL L CORE RD	MORGANTOWN	WV	26508
RIVERSIDE	SCHOOLS ALTERNATIVE LEARNING CENTER	417 HOLLAND AVE	MORGANTOWN	WV	26501
SOUTHPARK	HEAD START PROGRAM DORSEY CENTER	1433 DORSEY AVE	MORGANTOWN	WV	26501
STAR CITY	DUSEYLAND	375 BOYERS AVE	MORGANTOWN	WV	26505
STAR CITY	SERENDIPITY PRE SCHOOL & KINDERGARTEN	3529 UNIVERSITY AVE	MORGANTOWN	WV	26505
STURGISSON	CHILD CARE RESOURCE CENTER	14 MARVINS GDNS	MORGANTOWN	WV	26508
SUNCREST	ST MARYS PRE SCHOOL	3344 UNIVERSITY AVE	MORGANTOWN	WV	26505
THE FLATTS	KIDS KORNER DAY CARE	464 INGLEWOOD BLVD	MORGANTOWN	WV	26505
THE MILEGROUND	PLEASANT DAY SCHOOLS	1315 AIRPORT BLVD	MORGANTOWN	WV	26505
THE MILEGROUND	SERENDIPITY PRESCHOOL	1850 MILEGROUND RD	MORGANTOWN	WV	26505
WEST SABRATON	PEEK A BOO DAYCARE	2005 LISTRAVIA AVE	MORGANTOWN	WV	26505

Hospitals/Medical Centers, Monogalia Co. WV

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
BRAEWICK WOODS	MONONGALIA GEN HOSP THE COMMUNITY RELATIONS		MORGANTOWN	WV	26501
THE FLATTS	RUBY MEMORIAL HOSPITAL PATIENT INFORMATION		MORGANTOWN	WV	26501
THE FLATTS	UNIVERSITY HEALTH ASSOCIATES ADMINISTRATION		MORGANTOWN	WV	26501

Nursing Homes, Monogalia Co. WV

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
BRAEWICK WOODS	MORGANTOWN HOSPICE	989 MAPLE DR	MORGANTOWN	WV	26505
SUNCREST	TENDER LOVING CARE HOME CARE	3280 UNIVERSITY AVE	MORGANTOWN	WV	26505
THE FLATTS	THE MADISON	445 VAN VOORHIS RD	MORGANTOWN	WV	26505

Schools, Marion Co. WV

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
BARRACKVILLE	MARION COUNTY AREA SCHOOLS	101 HIGH ST	FAIRMONT	WV	26554
BARRACKVILLE	MARION COUNTY AREA SCHOOLS		BARRACKVILLE	WV	26559

CHESAPEAKE	BARNES ELEMENTARY TITLE I PARENT RESOURCE CENTER	100 NAOMI ST	FAIRMONT	WV	26554
FAIRMONT	AREA SCHOOLS MARION COUNTY EAST DALE ELEMENTARY	RR 3	FAIRMONT	WV	26554
FAIRMONT	MARION COUNTY AREA SCHOOLS	601 LOCUST AVE	FAIRMONT	WV	26554
FAIRMONT	MARION COUNTY AREA SCHOOLS	1025 FAIRFAX ST	FAIRMONT	WV	26554
FAIRMONT	MARION COUNTY AREA SCHOOLS	2 PENNSYLVANIA AVE	FAIRMONT	WV	26554
FAIRMONT	MARION COUNTY AREA SCHOOLS	1119 MINOR AVE	FAIRMONT	WV	26554
FAIRMONT	SCHOOLS PUBLIC SCHOOLS	200 GASTON AVE	FAIRMONT	WV	26554
FAIRMONT	AREA SCHOOLS MARION COUNTY	PO BOX 65	FAIRMONT	WV	26554
FAIRMONT	CALVARY CHRISTIAN SCHOOLS		FAIRMONT	WV	26554
FAIRMONT	EAST FAIRMONT JUNIOR HIGH	1 ORION LN	FAIRMONT	WV	26554
FAIRMONT	MARION COUNTY AREA SCHOOLS	215 7TH ST	FAIRMONT	WV	26554
FAIRVIEW	DAYBROOK ELEM SCHOOL TITLE ONE READING PROGRAM		FAIRVIEW	WV	26570
PALATINE	MARION COUNTY AREA SCHOOLS		FAIRMONT	WV	26554
RIVESVILLE	MARION COUNTY AREA SCHOOLS		RIVESVILLE	WV	26588

