ABSTRACT

Title of Document: GIS-BASED ODOR DISPERSION MODELING FOR MEASURING THE EFFECT OF DCWASA BIOSOLIDS IN REUSE FIELDS

Eakalak Intarakosit, Master, 2006

Directed By: Professor, Gregory B. Baecher, Civil & Environmental Engineering

Biosolids distributed to reuse fields for recycling and beneficial purposes can potentially create nuisance condition to surrounding community and possibly lead to odor complaints. Consequently, the public's lack of understanding of biosolids can limit the implementation of a worthwhile beneficial reuse program. This study developed a GIS-Based odor dispersion model as an alternative method for biosolids manager to measure the impact of biosolids odorants in the reuse fields by using the DCWASA biosolids fields as the case study. The results show the prediction maps expressed as concentration contours of predicted odorant area so-called sensation area or the area that concentration above the detection threshold (DT) or 1 g/m^3. The results show that the sensation area usually occurs at low wind speed condition especially in early morning and night. The sensation area, moreover, is also sensitive to topographic features particularly elevated terrain.

GIS-BASED ODOR DISPERSION MODELING FOR MEASURING THE EFFECT OF DCWASA BIOSOLIDS IN REUSE FIELDS

By

Eakalak Intarakosit

Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Master of Science
2006

Advisory Committee:

Professor Gregory B. Baecher, Chair
Assistant Professor Steven A. Gabriel
Associate Professor Eric A. Seagren

Acknowledgements

I would like to express my gratitude to Dr. Gregory B. Baecher, my advisor, for his kindly guidance thorough the development of this thesis. His technical and editorial advice was essential to the completion of this thesis.

I would like to express my sincere thanks to Chris Peot who gave me an opportunity to work as an intern at DCWASA, permission to use DCWASA data, and useful discussions thorough the development of this thesis. I would like to thank Mark Ramirez from DCWASA and Al Razik from MES for their valuable advices and information.

I am grateful to Dr. Steven A. Gabriel and Dr. Eric A. Seagren for agreeing to be my committee members, and for reviewing this thesis.

Lastly, to my parents and family, I would like to express my grateful for their love and giving me a great opportunity to study master degree at the University of Maryland, College Park.

Table of Contents

List of Tables

List of Figures

Executive Summary

District of Columbia Water and Sewer Authority (DCWASA) operates Blue Plains Advanced Wastewater Treatment Plant (AWTP) that serves two million customers in Washington metro area. Today, the plant has capacity to treat 370 million gallons per day (MGD) of wastewater. More than 1,200 tons of biosolids per day are produced from the plant and then distributed to the reuse fields in Maryland and Virginia areas for recycling and beneficial purposes. DCWASA's contractors and inspectors periodically experience odor complaints from neighborhoods surrounding field areas. The cause of malodorous condition or odor complaints in DCWASA reuse fields, obviously, does not only come from the quality of biosolids itself but also from the site location and atmospheric condition. The exiting method such as olfactometer is lack of continuity because it can only be used to measure the impact of biosolids at the certain point of time, specific location, and exact weather location. Thus, there is a need to have an alternative method to measure the effect of biosolids in reuse field.

This thesis developed a GIS-Based Odor Dispersion Model to measure the effect of biosolids in DCWASA reuse field especially James Garrett Farm 12 in Caroline County, Virginia. The United States Environmental Protection Agency (U.S. EPA)'s steady-state atmospheric dispersion model, AERMOD, and Geographic Information System were employed to generate predicted concentration and display it as concentration prediction maps. The predication maps were created focusing on the sensation area, predicted concentration over 1 g/m^3. The results show that sensation area was sensitive to topographic features and meteorological conditions. Furthermore, the results obtained suggested that the validation of the model is a major concern since

missing data, such as emission rate, release height, and field size, were required to collect more by the DCWASA's contractors. In addition, the distance between locations of weather stations and field is still an issue of accuracy since they are so far away from study area and thus might be different from the exact local flow condition. The calibration between the model and the field also needs further investigation.

However, DCWASA could still get benefits from this work. First of all, it would make biosolids manager and contractors better understand factors, especially source-transport-receptor, associated with malodorous condition in reuse fields. The results also suggested DCWASA's contractors to collect more field data, i.e. emission rate and field size to make the model more reliable. In addition, DCWASA needs to create a systematically organized odor complaints record and it would be more useful when performing dispersion model against complaints. Moreover, it might be used as a screening tool for assessing the impact of biosolids in DCWASA reuse fields and ultimately used as a primary step for developing biosolids planning process for contractors and improving decision making process for biosolids manager.

Chapter 1: Introduction

1.1 Rationale

Biosolids, a byproduct from wastewater treatment processes, contain nutrient-rich organic matter that can be used in recycling and beneficial purposes. Today, there are approximately 6.8 million dry tons per year of biosolids produced from about 16,000 publicly owned wastewater treatment facilities (POWT) in the United States (US). The disposal and reuse of biosolids are carefully regulated by the United States Environmental Protection Agency (U.S. EPA). Several methods of disposal for biosolids are available ranging from landfilling, incineration, to land application. Each method has several advantages and some disadvantages, but land application is the most widely used method because it is usually less expensive and it is an excellent way to recycle wastewater solids as long as the material is quality controlled. Furthermore, it returns valuable nutrients to the soil and enhances conditions for vegetation. More importantly, it does not contribute to the global warming problem while others approaches do. However, the method of land application possibly creates the inherent problem of biosolids-malodor, which directly affects to surrounding community areas.

The malodorous condition of biosolids is a major concern in the wastewater treatment industry. Normally, it occurs from processes on-site and impacts surrounding areas in the reuse field. Organic and inorganic forms of reduced sulfur, mercaptans, ammonia, amines, and organic fatty acids are identified as the most offensive odor causing compounds associated with biosolids production (EPA (1), 2000). Recently, research shows that protein and, more specifically, sulfur-containing amino acids that make up proteins, are the main precursors for volatile sulfur compounds (VSC) production from stored cake samples (Witherspoon et al, 2004). These compounds typically are released from biosolids by heat, aeration, and digestion (EPA (1), 2000).

Potentially, odorants from biosolids disposed to the fields can create nuisance odors. Moreover, they do not only create odor problems but also lead to odor complaints from neighborhoods near the fields. Consequently, the anticipation of nuisance odor from land application and the public's lack of understanding of biosolids can limit the implementation of a beneficial reuse program. In Southern California, for example, a grand jury recently released a 16-page report titled "Does Anyone Want Orange County Sanitation District's 230,000 Tons of Biosolids?" The report recommended four specific actions the Orange County Sanitation District (OCSD) could take to enhance public acceptance of existing programs. Despite OSCD's extensive and exemplary public outreach and the Orange County grand jury's apparent understanding of the district's environmentally responsible actions, the grand jury recommended that OSCD phase out Class B biosolids land application except in remote areas (Frank, 2005).

From the example described above, there is a high need of having a good strategy to control and manage biosolids odor produced offsite. Unlike odorants from the liquid process in the wastewater treatment facility, the odor problem in reuse field itself depends on factors such as atmospheric condition and topographic features. Due to the inevitable factors that efficiently create malodorous condition of biosolids in the field, that challenge encourages managers, operators, and also researchers to seek for an efficient solution to minimize odor impact in reuse field. As a result, this thesis was implemented to respond the need for managing and controlling malodorous condition in reuse field in order to minimize odor impact and odor complaints from surrounding communities.

1.2 Research Overview

1.2.1 DCWASA Background

Blue Plains Advanced Wastewater Treatment Plant (AWTP) started operation in 1938. It is claimed to be the largest such facility in the world. In 1996, the District of Columbia Water and Sewer Authorities (DCWASA) assumed management of the Blue Plains AWTP from the Washington, D.C. government. The plant serves more than two millions Washington metro area customers in the District of Columbia, portions of Montgomery and Prince George's Counties in Maryland, and portions of Fairfax and Loudoun Counties in Virginia, and has capacity to treat 370 million gallons per day (MGD) of wastewater, with a complete treatment peak flow of 740 MGD, and an excess flow of 336 MGD. More than 1,200 wet tons per day of biosolids are generated from the plant and distributed to Maryland and Virginia areas for recycling and beneficial uses such as agriculture, silviculture, and gravel mine reclamation (DCWASA (1), 2005).

In order to handle increased amounts of biosolids, DCWASA, in 1996, developed a new, long-term biosolids management program, or BMP, that focuses on end-use options for biosolids, including odor control. The program consists of three phases:

Phase I – Baseline Improvements Program: projects that support continuing and improving the current solids-processing and land application operation. Odor management is an important part of this phase.

Phase II – Core Projects: facilities that must support the BMP in the long term, regardless of changes in market trends, new egg-shaped anaerobic digesters for example.

Phase III – Future Projects: projects that can be implemented as future circumstances allow, with assessment of new technologies as they arise (DCWASA (2), 2005).

1.2.2 Wastewater Treatment Process

Current Liquid Process

On an average day, more than 330 million gallons of raw sewage flow into the plant from area jurisdictions. This is expected to rise to 370 million gallons a day by 2030 (DCWASA (2), 2005). The first treatment processes begins with removing debris and grit and they, then, are trucked to a landfill. The sewage then flows into primary sedimentation tanks that separate about half of the suspended solids from the liquid.

The liquid flows to secondary treatment tanks where oxygen is bubbled into it so bacteria can break down organic matter. In the next stage of treatment, microbes convert ammonia into harmless nitrogen gas. Residual solids are settled out and the water is percolated down through sand filters that remove the remaining suspended solids and associated phosphorus. The water is disinfected, dechlorinated, and discharged into the Potomac (DCWASA (2), 2005)

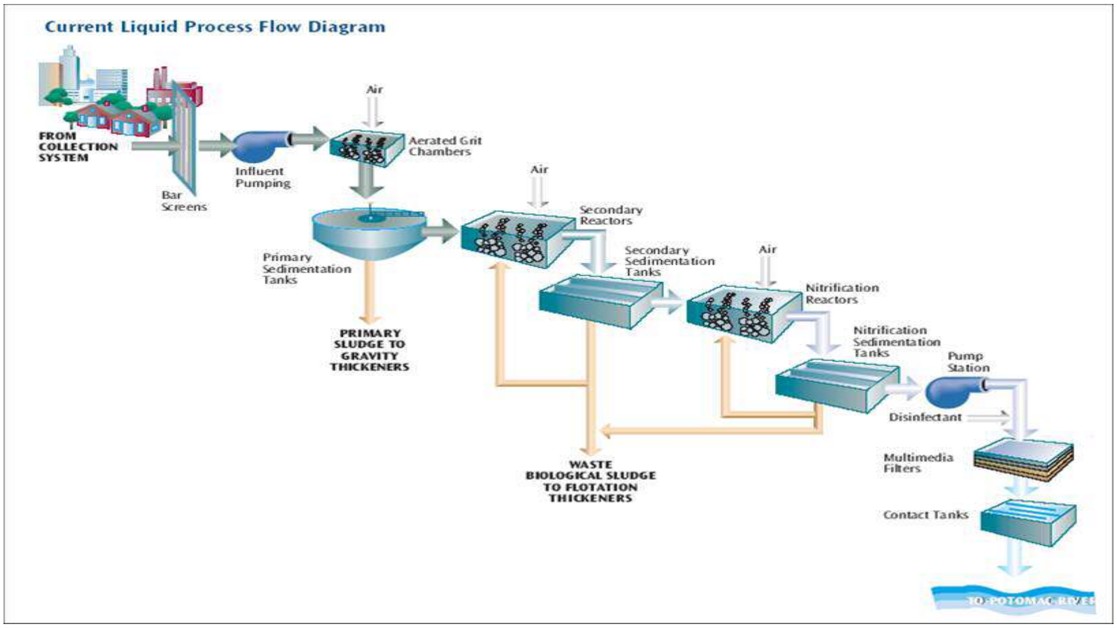


Figure 1-1 Current Liquid Process Flow Diagram (DCWASA (2), 2005)

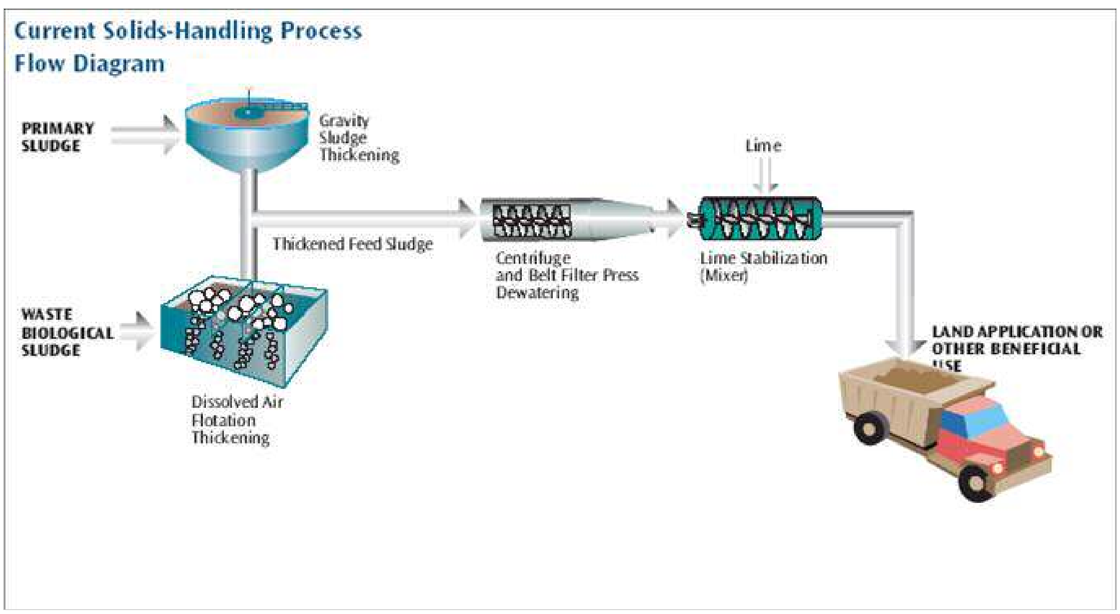


Figure 1-2 Current Solids-Handling Process Flow Diagram (DCWASA (2), 2005)

Current Solids Process

The solids – or sludge – from the primary sedimentation tanks go to tanks where gravity causes the dense sludge to settle to the bottom and thicken. Biological solids from the secondary and nitrification reactors are thickened separately using flotation thickeners. The thickened sludge is dewatered, lime is added to remove pathogens and the organic biosolids are applied to land in Maryland and Virginia (DCWASA (2), 2005).

1.3 Problem under Consideration

Today, more than 1,200 wet tons per day of biosolids class B are generated from the Blue Plains AWTP and then distributed to approximately 5,000 fields in Maryland and Virginia in the purposes of recycling and beneficial uses. DCWASA's contractors and inspectors from the Maryland Environmental Services (MES) periodically experience operational problem (e.g., noise and pollution from trucks) and odor complaints from neighborhoods surrounding field areas. Even though the quality of biosolids reaches the minimum standard of the EPA, the odor complaints are still occasionally reported from contractors and inspectors. The cause of odor complaints apparently does not only come from the quality of biosolids itself but also include site locations and atmospheric condition of each local area. As a result, the challenge of managing and controlling biosolids odor in the fields is firstly considered to be able to measure the biosolids odor impact, i.e. the odor concentration released from biosolids source, and to be able to understand the factors that would effect to malodorous condition of biosolids odor and perception of human.

1.4 Scope and Methodology

The research focused on the DCWASA reuse fields in the Virginia area, specifically Caroline County. Three main components namely source, transport, and receptor were associated with malodorous situations. The steady state atmospheric dispersion model (AERMOD) was employed to generate odor concentration released from biosolids. It was also used as a sensitivity analysis tool to determine the factors effecting to malodorous condition. Geographic Information Systems (GIS) were used as a tool for analyzing topographical data and generating odor concentration plot.

1.5 Objectives

The DCWASA's biosolids management program (BMP) has the ultimate goal of developing a world-class strategy for managing and controlling biosolids odor problem in reuse field. This study is a primary step for DCWASA to reach the goal. The three main objectives were set to be accomplished in the thesis responding to DCWASA's Biosolids Management Program (BMP). Those objectives are:

1. To calculate odorant concentration of biosolids released in the reuse field by using odor dispersion model for assessing biosolids odor impact in reuse fields.

2. To generate odor concentration prediction map focusing on the sensation area to measure impact and potential impact of biosolids to community.

3. Ultimately, the model calculations were evaluated by odor impact criteria such as meteorological conditions and terrain effects to determine the effect to the sensation area.

1.6 Expected Contribution

The contribution of this study is expected to be used as a primary step for the DCWASA to better understand the effect of biosolids odor and to mitigate the potential adverse effect from biosolids odor in reuse fields. It would directly help a biosolids manager to better manage and control malodorous condition produced from biosolids. Moreover, it would be particularly useful for researchers in the area of environmental management and program management to develop planning and decision-making process in biosolids management program in wastewater treatment industry.

The remaining chapters are organized as followed. Chapter 2 discusses biosolids and regulations that used in biosolids odor control management, and works related to biosolids odor control. Chapter 3 shows the procedure for selecting the DCWASA study area. Chapter 4 deals with the methodologies, atmospheric dispersion model and Geographic Information System (GIS) used to generate the results. Chapter 5 shows the results and discussion of the results. Lastly, chapter 6 will conclude main results of research and recommends for future works.

Chapter 2: Background and Literature Review

Biosolids, a term that was introduced to wastewater industry in early 1990's by the United States Environmental Protection Agency (U.S. EPA), are primary organic materials produced during wastewater treatment that may be put to beneficial use (Evanylo, 2003). It is used as an additive to soil to supply nutrients that are essential for plant growth and replenish soil organic matter (EPA (3), 2000). Typically, there are known as land application. As an alternative to disposal by landfilling or incineration, land application offers several advantages as well as some disadvantages that must be considered during the execution. In addition to the agricultural benefits of properly treated biosolids, land application is usually less expensive than alternative method of disposal (Evanylo, 2003). Although land application requires relatively less capital, the process can be labor intensive. Land application is also limited to certain times of the year, especially in colder climates. Biosolids, therefore, should not be applied to frozen or snow covered grounds. Another disadvantage of land application is potential public opposition mostly when the site is close to residential areas (EPA (3), 2000). One of the primary reasons for public concern is odor that can lead to complaints. In fact, more than 70% of all air pollution complaints to the EPA are odor related (McGinley et al, 1999).

Malodorous conditions due to odorants released from biosolids can potentially lead to complaints. A conceptual model for what leads to an odor nuisance is the "Citizen Complaint Pyramid" which starts and builds with "Odor Character", followed by "Odor Intensity", Episode Duration", and "Episode Frequency". The cumulative effect of these four building blocks creates the nuisance experience that may lead to a citizen complaint

(McGinley et al, 2000). The odor character is basically what the odor “smells like”. It is sometimes called the “quality” of odor or the “offensiveness” of the odor. The odor intensity is the second building block of the complaint pyramid and refers to overall strength of the perceived odor (McGinley et al, 2000). The perception of odor intensity is the relative magnitude of the odor above the recognition threshold, as defined in ASTM E544-99, “Standard Practice for Referencing Suprathreshold Odor Intensity”. The odor perception in the olfactory system can be compared with keys on a piano. As a chemical odorant hits the piano keyboard (the olfactory epithelium), a tone is played. Therefore, when multiple chemical odorants are present the result is a perception. The loudness of the cord is analogous to the intensity of the odor perception (McGinley et al, 2000).

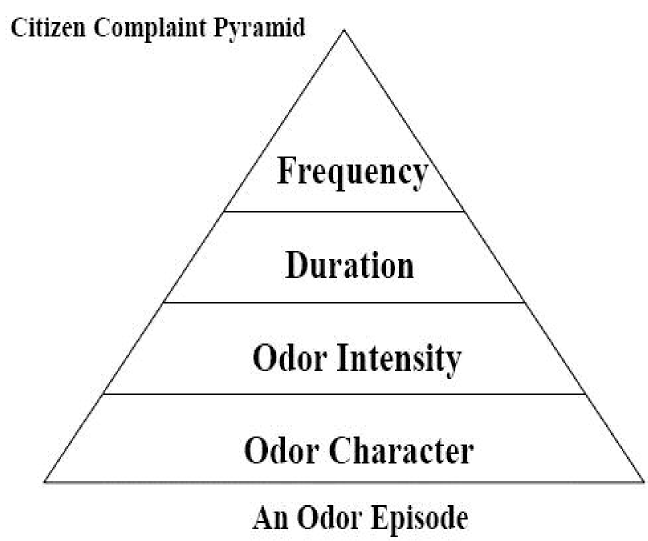


Figure 2-1 Citizen Complaint Pyramid (McGinley et al, 2000)

Duration, the next building block in complaint pyramid, is the period of time in which odorants are transported downwind to citizens and are perceived as odor. Longer period of perception can cause more nuisances to community. The last building block is frequency which refers to how often the citizen experience odor episodes of any type. As discussed previously, knowing that the odor complaints come from the cumulative of these four building blocks, and understanding them will help minimizing nuisance from odor and eventually complaints.

Additionally, the potential adverse effect of biosolids not only creates unpleasant condition to the community but also can possibly lead to symptoms such as headaches, nausea, eye irritation, etc. The evidence of health effect by odor can be seen from a survey near a wastewater treatment plant in 1983, one in nine respondents reported that odor had made them sick (Bruvold et al, 1983). However, it is unclear when the odorant becomes a health effect for the community at large, because each individual in the community has a different point at which an adverse health effect appears. Furthermore, it is unclear whether the odor perception or specific odorants cause the health effect (McGinley et al, 1999). In 2002, however, the researchers conducted a survey regarding complaints of a community surrounding land when biosolids were applied. The symptoms experienced in the neighborhood were recorded and were begun approximately two weeks after sludge were applied and continued for approximately two years. The results showed that an outbreak of Staphylococcal infections occurred near a land application site in Robesonia, PA. They also found that affected residents lived within approximately 1 km of land application sites and generally complained of irritation (e.g. skin rashes and burning of the eyes, throat, and lungs) after exposure to winds blowing from treated fields (Lewis et al, 2002). Particularly, in recent years, a dramatic increase in local ordinances that ban or restrict the use of biosolids has been observed as a result of odor complaints. Therefore, the measurement of odor from wastewater treatment facilities is usually a requirement for compliance monitoring, planning, site expansion, and review of operational practices (McGinley et al, 2002).

It was back in 1850's when people first tried to think seriously about how to measure sensation. It was the time when Psychophysics was born. Long before that time, though, people had classified the measurement of sensation by telling how it is different in quality. Most scientists had concluded that there was no direct method to measure sensation (Stevens, 1975). The discovery of a direct method or we might call social psychophysics changed many things. Psychophysics involves the response of an organism to changes in the environment perceived by the five senses (Stevens, 1960). The response of sensation by the strength of external stimulus or psychophysics phenomena was found to follow a power law. S.S. Stevens showed that this power law (Steven's Law) follows the equation:

$$I = kC^{n}$$

Where I is the intensity (strength), C is the mass concentration (i.e. mg/m^3), and k and n are constants that are different for every odorant (Stevens, 1962). Figure 2-2 shows the equation is a straight line when plotted on a log-log scale.

The measurement of odor impacts which could be said to be a psychophysics phenomenon as well usually begins with assessment of odor parameters. The U.S. EPA recommends five independent factors that are required for the complete assessment: intensity or pervasiveness, character, hedonics, detectability or quality, and mass (EPA (1), 2000).

