MODELING OF PARTICULATE MATTER EMISSIONS FROM AGRICULTURAL OPERATIONS

A Thesis

by

JNANA BAIRY

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Approved by:

Chair of Committee,	Calvin B. Parnell, Jr.
Committee Members,	Ronald E. Lacey
	Dennis L. O'Neal
Head of Department,	Stephen W. Searcy

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ABSTRACT

State Air Pollution Regulation Agencies (SAPRAs) issue and enforce permits that limit particulate matter emissions from all sources including layer and broiler facilities, cattle feedyards, dairies, cotton gins, and grain elevators. In this research, a process was developed to determine distances from emitting sources to where the estimated concentrations were less than the National Ambient Air Quality Standards (NAAQS). These distances are a function of emission rates and meteorological conditions. Different protocols were used to develop emission factors for cattle feedyards and layer houses. Dispersion modeling with American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) was conducted to determine the emissions of particulate matter. These data were used to determine the distances from the sources to where the concentrations of particulate matter (PM) would be less than the NAAQS. The current air-permitting process requires that concentrations from a source do not exceed the NAAQS at the property line and beyond for the facility to be in compliance with its permit conditions.

Emission factors for particulate matter less than 10 micrometers (PM_{10}) were developed for cattle feedyards using a reverse modeling protocol and Tapered Element Oscillating Microbalance (TEOM) sampler data. Corrections were applied to the TEOM measurements to account for TEOM vs. filter-based low-volume (FBLV) sampler bias and over-sampling of PM_{10} pre-collectors. Invalid concentrations and dust peaks larger than mean ± 3 times the standard deviation were excluded from this study. AERMOD predictions of downwind concentrations at cotton gins were observed for compliance with 24-hour PM$_{10}$ and PM$_{2.5}$ NAAQS at property lines. The emissions from three cotton gins were analyzed at 50 m and 100 m distances. TEOM and FBLV samplers were used to collect 24-hour PM$_{10}$ measurements inside a laying hen house. The distances to the property lines at which the emissions of PM$_{10}$ were below the 24-hour average PM$_{10}$ standards were estimated using AERMOD. The results suggested that the special use of the NAAQS for as the property-line concentration not to be exceeded, could be problematic to agriculture. Emission factors that were comparable of published emission factors were obtained in this study. Large distances to property lines were required when minimum flow rate recommendations were not considered. Emission factors that are representative of the emissions in a particular facility are essential; else facilities could be inappropriately regulated.

DEDICATION

This thesis is dedicated to my family and friends for all their love and encouragement.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Calvin Parnell, Jr., for the encouragement and guidance throughout the course of my research. It has been my fortune to work with such an extraordinary professor. I am thankful for all the opportunities provided to me to learn and grow as a professional. I have derived great inspiration from you.

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Special thanks to Col. Russell McGee for all the valuable suggestions and support for my research work. Thanks to the 'Parnell's Crew' and colleagues at 324 Scoates Hall and the department faculty and staff for making my time at Texas A&M University a great experience.

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Finally, thanks to the almighty for everything he has given me, and my family for their encouragement to pursue my dreams.

NOMENCLATURE

AED	Aerodynamic Equivalent Diameter
AERMOD	American Meteorological Society/EPA Regulatory Model
AP-42	United States Environmental Protection Agency's Compilation of Air Pollution Emission Factors Volume I
CAA	Clean Air Act
CAAQES	Center for Agricultural Air Quality Engineering and Science
CFY	Cattle Feedyard
FRM	Federal Reference Method
GSD	Geometric Standard Deviation
ISCST-3	Industrial Source Complex – Short Term Version 3 Dispersion Model
FBLV-PM_{10}	Filter Based Low-Volume PM_{10}
FBLV-TSP	Filter Based Low-Volume TSP
µm	Micrometer
$\mu g/m^3$	Micrograms per Cubic Meter
m^3/min	Cubic Meter per Minute
MMD	Mass Median Diameter
MWPS	Midwest Plan Service
NSR	New Source Review
NAAQS	National Ambient Air Quality Standards