Child Day Care Facilities, Marion Co. WV

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
FAIRMONT	BAPTIST TEMPLE PRE	430 MORGANTOWN	FAIRMONT	WV	26554

	SCHOOL	AVE			
FAIRMONT	CHILDRENS LEARNING CENTER	424 MONROE ST	FAIRMONT	WV	26554
FAIRMONT	HEAD START	107 MAPLE AVE	FAIRMONT	WV	26554
FAIRMONT	HEAD START	1000 COUNTRY CLUB RD	FAIRMONT	WV	26554
FAIRMONT	HEAD START	213 JACKSON ST	FAIRMONT	WV	26554
FAIRMONT	METHODIST DAY CARE CENTER		FAIRMONT	WV	26554
FAIRMONT	NOAHS ARK NURSERY SCHOOL		FAIRMONT	WV	26554
FAIRMONT	SMALL WORLD CENTER INCORPORATED	303 COLUMBIA ST	FAIRMONT	WV	26554
FAIRMONT	SUNBEAM CHILD CARE CENTER	1654 MARY LOU RETTON DR	FAIRMONT	WV	26554
FAIRMONT	CHILD CARE RESOURCES CENTER	309 CLEVELAND AVE	FAIRMONT	WV	26554
PALATINE	VALLEY CHAPEL CHILD DEVELOPMENT CENTER	1511 PLEASANT VALLEY RD	FAIRMONT	WV	26554
RIVESVILLE	HEAD START		RIVESVILLE	WV	26588

Hospitals/Medical Centers, Marion Co. WV

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
FAIRMONT	FAIRMONT GENERAL HOSPITAL	214 MERCHANT ST	FAIRMONT	WV	26554
FAIRMONT	GENERAL HOSPITAL	1325 LOCUST AVE	FAIRMONT	WV	26554
FAIRMONT	WOUND HEALING CENTER OF FAIRMONT GENERAL HOSPITAL	1224 COUNTRY CLUB RD	FAIRMONT	WV	26554
FAIRVIEW	FAIRVIEW EMERGENCY		FAIRVIEW	WV	26570

Nursing Homes, Marion Co. WV

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
FAIRMONT	FAIRMONT CLINIC	132 LOCUST AVE	FAIRMONT	WV	26554

Schools, Preston Co. WV

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
ARTHURDALE	VALLEY ELEMENTARY SCHOOL		ARTHURDALE	WV	26520
BRUCETON MILLS	PRESTON COUNTY OF SCHOOLS BRCTN SCH K 8 CTRL PRSTN		BRUCETON MILLS	WV	26525
MASONTOWN	AREA SCHOOLS PRESTON COUNTY		MASONTOWN	WV	26542

Child Day Care Facilities, Preston Co. WV

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
BRUCETON MILLS	GUARDIAN ANGEL CHILD CARE CENTE	PO BOX 26	BRUCETON MILLS	WV	26525
MASONTOWN	HEAD START		MASONTOWN	WV	26542
REEDSVILLE	DAYCARE HUGS AND KISSES		REEDSVILLE	WV	26547
REEDSVILLE	PRECIOUS HUGS CHILDRENS CENTER		REEDSVILLE	WV	26547

Hospitals/Medical Centers, Preston Co. WV

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
BRUCETON MILLS	HARNED MEMORIAL MEDICAL CLINIC		BRUCETON MILLS	WV	26525
REEDSVILLE	WEST PRESTON MEDICAL CLINIC		REEDSVILLE	WV	26547

Schools, Greene Co. PA

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
CARMICHAELS	CARMICHAELS AREA SCHOOL DISTRICT CARMICHAELS AREA ELEM	225 N VINE ST	CARMICHAELS	PA	15320
JEFFERSON	SCHOOLS PUB SCHOOLS ACADEMIC ELEM SECONDARY		JEFFERSON	PA	15344
MAPLETOWN	PUB SCHOOLS - ACADEMIC - ELEM - SECONDARY GREENE CNT		GREENSBORO	PA	15338
MAPLETOWN	SOUTHESTRN GRNE SCHOOL DISTRICT BUS MGR PENN PITT ELEM		GREENSBORO	PA	15338
MOUNT MORRIS	CENTRAL GREENE SCHOOL DISTRICT PERRY ELEMENTARY		MOUNT MORRIS	PA	15349
MOUNT MORRIS	SCHOOLS PUB SCHOOLS ACADEMIC ELEM SECONDARY		MOUNT MORRIS	PA	15349
WAYNESBURG	CENTRAL GREENE SCHOOL	RR 2	WAYNESBURG	PA	15370