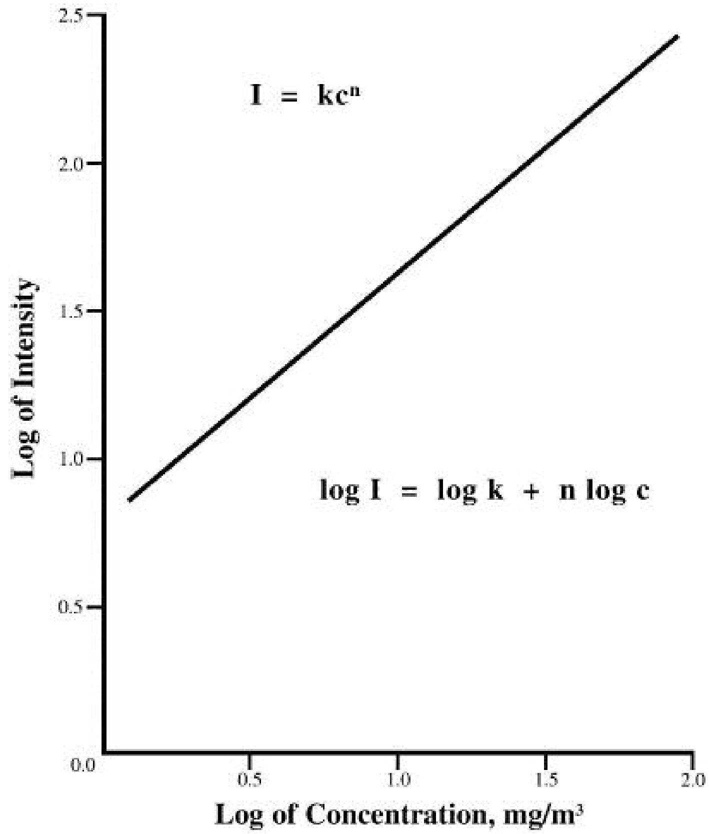


Figure 2-2 Power Law (McGinley et al, 2002)

Following the EPA recommendation, Charles and Michael McGinley, from St.Croix Sensory Inc., present the odor parameters including odor concentration (thresholds), odor intensity (intensity referencing), odor character (standard descriptors), odor persistency (the hang time of the odor), and odor hedonic tone (subjective measure of pleasantness/ unpleasantness). The odor parameters are used to estimate the effect of odor, which usually requires field and laboratory odor testing. The laboratory odor testing requires samples that are collected and shipped overnight to an odor-testing laboratory. A field olfactometry is an instrument used to measure the effect of odor at downwind of odor source and at the property line. The olfactometry creates a series of dilutions by mixing the odorous ambient air with odor-free air. The dilution factor is defined as

Dilution to Threshold, D/T that is a measure of the number of dilutions needed to make the odorous ambient air non-detectable (McGinley et al, 2005). An example of using olfactometry to measure odor strength can be seen from the experiment conducted by the Western Lake Superior Sanitary District (WLSSD), Duluth, Minnesota. WLLSD, during the spring 2003, received several comments from farmers expressing concern that biosolids odors were upsetting neighbors surrounding land application sites, the study, consequently, was conducted to document odor strength, extent and duration at 18 agricultural land application sites during the summer of 2003 using a Nasal Ranger Field olfactometer developed by St. Croix Sensory (Hamel et al, 2004). However, a major disadvantage of olfactometry is the infeasibility of continuous or semi-continuous olfactometric measurement (Harreveld, 2004).

On the other hand, another method that might be considered for use in measuring odor impact is atmospheric dispersion models. Dispersion models are widely used in the literature to measure odor impact in livestock or swine operations, not so much use for biosolids odor. The application of a dispersion model implies a need for models that take into account local flow conditions, caused by building, valleys and hills, and that would model fluctuations in a time-frame of seconds (Harreveld, 2004).

To efficiently minimize the odor impact from biosolids, the use and disposal of biosolids are officially regulated by EPA's Title 40 Code of Federal Regulations (CFR) Part 503, Standards for the Use and Disposal of Sewage Sludge. The Part 503 Rule requires wastewater solids be processed before they are land applied in order to minimize odor generation and destroy pathogens. The rule also defines two types of biosolids with respect to pathogen reduction that are known as Class A and Class B biosolids (EPA (3), 2000)

The goal of Class A requirements is to reduce the pathogens (including Salmonella sp., bacteria, enteric viruses, and viable helminth ova) to below detectable levels. Class A biosolids can be land applied without any pathogen-related site restrictions. Processes to further reduce pathogens (PFRP) treatment, such as those involving high temperature, high pH with alkaline addition, drying, and composting, or their equivalent are most commonly used to demonstrate that biosolids meet Class A requirements. The goal of Class B requirements is to ensure that pathogens have been reduced to levels that are unlikely to cause a threat to public health and the environment under specified use conditions, Processes to significantly reduce pathogens (PSRP), such as digestion, drying, heating, and high pH, or their equivalent are most commonly used to demonstrate that biosolids meet Class B requirements (Evanylo, 2003). Because of Class B biosolids contain some pathogens, the finished product may contain a wide variety of contaminants with a potential for adverse health effects (Lewis, 2002). Consequently, certain site restrictions are required.

The U.S. EPA Guide to Field Storage of Biosolids recommends management practices that meet state and federal standards and are suitable for use in a land application program. The recommendations include site selection considerations, which are site selection factors that should be considered before land applied. The site selection considers the factors that would potentially create malodorous condition during field storage and land applied such as climate, topography, soil and geology, buffer zones, odor prevention, accessibility and hauling distance, and property issues (EPA (2), 2000).

In Virginia, more specifically, the Virginia Department of Health (VDH) is primary responsible for regulating biosolids and land applications in Virginia State. VDH has permitted land application in 54 counties. Statistically, a VDH report conducted by the County Administrator's Assessment showed that only 8% of citizens supported biosolids application, 8% opposed, 30% undecided, and 54% wary (JLARC, 2005). Consequently, Joint Legislative Audit and Review Commission of the Virginia General Assembly (JLARC) recommended that VDH develop and implement a schedule to conduct more routine inspections of land applications and that they need to develop a guidance document to assist department staff and the localities with compliance and enforcement activities.

To response to federal and state biosolids regulation, DCWASA by the Department of Wastewater Treatment (DWT) and a team of professors and graduate students from the University of Maryland, College Park is conducting ongoing research that has an ultimate goal to mitigate adverse effect from biosolids for both on-site in the plant and off-site in reuse fields.

Chapter 3: DCWASA Study Area

3.1 DCWASA Field Data

The DCWASA biosolids field data used in this thesis was obtained from the Maryland Environmental Services (MES). The field data were collected from Maryland and Virginia sites during the period from 01/03/2005 to 11/30/2005. However, the area of study in the research is focused only on field sites in Virginia areas since biosolids produced in 2005 from the Blue Plains Advanced Wastewater Treatment Plant (AWTP) were mostly distributed to Virginia field sites.

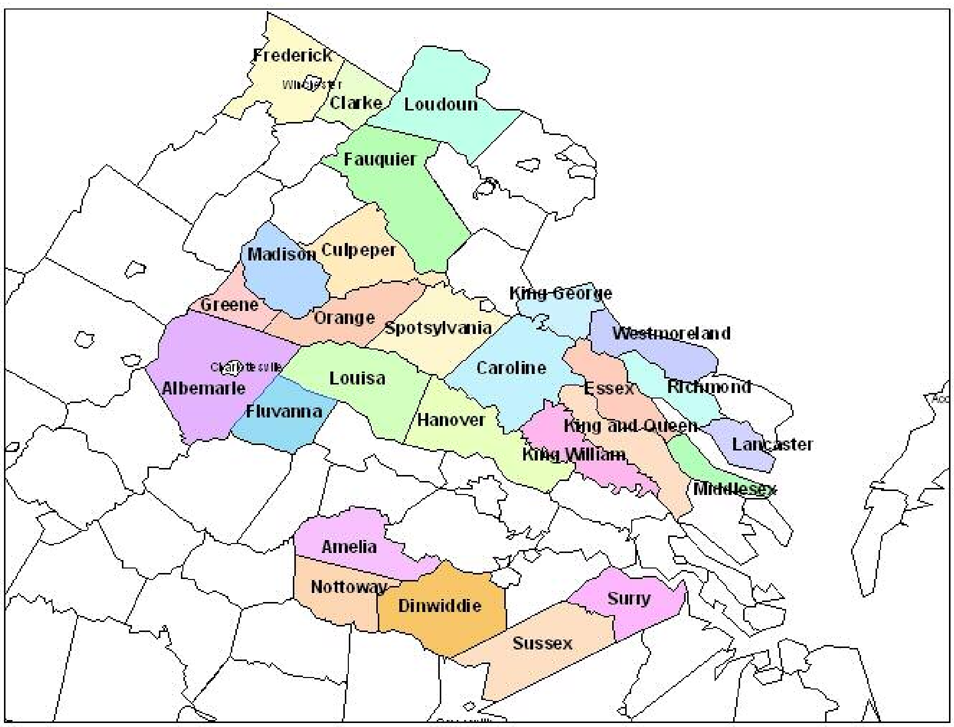


Figure 3-1 Virginia Biosolids Distributed Counties

From the MES field data, the biosolids were distributed to 27 counties in the state of Virginia as shown in figure 3-1. The data were collected from 01/03/2005 to 11/29/2005, after biosolids were applied. The data provided by the MES included: date unloaded, county, state, site name, field ID, field Location (XY data), field size acres permitted, tonnage applied, type of application, wind speed, wind direction, and temperature. Due to the large size of the data file, only data used in this thesis are presented. The summary of Virginia field sites data recreated from the original MES data based on time variation, field size, amount of tonnage applied, and frequency is shown in table 3-1.

Table 3-1 Summary of Virginia Field Sites Data

County	From	To	Field Size (Acres Permitted)	Tonnage Applied (Wet Tons)	Frequency
Albermarle	09/02/05	11/16/05	2346.57	18875.54	77
Amelia	02/21/05	10/27/05	741.10	4789.85	17
Caroline	01/05/05	11/29/05	2368.22	21708.42	80
Clarke	09/22/05	11/21/05	615.50	2283.73	13
Culpeper	03/14/05	10/21/05	4932.03	34865.57	148
Dinwiddie	01/10/05	11/14/05	1729.70	12371.09	52
Essex	01/04/05	04/18/05	1142.30	7616.28	30
Fauquier	06/02/05	08/05/05	913.00	7698.99	40
Fluvanna	08/02/05	11/21/05	1546.83	10018.70	41
Frederick	06/28/05	11/11/05	3639.63	33480.03	187
Greene	07/12/05	09/01/05	1155.37	12544.95	64
Hanover	01/03/05	11/28/05	1154.30	6811.54	29
King and Queen	01/03/05	11/18/05	4591.82	24418.46	91
King George	02/10/05	11/16/05	87.00	1558.37	13
King William	01/04/05	10/21/05	1940.01	9062.78	28
Lancaster	01/25/05	02/24/05	790.33	6821.31	27
Loudoun	04/27/05	06/28/05	1760.58	14453.40	68
Louisa	05/09/05	08/18/05	1850.80	17751.32	86
Madison	05/23/05	09/16/05	76.80	925.92	7
Middlesex	04/19/05	05/18/05	702.10	2326.62	12
Nottoway	01/24/05	11/10/05	568.00	4873.64	27
Orange	04/25/05	09/09/05	1839.74	13391.24	61
Richmond	01/04/05	04/18/05	442.30	3036.37	21
Spotsylvania	04/18/05	09/16/05	1882.68	14053.83	73
Surry	08/15/05	11/28/05	6921.19	5983.84	18
Sussex	01/03/05	11/29/05	1286.40	17879.66	94
Westmoreland	01/03/05	04/13/05	654.40	2641.57	20

Table 3-1 shows that the field sizes vary from 77 acres permitted in Madison County to 6921 acres permitted in Surry County. The amounts of tonnages applied range from 926 wet tons in Madison County to 34,866 wet tons in Culpeper County. Figure 3-2 and 3-3 show the permitted field size and tonnage applied for each county and the frequency of biosolids applied to Virginia Counties, respectively.

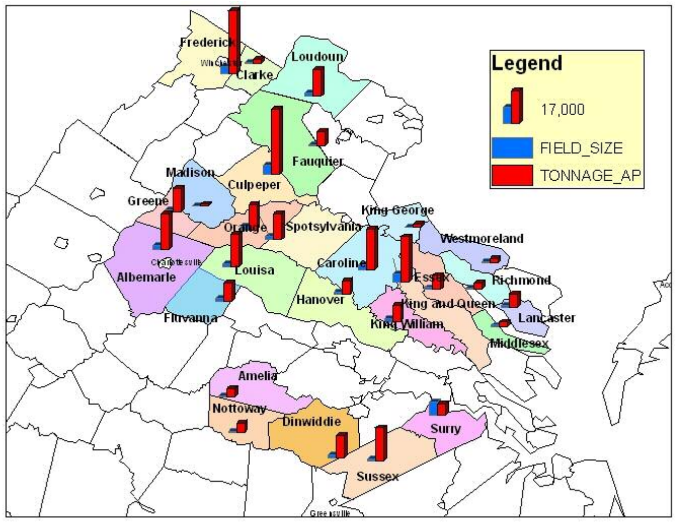


Figure 3-2 Field Size and Tonnage Applied of 27 Counties

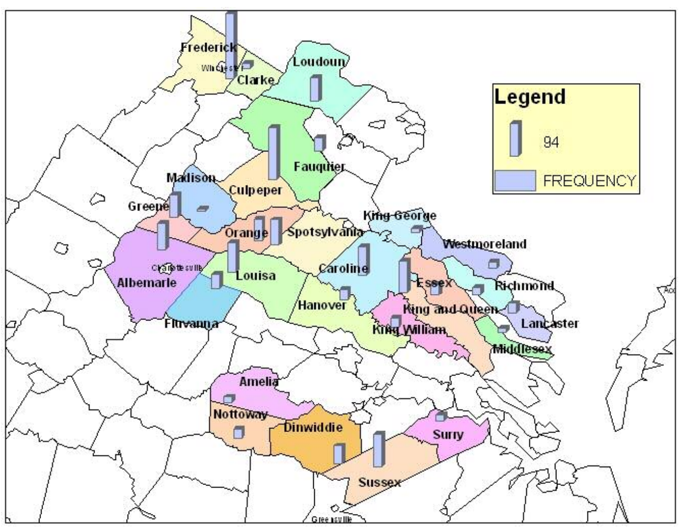


Figure 3-3 Frequency of Biosolids Applied 2005

3.2 Selected Study Area

To select the study area, several criteria were considered, such as time biosolids applied, amount of biosolids applied, and how frequency biosolids applied. The greater the amount of biosolids, the higher the risk of biosolids affecting surrounding communities. The five counties that have the highest amount of biosolids applied are Culpeper, Frederick, King and Queen, Caroline, and Albermarle. If we look at the frequency, however, Frederick County has the highest frequency of biosolids distributed within the shortest period of time, followed by Culpeper, Sussex, King and Queen, Louisa, and Caroline, respectively.

To complete selection of the study area, two more criteria were considered: the location of weather stations and population density. The location of weather stations in the region of interest including both a surface weather station and an upper air weather stations, are shown in Figure 3-4. The county that is closest to the weather stations is King and Queen County, followed by Caroline County. Thus, Frederick County and Culpeper County were eliminated even though the biosolids were distributed at the highest amount. Because the location of weather stations would possibly affect the accuracy of weather data used, as an input to the atmospheric dispersion model with different location, minimizing the distance from the weather station to various sites location is a good strategy. The issues of weather stations and weather data are discussed more details in Chapter 4.

Unlike the weather locations, the population around biosolids source does not directly affect the process of transporting the pollutant source to receptor but would be significant in producing odor complaints from communities surrounding biosolids fields.

Consequently, the population nearby the fields that has the potential to odor complaints should be taken into account when selecting a distributed field. The population density, also, could be determined by using the GIS. Figure 3-5 and 3-6 show population density per square mile of King and Queen County and Caroline County respectively. Caroline County is more populated and more distributed. Therefore, Caroline county has more potential to be effected when a malodorous condition occurs and ultimately was selected to be the study area.

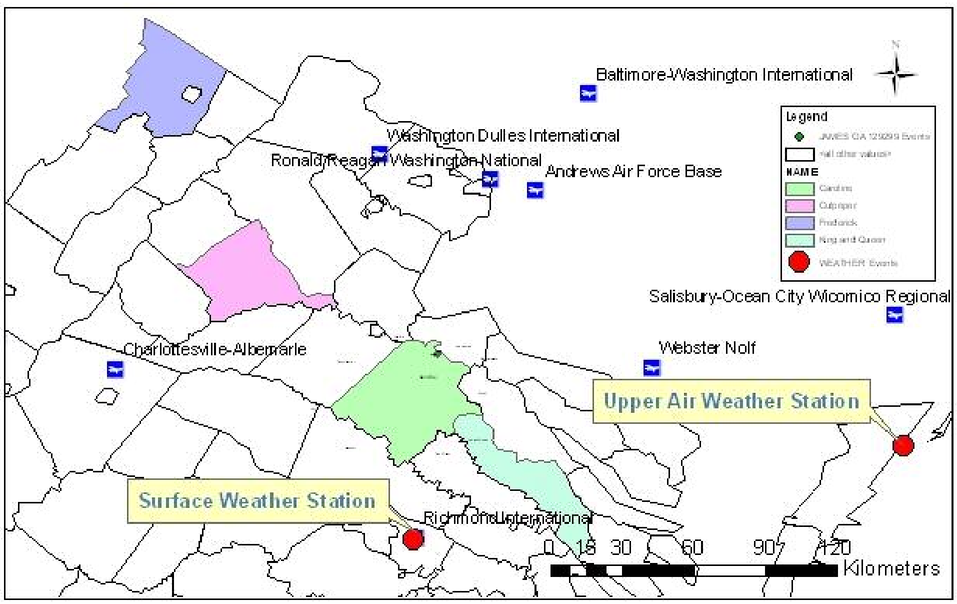


Figure 3-4 Locations of Weather Stations

Caroline County has an area of 537 square miles. The estimated population in the county is 22,121 in 2000 with an average population density 41.2 square mile. The total number of households is 8021 units. Geographically, the elevations vary from 15 to 93 meters with slopes between 0.2 and 1.6 percent (Figure 3-7).

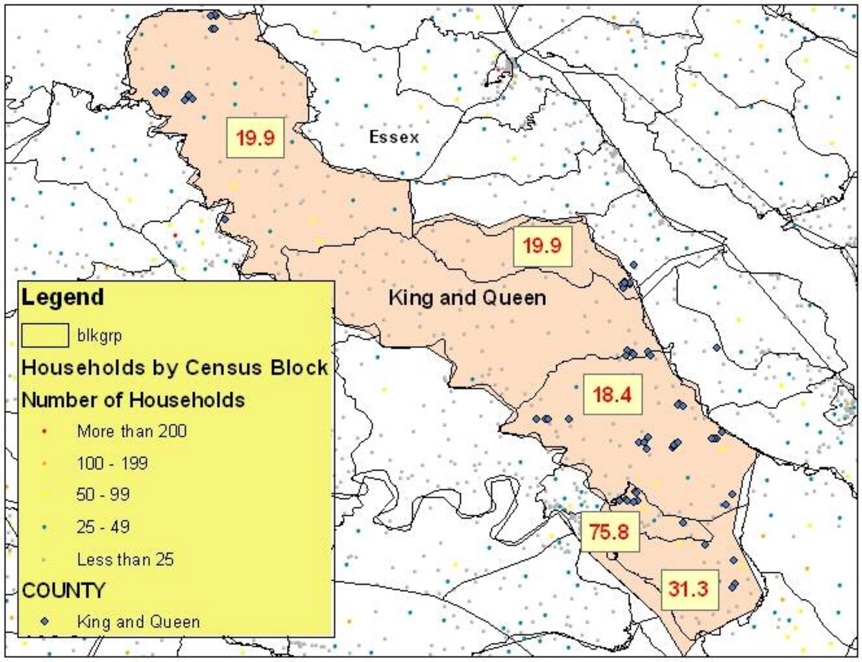


Figure 3-5 King and Queen Population Density/Square Mile

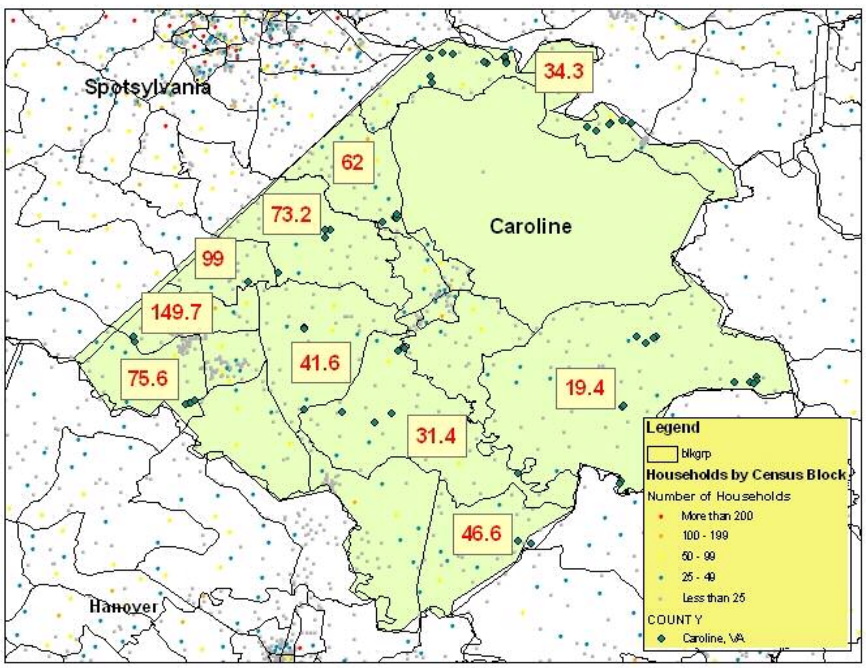


Figure 3-6 Caroline Population Density/Square mile

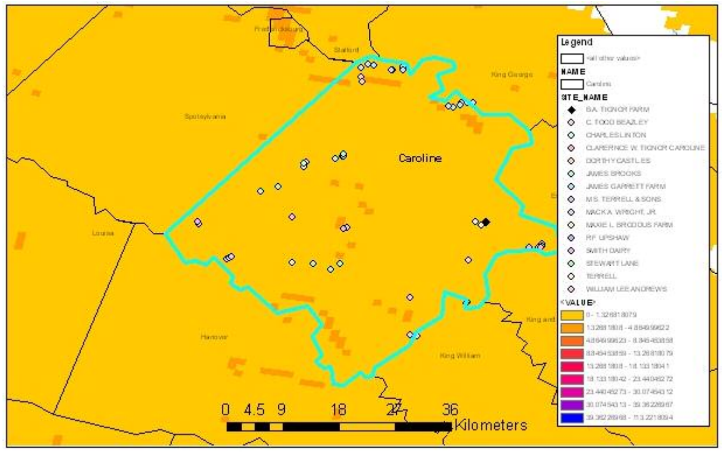


Figure 3-7 Slope of Caroline County

The MES data showed that there are 15 biosolids sites in Caroline County. Each site has a different amount of biosolids applied, shown in Figure 3-8. The amount varies from 429 wet tons in B.A. TIGNOR FARM to 6017 wet tons in JAMES GARRETT FARM.