NCDAQ	North Carolina Department of Air Quality
OSC	Oversampling Correction Factor
PBR	Permit by Rule
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter Less Than 2.5 μm AED
PM_{10}	Particulate Matter Less Than 10 μm AED
PSD	Particle Size Distribution
SAPRA	State Air Pollution Regulatory Agency
SD	Standard Deviation
SIP	State Implementation Plan
TCEQ	Texas Commission on Environmental Quality
TEOM	Tapered Element Oscillating Microbalance
tpy	Tons per Year
TSP	Total Suspended Particulate Matter
USEPA	United States Environmental Protection Agency

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

The first federal legislation addressing air pollution was the Air Pollution Control Act of 1955 (Cooper and Alley, 2011). Congress amended federal air quality legislation in 1963, 1967, 1970, 1977, and 1990. The 1970 Clean Air Act (CAA) amendments required the United States Environmental Protection Agency (USEPA) to establish the National Ambient Air Quality Standards (NAAQS) for six criteria pollutants. The primary NAAQS were concentrations set at levels that protected public health with an "adequate margin of safety". Secondary standards were set at concentrations that protected public welfare. State Air Pollution Regulatory Agencies (SAPRAs) were required to monitor concentrations in populated areas and report exceedences to the USEPA (NRC, 2003). These community oriented monitors could not be placed where the results would be impacted by a single source. If sufficient numbers of exceedences were detected, the area was designated as nonattainment (Watson et al., 1997).

Today, areas can be designated as attainment or nonattainment based on modeled or measured concentrations. If areas are classified as non-attainment, the respective states are required to submit State Implementation Plans (SIPs) to the USEPA outlining planned actions designed to bring these areas into attainment (NRC, 2003). These actions typically consist of mandating reductions of pollutant emissions from sources affecting the ambient concentrations of the area.

PM_{10} and $PM_{2.5}$ refer to particulate matter (PM) with aerodynamic equivalent diameters (AEDs) less than or equal to 10 μm and 2.5 μm, respectively (USEPA, 2001). The current 24-hour NAAQS for PM_{10} and $PM_{2.5}$ are 150 micrograms per cubic meter (μg/m^3) and 35 μg/m^3, respectively (USEPA, 2001). The current annual NAAQS for $PM_{2.5}$ is 15 μg/m^3 (USEPA, 2001).

The NAAQS are also used for permitting purposes. SAPRAs issue and enforce permits that limit PM emissions from all sources including layer and broiler facilities, cattle feedyards, dairies, cotton gins, and grain elevators. Minor sources emit less than 100 tons per year of a regulated pollutant. For minor sources, the permit may be a permit by rule (PBR), standard permit, or New Source Review (NSR) permit.

In order to limit source emissions, using the permitting process, the SAPRA must have an enforceable threshold. Although the justification of Congress mandating that the USEPA promulgate NAAQS for the criteria pollutants was to define areas as attainment or nonattainment, SAPRAS have adopted the NAAQS as the threshold to be used to permit sources. This is referred to as the "special" use of the NAAQS. The special use of the NAAQS for permitting purposes is a concentration limit that may not be exceeded at the property line and beyond (NRC, 2003). Thus, for a source to be in compliance with its permit conditions, no concentration off property determined by modeling or measurement may exceed the NAAQS; else the facility could be subjected to enforcement actions. This criterion must be met for the emitting source to be in agreement with its permit conditions (NRC, 2003).

Ground level concentrations near the source typically exceed the NAAQS and decrease with increased distances from the source due to dispersion. It is assumed that most agricultural sources would want to know the distance needed to be in compliance with their permit conditions. If emissions of a regulated pollutant from a permitted source result in concentrations higher than the NAAQS off property, the source may be subjected to enforcement actions to include fines and mandated additional controls (NRC, 2003). For estimating the emissions from a source, the USEPA designated AERMOD as the preferred dispersion model in Dec 2006.