	WAYNESBURG CENTRAL HIGH SCHOOL				
WAYNESBURG	CTRL GREENE SCHOOL DISTRICT MARGARET BELL MILLER MID	126 E LINCOLN ST	WAYNESBURG	PA	15370
WAYNESBURG	OPEN DOOR CHRISTIAN SCHOOL	793 LIPPENCOTT RD	WAYNESBURG	PA	15370
WAYNESBURG	WARRIOR TRAIL SCHOOL	30 E WAYNE ST	WAYNESBURG	PA	15370
WAYNESBURG	CENTRAL GREENE SCHOOL WAYNESBURG CENTRAL ELEMENTARY SCHOOL	90 ZIMMERMAN DR	WAYNESBURG	PA	15370

Child Day Care Facilities, Greene Co. PA

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
CARMICHAELS	HEAD START		CARMICHAELS	PA	15320
CARMICHAELS	LIGHTHOUSE CHRISTIAN DAY SCHOOL	508 E GEORGE ST	CARMICHAELS	PA	15320
CARMICHAELS	DONNAS DAY CARE		CARMICHAELS	PA	15320
JEFFERSON	HEAD START		JEFFERSON	PA	15344
RICES LANDING	HEAD START		RICES LANDING	PA	15357
WAYNESBURG	HEAD START	300 NORTH ST	WAYNESBURG	PA	15370
WAYNESBURG	NANNYS CREATIVE LEARNING CENTER	RR 5	WAYNESBURG	PA	15370
WAYNESBURG	RAINBOWS END LEARNING CENTER	300 NORTH ST	WAYNESBURG	PA	15370
WAYNESBURG	DAY CARE CHILDREN GREENE COUNTY VO TECH SCHOOL		WAYNESBURG	PA	15370
WAYNESBURG	INTERMEDIATE UNIT 1 PRESCHOOL PROGRAM	90 ZIMMERMAN DR	WAYNESBURG	PA	15370

Hospitals/Medical Centers, Greene Co. PA

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
WAYNESBURG	OCCUPTNL MEDCN CENTER WASHINGTON HOSP	343 E ROY FURMAN HWY	WAYNESBURG	PA	15370

Nursing Homes, Greene Co. PA

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
WAYNESBURG	HOSPICE CARE INCORPORATED	58 E GREENE ST	WAYNESBURG	PA	15370

Schools, Fayette Co. PA

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
FAIRCHANCE	ALBERT GALLATIN AREA SCHOOL DISTRICT TRI VLY SR HIGH A		FAIRCHANCE	PA	15436
MASONTOWN	ALBERT GALLATIN AREA SCHOOL DISTRICT FOOD SERVICE SUPVSR		MASONTOWN	PA	15461
MC CLELLANDTOWN	ALBERT GALLATIN AREA SCHOOL DISTRICTSECONDARY SCHOOLS		MC CLELLANDTOW N	PA	15458
NEW SALEM	BROWNSVILLE AREA SCHOOL DIST INTERMEDIATE UNIT CLASSROOM	239 ROYAL RD	NEW SALEM	PA	15468
POINT BREEZE	WHARTON SCHOOL		FARMINGTON	PA	15437

POINT BREEZE	LIGHTHOUSE CHRISTIAN ACADEMY	RR 1	FARMINGTON	PA	15437
POINT MARION	ALBERT GALLATIN AREA SCHOOL DIST ELEM SCHOOLS		POINT MARION	PA	15474
REPUBLIC	BROWNSVILLE AREA SCHOOL DIST REDSTONE MID SCHOOL		REPUBLIC	PA	15475
SMITHFIELD	ALBERT GALLATIN AREA SCHOOL DISTRICT SMITHFLD ELEM SCH		SMITHFIELD	PA	15478
SOUTH UNIONTOWN	FAYETTE COUNTY AREA VOCATIONAL TECHNICAL SCHOOL	175 GEORGES FAIRCHANCE RD	UNIONTOWN	PA	15401
SOUTH UNIONTOWN	LAUREL HGLNDS SCHOOL DISTRICT LAUREL HIGHLANDS JR HIGH		UNIONTOWN	PA	15401
UNIONTOWN	COMMUNITIES IN SCHOOLS	137 N BEESON AVE	UNIONTOWN	PA	15401
UNIONTOWN	LAUREL HGLNDS SCHOOL DISTRICT GEN GEORGE C MRSHLL ELEM		UNIONTOWN	PA	15401
UNIONTOWN	LAUREL HIGHLANDS SCHOOL DIST R W CLARK ELEMENTARY	304 BAILEY AVE	UNIONTOWN	PA	15401
UNIONTOWN	LAUREL HIGHLANDS SCHOOL DISTRICT R W CLARK ELEMENTARY	200 WATER ST, UNIONTOWN, PA	UNIONTOWN	PA	15401
UNIONTOWN	PRESSLEY RIDGE SCHOOL	UNIONTOWN, PA	UNIONTOWN	PA	15401
UNIONTOWN	ABC SCHOOL HOUSE	144 N GALLATIN AVE	UNIONTOWN	PA	15401