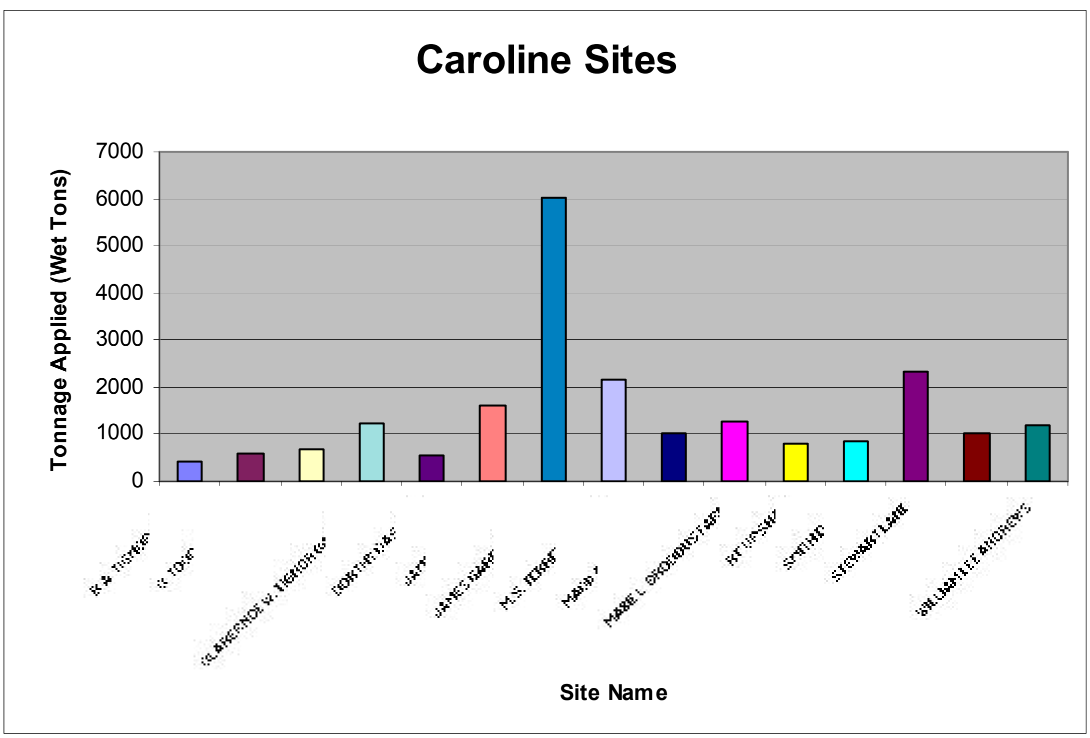


Figure 3-8 Caroline Sites Tonnage Applied

Chapter 4: Tools and Methodology

A model is a simplified picture of reality. It does not contain all the features of a real system but contains features of interest for the management issue or scientific problem at hand. Models are widely used in the scientific community to make predictions or solve problems, or to identify the best solution for a decision maker. As the real system becomes more complex, models help the decision makers make better decisions.

This thesis used models to represent various circumstances of interest. It also took advantage of the advanced computing of personal computers (PC) to generate more results. The following section presents details of the U.S. EPA's Air Quality Models and the Geographic Information System (GIS) used in this study.

4.1 Atmospheric Dispersion Model

An atmospheric dispersion model is a mathematical simulation of the physics and chemistry governing the transport, dispersion and transformation of pollutants in the atmosphere (New Zealand Ministry of the Environment (NZMOE), 2004). The U.S. EPA's Appendix W to Part 51- Guideline on Air Quality Models specifically classified dispersion models into four generic classes: Gaussian, numerical, statistical or empirical, and physical (EPA, 2001). The U.S. EPA, in addition, classified the models to two levels of sophistication; screening models and refined models. The screening model is a model used preset, worst-case meteorological conditions to provide conservative estimates of the air quality impact of specific sources. On the other hand, the refined model provides more detailed treatment of physical and chemical of atmospheric processes, precise input data, and more specialized concentration estimates. Officially, it is referred as a regulatory model. For convenience, dispersion model types can be divided broadly into steady state and non-steady-state models. The greatest difference between model types is in the requirements of their meteorological input data that depends on the complexity of dispersion and effects, e.g., terrain effect (Figure 4-1). Both types of models attempt to generate results expressed as pollutant concentration discharged from different types of pollutant sources.

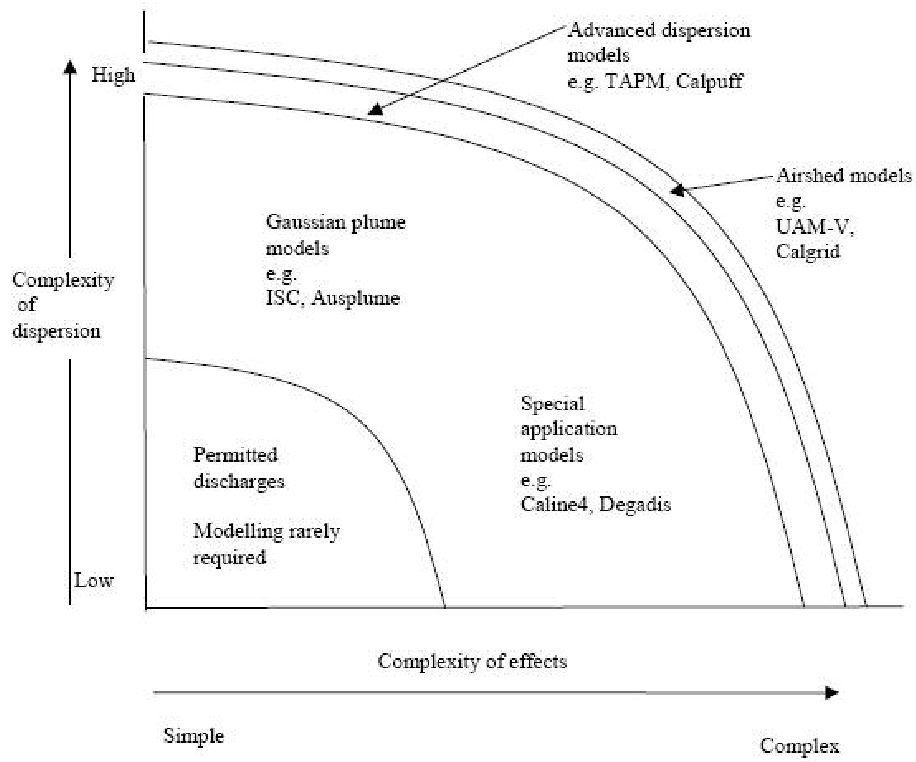


Figure 4-1 Type of Model VS Complex of Effects (NZMOE, 2004)

Consequently, selecting the type of model used is an important issue when using dispersion models. In fact, especially in case of modeling biosolids odor dispersion in reuse fields, it makes more sense to use a non-steady-state model because of taking local flow condition into account, but the requirement of extensive input data and interpretation of results are still a big concern (Harreveld, 2004). Thus, a steady-state model was selected to be the main model playing a significant role in this study.

This thesis utilized the air quality model available from the U.S. EPA Air Quality Modeling Group, Support Center for Regulatory Air Models (SCRAM). The source code and related documents can be downloaded from the U.S. EPA SCRAM's web site www.epa.gov/scram001/ . Specifically, the refined/recommended model, AERMOD was selected to be the main model.

4.1.1 AERMOD

In 1991, the U.S. Environmental Protection Agency (EPA) and the American Meteorological Society (AMS) collaborated to develop a new air quality model, the **A**MS/**E**PA **R**egulatory **MOD**el (AERMOD). It is promulgated by the U.S. EPA to replace the thus popular model, Industrial Source Complex (ISC3) model. The rule is effective December 9, 2005. However, as a new model to the U.S. EPA, the screening model of AERMOD is still in development process.

AERMOD is a steady-state plume dispersion model for assessing pollutant concentrations from a variety of sources based on the assumption of a planetary boundary layer (PBL). The PBL is the part of the atmosphere closest to the ground: it varies in thickness between 100 m at night to 3 km during daytime (Susan et al, 2004). AERMOD uses the Gaussian distributions in the vertical and horizontal for stable conditions, and in the horizontal convection condition. The vertical concentration distribution for the convection condition results from an assumed bi-Gaussian probability density function of the vertical velocity (EPA, 2004). Typically, AERMOD is a modeling system that contains: 1) an air dispersion model, 2) a meteorological data preprocessor called AERMET, and 3) a terrain data preprocessor called AERMAP.

One of the basic inputs to AERMOD is the runstream setup file that contains the selected modeling options, as well as source location, receptor locations, and meteorological data file, and output options. Another type of basic input data needed to run the model is meteorological data. AERMOD requires two types of meteorological data files that are provided by the AERMET meteorological preprocessor program. One file consists of surface scalar parameters, and the other file consists of vertical profiles of meteorological data.

The input file or input runstream file that works as a command language is divided into 5 functional "pathways" namely:

1. Control Pathway (**CO**)
2. Source Pathway (**SO**)
3. Receptor Pathway (**RE**)
4. Meteorology Pathway (**ME**) and
5. Output pathway (**OU**)

Each pathway contains a "keyword" and types. Four types of keywords are identified as M-Mandatory, O-Optional, N-Non-Repeatable, and R-Repeatable. The mandatory keywords are important and required to run a model.

The control pathway (**CO**) works as a command language to control dispersion options as well as the output pathway (**OU**) used to control output options. The control pathway for this study was set to be non-regulatory default option that does not include the use of stack-tip downwash because biosolids odor is released from the ground. The model was specified that concentration values would be calculated as an output of odor dispersion model. The averaging periods of concentration were selected to be the most common used short term averaging periods of 1, 3, 8, and 24 Hrs (Karl et al, 2004). The type of pollutant was assumed to be Hydrogen Sulfide (HO_2). The example of control pathway is shown in Figure 4-2. The output of the model as previously mentioned is odor concentration in micrograms per cubic meters. The output pathway was set to show high value summary table by selected receptor network for selected averaging time.

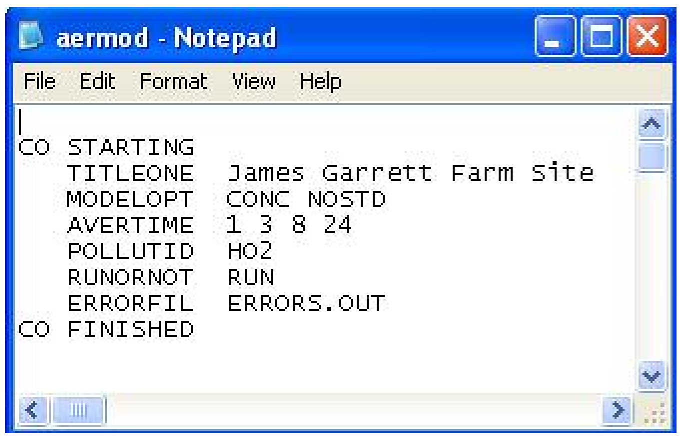


Figure 4-2 Control Pathway

The source pathway (**SO**) is defined as a source location and characteristic source. The source location or source coordinate is input as a user-defined origin that is horizontal (X) and vertical (Y) values (0, 0). The elevation of source is taken into account and is determined by the use of the Geographic Information System (GIS) data.

Three source types, identified as point, volume, and area source are available as options to the source pathway. The area source typically is used to model low level or ground level releases with no plume rise, and was selected as the model responding for biosolids being applied. The example of area source is shown in figure 4-3.

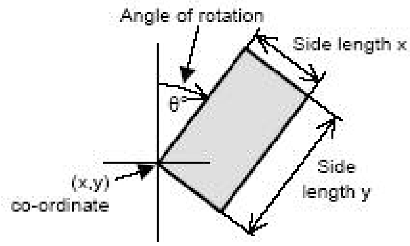


Figure 4-3 Example of Area Source

One of the critical inputs to the atmospheric dispersion model included in the source pathway is emission rate. Emission rate is defined as a rate of released pollutant from a source and usually expressed in $g/(\sec - m^2)$. The Maryland Environmental Services (MES) provided emission rate data used in the study. The tests were taken in 2003 using the flux chamber method. Only eight samples of emission rate data were obtained with the range values from 0.0822 to 0.4279 $g/(s - m^2)$, shown in Table 4-1.

Table 4-1 Emission Rate from MES (2003)

Sample ID	Emission Rate (g/sec-m2)
AR-120203-01	0.1868
AR-120203-01-D	0.1256
AR-120303-01	0.3310
LS-120303-02	0.3922
AR-120403-01	0.4279
AR-120403-01-D	0.4279
LS-120403-01	0.3605
LS-011204-01	0.0822
AR-011204-01	NA
AR-011304-01	0.1581

In addition, the other two data needed as input to the source pathway involve the release height above ground and the size of the area. The release height is the vertical distance that a pollutant could be released to the air. There is no certain method to determine an approximate release height value used in the model. Thus, the release height could be subjectively determined and was assumed to be 7.00 m above ground in the base model. The size of the area source is the length of the X side and Y side of the field after the biosolids are applied, expressed in square meters. Because the tonnage of biosolids applied is in wet tons and the field sized is limited by the number of acres permitted, there is a need to calculate the daily-biosolids applied for each size in square meters. The example of calculating the field size used in the model is demonstrated below.

Table 4-2 James Garrett Field, Farm 12

Date Unloaded	Site Name	Field ID	Latitude	Longitude	Acres Permitted	Tonnage Applied (Wet tons)
4/18/2005	James Garrett	12	38.18	-77.24	43.03	459.02
4/19/2005	James Garrett	12	38.18	-77.24	43.03	673.62

Table 4-2 shows the biosolids data of James Garrett Field, Farm 12 that had a permitted area of 43.03 acres. The total of tonnage applied for two days was 1132 wet tons of biosolids. It was assumed that the field size permitted was fulfilled by the amount of biosolids applied. Therefore, the amount of biosolids applied per day could be calculated by percentage. For instance, on April 18th the amount of tonnage applied in wet tons equal to (459.02/1132.64)*43.04 or 17.44 acres or approximately 266 square meters, multiply by 4047 to convert from acres to square meters (Shamsi, 2005).

Another important pathway used to measure the effect of the pollutant in the AERMOD is receptor pathway. The receptor pathway contains keywords that define the receptor information for a particular run. There are two types of receptor grid: Cartesian grid and Polar grid, shown in Figure 4-4. The difference between those two grid systems is mainly the grid spacing which could be evenly space (Cartesian gird) or unevenly space (Polar grid). The Cartesian gird was selected to be the receptor network when running the model because it is more uniform than the polar grid. The dimension of grid network is based on the result of previous study shows that the affected residents lived within approximately 1 km of land application sites (Lewis et al, 2002). Unless defining type of receptor grid network in the receptor pathway, terrain elevation and hill height for each receptor can also be included to the model when applying AERMOD in an elevated terrain situation. To facilitate the generation of elevated terrain and hill height, the terrain preprocessor called AERMAP, which uses U.S. Geological Survey (USGS) Digital Elevation Model (DEM) data as an input, may be used to generate terrain elevation for each receptor. This study, however, did not use the terrain preprocessor, AERMAP, but it took advantage of GIS to determine receptor elevations.

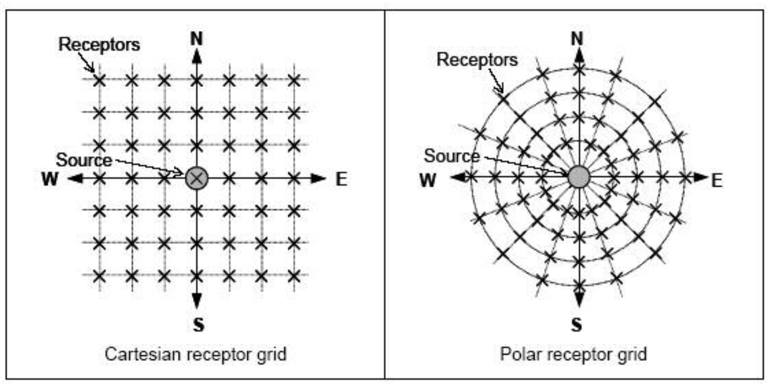


Figure 4-4 Types of Receptor Networks (NZMOE, 2004)

The other important pathway, meteorological data, is included in the meteorology pathway (ME). The meteorology pathway requires a minimum of two meteorological data: surface observation data and twice daily upper air data. The other data that might be taken into account is on-site data that was not used in this study. To obtain such data, a meteorological preprocessor is needed to generate data and used as data inputs for the meteorology pathway (ME) in AERMOD. The next section discusses the meteorological data in more details.

4.1.2 AERMET

AERMET or AERMOD METEOROLOGICAL PREPROCESSOR is a meteorological preprocessor for organizing available meteorological data into a format suitable for use by the AERMOD dispersion model. The minimum two types of data, which are National Weather Service (NWS) hourly surface observations and NWS twice-daily upper air soundings, are needed as inputs for AERMET. Surface data are meteorological data that are measured at the earth's surface and include physical parameters that are measured directly by instrumentation, such as temperature, dew point, wind direction, wind speed, cloud cover, ceiling height, etc. Upper air data are meteorological data that are measured in the vertical layers of the atmosphere.

Typically, there are three stages to processing the data as shown in Figure 4-5. The first stage extracts meteorological data from archive data files and processes the data through quality assessment (QA) checks. The second stage merges all data available for 24-hour periods and stores these data together in a single file. The third stage reads the merged meteorological data and estimates the necessary boundary layer parameters for dispersion calculations by AERMOD. Two files are written for AERMOD: a file of hourly boundary layer scaling parameter estimate which contains surface friction velocity and mixing height, and a file of multiple-level observations (profiles) of wind speed and direction, temperature, and standard deviation of the fluctuating components of the wind.

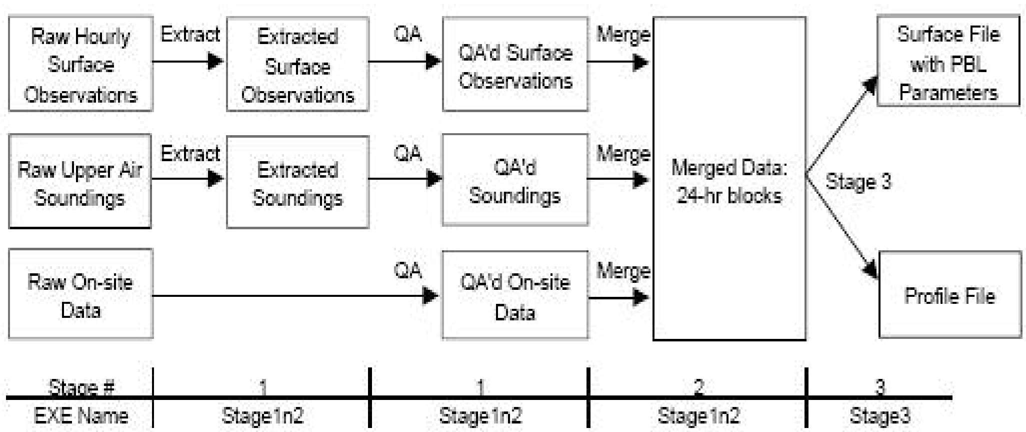


Figure 4-5 AERMET Processing

Similar to AERMOD, AERMET requires an input runstream file or, simply, a runstream to work as a command language with different functional groups, or pathways, to run the program. The statements in a runstream are divided into six different pathways:

1. **JOB** pathway for specifying information pertaining to the entire run;
2. **SURFACE** pathway for extracting and QA NWS hourly surface observation data;
3. **UPPERAIR** pathway for extracting and QA NWS upper air sounding data;
4. **ONSITE** pathway for QA'ing user-supplied, on-site meteorological data;
5. **MERGE** pathway for combining the meteorological data;
6. **METPREP** pathway for estimating boundary layer parameters for AERMOD.

The purpose of AERMET is to work as a meteorological preprocessor for AERMOD and required surface observation data and upper air data. The surface data are generally available from weather stations located in airports. Figure 4-6 shows the location of airports around study area, Caroline county in Virginia.

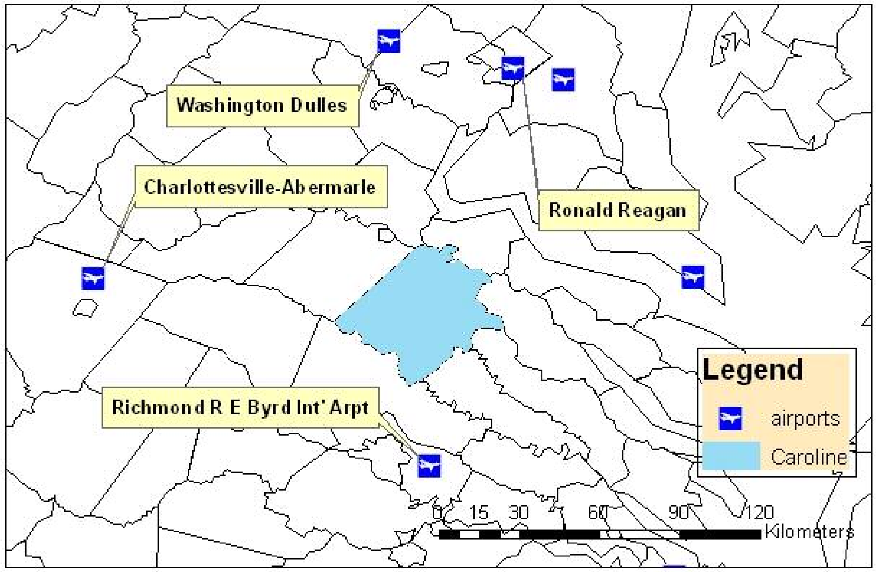


Figure 4-6 Airport Locations around Caroline County

From the EPA'SCRAM web site that provides free download for surface observation data, the Virginia surface observation data that could be used in stage 1 and 2 are available at weather station from five different airports:

1. Norfolk International Airport (VA 13737)
2. Richmond/ R E Byrd International Airport (VA 13740)
3. Roanoke/ Woodrum Airport (VA 13741)
4. Washington DC/Dulles Airport (VA 93738)
5. Washington DC/National Airport (VA 13743)

These data have been obtained from the National Climatic Data Center (NCDC) in Asheville, North Carolina. The Virginia surface data are available from 1984-1992. Based on the nearest station to the study area, Caroline County, the Richmond/R E Byrd International Airport (VA 13740) was selected to be the station that provides a raw hourly surface observations data used in AERMET processes. The station VA 13740 is located at 37.500N, 77.333W. Generally, the data offered from SCRAM's surface meteorological data is in an ASCII data file (.dat) and first needed to be edited and expanded by using MET144. MET144 is a Microsoft FORTRAN complied program performs two very important functions: editing and expanding shown in Figure 4-7. The editing function, more specifically, checks each parameter and prints a line to the screen when it finds a missing value.