In this research, (1) A process was developed to determine distances from emitting sources to where concentrations would be less than the NAAQS; (2) Emission rates and emission factors were determined for cattle feedyards and laying hen operations using recently measured ambient concentrations; (3) Tapered Element Oscillating Microbalance (TEOM) sampler concentrations were compared to co-located filter-based low-volume (FBLV) sampler concentrations measured in a laying hen house. The term "distance to the property line" would be used to define the modeled distance from the source to where the concentrations would be lower than the NAAQS. These distances are a function of emission factors, emission rates, and meteorological conditions. It is essential that the emission factors are accurate.

Different protocols were used to develop emission factors for cattle feedyards and layer houses. Dispersion modeling with AERMOD was used to determine the predicted concentrations of PM, downwind from the source. Subsequently, the average distance required from the source such that the facility would not exceed the NAAQS off-property, was estimated.

States have adopted the special use of the NAAQS for permitting purposes.

Modeled or measured concentrations of PM_{10} must not exceed the NAAQS at the property line and beyond, or the facility could be in violation of its permit conditions and could be subjected to enforcement actions (NRC, 2003). Many minor sources acquire their permits without demonstrating compliance with the special use of the NAAQS. However, a SAPRA receiving a complaint from affected public will automatically trigger requirements that dispersion modeling be performed to demonstrate compliance in many states (NRC, 2003). Many agricultural sources have short distances from their facility to the property lines. It is likely that dispersion modeling results will demonstrate non-compliance. This situation is a consequence of using the NAAQS for unintended regulatory purposes. It is probable that a large number of agricultural operations in the U.S. can be found to be not in compliance with their permit conditions based upon the special use of the NAAQS.

The permitting use of the NAAQS is very different from the original concept where exceedences can result in classifications of non-attainment areas. In contrast to the permitting application of the NAAQS, locations of the samplers for classification of nonattainment must (1) not result in concentrations dominated by a single source and (2) be located where “large numbers of people live, work, and play” (Watson et al, 1997). Measured concentrations at the property line of a source could not be used for classification of nonattainment.

SAPRAs have utilized this use of the NAAQS for determining permit compliance of pollutant emissions of rural agricultural and industrial operations. Buckeye Egg Farms is an example of a laying hen operation subjected to enforcement actions by the USEPA. The enforcement action included a fine of more than $800,000 and a requirement that the facility invest more than $1M in controls (USEPA, 2004). These actions were the result of incorrect emission estimates (Lange, 2008). In this study, particulate matter emission factors were developed for agricultural operations. Using these emission factors, distances from the source to the property lines needed so that off-property concentrations did not exceed the NAAQS were determined.

To estimate PM concentrations using dispersion modeling, an emission factor is required. The USEPA (USEPA, 1995; USEPA, 2000) defines an emission factor as follows:

"An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilograms of particulate emitted per megagram of coal burned). Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category (i. e., a population average)."

The emission factors listed in AP-42 Compilation of Air Pollutant Emission Factors are often used by the USEPA and SAPRAs to permit facilities (USEPA, 1993). Modeled PM_{10} or $PM_{2.5}$ concentrations require emission factors that represent emission rates in an operation. The emission factors used for predicting downwind PM concentrations using the AERMOD dispersion model must be accurate.

Price and Lacey conducted studies on the uncertainty associated with the gravimetric sampling of PM (Price and Lacey, 2003). Systematic errors in the analysis of concentrations would lead to a large error in final concentration values. TAMU high-volume sampling and TAMU low-volume sampling resulted in uncertainties of 8.67% and 11.9%, respectively (Price and Lacey, 2003).

In this research, the TEOM sampler concentration data from both layer hen and cattle feedyards included negative and zero concentrations. TEOM sampler concentration measurements mimic filter-based measurements. No valid filter-based concentration measurements will result in negative or zero concentrations. In addition, spikes in TEOM concentration *vs*. time data are questionable. For example, a concentration measured to be 400 μg/m^3 rising to 20,000 μg/m^3 and returning to 400 μg/m^3 in a 5 minute period. These spikes were anomalies that occurred for both the layer hen and cattle feedyard data. These spike data were removed from the 24-hour TEOM data set if the questionable concentration exceeded the average ± 3 standard deviations (SD). The resulting measured TEOM concentration data were used to calculate emission rates and emission factors.