Child Day Care Facilities, Fayette Co. PA

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
HOPWOOD	HOPWOOD UNITED METHODIST PRE SCHOOL		HOPWOOD	PA	15445
MASONTOWN	ECHO CHILD DEVELOPMENT CENTER	10 S MAIN ST	MASONTOWN	PA	15461
POINT BREEZE	COUNTRY KIDS LEARNING CENTER	RR 2	FARMINGTON	PA	15437
SMITHFIELD	SMITHFIELD LEARNING CENTER		SMITHFIELD	PA	15478
SMITHFIELD	HEAD START	25 MAIN ST	SMITHFIELD	PA	15478
SOUTH UNIONTOWN	CHESTNUT RIDGE DAY CARE	308 MCCLELLANDTOWN RD	UNIONTOWN	PA	15401
UNIONTOWN	CHILD DEVELOPMENT CENTER		UNIONTOWN	PA	15401
UNIONTOWN	COORDINATED CHILD CARE	137 N BEESON AVE	UNIONTOWN	PA	15401
UNIONTOWN	ECHO CHILD DEVELOPMENT CENTER	23 S GALLATIN AVE	UNIONTOWN	PA	15401
UNIONTOWN	HEAD START	21 WEST PL	UNIONTOWN	PA	15401
UNIONTOWN	HEAD START	80 OLD NEW SALEM RD	UNIONTOWN	PA	15401
UNIONTOWN	PRIVATE INDUSTRY COUNSEL CHILD CARE	PO BOX W	UNIONTOWN	PA	15401
UNIONTOWN	TRESSLERS FAITH LEARNING CENTER	665 CHERRY TREE LN	UNIONTOWN	PA	15401
UNIONTOWN	BETHS CHILD DAY CARE CENTER	226 N GALLATIN AVE	UNIONTOWN	PA	15401

Hospitals/Medical Centers, Fayette Co. PA

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
FAIRCHANCE	SEWICKLEY VALLEY HOSPITAL CREDIT		GEORGES TWNSHP	PA	15436
NEW SALEM	FAYETTE EMERGENCY MEDICAL SERVICE INCORPORATED		NEW SALEM	PA	15468
REPUBLIC	FAYETTE EMERGENCY MEDICAL SERVICE INCORPORATED		REPUBLIC	PA	15475
SOUTH UNIONTOWN	SOUTHWEST WOMENS HEALTH CARE INC	104 DELAWARE AVE STE 244, UNIONTOWN, PA	UNIONTOWN	PA	15401
UNIONTOWN	LAUREL RIDGE CENTER	75 HICKLE ST	UNIONTOWN	PA	15401
UNIONTOWN	UNIONTOWN HOSPITAL PRIORITY CARE		UNIONTOWN	PA	15401
UNIONTOWN	UNIONTOWN HOSPITAL UNIONTOWN HOSPITAL FOUNDATION	500 W BERKELEY ST	UNIONTOWN	PA	15401
UNIONTOWN	CENTRAL MEDICAL CENTER AND HOSPITAL		UNIONTOWN	PA	15401

Nursing Homes, Fayette Co. PA

Populated Place DBF	Yellowpages.com Results				
Point Name	Sensitive Receptor Name	Address	City/Town	State	Zip
UNIONTOWN	MABELS PERSONAL CARE HOME	54 WILSON AVE	UNIONTOWN	PA	15401
UNIONTOWN	PERSONAL CARE SERVICES	100 NEW SALEM RD	UNIONTOWN	PA	15401

Appendix C - Complete List of Facilities per Category of Sensitive Receptors within Study Area