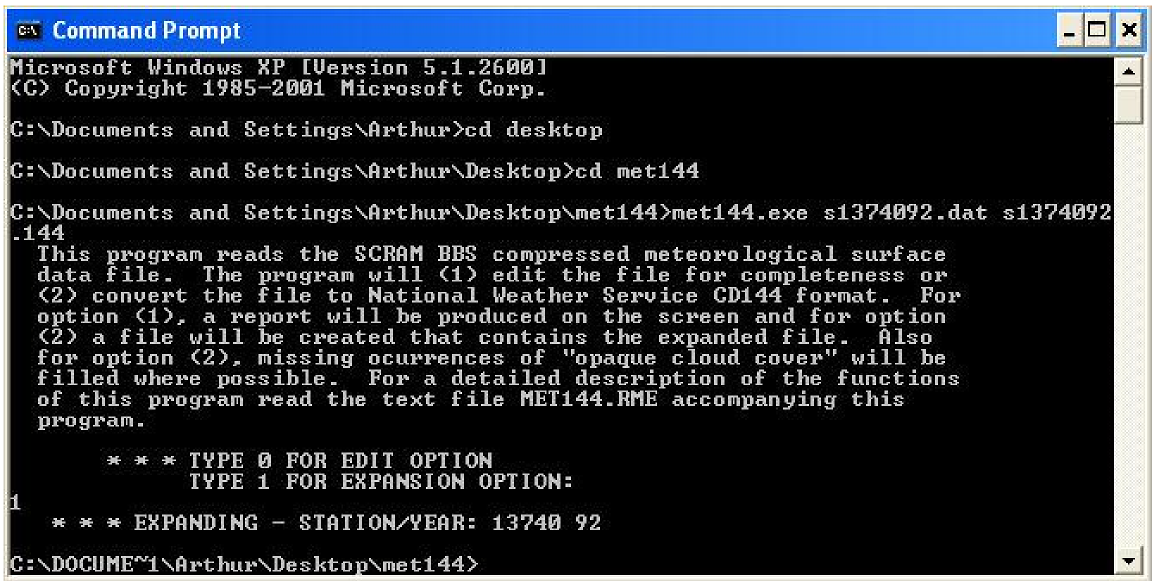


Figure 4-7 MET144

The Expanding function is used to expand SCRAM's surface observation data into CD144 format that is an hourly surface weather observation time-based required for an input in AERMET. The surface observation data included in the ASCII data file format are station number (ID), year, month, date, and hour, ceiling height in hundreds of feet, wind direction in tens of degrees, wind speed in knots, dry bulb temperature in degree Fahrenheit, cloud cover in tens of percent, opaque cloud cover in tens of percent.

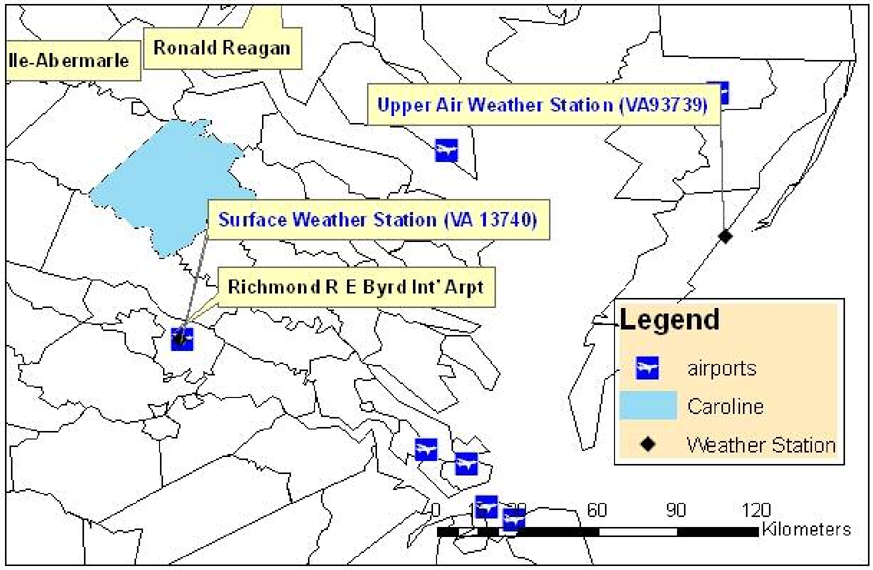


Figure 4-8 Weather Station Locations

The upper air data, on the other hand, used in stage 1 and 2 are available from EPA's SCRAM web site and some other vendors. SCRAM mixing height data that offered twice daily values and could be obtained from the National Climatic Data Center (NCDC), Asheville, North Carolina. The data are in text format and available from 1984 to 1991. Moreover, an upper air data available from Forecast Systems Laboratory (FSL) in FSL format is another option to obtain that data. The FSL data are available from 1998-2005 and can be requested electronically from www.fsl.noaa.gov. This thesis, however, used an upper air data from the vendor called Lakes Environmental and the data could be downloaded from www.webmet.com without cost. The upper air data at Wallops Island station (93739) shown in figure 4-8 which are located at 37.941N, 75.463W were used as the upper air data in the AERMET. The data are in TD-6201 format and consist of data from 3 different levels namely:

1. Mandatory level
2. Standard level, and

3. Significant level

Each level, in addition, consists of pressure surface, height of the pressure surface, temperature, relative humidity, wind direction, and wind speed. All data used as input to AERMET are step-by-step run follow the AERMET processing in Figure 4-5. The examples of running AERMET stages are shown in Figure 4-9 and 4-10. Figure 4-9 shows the stage 1 for extracting and QA for surface and upper air data during from 04/18/92 to 05/18/92. Figure 4-10 shows the stage 2, merging data. Ultimately, two meteorological files, surface and profile data, are generated from stage 3 which would, then, be used in AERMOD (Figure 4-11).

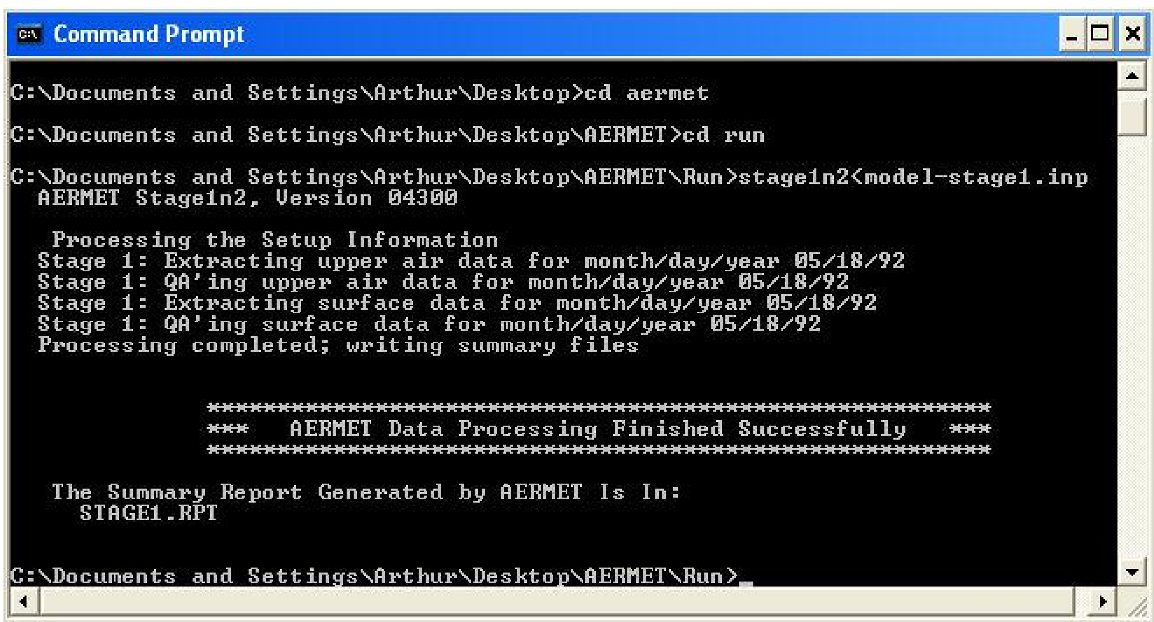


Figure 4-9 Stage 1- Extracting & QA for Surface and Upper Air Data

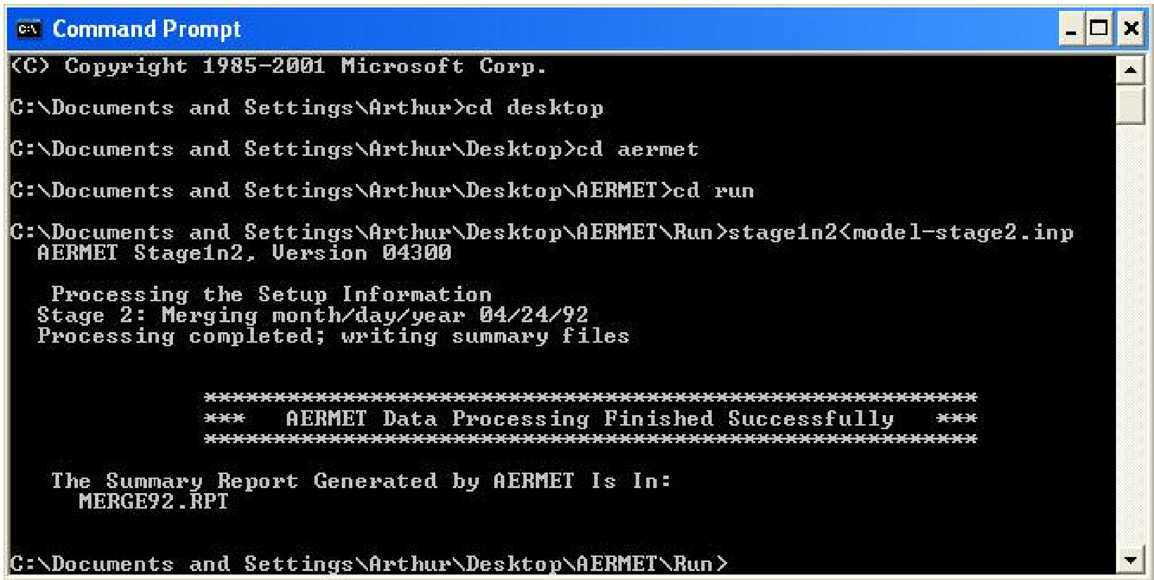


Figure 4-10 Stage 2 - Merging Files

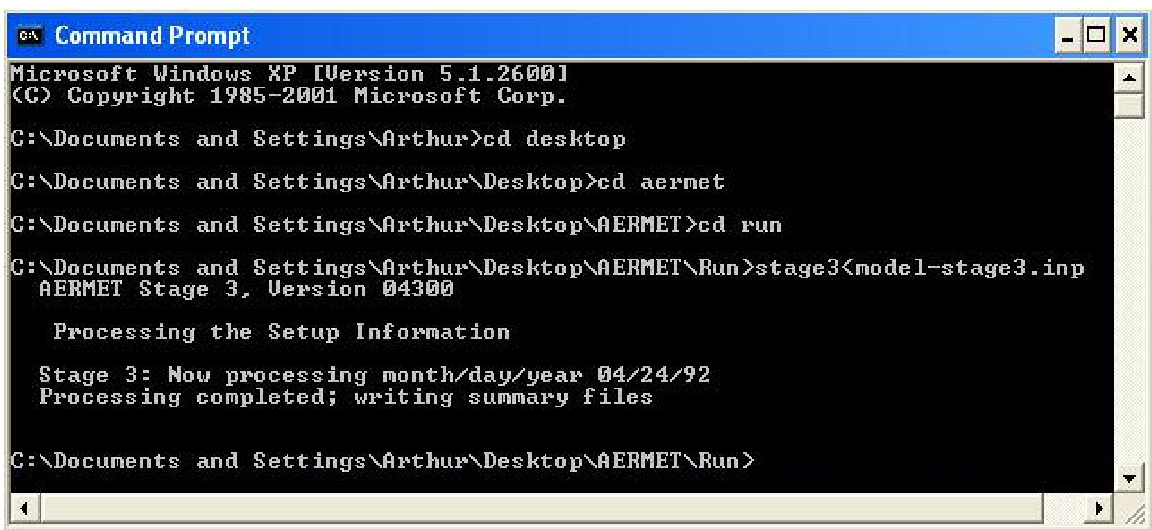


Figure 4-11 Stage 3 - Creating Meteorological Files

The two meteorological files generated from meteorological preprocessor AERMET are the required data used as input data to meteorology pathway (**ME**) in AERMOD. The data generated from AERMET, in fact, can be retrieved for entire year or specific period, for instance, seasonal.

Table 4-3 Example of the Profile Data

Year	Month	Date	Hours	Height	WDIR (Degree)	WSPD (m/s)	AM_TEM (Celsius)
92	4	18	1	6.1	185	4.6	18.9
92	4	18	2	6.1	209	4.1	19.4
92	4	18	3	6.1	199	2.1	18.3
92	4	18	4	6.1	200	2.6	17.8
92	4	18	5	6.1	200	3.1	17.8
92	4	18	6	6.1	185	2.1	16.7
92	4	18	7	6.1	176	2.6	17.2
92	4	18	8	6.1	215	5.1	20
92	4	18	9	6.1	223	5.1	20.6
92	4	18	10	6.1	197	3.6	22.8
92	4	18	11	6.1	177	4.6	25.6
92	4	18	12	6.1	188	4.1	27.8
92	4	18	13	6.1	171	5.1	28.3
92	4	18	14	6.1	176	7.7	28.3
92	4	18	15	6.1	176	4.1	30
92	4	18	16	6.1	188	7.2	25.6
92	4	18	17	6.1	180	6.2	28.3
92	4	18	18	6.1	66	6.7	22.8
92	4	18	19	6.1	33	5.1	20
92	4	18	20	6.1	28	5.1	17.2
92	4	18	21	6.1	65	5.1	15
92	4	18	22	6.1	34	4.6	13.9
92	4	18	23	6.1	30	4.6	12.8
92	4	18	24	6.1	9	5.7	12.2

After all data are input to the AERMOD codes, the AERMOD is ready to run. AERMOD that is written in FORTRAN runs on MS-DOS by default. To run the AERMOD, input file and output file need to be created in the same directory with AERMOD program. An input file is basically a file contains all input data and pathway code manually created by users and preprocessor AERMET. An output file is simply a blank file that all result would be created in that file. The example of running an AERMOD is shown in Figure 4-12. The result generated from AERMOD is the average concentration values with relative date of concentration for selected receptor network, Cartesian grid (CAR), and selected average concentration time. In addition, if the model accounts for elevated terrain situation, the result would show relative elevation values for each grid location. Figure 4-13 shows an example of result in produced file of design values that can be imported into graphics software like the GIS for plotting contours.

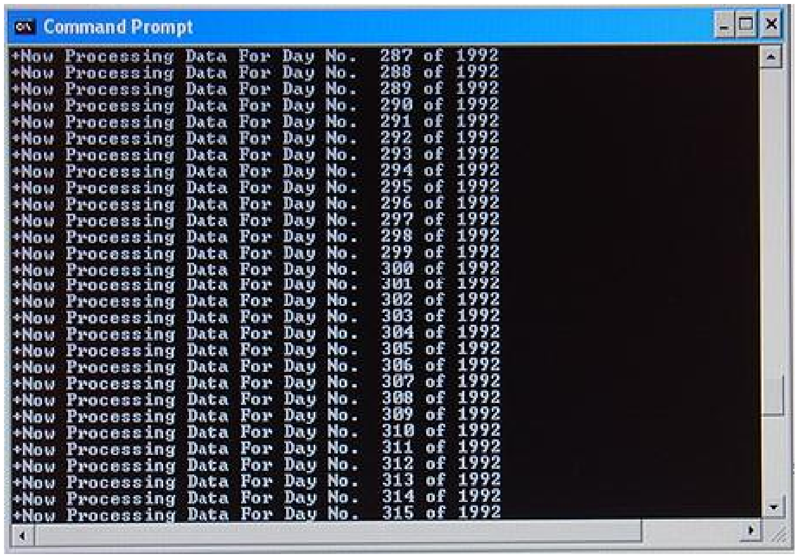
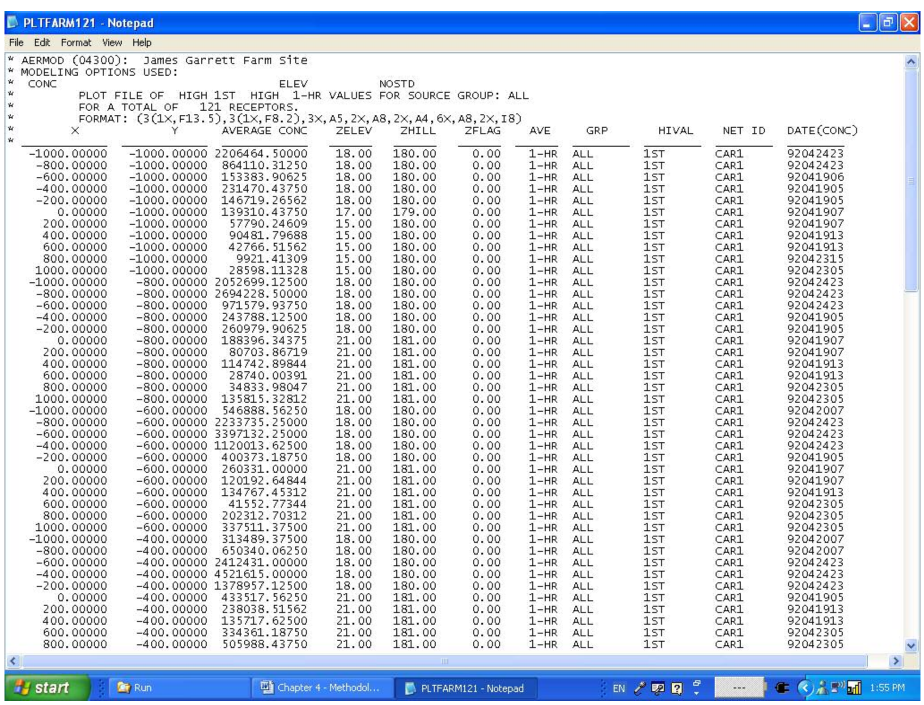


Figure 4-12 Running AERMOD




```
* AERMOD (04300):  James Garrett Farm Site
* MODELING OPTIONS USED:
*  CONC                          ELEV           NOSTD
*        PLOT FILE OF  HIGH 1ST  HIGH  1-HR VALUES FOR SOURCE GROUP: ALL
*        FOR A TOTAL OF    121 RECEPTORS.
*        FORMAT: (3(1X,F13.5),3(1X,F8.2),3X,A5,2X,A8,2X,A4,6X,A8,2X,I8)
*        X             Y      AVERAGE CONC    ZELEV    ZHILL    ZFLAG    AVE     GRP       HIVAL     NET ID    DATE(CONC)
*
  -1000.00000  -1000.00000 2206464.50000    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92042423
   -800.00000  -1000.00000  864110.31250    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92042423
   -600.00000  -1000.00000  153383.90625    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92041906
   -400.00000  -1000.00000  231470.43750    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92041905
   -200.00000  -1000.00000  146719.26562    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92041905
      0.00000  -1000.00000  139310.43750    17.00   179.00     0.00  1-HR  ALL       1ST       CAR1      92041907
    200.00000  -1000.00000   57790.24609    15.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92041907
    400.00000  -1000.00000   90481.79688    15.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92041913
    600.00000  -1000.00000   42766.51562    15.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92041913
    800.00000  -1000.00000    9921.41309    15.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92042315
   1000.00000  -1000.00000   28598.11328    15.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92042305
  -1000.00000   -800.00000 2052699.12500    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92042423
   -800.00000   -800.00000 2694228.50000    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92042423
   -600.00000   -800.00000  971579.93750    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92042423
   -400.00000   -800.00000  243788.12500    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92041905
   -200.00000   -800.00000  260979.90625    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92041905
      0.00000   -800.00000  188396.34375    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92041907
    200.00000   -800.00000   80703.86719    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92041907
    400.00000   -800.00000  114742.89844    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92041913
    600.00000   -800.00000   28740.00391    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92041913
    800.00000   -800.00000   34833.98047    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92042305
   1000.00000   -800.00000  135815.32812    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92042305
  -1000.00000   -600.00000  546888.56250    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92042007
   -800.00000   -600.00000 2233735.25000    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92042423
   -600.00000   -600.00000 3397132.25000    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92042423
   -400.00000   -600.00000 1120013.62500    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92042423
   -200.00000   -600.00000  400373.18750    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92041905
      0.00000   -600.00000  260331.00000    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92041907
    200.00000   -600.00000  120192.64844    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92041907
    400.00000   -600.00000  134767.45312    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92041913
    600.00000   -600.00000   41552.77344    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92042305
    800.00000   -600.00000  202312.70312    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92042305
   1000.00000   -600.00000  337511.37500    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92042305
  -1000.00000   -400.00000  313489.37500    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92042007
   -800.00000   -400.00000  650340.06250    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92042007
   -600.00000   -400.00000 2412431.00000    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92042423
   -400.00000   -400.00000 4521615.00000    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92042423
   -200.00000   -400.00000 1378957.12500    18.00   180.00     0.00  1-HR  ALL       1ST       CAR1      92042423
      0.00000   -400.00000  433517.56250    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92041905
    200.00000   -400.00000  238038.51562    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92041913
    400.00000   -400.00000  135717.62500    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92041913
    600.00000   -400.00000  334361.18750    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92042305
    800.00000   -400.00000  505988.43750    21.00   181.00     0.00  1-HR  ALL       1ST       CAR1      92042305
```


Figure 4-13 Example of Result

4.2 Geographic Information System (GIS)

Geographic Information System (GIS) is the integrated systems of computer hardware, software, and geographic data that people interact with to integrate, analyze, and visualize the data; identify relationships, patterns, and trends; and find solutions to problems (GIS Dictionary, ArcGIS 9.0). A GIS system is designed to capture, store, query, analyze, display, and output geographic information. Roger Tomlinson first is accredited with developing the "first GIS" – the national natural resource inventory for Canada created under his directorship. In U.S, GIS was first used in the military and intelligence imagery programs of the 1960s. Jumping from the military mission, GIS has been used in many industries. For instance, it is used in the water and wastewater industries especially in the area of natural hydrology and large-scale, river-basin hydrology. The survey conducted by the American Water Works Association (AWWA) showed that 90% of the water utilities in the U.S. were using GIS technology by the end of the year 2000.

ArcGIS, the most widely used GIS software developed by the Environmental Systems Research Institute (ESRI), is an integrated collection of software products for building a complete GIS. It enables users to employ GIS functionality in desktops, servers, over the web, or in the field. Desktop GIS was used in this thesis.