The distances from the source to the property lines such that the concentrations of PM_{10} were below the 24-hour average PM_{10} NAAQS were estimated using dispersion modeling. The dispersion model AERMOD was the model used in this study (USEPA, 2001).

The PM_{10} emission rates for laying hen operations were determined using measured PM_{10} concentrations inside the layer house and estimates of the flow rates of the ventilation fans. The concentrations were measured with co-located FBLV PM_{10} samplers and TEOM samplers. Both samplers were configured with the same PM_{10} pre-collectors. The TEOM samplers recorded 30-minute PM concentrations while the FBLV samplers were used to obtain 24-hour concentration measurements. 24-hour concentrations of the TEOM data were approximated by averaging valid 30-minute data. TEOM and FBLV measurements were compared on a 24-hour basis. It was hypothesized that TEOM with corrections and FBLV 24-hour concentrations were not different.

PM_{10} emission concentrations for cattle feedyards were measured using TEOM samplers. The ambient TEOM concentrations measurements were 5-minute measurements. The 24-hour average concentrations were the basis for estimating emission rates. The PM_{10} emission factor for cattle feedyards was developed using the reverse modeling protocol developed by the Center for Agricultural Air Quality Engineering and Science (CAAQES).

The particle size distribution of PM was used to estimate the PM_{10} and $PM_{2.5}$ emission factors from documented TSP emission factor (USEPA, 1996). These emission factors were utilized to estimate the 24-hour emissions from 20, 40 and 60 bale per hour (BPH) gins. The 24-hour PM_{10} and $PM_{2.5}$ concentrations at property lines of 50 m and 100 m were predicted by running tests on AERMOD.

Objectives

The special use of the NAAQS for permitting purposes is problematic for agricultural sources. This research focused on different protocols for estimating emissions from agricultural sources; particularly from cattle feedyards, laying hen houses and cotton gins. The goals of this research were to (1) develop a protocol to determine distances from layer hen facilities, cattle feedyards and cotton gins to where the PM_{10} concentrations would be less than the NAAQS; (2) compare TEOM-PM_{10} and FBLV-PM_{10} sampling methods; and (3) develop PM_{10} emission factor for cattle feedyard and layer hen facilities.

To achieve the goals, the following were the specific objectives:

1) Determine PM_{10} emission factors for cattle feedyards using corrected TEOM 5-minute concentration data and the CAAQES reverse modeling protocol with the USEPA recommended dispersion model, AERMOD.
2) Estimate the 24-hour PM_{10} and $PM_{2.5}$ concentrations at 50 m and 100 m distances using AERMOD and the estimated emission factors for three cotton gins.
3) Develop PM_{10} emission factors for layer hen houses using corrected TEOM 30-minute concentration data and FBLV PM_{10} for four models of ventilation flow rates. Estimate the distances t o the property lines such that the emissions of PM_{10} did not exceed the NAAQS.

CHAPTER II

EMISSION FACTORS FOR CATTLE FEEDYARDS: REVERSE MODELING USING AERMOD

Introduction

TEOM samplers used to measure concentrations of PM_{10} and $PM_{2.5}$ are Federal Equivalent Method (FEM) samplers. The FBLV samplers used in this study are Federal Reference Method (FRM) samplers. FBLV and TEOM samplers are configured with identical PM_{10} and $PM_{2.5}$ pre-collectors. It is commonly assumed that because they both have the same pre-collectors, they will yield the same concentrations. TEOM samplers provide continuous monitoring data and are less laborious to use. The federal reference methods using FBLV samplers for PM_{10} and $PM_{2.5}$ take more labor and time to acquire concentrations. The procedure consists of placing pre-weighed filters in the sampler, monitoring flow rate of air containing PM passing through the filter, replacing the filter, post-weighing the exposed filter, and calculating the resulting concentrations. The net mass of PM divided by the sampled air volume is the FRM or FBLV concentration. In general, 24-hour samples are estimated from both FBLV and TEOM sampling. The resulting FBLV concentrations are averages over time and do not show short term variations of concentrations as a function of time. In contrast, TEOM concentrations are reported measurements of 30 to five minutes or less, and short term variations *vs*. time are clearly present.