Child Day Care Facilities

Density within Distance to Stack Range (km)	Populated Places Name	Sensitive Receptor Name	State	FIPS	County
3 in 0-5					
1	BAKER RIDGE	CONTINUOUS LEARNING CENTER	WV	54061	MONONGALIA
2	BRAEWICK WOODS	LIFE CARE LEARNING CENTER	WV	54061	MONONGALIA
3	BRAEWICK WOODS	CHYLEENS 2S & 3S DAYCARE LLC	WV	54061	MONONGALIA
24 in 5-10					
1	MASONTOWN	ECHO CHILD DEVELOPMENT CENTER	PA	42051	FAYETTE
2	SMITHFIELD	SMITHFIELD LEARNING CENTER	PA	42051	FAYETTE
3	SMITHFIELD	HEAD START	PA	42051	FAYETTE
4	CANYON	CHOICE CHILDRENS CENTERS LLC	WV	54061	MONONGALIA
5	FAIRMOR	SHEPHERDS CARE	WV	54061	MONONGALIA
6	FAIRMOR	BUNDLES OF JOY	WV	54061	MONONGALIA
7	HILDERBRAND	CHILD DEVELOPMENT RESOURCE	WV	54061	MONONGALIA
8	HOPECREST	CHILD CARE RESOURCE CENTER	WV	54061	MONONGALIA
9	HOPECREST	KINDER HAUS CHILD CARE CENTER	WV	54061	MONONGALIA
10	MORGANTOWN	HEAD START	WV	54061	MONONGALIA
11	MORGANTOWN	HIGH STREETS A PLUS LEARNING CENTER	WV	54061	MONONGALIA
12	MORGANTOWN	KLINGBERG CENTER FOR CHILD DEVELOPMENT	WV	54061	MONONGALIA
13	MORGANTOWN	PRESBYTERIAN CHILD DEVELOPMENT CENTER	WV	54061	MONONGALIA
14	RICHARD	SMALL WONDERS CHILD CARE SERVICE	WV	54061	MONONGALIA
15	RIVERSIDE	SCHOOLS ALTERNATIVE LEARNING CENTER	WV	54061	MONONGALIA
16	SOUTHPARK	HEAD START PROGRAM DORSEY CENTER	WV	54061	MONONGALIA
17	STAR CITY	DUSEYLAND	WV	54061	MONONGALIA

18	STAR CITY	SERENDIPITY PRE SCHOOL & KINDERGARTEN	WV	54061	MONONGALIA
19	STURGISSON	CHILD CARE RESOURCE CENTER	WV	54061	MONONGALIA
20	SUNCREST	ST MARYS PRE SCHOOL	WV	54061	MONONGALIA
21	THE FLATTS	KIDS KORNER DAY CARE	WV	54061	MONONGALIA
22	THE MILEGROUND	PLEASANT DAY SCHOOLS	WV	54061	MONONGALIA
23	THE MILEGROUND	SERENDIPITY PRESCHOOL	WV	54061	MONONGALIA
24	WEST SABRATON	PEEK A BOO DAYCARE	WV	54061	MONONGALIA
5 in 20-25					
1	CARMICHAELS	HEAD START	PA	42059	GREENE
2	CARMICHAELS	LIGHTHOUSE CHRISTIAN DAY SCHOOL	PA	42059	GREENE
3	CARMICHAELS	DONNAS DAY CARE	PA	42059	GREENE
4	RIVESVILLE	HEAD START	WV	54049	MARION
5	MASONTOWN	HEAD START	WV	54077	PRESTON
34 in 25-30					
1	HOPWOOD	HOPWOOD UNITED METHODIST PRE SCHOOL	PA	42051	FAYETTE
2	POINT BREEZE	COUNTRY KIDS LEARNING CENTER	PA	42051	FAYETTE
3	SOUTH UNIONTOWN	CHESTNUT RIDGE DAY CARE	PA	42051	FAYETTE
4	UNIONTOWN	CHILD DEVELOPMENT CENTER	PA	42051	FAYETTE
5	UNIONTOWN	COORDINATED CHILD CARE	PA	42051	FAYETTE
6	UNIONTOWN	ECHO CHILD DEVELOPMENT CENTER	PA	42051	FAYETTE
7	UNIONTOWN	HEAD START	PA	42051	FAYETTE
8	UNIONTOWN	HEAD START	PA	42051	FAYETTE
9	UNIONTOWN	PRIVATE INDUSTRY COUNSEL CHILD CARE	PA	42051	FAYETTE
10	UNIONTOWN	TRESSLERS FAITH LEARNING CENTER	PA	42051	FAYETTE
11	UNIONTOWN	BETHS CHILD DAY CARE CENTER	PA	42051	FAYETTE
12	JEFFERSON	HEAD START	PA	42059	GREENE
13	RICES LANDING	HEAD START	PA	42059	GREENE
14	WAYNESBURG	HEAD START	PA	42059	GREENE
15	WAYNESBURG	NANNYS CREATIVE LEARNING CENTER	PA	42059	GREENE
16	WAYNESBURG	RAINBOWS END LEARNING CENTER	PA	42059	GREENE
17	WAYNESBURG	DAY CARE CHILDREN GREENE COUNTY VO TECH	PA	42059	GREENE