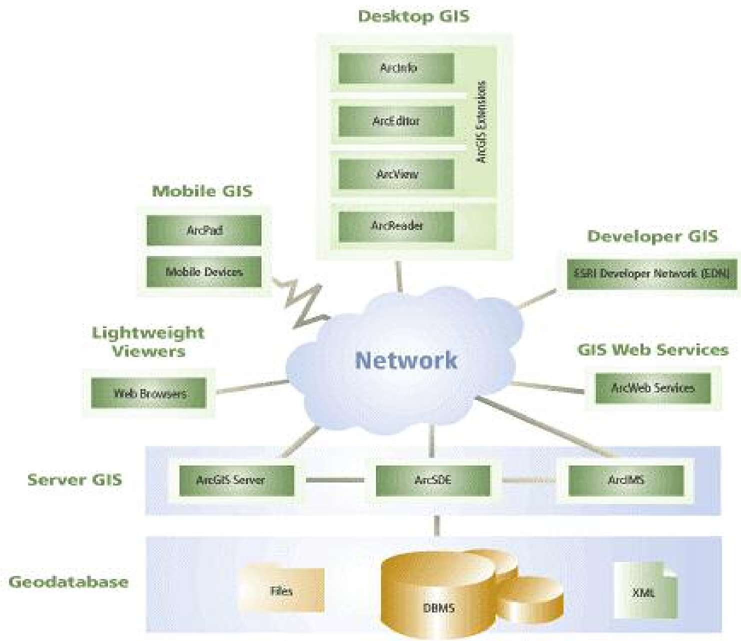


Figure 4-14 ArcGIS Platform

The Desktop GIS as shown in Figure 4-14 consists of three functionality levels, ArcView, ArcEditor, and ArcInfo; and a special functionality, ArcGIS Extension. ArcView makes the maps and data that ArcReader can view and print. It can also be used to query data; analyze spatial relationships like distance, and containment among map features; and overlay layers to discover how different types of data are interrelated at particular locations. ArcEditor gives ArcView functionality and has additional data creation and editing tools. ArcInfo, in addition, gives complete ArcEditor functionality plus a full set of spatial analysis tools. This thesis utilized ArcView and ArcGIS Extension; particularly Geostatistical Analyst. More specifically, ArcView which can be broadly divided into two categories, one including mapmaking, editing, and spatial analysis, the other including data management, was used to create map in study areas, determine receptor elevations, and used for spatial analysis. Geostatistical Analyst that is part of ArcGIS Extension was used to statistically analyze the values of concentration data and to create a prediction map of biosolids odor concentration.

4.2.1 ArcView

ArcView plays significant role for analyzing and making a map, and for data management through ArcMap and ArcCatalog, respectively. In addition, ArcView also has a geoprocessing tool called ArcToolbox that provides an environment for performing geographic analysis.

Typically, there are two ways to obtain data to display in ArcMap; one is from ArcCatalog while the other one is importing from external files. Accordingly, the basic data needed to create biosolids fields were obtained from ArcCatalog. ArcCatalog has the built-in tools to preview the data in geography format or table format before exporting to ArcMap. The example of highway class data in layer file format in ArcCatalog is shown in figure 4-15. In order to accomplish the research objectives, all data in vector and raster format that would be used as criteria were investigated and imported to ArcMap. Furthermore, all GIS data used in the study were obtained from ESRI Data & Maps Media kit which contains many types of map data at many scales of geography, and the entire data set can be read directly from two DVD-ROMs in the media kit.

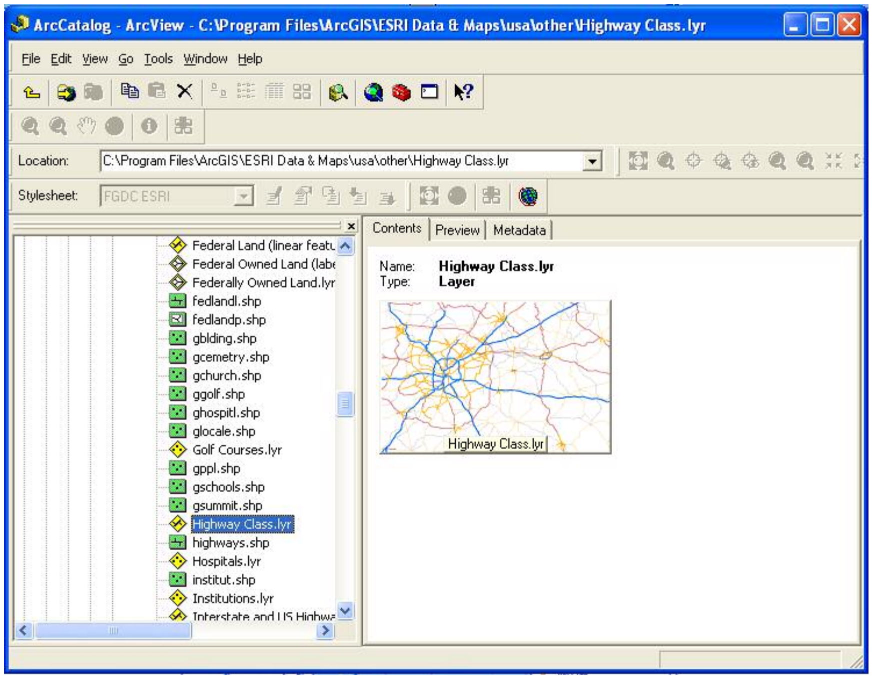


Figure 4-15 ArcCatalog

The following data were imported to ArcMap that used to create biosolids study area map.

1. United States County vector data in shapefile format that contains demographic data and population data

2. United States Elevation was used to determine receptor elevations that could be displayed in ArcView (Figure 4-16) or new 3D visualization tool called ArcGlobe (Figure 4-17).

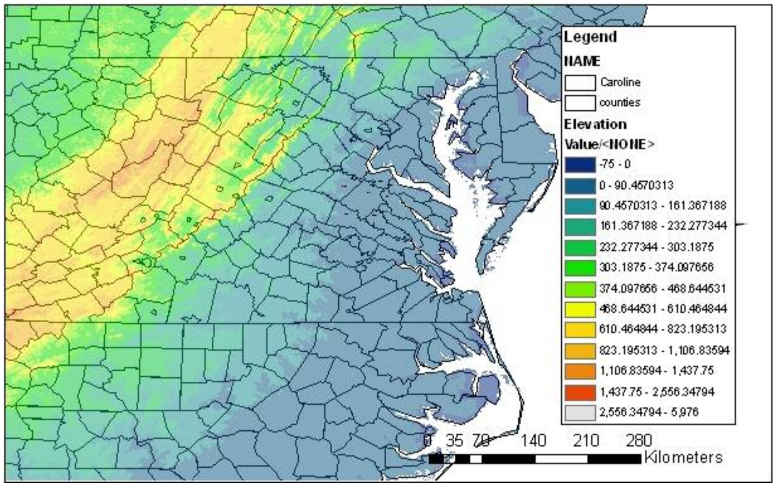


Figure 4-16 Virginia State Elevation in ArcView

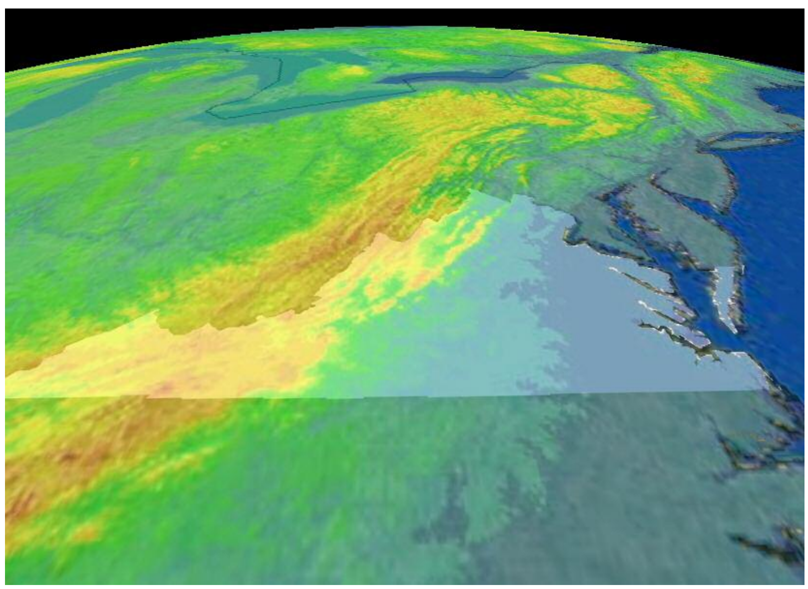


Figure 4-17 Virginia State Elevation in ArcGlobe

Determining receptor elevation that is a primary step for setting up the receptor pathway (RE) in odor dispersion model to involve the effect of terrain needs to use one of the basic functions of the GIS. Once the United States elevation data are imported from ArcCatalog to ArcMap, the elevation of interested area is determined by the tool in ArcMap called “identify”. Because the biosolids field location and receptor location first need to be located in ArcMap, XY data are needed in database format (dbf). In order to do that, there is a need to create an external file and then import it to ArcMap. The biosolids XY data, therefore, were created in Excel format and exported to Microsoft Access, from which the file was translated to the dbf format. Finally, the biosolids XY data file in database format could be directly imported to ArcMap via ArcCatalog or the built-in ArcMap button called “Add Data”. The imported file is displayed in the map as points. Figure 4-18 shows “Add XY Data” screen in ArcMap of James Garrett Farm 12. The accuracy of map depends on the coordinate system. The coordinate system used in this study was based on the North America Datum of 1983 (NAD 83). Once the biosolids XY data are imported to the map, determining receptor elevations is easy. The elevation value stored in elevation data in layer format of ArcCatalog has a unit in meters that can be directly input to the odor dispersion model. The elevation data are raster data created by the U.S. Geological Survey (USGS). An elevation map is used as the base map layer derived from the global digital elevation model (DEM).

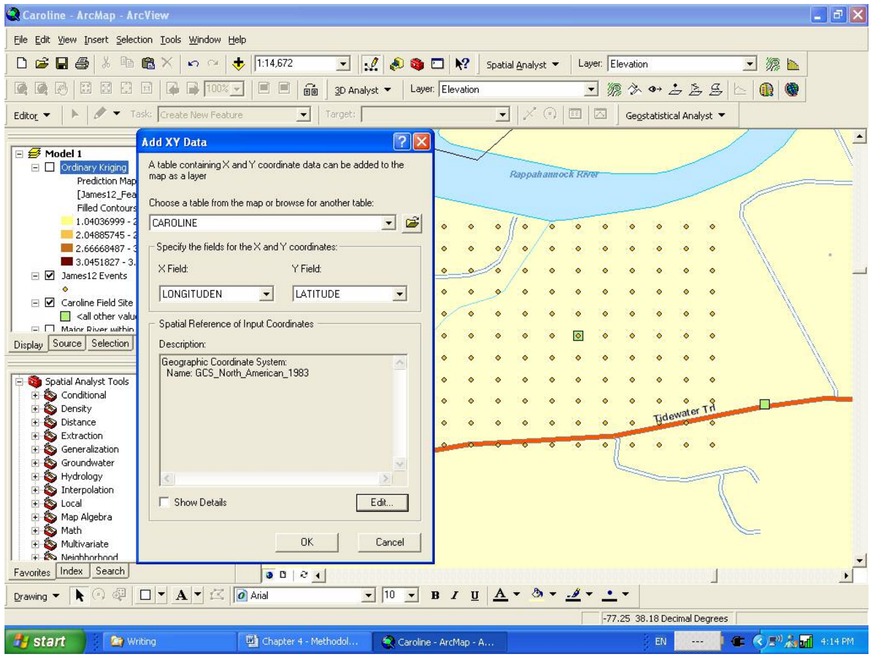


Figure 4-18 Add XY Data

3. Households by Census Block data in shapefile format.

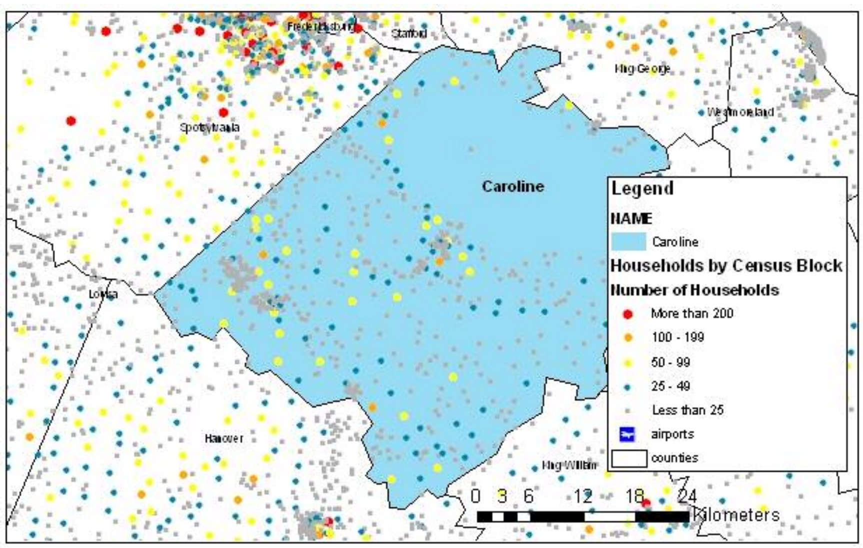


Figure 4-19 Caroline Households by Census Block

4. School locations vector data in shapefile format

5. StreetMap USA

Figure 4-20 Caroline School Location and StreetMap

6. Hillshade Elevation

The United States Hillshade Elevation raster format shown in figure 4-21 was created from the elevation data in ESRI Data & Maps for obtaining hillshade value needed as an input to the receptor pathway (RE) in case of counting for complex terrain. To create Hillshade layer in raster format, using ArcGIS Extension tool called Spatial Analyst has the option to create hillshade through utilizing ArcToolbox with 315 degrees of Azimuth angle of the light source and 45 degrees of Altitude angle of the light source above the horizon. After the hillshade layer was created in ArcMap, the identify tool was easily used to determine the hillshade value in the defined receptor grid network. The data, then, could be input to the odor dispersion runstream file.

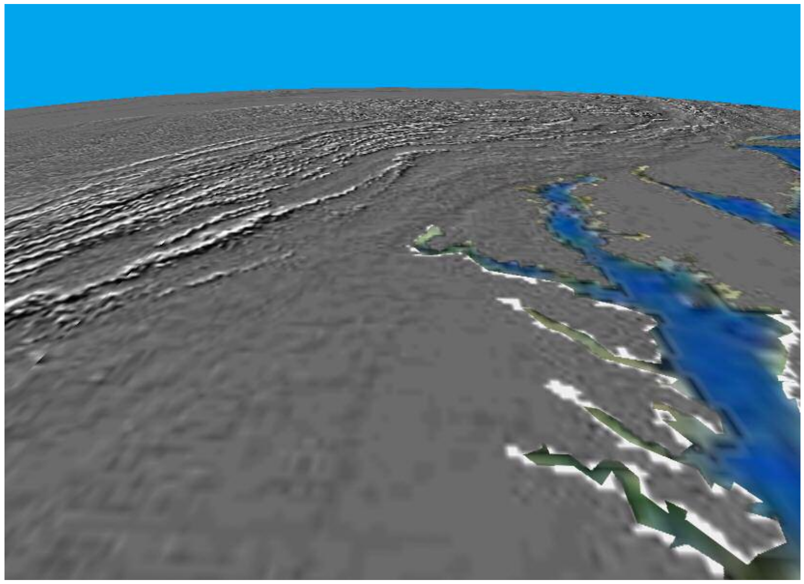


Figure 4-21 Hillshade Elevation

Unless obtaining data directly from ArcCatalog, the other way to obtain data that is from an external file. Importing external file to display in ArcMap is the same as previously described in determining receptor elevation. That kind of external data used in the research was the results from the odor dispersion model. The result, concentration values, generated from odor dispersion model is required to create concentration prediction map and probability map described more in next section, Geostatistical Analyst.

4.2.2 Geostatistical Analyst

The odor emission is the physical process that occurs in the atmosphere downwind of the odor source. The receptor sniffs the diluted odor. The dilution ratio is the number of dilutions needed to make the actual odor emission "non-detectable" (Detection Threshold). If the receptor detects the odor, then the odor in the atmosphere is above the detection threshold level. The detection threshold normally is determined using the "best estimate criteria" which is equal to odor concentration value of 1 gram per cubic meter calculated by the odor dispersion model (McGinley et al, 2004). A value less than 1 represents no odor or sub-threshold. In contrast, a value of greater than 1 represents odor at supra-threshold level. Consequently, the result from odor dispersion model, which is, by default, micrograms per cubic meters needs to be converted to grams per cubic meters or odor units (O.U.) per cubic meters taking place of grams per cubic meters (McGinley et al, 2004). The concentration value, ultimately, results in grams per cubic meters with their XY location in specified receptor grid network. Due to the impossibility of measuring concentration values at any location because of limited number of sample points, a tool like Geostatistical Analyst in ArcGIS Extension is used for generating continuous concentration data.

Geostatistical Analyst is the integration of geostatistics and GIS. It is the advanced surface modeling that provides the tool for exploratory spatial data analysis (ESDA) and for creating statistical surface. It could, subsequently, be used in geographic information system (GIS) models to create four output maps: prediction, prediction standard errors, probability, and quantile. But since input data are contaminated by errors and models are only approximations of reality, predictions made by Geostatistical Analyst are accompanied by information on uncertainties. Including the concentration value produced by dispersion model used as input data to Geostatistical Analyst, the data first need to be investigated by using ESDA tool. To investigate the data statistically, there are three data features that need to verify: dependency, stationarity, and distribution. Theoretically, Geostatistics works best when input data are Gaussian. If not, data have to be made to be close to Gaussian distribution. The tools available in Geostatistical Analyst could be used to explore data and define the type of distribution, concentration value in this case. Figure 4-22 and 23 show examples for exploring data by using histogram and normal QQ plots. The Histogram tool plots frequency histograms for the attributes in the dataset. The important features of the distribution are its central value, its spread, and its symmetry. As a quick check, if the mean and the median are approximately the same value, we have one piece of evidence that the data may be normally distributed.

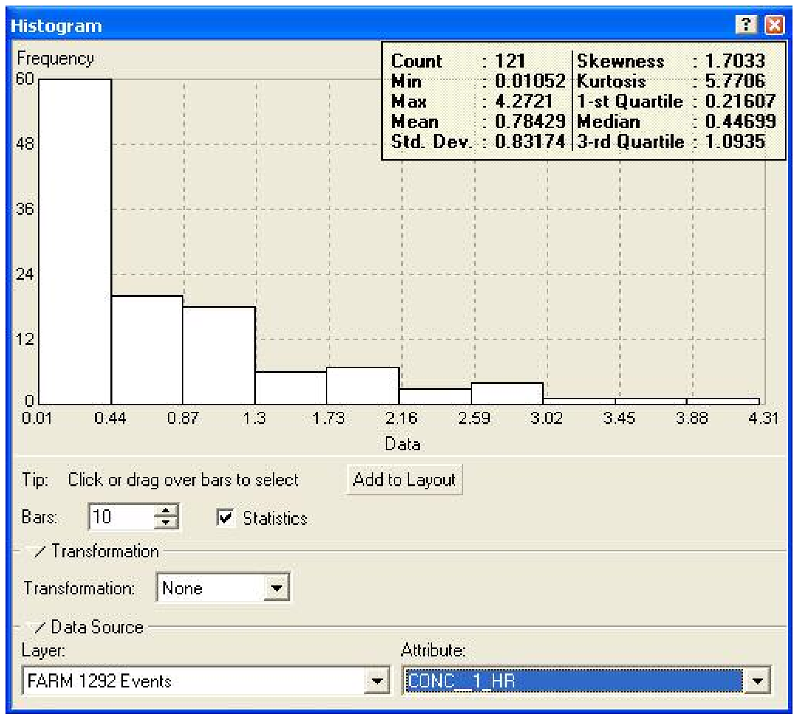


Figure 4-22 Exploring Data using Histogram

The normal QQ Plot, on the other hand, compares the distribution of the data to a standard normal distribution providing another measurement of normality. The closer the points are to creating a straight line, the closer the distribution is to being normally distributed.

Exploring the data by using Histogram and Normal QQ Plot, if the data did not exhibit a normal distribution in either the Histogram or the Normal QQ Plot, it may be necessary to transform the data to make it close to a normal distribution before using certain kriging interpolation techniques. Figure 4-20 shows the Histogram Plot when the data is transformed by using log.

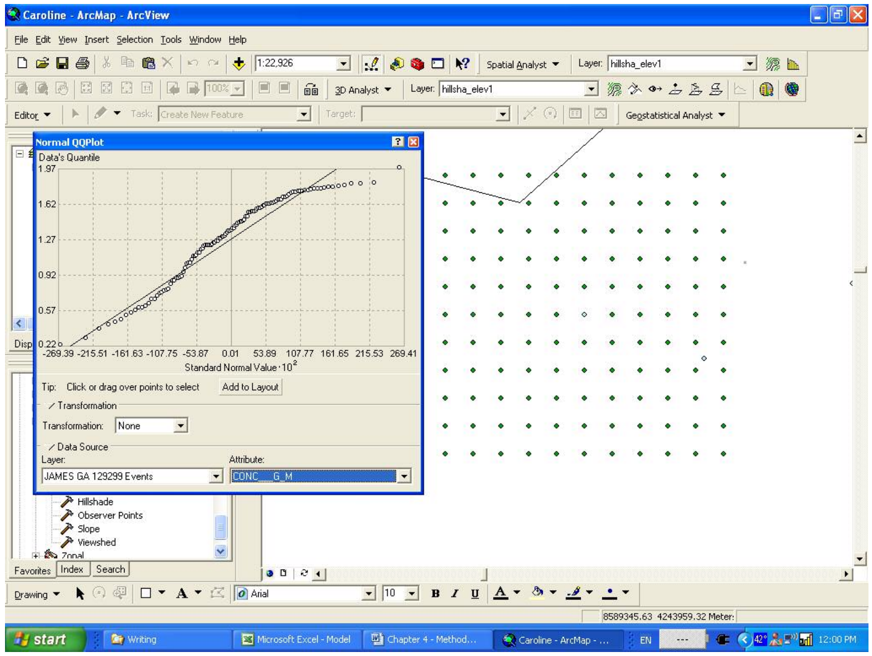


Figure 4-23 Exploring Data using Normal QQ Plot

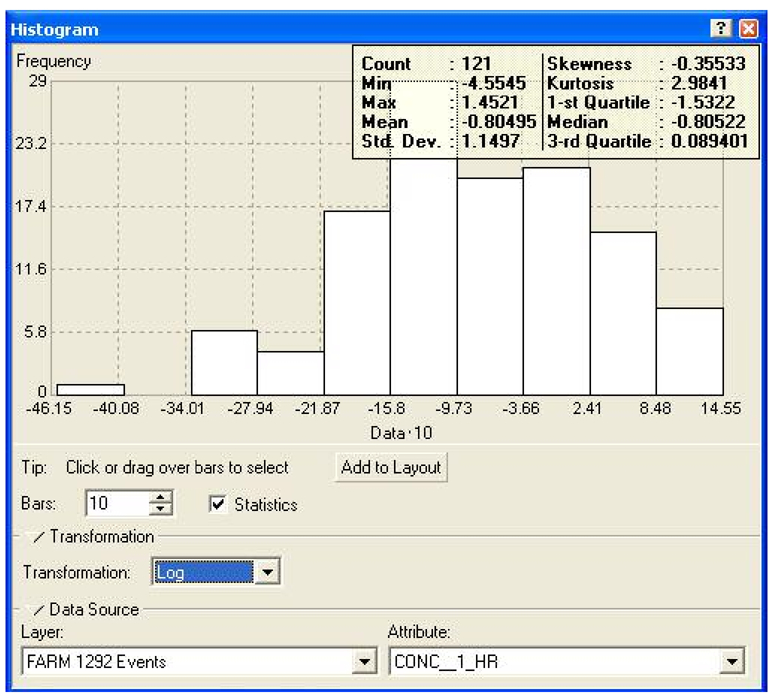


Figure 4-24 Histogram Plot with Transformation

Another data feature that is important when performing geostatistical data analysis is spatial dependency. Since the goal of geostatistical analysis is to predict values where no data have been collected, the tools and models of Geostatistical Analyst will only work on spatially dependent data. To check the dependency of data, several tools are available in the Geostatistical Analyst's ESDA and Geostatistical Wizard.

In spatial autocorrelation, it is assumed that things that are close to one another are more alike. The Semivariogram/Covariance cloud allows us to roughly examine that relationship. Moreover, the Semivariogram/Covariance modeling in Geostatistical Wizard has more potential to allow us taking a look at more details of spatial dependency. Figure 4-20 shows a semivariogram of concentration data with spatial dependence. The semivariogram surface in the figure also shows a clear structure of spatial dependence, especially in the east-west direction.

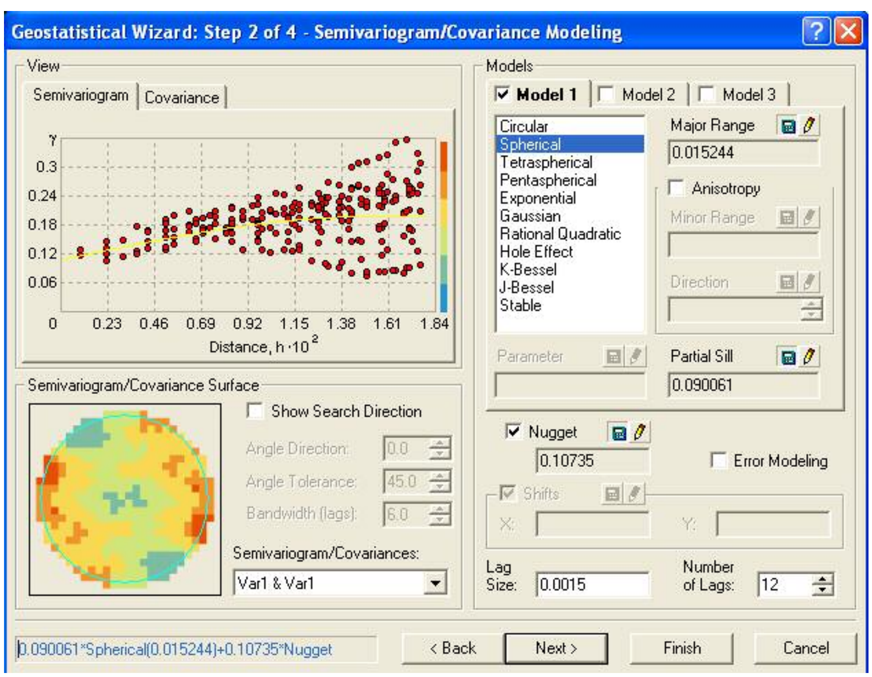


Figure 4-25 Semivariogram and Covariance Modeling

The other important feature, stationarity, also needs to be investigated when analyzing statistical data. Stationarity means that statistical properties do not depend on location. Therefore, the mean (expected value) of a variable at one location is equal to the mean at any other location. The figure below (Figure 4-21), created using the Semivariogram/Covariance Cloud exploratory tool, shows many pairs of locations, linked by green lines that are approximately the same length and orientation.

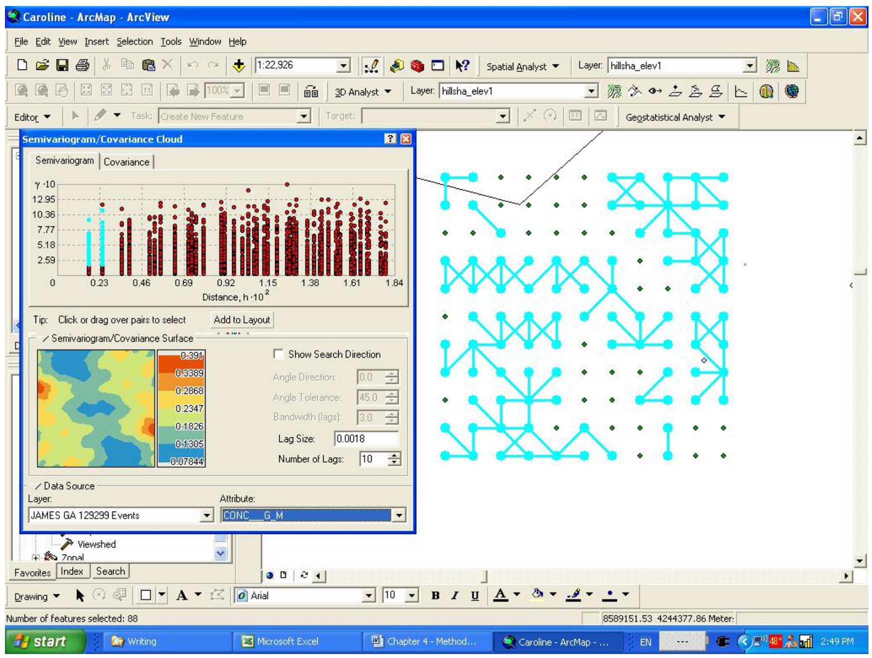


Figure 4-26 Stationarity of Data

After exploring the data, the interpolation technique could then be employed to generate a continuous surface, concentration plot in this case. Typically, there are two groups of interpolation techniques: deterministic and geostatistical interpolation or “kriging” models. Kriging methods depend on mathematical and statistical models. The statistical model that includes probability separates kriging methods from the deterministic methods. Deterministic models are based on either the distance between points (e.g., Inverse Distance Weighted) or the degree of smoothing (e.g., Radial Basis

Functions and Local Polynomials). Geostatistical models or kriging are based on the statistical properties of the observations and provide some measure of the certainty or accuracy of the predictions while deterministic models do not. It also tells us how good the predictions are. Theoretically, if the input data can statistically be defined as Gaussian or close to Gaussian, it makes more sense to use the geostatistical models. Kriging is normally divided into two distinct tasks: quantifying the spatial structure of the data and producing a prediction. Quantifying the structure, known as variography, is fitting a spatial-dependence model to data. Then, kriging will use the fitted model from variography, the spatial data configuration, and the values of the measured sample points around the prediction location to make a prediction for an unknown value. Geostatistical models in Geostatistical analyze provide six kriging models shown in Figure 4-27.

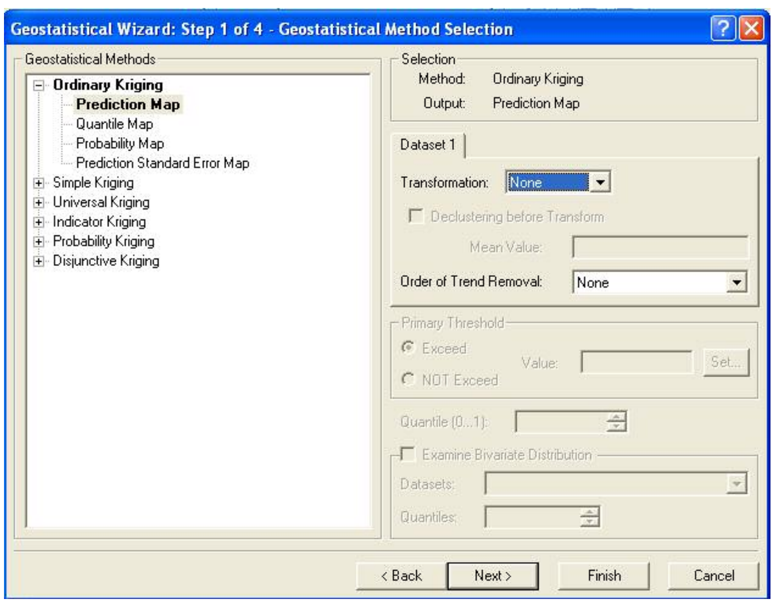


Figure 4-27 Kriging Methods

Basically, each kriging method relies on the notion of autocorrelation. The typical kriging equation could be expressed in a simple mathematical formula,

$$z(s) = \mu(s) + \varepsilon(s)$$

where z(s) is the variable of interest, decomposed into a deterministic trend $\mu(s)$, and random, autocorrelated errors form $\varepsilon(s)$. The symbol "s" simply indicates the location, for example the spatial x-(longitude) and y-(latitude) coordinates. Variations on this formula form the basis for all of the different types of kriging. The summary of the different kriging methods based on the variation of the formula is briefly described below.

1. Ordinary kriging assumes trend, $\mu(s)$ is constant and unknown.
2. Universal kriging, on the other hand, assumes trends vary and regression coefficients are unknown.
3. Simple kriging would be used when trend is completely known whether constant or not.
4. Indicator kriging is used when you perform transformation on z(s). For example, you can change it to indicator variable, where it is 0 if z(s) is below some value (e.g., 1 for odor concentration).
5. Probability kriging may be used when you wish to predict the probability that z(s) is above the threshold value or not.
6. Lastly, disjunctive kriging used when you want to make unspecified transformation of the z(s), which is not used in this research.

To generate a continuous surface of biosolids concentration, the available kriging methods would be carefully chosen depending on the statistical properties of the data.

Chapter 5: Results and Discussion

In previous chapter, the methodology used to generate results was described. Accordingly, this chapter shows the results using the personal computer (PC) IBM ThinkPad T43 with Pentium M processor 1.73 GHz. and 1 GB of RAM. The reason why the specification of computer is mentioned here is because of the requirement of computer memory to generate the results from the AERMOD and to perform the GIS task. However, the only problem often occurred was the required memory when performing the GIS tasks.

5.1 Base Model

The base model was set to be the preliminary model to generate a result based on the assumption for setting the AERMOD runstream file as followed:

1. The model was setup for calculation of average concentration.
2. The model used rural dispersion only.
3. The model assumed using the non-default option of no stack-tip downwash.
4. The model did not account for elevated terrain effect.
5. The model assumed no flagpole receptor.
6. The model calculated 4 short term average(s) of: 1-Hr, 3-Hr, 8-Hr, and 24-Hr which are the most common short term periods used when performing a dispersion model.
7. The type of pollutant released from biosolids was assumed to be Hydrogen Sulfide (H_2S).

8. James Garrett Farm 12 located at 38.18N, 78.23W was selected to be the site model. The date biosolids applied was 04/18/05 with 459.02 wet tons of biosolids or approximately 17 acres (266*266 square meters).
9. The type of source was assumed to be an area source and located at the middle of receptor network.
10. The emission rate was calculated by using an average value of the emission rate from the MES data, table 4-1, which was 0.315 $g/(s-m^2)$.
11. The release height above ground was set to be 7.0 m.
12. The Cartesian grid network was selected to be the receptor network. The dimension of grid network is 2 by 2 kilometers (1 km from source) with grid spacing 200 meters.
13. Two meteorological data required to process the AERMET were 1992 hourly surface observation and upper air data. The time period of weather data used was from 04/18/92 to 04/24/92 or about a week. Two files which are files of hourly boundary layer (surface layer) and multiple-level observations (profile layer) were generated by the AERMET for that particular period and then were used as the input files for the meteorological pathway (ME) in the AERMOD.
14. The upper bound wind speeds divided into five categories were set by the model as follows (meters/sec): 1.54, 3.09, 5.14, 8.23, and 10.80.

Using the tools and the methodology described in Chapter 4, the odor concentration and relative date and time of concentration for four short-term averaging times 1, 3, 8, and 24 hours were generated from the odor dispersion model (AERMOD). The model indicated that 1.2 Mb of RAM was required for processing. The model originally reported the first highest concentration values of selected receptor locations for different averaging times in micrograms per cubic meters ($\mu g / m^3$) over a week period from 04/19 to 04/24. Table 5-1 shows the example result of 1-Hr averaging time. The X, Y locations were set as 2 square kilometers in a Cartesian grid with 200-grid spacing. The date and time occurred are also reported. By using the Geostatistical Analyst the statistical properties of concentration values especially distribution type were firstly investigated through the ESDA tool. The distribution of sample data, concentration values, in this case was not a normal distributed and was transformed using a log function to make its distribution closer to normal. Using the interpolation method-ordinary kriging- the concentration values then were plotted as contours in the prediction maps shown in Figure 5-1 through 5-4. The concentration prediction maps show the concentration contours with relative concentration values over topographic features of the field site such as a river or roadway. The unit of concentration values was converted from micrograms per cubic meters ($\mu g / m^3$) to grams per cubic meters (g / m^3) and the values are categorized and displayed in the legend of the maps. The legend generally shows name of field, field location, and filled contours that are divided based on the minimum and maximum concentration values for particular case. The increment of contours is 0.2 until the concentration value reach 1.0 g / m^3 and greater than 4 g / m^3 .

Table 5-1 Result of Concentration (1-Hr)

X	Y	Average Concentration ($\mu g / m^3$)	Averaging Time	Date/Time
-1000	-1000	2271331.75	1-HR	92042423
-800	-1000	1042835.5	1-HR	92042423
-600	-1000	138257.2813	1-HR	92041906
-400	-1000	209389.6094	1-HR	92041905
-200	-1000	148875.2813	1-HR	92041905
0	-1000	127330.0547	1-HR	92041907
200	-1000	63277.01953	1-HR	92041907
400	-1000	77387.63281	1-HR	92041913
600	-1000	44072.88672	1-HR	92041913
800	-1000	10385.6377	1-HR	92042315
1000	-1000	42734.67188	1-HR	92042305
-1000	-800	2175100.5	1-HR	92042423
-800	-800	2802104.5	1-HR	92042423
-600	-800	1172437.875	1-HR	92042423
-400	-800	229757.9844	1-HR	92041905
-200	-800	249192.2656	1-HR	92041905
0	-800	173034.0625	1-HR	92041907
200	-800	86177.15625	1-HR	92041907
400	-800	100152.0156	1-HR	92041913
600	-800	35133.12891	1-HR	92041913
800	-800	50268.8125	1-HR	92042305
1000	-800	146378.875	1-HR	92042305
-1000	-600	611152.6875	1-HR	92042423
-800	-600	2416477.75	1-HR	92042423
-600	-600	3543463.75	1-HR	92042423
-400	-600	1317930.375	1-HR	92042423
-200	-600	378433.1563	1-HR	92041905
0	-600	244345.4688	1-HR	92041907
200	-600	125941.4609	1-HR	92041907
400	-600	123552.5156	1-HR	92041913
600	-600	58407.87109	1-HR	92042305
800	-600	213745.2344	1-HR	92042305
1000	-600	312635.1875	1-HR	92042305
-1000	-400	327539.75	1-HR	92042007
-800	-400	610147	1-HR	92042007
-600	-400	2614798.25	1-HR	92042423
-400	-400	4573558.5	1-HR	92042423
-200	-400	1464716.5	1-HR	92042423
0	-400	434749.1563	1-HR	92041905
200	-400	222760.5156	1-HR	92041913
400	-400	134916.6719	1-HR	92041913
600	-400	347307.375	1-HR	92042305
800	-400	474758.2188	1-HR	92042305
1000	-400	325588.125	1-HR	92042305
-1000	-200	166650.7031	1-HR	92041923

X	Y	Average Concentration ($\mu g / m^3$)	Averaging Time	Date/Time
-800	-200	220214.2813	1-HR	92042007
-600	-200	631487.625	1-HR	92042007
-400	-200	2666307.5	1-HR	92042423
-200	-200	5696063.5	1-HR	92042423
0	-200	1455802.25	1-HR	92042423
200	-200	503117.7188	1-HR	92041913
400	-200	689010.625	1-HR	92042305
600	-200	775270.8125	1-HR	92042305
800	-200	376167.25	1-HR	92042303
1000	-200	193406.875	1-HR	92042303
-1000	0	340252.3438	1-HR	92041924
-800	0	421099.2813	1-HR	92041924
-600	0	530180.875	1-HR	92041924
-400	0	684681	1-HR	92041924
-200	0	2248747.25	1-HR	92042423
0	0	3540755	1-HR	92042007
200	0	1503169.625	1-HR	92042305
400	0	1282868.375	1-HR	92042305
600	0	451545.5625	1-HR	92042302
800	0	342256.875	1-HR	92042302
1000	0	270701.9688	1-HR	92042302
-1000	200	225359.5938	1-HR	92041924
-800	200	289818.5625	1-HR	92041924
-600	200	393256.5	1-HR	92041924
-400	200	584647.75	1-HR	92041924
-200	200	1557610	1-HR	92042319
0	200	2882290.75	1-HR	92042424
200	200	2509624.25	1-HR	92042307
400	200	1854103.125	1-HR	92042220
600	200	677923.8125	1-HR	92042220
800	200	380068.625	1-HR	92042302
1000	200	278419.0625	1-HR	92042302
-1000	400	128361.8594	1-HR	92042019
-800	400	205063.4219	1-HR	92042319
-600	400	680018.875	1-HR	92042319
-400	400	1623312.5	1-HR	92042319
-200	400	3819384	1-HR	92042420
0	400	3934338.25	1-HR	92042420
200	400	2959686.5	1-HR	92041806
400	400	1208677.5	1-HR	92042224
600	400	1151058.25	1-HR	92042220
800	400	835034.6875	1-HR	92042220
1000	400	472198.25	1-HR	92042220
-1000	600	412401.5313	1-HR	92042319
-800	600	832984.375	1-HR	92042319
-600	600	1416566.375	1-HR	92042424
-400	600	2690307.75	1-HR	92042420

X	Y	Average Concentration ($\mu g / m^3$)	Averaging Time	Date/Time
-200	600	4138889.75	1-HR	92042420
0	600	902184.125	1-HR	92042420
200	600	2168388.5	1-HR	92041806
400	600	1214948.875	1-HR	92041803
600	600	600302.3125	1-HR	92042224
800	600	495527.7188	1-HR	92042221
1000	600	565851	1-HR	92042220
-1000	800	790680.3125	1-HR	92042424
-800	800	1041715.25	1-HR	92042424
-600	800	1903975.875	1-HR	92042420
-400	800	3124448	1-HR	92042420
-200	800	1549286.875	1-HR	92042420
0	800	621188.625	1-HR	92042322
200	800	1642326.25	1-HR	92041806
400	800	1220094.75	1-HR	92041803
600	800	263900.0313	1-HR	92042206
800	800	369405.2188	1-HR	92042224
1000	800	334353.0625	1-HR	92042224
-1000	1000	717940.5	1-HR	92042424
-800	1000	1416487.75	1-HR	92042420
-600	1000	2306321.5	1-HR	92042420
-400	1000	1708578.875	1-HR	92042420
-200	1000	371652.4375	1-HR	92042420
0	1000	454154.2188	1-HR	92042322
200	1000	1272087	1-HR	92041806
400	1000	944841.5	1-HR	92041803
600	1000	497069.7188	1-HR	92041803
800	1000	150790.9844	1-HR	92042206
1000	1000	254531.9219	1-HR	92042224