		SCHOOL			
18	WAYNESBURG	INTERMEDIATE UNIT 1 PRESCHOOL PROGRAM	PA	42059	GREENE
19	FAIRMONT	BAPTIST TEMPLE PRE SCHOOL	WV	54049	MARION
20	FAIRMONT	CHILDRENS LEARNING CENTER	WV	54049	MARION
22	FAIRMONT	HEAD START	WV	54049	MARION
23	FAIRMONT	HEAD START	WV	54049	MARION
24	FAIRMONT	HEAD START	WV	54049	MARION
25	FAIRMONT	METHODIST DAY CARE CENTER	WV	54049	MARION
26	FAIRMONT	NOAHS ARK NURSERY SCHOOL	WV	54049	MARION
27	FAIRMONT	SMALL WORLD CENTER INCORPORATED	WV	54049	MARION
28	FAIRMONT	SUNBEAM CHILD CARE CENTER	WV	54049	MARION
29	FAIRMONT	CHILD CARE RESOURCES CENTER	WV	54049	MARION
30	PALATINE	VALLEY CHAPEL CHILD DEVELOPMENT CENTER	WV	54049	MARION
31	RAGTOWN	COUNTRY ANGEL DAY CARE	WV	54061	MONONGALIA
32	BRUCETON MILLS	GUARDIAN ANGEL CHILD CARE CENTE	WV	54077	PRESTON
33	REEDSVILLE	DAYCARE HUGS AND KISSES	WV	54077	PRESTON
34	REEDSVILLE	PRECIOUS HUGS CHILDRENS CENTER	WV	54077	PRESTON

Schools

Density within Distance to Stack Range (km)	Populated Places Name	Sensitive Receptor Name	State	FIPS	County
1 in 0-5					
1	BRAEWICK WOODS	CHRISTIAN SCHOOLS INCORPORATED	WV	54061	MONONGALIA
25 in 5-10					
1	POINT MARION	ALBERT GALLATIN AREA SCHOOL DIST ELEM SCHOOLS	PA	42051	FAYETTE
2	HOPECRESRT	AREA SCHOOLS MONANGALIA COUNTY	WV	54061	MONONGALIA
3	HOPECRESRT	MORGANTOWN SCHOOL	WV	54061	MONONGALIA

4	HOPECRESRT	MORGANTOWN SCHOOL	WV	54061	MONONGALIA
5	MORGANTOWN	MORGANTOWN SCHOOL	WV	54061	MONONGALIA
6	MORGANTOWN	PRESSLEY RIDGE SCHOOLS OF W V MORGANTOWN SITE	WV	54061	MONONGALIA
7	MORGANTOWN	SCHOOLS CLAY BATTELLE HIGH & JR HIGH BLACKSVILLE	WV	54061	MONONGALIA
8	MORGANTOWN	UNIVERSITY HIGH SCHOOL	WV	54061	MONONGALIA
9	OSAGE	ADVENTURE HIGH SCHOOL	WV	54061	MONONGALIA
10	OSAGE	MORGANTOWN SCHOOL	WV	54061	MONONGALIA
11	RIVERSIDE	MORGANTOWN SCHOOL	WV	54061	MONONGALIA
12	RIVERSIDE	MORGANTOWN SCHOOL	WV	54061	MONONGALIA
13	SABRATON	TRINITY HIGH SCHOOL	WV	54061	MONONGALIA
14	SABRATON	AREA SCHOOLS MONANGALIA COUNTY	WV	54061	MONONGALIA
15	SOUTHHILLS	MORGANTOWN SCHOOL	WV	54061	MONONGALIA
16	SOUTHHILLS	SCHOOLS WAITMAN BARBE ELEMENTARY	WV	54061	MONONGALIA
17	SOUTHPARK	MORGANTOWN SCHOOL	WV	54061	MONONGALIA
18	SOUTHPARK	MORGANTOWN CHRISTIAN ACADEMY	WV	54061	MONONGALIA
19	SUNCREST	AREA SCHOOLS MONANGALIA COUNTY	WV	54061	MONONGALIA
20	SUNCREST	AREA SCHOOLS MONANGALIA COUNTY	WV	54061	MONONGALIA
21	SUNCREST	ADVENTIST CHRISTIAN SCHOOL FOR NCENTRAL W VA	WV	54061	MONONGALIA
22	SUNSET BEACH	AREA SCHOOLS MONANGALIA COUNTY	WV	54061	MONONGALIA
23	SUNSET BEACH	SHAFFRON PETE & DONNA	WV	54061	MONONGALIA
24	WESTOVER	MORGANTOWN SCHOOL	WV	54061	MONONGALIA
25	WILES HILL	MORGANTOWN SCHOOL	WV	54061	MONONGALIA
4 in 10-15					
1	MAPLETOWN	PUB SCHOOLS - ACADEMIC - ELEM - SECONDARY GREENE CNT	PA	42059	GREENE
2	MAPLETOWN	SOUTHESTRN GRNE SCHOOL DISTRICT BUS MGR PENN PITT ELEM	PA	42059	GREENE
3	MOUNT MORRIS	CENTRAL GREENE SCHOOL DISTRICT PERRY ELEMENTARY	PA	42059	GREENE
4	MOUNT MORRIS	SCHOOLS PUB SCHOOLS ACADEMIC ELEM	PA	42059	GREENE