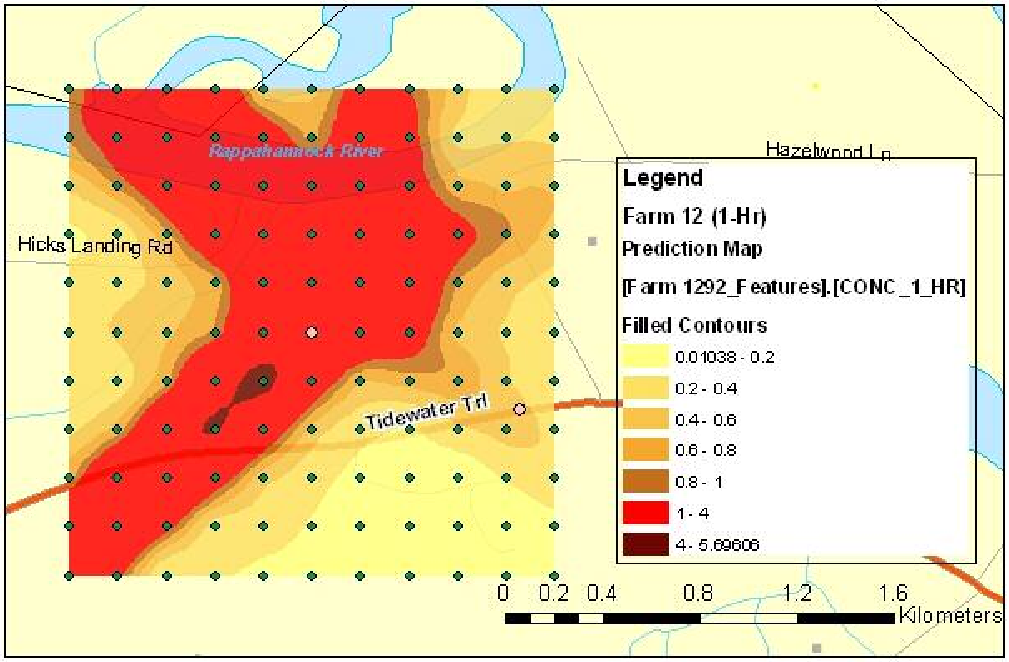


Figure 5-1 1-Hr Concentration Prediction Map

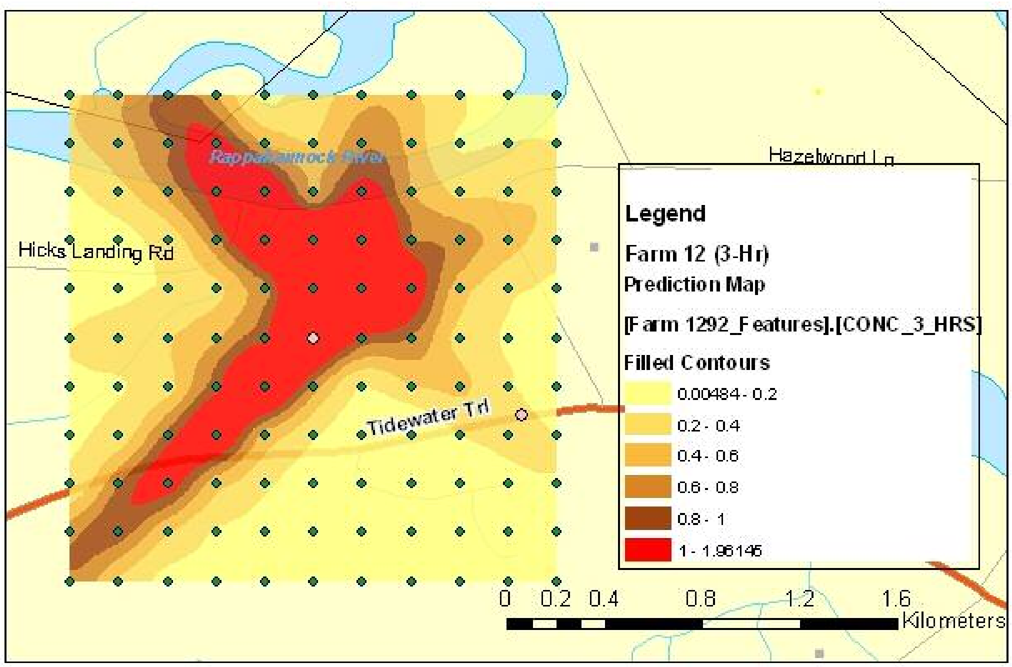


Figure 5-2 3-Hr Concentration Prediction Map

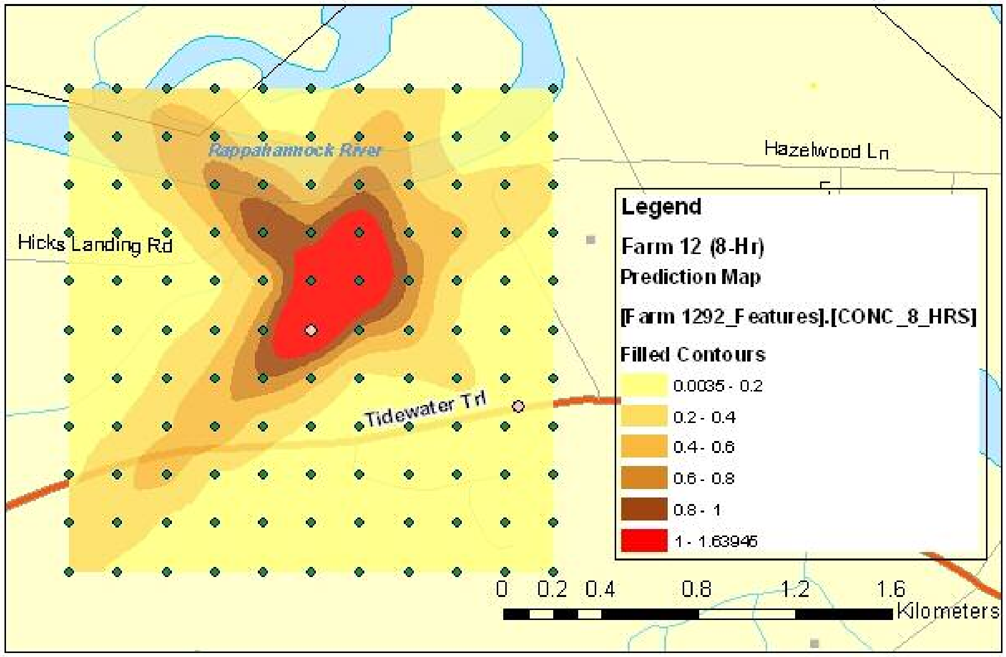


Figure 5-3 8-Hr Concentration Prediction Map

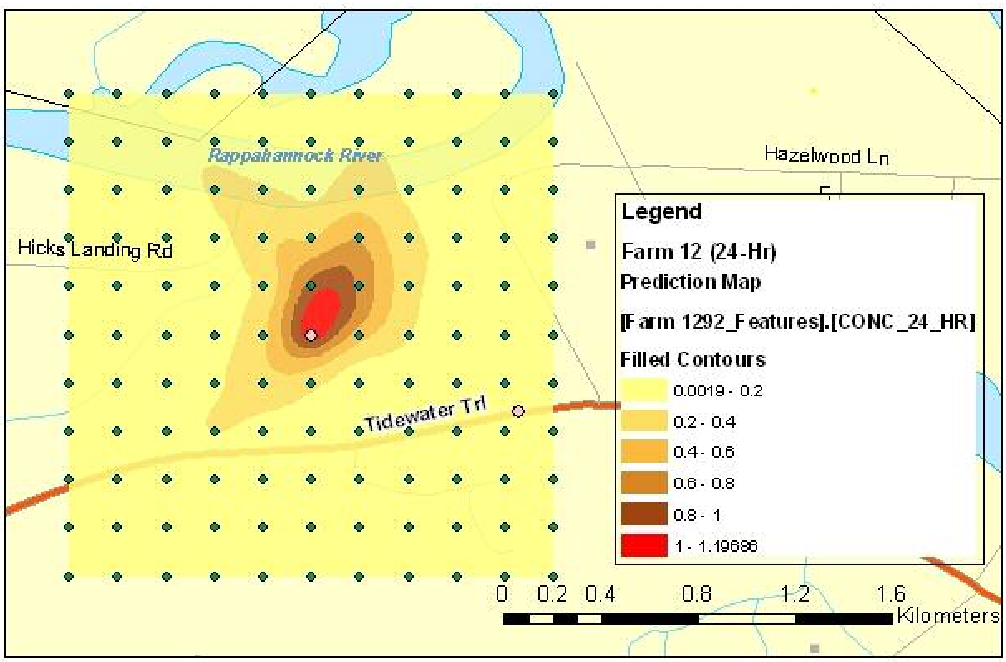


Figure 5-4 24-Hr Concentration Prediction Map

As mentioned in Chapter 4, if the result of concentration values from an odor dispersion model is above the detection threshold (DT) or 1 gram per cubic meters, it means that there is an odor in the area. Concentration prediction maps therefore were focused on the contour plots that have concentration values above the detection threshold (DT) responding to the potential of biosolids effecting to surrounding community. Figure 5-1 through 5-4 show the effect of biosolids odor on the surrounding area. Obviously, the prediction map of 1-Hr concentration prediction map shows the biggest potential area that the concentration values above the detection threshold, the so-called sensation area, over the selected receptor area and surrounding area such as the Rappahannock River and the roadway. It was found that the concentration dramatically changes from 1-Hr averaging time, approximately 1,680,000 m^2 over 4,000,000 m^2 or 42% of the field area, to 24-Hr averaging time, roughly about 1% of the area. In fact, the sensation area on the Rappahannock River and on the roadway in case of 8-Hr and 24-Hr averaging times could not be found at all. Therefore, it would be interesting to know that kind of relationship because it would be useful when estimating concentrations for other sampling times.

Theoretically, particularly in the case of short term averaging periods, the concentration values of the same location over different period of times follow a power law (Karl etc, 2000). A power law as a result is suggested as possible conversion law for use with single sources and averaging times of 24 hrs or less and it follows the relationship on next page (Karl etc, 2000):

$$C_s = C_k \left[\frac{t_k}{t_s} \right]^p$$

where C_s = concentration for time t_s

C_k = concentration for time t_k

t_s = longer averaging time

t_k = shorter averaging time

P = power (values of p have ranged from 0.17 to 0.75; the suggested value is 0.17)

Figure 5-5 shows the graph of selected location with relative concentration values generated by the AERMOD model changing over the 24-Hr period of averaging times which follow a power law but, interestingly, do not follow the power values suggested by the equation above (from 0.17 to 0.75) for each receptor location. Thus, estimating concentration values generated by the AERMOD model requires further study.

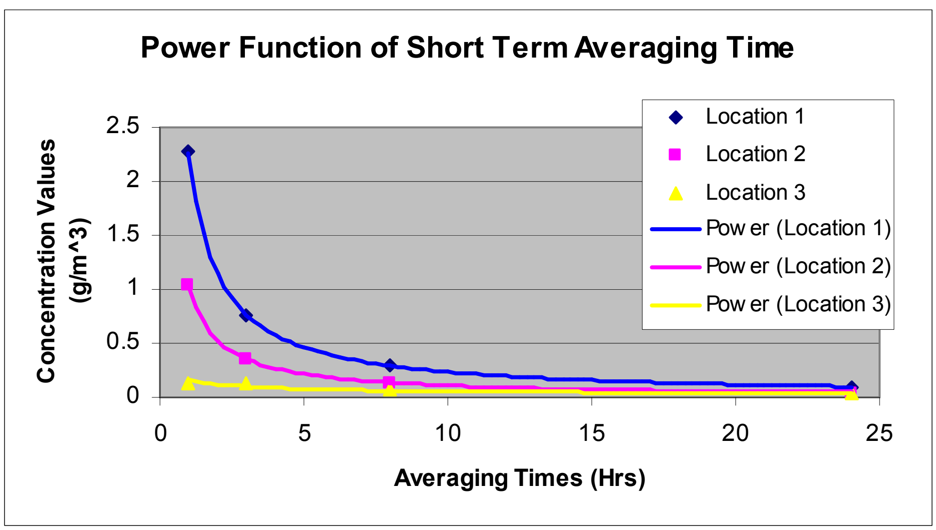


Figure 5-5 Power Function of Short Term Averaging Times

Besides considering the effect of the averaging times to the estimation of concentration, there are some input parameters that need to be considered when performing a dispersion model, as it would potentially affect the accuracy of a result. Such parameters are emission rate, release height, and weather location.

Defining the source factor, the source pathway (SE), is difficult in most cases (Karl et al, 2000). We need to consider first whether it is mobile or stationary and whether it is emitted from point, line, or more generally area source. We also need to determine other factors such as velocity of emission, temperature of emission, pressure of emission, and effective height of emission. Consequently, as the emission rate data obtained from the MES 2003 database and available only 9 samples and were not measured at the selected study area, there is a need to collect more emission rate data for the DCWASA reuse fields. In addition, it is important to find the method that would accurately determine the effective height of emission.

Even though the receptor factor in this study is not critical, it is much better to utilize the advantage of an aerial photograph to virtualize a location of an interested receptor area in order to correctly specify the receptor location when performing odor impact assessment.

The transport factor is taken into account through the meteorological pathway (ME) in the AERMOD. The transport characteristics basically are affected by the meteorological condition that is, particularly in this study, from an hourly surface observation and an upper air sounding data generated from the AERMET. The data, however, were obtained from the weather stations located far away from the study area. The surface weather station located at the Richmond, R. E. Byrd International airport is approximately 70 kilometers away from the study area. The upper air weather station is located about 140 kilometers farther than the surface weather, as shown in Figure 4-8. The exact local flow condition of the field area might possibly differ from the weather data used. Then, it might be helpful to find the method to calibrate the accuracy of the meteorological condition.

5.2 Elevated Terrain Effect

The base model discussed in Section 5.1 based on the assumption of flat terrain situation meaning that the model does not account for elevated terrain. In fact, the terrain of a field area is not always entirely flat but mostly elevated. Thus, accounting for complex terrain in the odor dispersion model would make the model more realistic. In addition, it would be useful in decision-making process when planning for distribution of biosolids to minimize an adverse affect of biosolids.

In order to include the complex terrain situation to the model, AERMOD allows users to manually input the terrain data through the receptor pathway (RE). As mentioned in Chapter 4, there are two kinds of input data needed: elevation and hillshade data. These two types of data were obtained by performing the simple task in the GIS and were input to the dispersion model. Figure 5-6 shows elevation data of the study area, James Garrett Farm 12, in vector format assuming that the biosolids source location is in the middle of receptor network with elevation 30 m. The elevations in the farm vary from 15-50 meters above the mean sea level (MSL) and more elevated in the southwest direction, from 30 to 50 m. The elevation data in raster format was also created using the deterministic interpolation method (Figure 5-7). The hillshade raster data, as described in Chapter 4, were created from elevation raster surface. The reason for the need of hillshade data in complex terrain situation is due to the requirement of the receptor pathway (RE) to use the elevation data with the hillshade data. Using the same runstream file but adding the elevation, the results in complex terrain situation were generated and are shown in Figure 5-9 with the results of flat terrain situation also shown in order to compare the difference.

8	18	18	18	18	17	15	15	15	15	15
18	18	18	18	18	21	21	21	21	21	21
18	18	18	18	18	21	21	21	21	21	21
18	18	18	18	18	21	21	21	21	21	21
18	18	18	18	21	21	21	21	21	21	21
36	36	36	36	30	30	30	21	21	21	21
36	36	36	36	30	30	30	30	30	30	30
36	36	36	30	30	30	30	30	30	30	25
36	36	36	30	30	30	30	30	30	30	25
50	36	36	30	30	30	30	30	30	30	25
50	50	50	22	22	22	22	22	30	25	25

Figure 5-6 Elevation Vector Data

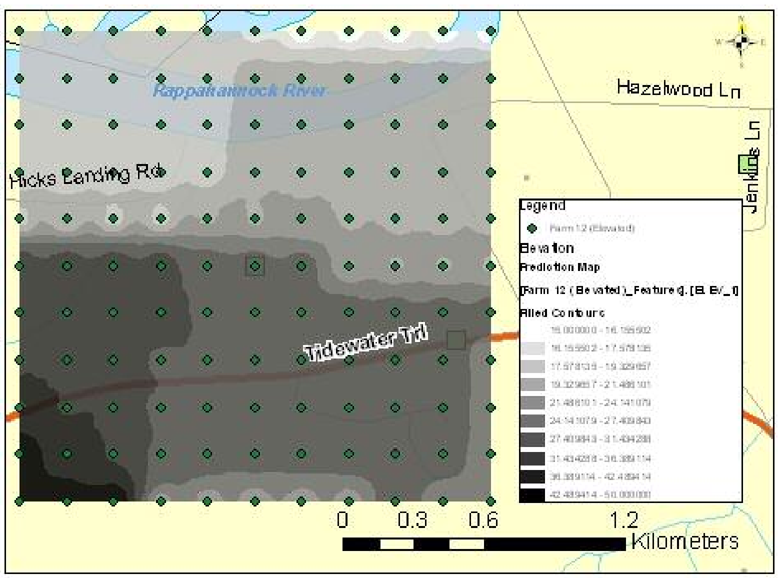


Figure 5-7 Elevation Raster Surface

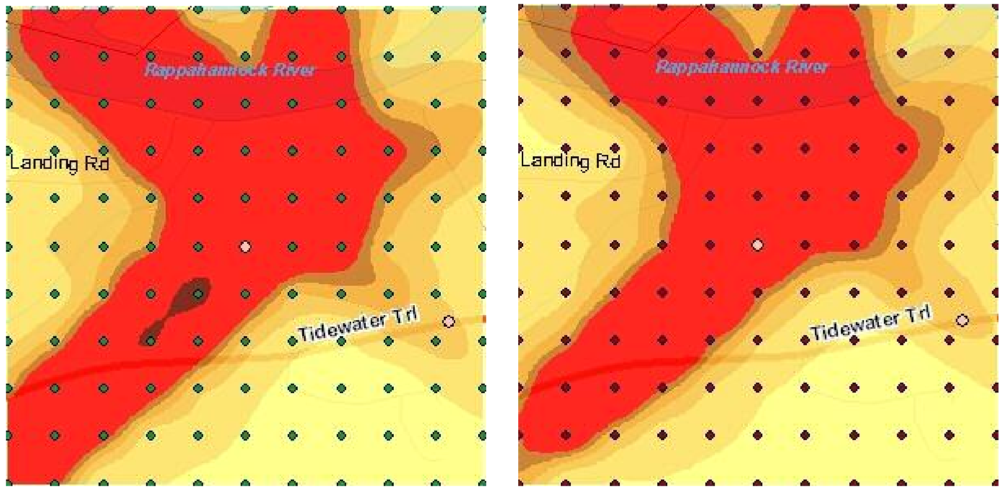


Figure 5-8 1-Hr Concentration of Flat (left) & Elevated Terrain (right)

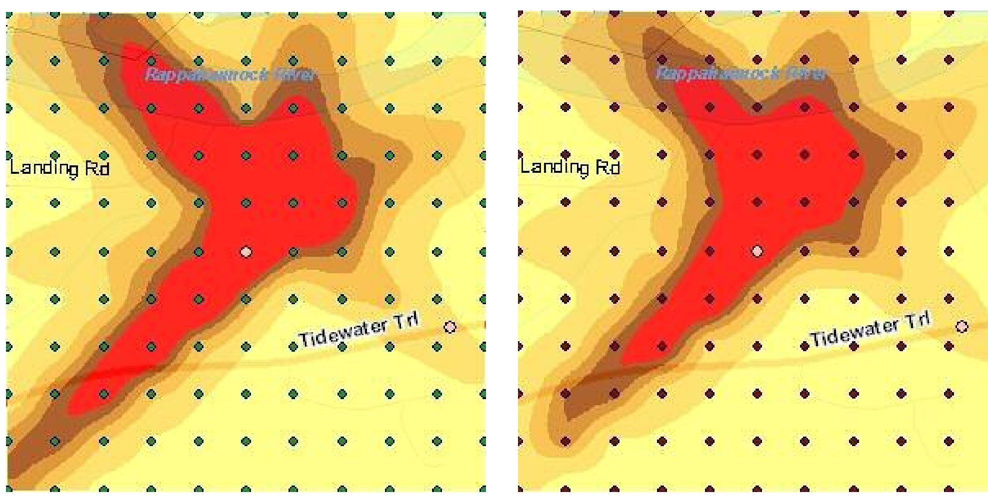


Figure 5-9 3-Hr Concentration of Flat (left) & Elevated Terrain (right)

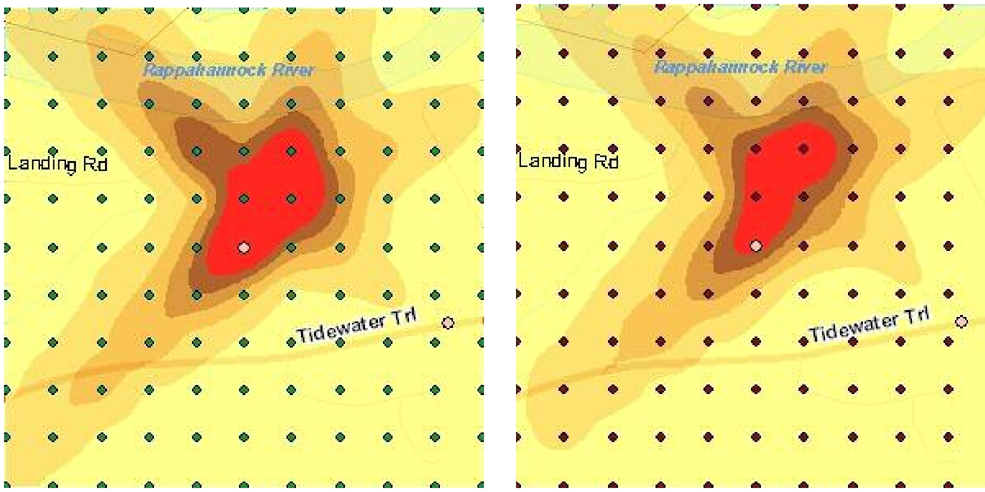


Figure 5-10 8-Hr Concentration of Flat (left) & Elevated Terrain (right)

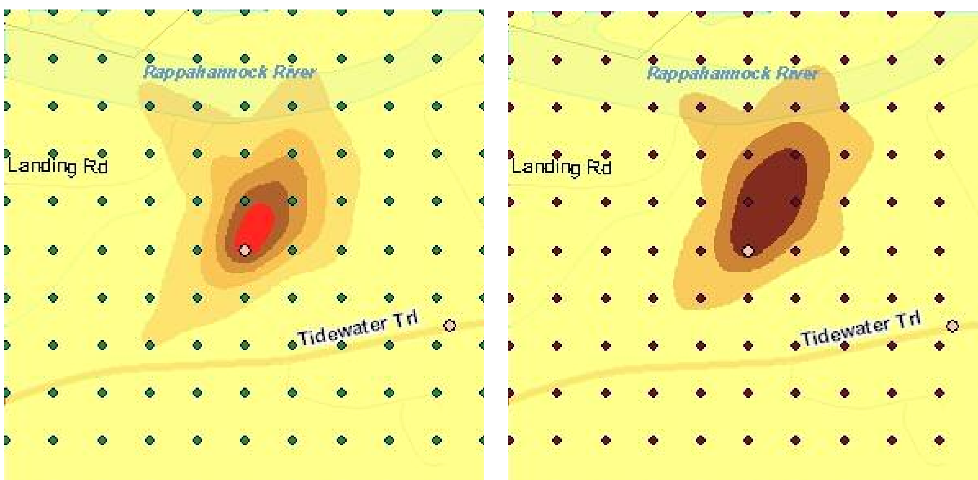


Figure 5-11 24-Hr Concentration of Flat (left) & Elevated Terrain (right)

By considering the prediction maps of flat and elevated terrain situation, we can see that the dispersion directions of the elevated terrain situations are almost exactly the same as with flat terrain, but slightly different sensation area, predicted odor dispersion that above the detection threshold (DT), especially in case of 24-Hr averaging time which indicates that the sensation area is found around 200 m in the northeast direction of the source in case of flat terrain but, in contrast, indicates no odor in complex terrain situation. Moreover, for 1-Hr concentration, the sensation area in flat terrain is greater than the one in complex terrain particularly in southwest direction where elevation values dramatically changed from 30 meters at biosolids source to 50 meters at receptor location shown in Figure 5-7. It is similar to 3-Hr concentration prediction maps where the sensation area of flat terrain in the southwest direction is greater than complex terrain. Relatively, that observation can apply to the situation of 8-Hr concentration as well. The interpretation of the results obviously might be that in complex terrain situation the elevated terrain would effect to the change of concentration by reducing the intense of the odor and then potentially effects to sensation area, but, moreover, it would be more interesting to see how effect would be when elevation is changed.

To investigate the effect on odor concentration when elevation is changed, the model of 1-Hr averaging time was reset with different elevation values at the selected locations as shown in green point but first only focusing on the change of concentration All of the locations, green and yellow point, originally have the elevation value equal to 50 m above MSL. The interested location, yellow point, was identified as part of sensation area in flat terrain situation but not affected in complex terrain situation with the same elevation value, Figure 5-9.

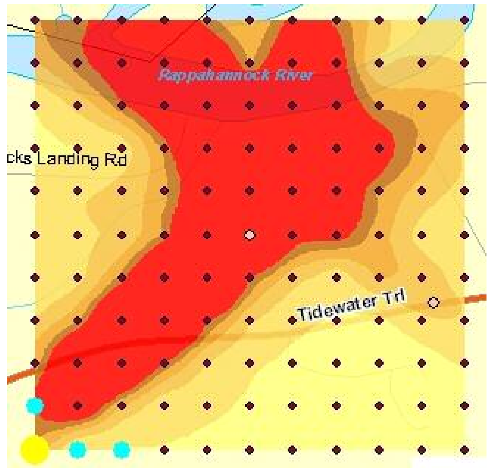


Figure 5-12 Location of Sensitivity Study

The model was run with eighteen different elevations, from 16 to 60 m, with the same runstream file used for processing the previous results. The results are plotted as a polynomial function displayed in Figure 5-13, blue line. It is easy to recognize that when the elevation is increased from 50 to 60 m the concentration value is decreased, but, in contrast, when the elevation is decreased from 50 m to 32 m the concentration value is increased until the elevation reaches 32 m the concentration is decreased again. It is also found that there is an elevation that makes the odor concentration less than 1 g/m^3 which is the elevation around 47 m. Furthermore, to investigate the issue of elevation in more details, three more location as shown in figure 5-14 were reset and rerun with the same eighteen elevation values. The results of location additionally plotted in figure 5-13 show that there exits a trend when elevation was gradually changed from 16 m to 60 m. Figure 5-15, moreover, shows the concentration of location of (-600, 1000) with different elevation values and different averaging time periods. Interestingly, the graph shows that elevated terrain situation does not affect the concentration when the concentration averaging time is increasing from 1-Hr to 24-Hr.

In conclusion, the elevated terrain study indicates that odor concentration would depend on a receptor's elevation as one of the factors that potentially create nuisance condition, but the concentration might not get affected from changing elevation in case of longer averaging time period.

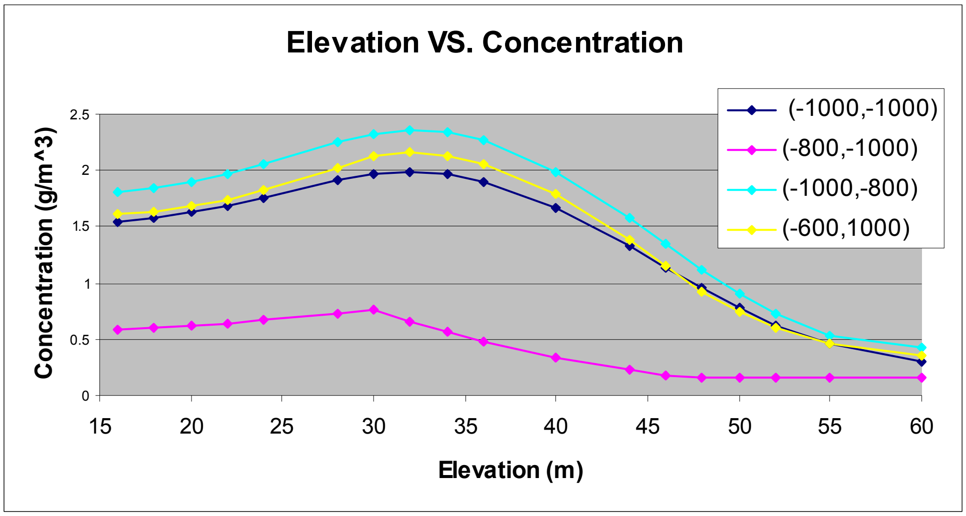


Figure 5-13 Elevation VS. Concentration of Different Locations

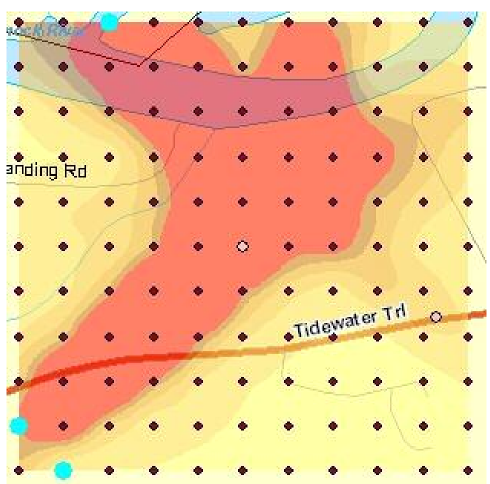


Figure 5-14 Three More Locations of Elevated Study

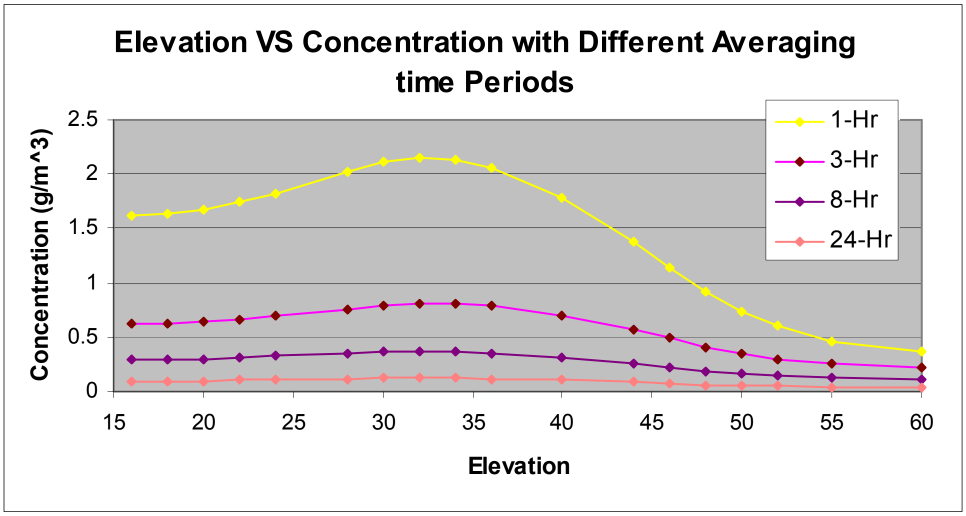


Figure 5-15 Elevation VS Concentration with Different Averaging Time Periods of Location (-600, 1000)

5.3 Meteorological Conditions

From the result of the base model, the concentration values of 1-Hr concentration averaging time in Table 5-1 assuming flat terrain situation are range from 0.014 g/m^2 to 5.700 g/m^2. The most intense area, as can easily be recognized, is in the southwest direction of biosolids source as shown in brown color (last label) of Figure 5-1. In addition, from the prediction maps, it is easy to distinguish that there is a certain direction that biosolids odor is dispersed. In fact, it looks like that biosolids odor is dispersed in the northeast-southwest direction and southeast-northwest direction from the source. It is similar to the concentration contours of 3-Hrs prediction map. The directions of biosolids odor dispersion from the source look almost exactly the same as 1-Hr prediction map. This occurrence was hypothesized by the effect of weather condition especially wind direction and wind speed on that particular date and time. To investigate that issue, we first need to know the date and time of concentration produced and its wind condition.

Beginning with 1-Hr concentration prediction map, the date/time, wind direction, and wind speed generated from surface and profile data of concentration values above 1 g/m^3 are listed in table 5-1. The number 01 in hour represents one o'clock in the morning and the number 24 represents twelve o'clock at night (12 PM). Table 5-2 shows the date/time that the concentration values exceed 1 g/m^3. It also shows that the occurrences of biosolids odor in the field vary almost over a selected period, one week, but the time occurrence is only between 7 pm to 7 am. Wind speed (WSPD) values vary from 1 m/s to 3.1 m/s that mostly fall in between wind speed category 1 to 3 defined by the model. The figure below graphically shows how wind direction (WDIR) effect to dispersion of biosolids odor.

Table 5-2 Date/Time for 1-Hr Concentration Values Exceed 1 g/m^3

Year	Month	Date	Hours	WDIR (Degree)	WSPD (m/s)
92	4	18	3	199	2.1
92	4	18	6	185	2.1
92	4	20	7	57	1.5
92	4	22	20	245	2.6
92	4	22	24	230	3.1
92	4	23	5	307	3.1
92	4	23	7	186	1
92	4	23	19	121	2.1
92	4	24	20	140	1.5
92	4	24	23	47	1.5
92	4	24	24	124	2.1

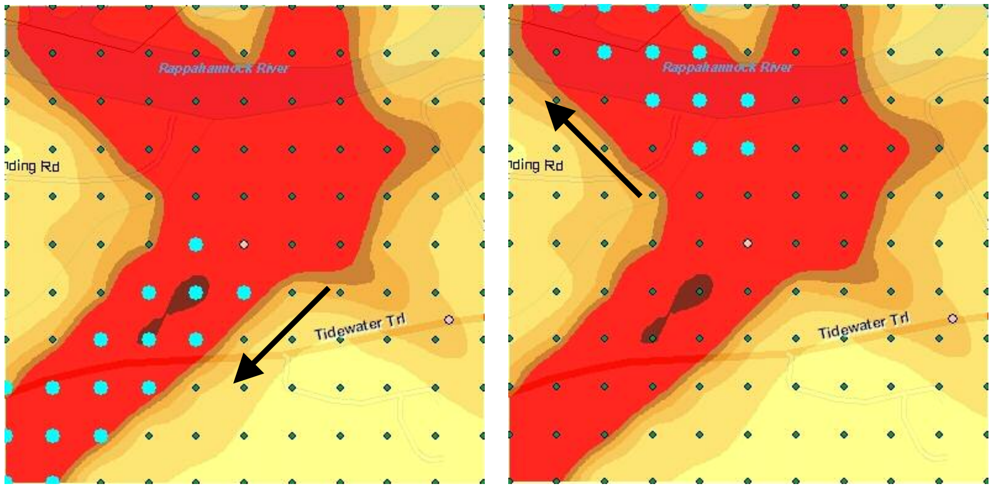


Figure 5-16 the Effect of Wind Direction

Figure 5-16 (left) shows the concentration values above the detection threshold (DT) occurred on 92042423 shown in green points. The direction of dispersion looks like in the northeast-southwest direction. It is actually consistent with the wind direction data on that date (Table 5-2) generated from the AERMET that is in the direction of 47 degrees with 1.5 m/s wind speed. It is similar to the Figure 5-16 on the right hand side that dispersion direction on 09042420 is in the southeast-northwest direction. It is consistent with the wind direction on that date which is 140 degrees and 1.5 m/s in wind speed. Thus, from the example shown above, we can observe that the odor dispersion followed the assumption of the AERMOD that is a steady-state dispersion model assuming steady-trajectory flow and followed the assumption that people in the reuse field sniff biosolids odor from downwind direction. This assumption can be applied to the other prediction maps of both flat terrain situation and complex terrain situation. Figure 5-17 shows the frequency of wind direction versus concentration. Apparently, there is an independence relationship between wind direction and odor concentration meaning that the same wind direction can produce different levels of concentrations. Thus, it could be claimed that the wind directions only affect to the direction of odor dispersion but not to how intense the odor could be. Therefore, it is assumed that there might be another factor that really affect to the concentration and then wind speed should be taken into account because its ability might potentially create nuisance condition by increasing level of concentration to surrounding area of biosolids applied.

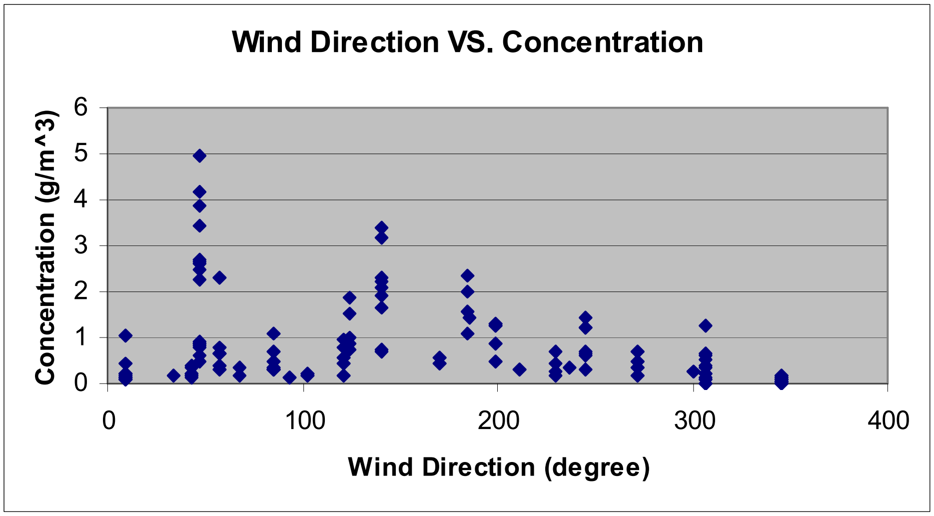


Figure 5-17 Wind Direction VS. Concentration

In reality, it makes sense to understand how wind direction effect to how people sniff the odor, but it is not easy to predict how strong of wind speed would create malodorous condition. Generally, under moderate atmospheric stability (e.g., partly sunny, wind speed 8-12 mph, moderate turbulence), on flat terrain area, source odorants undergo fairly rapid dilution as the distance from the source increase. As such, concentrations of odorants will likely not be objectionable to neighbors, if the biosolids are reasonably well stabilized. Conversely, if the biosolids are poorly stabilized, the pervasive odorant can be detected at considerable distances from the source. For sake of simplicity, this study assumed that the biosolids are well stabilized.

Using the same results of complex terrain situation previously shown in Section 5.2 but focusing on the relationship between wind speed and odor concentration, the correlation of wind speed and concentration for four series of averaging times: 1, 3, 8, and 24 Hrs were plotted as shown in Figure 5-18.

Apparently, considering 1-Hr averaging time, the concentration values are decreased from 4.950 g/m^2 at the wind speed of 1.5 m/s to 0.015 g/m^2 at the wind speed of 2.1 m/s or when the wind speeds are increased. It also shows that the concentration that above the DT are mostly found at the wind speed of 1.5 m/s. In contrast, the trends of the relationship between the concentration values and the wind speeds for the averaging times of 3,8, and 24-Hr are changed especially in case of 8-Hr averaging time it turns out that the concentration are increased when the wind speed are also increased (shown in yellow point). These interesting results tell us that at the lower averaging time, higher intense, low wind speed would potentially produce higher level of concentration than high wind speed. Conversely, in case of higher averaging time, lower intense, high wind speed has a tendency to produce higher concentration than low wind speed. The results could be interpreted that the nuisance condition, in case of short averaging time, might occur rapidly after biosolids applied when wind speed is low but, in case of longer averaging time, it would occur when wind speed is higher.

As the meteorological conditions can change with the season, day to day, and even with the time of day, it is necessary to investigate the issue of time when odor incident occur. It is known from the literature that odorants emitted from ground-level source will remain most concentrated during periods of high atmospheric stability, such as occur with air temperature inversions and low wind speeds at night and very early morning (EPA, 2000-Guide to Field Storage). The results of this study also show that the possible odor incidents, the location that the concentration above the DT, occur at nighttime and in the morning. Figure 5-19 shows the frequency of occurrence of concentration above the detection threshold (DT) for both elevated and flat terrain. Obviously, the occurrences of concentration above DT are in the early morning from 3 to 9 am and more often at nighttime especially between 8 to 12 pm (20-24 in the graph).

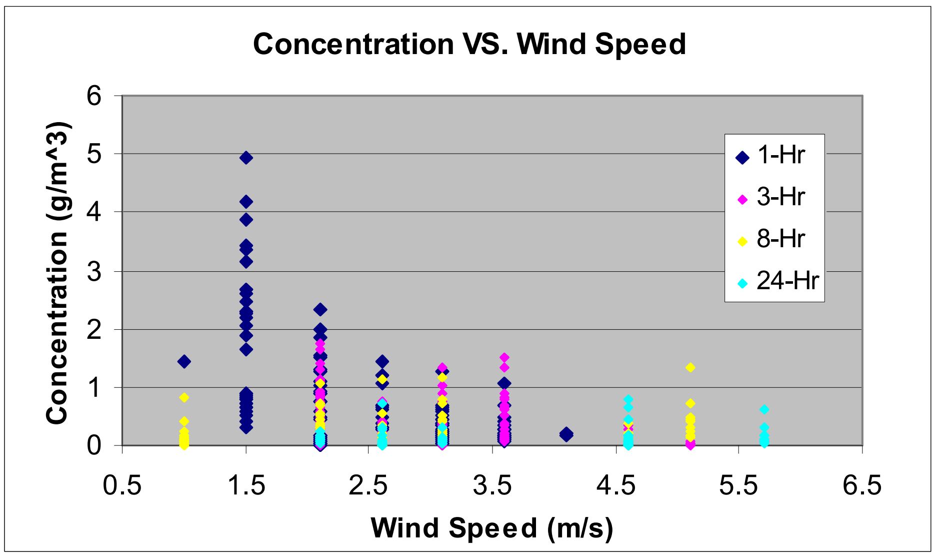


Figure 5-18 Concentration VS. Wind Speed

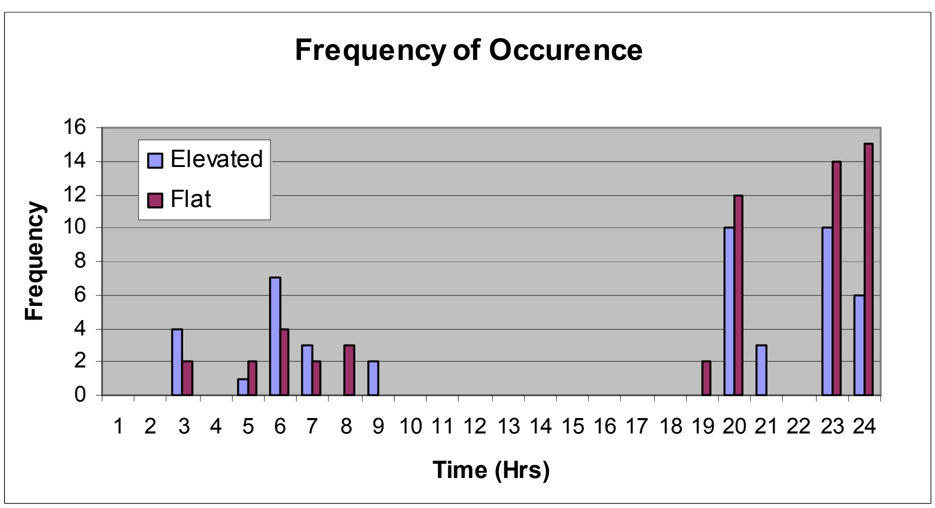


Figure 5-19 Occurrence of Odor above DT

Chapter 6: Conclusion and Future Works

6.1 Conclusion

Biosolids, a by product from a wastewater treatment plant, distributed to reuse fields can potentially create nuisance conditions for people in surrounding communities and sometimes lead to odor complaints. Consequently, the anticipation of nuisance odor from land application and public's lack of understanding can limit the implementation of biosolids reuse program. Unlike odorants from the liquid process in the wastewater treatment facility, the odor problem in reuse field itself depends on the factors such as atmospheric condition, topographic features, etc. The existing method used to measure the impact from biosolids odor such as the olfactometer is lack of continuity as it could be only used to measure at the certain point of time, specific location, and exact weather condition. Therefore, in order to mitigate the adverse affect of biosolids, an effectively continuous method is needed to measure the possible effect from biosolids to surrounding area at anywhere and anytime.

The study utilized existing tools such as the atmospheric dispersion model and the Geographic Information System (GIS) to generate the predicted concentration and display it as a concentration prediction map to visualize the odor impact from the biosolids. The United States Environmental Protection Agency (U.S. EPA) regulatory air quality steady-state plume model called AERMOD was employed as the main tool to generate the predicted concentration. As a new model to the U.S. EPA, the screening model that could be used to simulate worst-case meteorological conditions to provide conservative estimates of the air quality impact of specific sources is still in developing process. To perform the AERMOD, two basic inputs are needed to run the model: runstream file and meteorological files. Two meteorological input files that are surface data and profile data were generated from the meteorological preprocessor called AERMET. Those files then were used as inputs to the AERMOD runstream file which basically contains five pathways representing source-transport-receptor characteristics and controlling input/output options. The AERMOD models were run in DOS and displayed in ASCII file such as data format file (.dat) in different selected averaging times: 1, 3, 8, and 24 hrs. The result produced from the AERMOD was the concentration values in micrograms per cubic meters for the selected receptor locations and relative time and date occurred. Using the Geostatistical Analyst, the prediction maps were generated focusing on the areas that have concentration values above the detection threshold or one gram per cubic meters so-called sensation area. The sensation area is defined as the potential area that people could detect the odor and is basically caused by many factors. Some of them are critical such as pollutant emission and meteorological conditions such as wind condition which represent source and transport characteristics respectively. The emission data obtained from the Maryland Environmental Services (MES) are available only 9 samples and not for each field. Moreover, an estimated release height of pollutant and size of field applied for each load are not available. Thus, there is a need to collect and record more biosolids source data. The meteorological data used to generate the AERMET files based on the weather stations that are far from the field location could possibly differ from the exact meteorological conditions in reuse fields, thus the validity of weather data would be an issue. Besides the factors mentioned above, however, receptor location is also important since the odor incident occurs if people detect the odor.

In conclusion, this study is a primary step for measuring biosolids odor impact to communities surrounding DCWASA reuse fields. The model accounts for steady-state flow condition. It was applied for only one DCWASA reuse field and then needs to be further study for the general of the model. The weather data used (1992) did not match with the field data (2005) and the distance between weather locations and field is still an issue of accuracy. The missing data such as emission rate, release height, and field size are still needed. The calibration between the model and the field also needs further investigation.

6.2 Future Works

The future direction of this study should be to take non-steady state atmospheric dispersion into account to better model the complexity of dispersion and comparing the results to find more suitable model for biosolids odor impact assessment. Modeling dispersion of biosolids odor using wind tunnel might be another option to make a better visualization of odor dispersion. The ultimate goal is developing planning process and improving decision-making processes for biosolids managers.

References

Bruvold, W. H., Rappaport, S.M.,Wu, T.C., et. al. (1983). "Determination of Nuisance Odor in a Community." Journal of Water Pollution Control Federation **55**: 229-233.

DCWASA (1) (2005). Biosolids Management Program. Washington, DC, Department of Wastewater Treatment.

DCWASA (2) (2005). Blue Plains Advanced Wastewater Treatment Plant. Washington, DC, Department of Wastewater Treatment.

EPA, U. S. (1) (2000). Biosolids Technology Fact Sheet Land Application of Biosolids. Washington, D.C.

EPA, U. S. (2) (2000). Guide to Field Storage of Biosolids. Washington, DC, United States Environmental Protection Agency.

EPA, U. S. (3) (2000). Odor Control in Biosolids Management. Washington, D.C., Office of Water.

EPA, U. S. (2001). Appendix W to Part 51 - Guideline on Air Quality Models. Washington , D.C., United States Environmental Protection Agency.

EPA, U. S. (2004). AERMOD: Description of Model Formulation. Research Triangle Park, North Carolina, Office of Air Quality Planning and Standards Emissions Monitoring and Analysis Division**:** 89.

Evanylo, G. K. (2003). Land Application of Biosolids for Agricultural Purposes in Virginia, Department of Crop and Soil Environmental Sciences, Virginia Tech.

Frank, S. (2005). "Too Hot to Handle." Biosolids Technical Bulletin **10**(5): 1-4.

Hamel, C. K., P.E. ,Walters, Lauri, Sulerud, Courtney (2004). Land Application Odor Control Case Study. Residuals and Biosolids Management Conference, Salt Lake City, UT, Water Environment Federation.

Harreveld, V. (2004). "Odour management tools - filling the gaps." Water Science and Technology **50**(4): 1-8.

Karl, B. S., Jr.,Ph.D.,P.E. , Partha, R. Dey, Ph.D. (2000). Atmospheric Dispersion Modeling Compliance Guide, McGraw-Hill.

Lewis, L. D., Gattie, K. David, Novak, E. Marc, Sanchez, Susan,Pumphrey, Charles (2002). "Interactions of pathogens and irritant chemicals in land-applied sewage sludges (biosolids)." BMC Public Health **2**(11).

McGinley, A. M., MHS , McGinley, M. Charles, P.E. (2005). Measuring Composting Odors for Decision Making. U.S. Composting Council 2005 Annual Conference, San Antonio, TX.

McGinley, A. M., MHS ,McGinley M. Charles, P.E. (1999). The Gray Line Between Odor Nuisance and Health Effects. Air and Waste Management Association 92nd Annual Meeting and Exhibition, St. Louis, Mo.

McGinley, M. C., P.E. ,McGinley, A. Michael, P.E. (2002). Odor Testing Biosolids for Decision Making. Water Environment Federation Specialty Conference:Residuals and Biosolids Management Conference, Austin, TX.

New Zealand Ministry for the Environment , N. (2004). Good Practice Guide for Atmospheric Dispersion Modeling. Wellington, New Zealand, The National Institute of Water and Atmospheric Researh, Aurora Pacific Limited, and Earth Tech Inc.

Shamsi, U. M. (2005). GIS Applicatins for Water, Wastewater, and Stormwater Systems. Boca Raton, Florida, CRC Press.

Stevens, S. S. (1960). "The Psychophysics of Sensory Function." American Scientist **48**: 226-253.

Stevens, S. S. (1962). "The Surprising Simplicity of Sensory Metrics." American Psychologist **17**: 29-39.

Stevens, S. S. (1975). Psychophysics- Introduction to its perceptual, neural, and social prospects. Cambridge, Massachusetts, John Wiley & Sons.

Susan, S. S., Brendan, M, Gabriel, G. Katul, H. Troy Nagle (2004). Eulerian-Lagrangian model for prediction odor dispersion using instrumental and human measurements, ELSEVIER.

Witherspoon, J. R., Adams, G.,Cain, W.,Cometto-Muniz, E.,Forbes, B.,Hentz, L.,Novack, J.T.,Higgins, M.,Murthy, S.,Ong, H.T.,Daigger, G.T. (2004). "Water Environment Research Foundation (WERF) anaerobic digestion and related processes, odor and health effects study." Water Science and Technology **50**(4): 9-16.