		SECONDARY			
4 in 15-20					
1	FAIRCHANCE	ALBERT GALLATIN AREA SCHOOL DISTRICT TRI VLY SR HIGH A	PA	42051	FAYETTE
2	MASONTOWN	ALBERT GALLATIN AREA SCHOOL DISTRICT FOOD SERVICE SUPVSR	PA	42051	FAYETTE
3	MC CLELLANDTOWN	ALBERT GALLATIN AREA SCHOOL DISTRICTSECONDARY SCHOOLS	PA	42051	FAYETTE
4	SMITHFIELD	ALBERT GALLATIN AREA SCHOOL DISTRICT SMITHFLD ELEM SCH	PA	42051	FAYETTE
4 in 20-25	CARMICHAELS	CARMICHAELS AREA SCHOOL DISTRICT CARMICHAELS AREA ELEM	PA	42059	GREENE
1	NATIONAL	AREA SCHOOLS MONANGALIA COUNTY	WV	54061	MONONGALIA
2	NATIONAL	AREA SCHOOLS MONANGALIA COUNTY	WV	54061	MONONGALIA
3	MASONTOWN	AREA SCHOOLS PRESTON COUNTY	WV	54077	PRESTON
4					
36 in 25-30					
1	NEW SALEM	BROWNSVILLE AREA SCHOOL DIST INTERMEDIATE UNIT CLASSROOM	PA	42051	FAYETTE
2	POINT BREEZE	WHARTON SCHOOL	PA	42051	FAYETTE
3	POINT BREEZE	LIGHTHOUSE CHRISTIAN ACADEMY	PA	42051	FAYETTE
4	REPUBLIC	BROWNSVILLE AREA SCHOOL DIST REDSTONE MID SCHOOL	PA	42051	FAYETTE
5	SOUTH UNIONTOWN	FAYETTE COUNTY AREA VOCATIONAL TECHNICAL SCHOOL	PA	42051	FAYETTE
6	SOUTH UNIONTOWN	LAUREL HGLNDS SCHOOL DISTRICT LAUREL HIGHLANDS JR HIGH	PA	42051	FAYETTE
7	UNIONTOWN	COMMUNITIES IN SCHOOLS	PA	42051	FAYETTE
8	UNIONTOWN	LAUREL HGLNDS SCHOOL DISTRICT GEN GEORGE C MRSHLL ELEM	PA	42051	FAYETTE
9	UNIONTOWN	LAUREL HIGHLANDS SCHOOL DIST R W CLARK ELEMENTARY	PA	42051	FAYETTE
10	UNIONTOWN	LAUREL HIGHLANDS SCHOOL DISTRICT R W CLARK	PA	42051	FAYETTE

		ELEMENTARY			
11	UNIONTOWN	PRESSLEY RIDGE SCHOOL	PA	42051	FAYETTE
12	UNIONTOWN	ABC SCHOOL HOUSE	PA	42051	FAYETTE
13	JEFFERSON	SCHOOLS PUB SCHOOLS ACADEMIC ELEM SECONDARY	PA	42059	GREENE
14	WAYNESBURG	CENTRAL GREENE SCHOOL WAYNESBURG CENTRAL HIGH SCHOOL	PA	42059	GREENE
15	WAYNESBURG	CTRL GREENE SCHOOL DISTRICT MARGARET BELL MILLER MID	PA	42059	GREENE
16	WAYNESBURG	OPEN DOOR CHRISTIAN SCHOOL	PA	42059	GREENE
17	WAYNESBURG	WARRIOR TRAIL SCHOOL	PA	42059	GREENE
18	WAYNESBURG	CENTRAL GREENE SCHOOL WAYNESBURG CENTRAL ELEMENTARY SCHOOL	PA	42059	GREENE
19	BARRACKVILLE	MARION COUNTY AREA SCHOOLS	WV	54049	MARION
20	BARRACKVILLE	MARION COUNTY AREA SCHOOLS	WV	54049	MARION
21	CHESAPEAKE	BARNES ELEMENTARY TITLE I PARENT RESOURCE CENTER	WV	54049	MARION
22	FAIRMONT	AREA SCHOOLS MARION COUNTY EAST DALE ELEMENTARY	WV	54049	MARION
23	FAIRMONT	MARION COUNTY AREA SCHOOLS	WV	54049	MARION
24	FAIRMONT	MARION COUNTY AREA SCHOOLS	WV	54049	MARION
25	FAIRMONT	MARION COUNTY AREA SCHOOLS	WV	54049	MARION
26	FAIRMONT	MARION COUNTY AREA SCHOOLS	WV	54049	MARION
27	FAIRMONT	SCHOOLS PUBLIC SCHOOLS	WV	54049	MARION
28	FAIRMONT	AREA SCHOOLS MARION COUNTY	WV	54049	MARION
29	FAIRMONT	CALVARY CHRISTIAN SCHOOLS	WV	54049	MARION
30	FAIRMONT	EAST FAIRMONT JUNIOR HIGH	WV	54049	MARION
31	FAIRMONT	MARION COUNTY AREA SCHOOLS	WV	54049	MARION
32	FAIRVIEW	DAYBROOK ELEM SCHOOL TITLE ONE READING PROGRAM	WV	54049	MARION
33	PALATINE	MARION COUNTY AREA SCHOOLS	WV	54049	MARION
34	RIVESVILLE	MARION COUNTY AREA SCHOOLS	WV	54049	MARION
35	ARTHURDALE	VALLEY ELEMENTARY SCHOOL	WV	54077	PRESTON

36	BRUCETON MILLS	PRESTON COUNTY OF SCHOOLS BRCTN SCH K 8 CTRL PRSTN	WV	54077	PRESTON
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Hospitals/Medical Centers

Density within Distance to Stack Range (km)	Populated Places Name	Sensitive Receptor Name	State	FIPS	County
1 in 0-5					
1	BRAEWICK WOODS	MONONGALIA GEN HOSP	WV	54061	MONONGALIA
2 in 5-10					
1	THE FLATTS	RUBY MEMORIAL HOSPITAL	WV	54061	MONONGALIA
2	THE FLATTS	UNIVERSITY HEALTH ASSOCIATES	WV	54061	MONONGALIA
0 in 10-15					
0 in 15-20					
1 in 20-25					
1	FAIRCHANCE	SEWICKLEY VALLEY HOSPITAL CREDIT	PA	42051	FAYETTE
14 in 25-30					
1	NEW SALEM	FAYETTE EMERGENCY MEDICAL SERVICE INCORPORATED	PA	42051	FAYETTE
2	REPUBLIC	FAYETTE EMERGENCY MEDICAL SERVICE INCORPORATED	PA	42051	FAYETTE
3	SOUTH UNIONTOWN	SOUTHWEST WOMENS HEALTH CARE INC	PA	42051	FAYETTE
4	UNIONTOWN	LAUREL RIDGE CENTER	PA	42051	FAYETTE
5	UNIONTOWN	UNIONTOWN HOSPITAL PRIORITY CARE	PA	42051	FAYETTE
6	UNIONTOWN	UNIONTOWN HOSPITAL UNIONTOWN HOSPITAL FOUNDATION	PA	42051	FAYETTE
7	UNIONTOWN	CENTRAL MEDICAL CENTER AND HOSPITAL	PA	42051	FAYETTE

8	WAYNESBURG	OCCUPTNL MEDCN CENTER WASHINGTON HOSP	PA	42059	GREENE
9	BRUCETON MILLS	HARNED MEMORIAL MEDICAL CLINIC	WV	54077	PRESTON
10	FAIRMONT	FAIRMONT GENERAL HOSPITAL	WV	54049	MARION
11	FAIRMONT	GENERAL HOSPITAL	WV	54049	MARION
12	FAIRMONT	WOUND HEALING CENTER OF FAIRMONT	WV	54049	MARION
13	FAIRVIEW	FAIRVIEW EMERGENCY MEDICAL SERVICES	WV	54049	MARION
14	REEDSVILLE	WEST PRESTON MEDICAL CLINIC	WV	54077	PRESTON

Nursing Homes

Density withing Distance to Stack Range (km)	Populated Place Name	Sensitive Receptor Name	State	FIPS	County
1 in 0-5					
1	BRAEWICK WOODS	MORGANTOWN HOSPICE	WV	54061	MONONGALIA
2 in 5-10					
1	SUNCREST	TENDER LOVING CARE HOME CARE	WV	54061	MONONGALIA
2	THE FLATTS	THE MADISON	WV	54061	MONONGALIA
0 in 10-15					
0 in 15-20					
0 in 20-25					
3 in 25-30					
1	UNIONTOWN	MABELS PERSONAL CARE HOME	PA	42051	FAYETTE
2	WAYNESBURG	HOSPICE CARE INCORPORATED	PA	42059	GREENE
3	FAIRMONT	FAIRMONT CLINIC	WV	54049	MARION