Cattle feedyard PM emission factors were developed using concentrations measured with FRM samplers (Parnell et al., 1999). Skloss (2008) reported significant differences of PM_{10} concentrations measurements from co-located TEOM and FBLV (FRM) samplers off property of cattle feedyards. Vanderlick et al., (2011) reported results from analyzing Skloss's PM_{10} downwind and upwind concentrations measurements from side-by-side TEOM and FRM samplers. He found that FRM downwind concentrations were significantly lower than the TEOM measurements. He also found that the upwind FRM and TEOM concentrations differed by ten percent or less. This was also the finding that resulted when analyzing the data reported by Lambeth's (2008) study sampling 24-hour PM_{10} concentrations in urban areas with co-located FRM and TEOM samplers. It was concluded that PM_{10} sampling in locations with mass median diameters (MMD) that were less than 10 µm and characterized as having low concentrations (less than 100 $\mu g/m^3$), TEOM and FRM 24-hour average concentrations were not statistically different. However, in the presence of high 24-hour PM_{10} concentrations measurements (greater than 100 $\mu g/m^3$) with MMDs greater than 10 micrometers, typical of PM emitted by agricultural sources, TEOM and FRM concentration measurements were statistically different. The FRM/TEOM correction was that the FRM concentration was equal to 60% of the TEOM concentration. The emission factors of PM_{10} and TSP for cattle feedyards as documented in the literature are consolidated in Table 1.

Table 1. Emission factors of PM_{10} and TSP for cattle feedyards.

PM Emission Factor – CFY	PM	***kg/1000 head-day (lb/1000 head-day)***
Peters and Blackwood (1977)	TSP	127 (280)
Sweeten et al. (1988)	PM_{10}	31.8 (70)
S. Parnell (1992)	PM_{10}	4.54 (10)
McGee (1997)	PM_{10}	9.08 (20)
Parnell et al. (1999)	PM_{10}	6.81 (15)

The FRM-PM_{10} sampler performance characteristics recommended by the USEPA are a cut point of 10 ± 0.5 µm and a slope of slope of 1.5 ± 0.1 (USEPA, 2001). One method to find the true concentration of PM_{10} is by obtaining the mass particle size distribution (PSD) of the PM in question and determining the mass fraction of the TSP that is lower than 10µm (PM_{10}). For a PSD defined by a MMD of 20µm and a geometric standard deviation (GSD) of 2.0, 20% of the TSP concentration is PM_{10} (Vanderlick et al., 2011).

Faculty associated with CAAQES have reported that FRM sampling of PM_{10} in the presence of PM with large MMDs, results in concentrations that are 2 to 4 times higher than the true concentrations (Wang et al., 2005; Buser et al., 2007). This phenomenon has been referred to as "over-sampling". It is hypothesized that over-sampling is a consequence of larger particles penetrating the pre-collectors. The PSD of

PM emitted by agricultural sources is typically characterized as having 50% mass larger than 20 micrometers (μm). The TEOM monitors use the same pre-collectors for PM_{10} sampling as the FRM samplers. Hence, they share the same "over-sampling" problem. The TEOM-PM_{10} concentrations measured at the cattle feedyard were adjusted prior to calculating the emission factors by multiplying the TEOM measurements of PM_{10} by 0.5.

Hamm, (2005) reported sharp spikes in concentrations measured with TEOM samplers at cattle feedyards. These were referred to as "dust peaks" and they usually occurred in the evening. Hamm hypothesized that the dust peaks were a consequence of meteorological conditions such as reduced mixing height, reduction in wind velocity, and a more stable stability class during this time period. It has been hypothesized that these dust peaks are not readily apparent in average FRM concentrations results. In an attempt to prevent the dust peaks from inflating the calculated emission factors, all concentrations greater than mean ± 3 (SD) were considered as outliers (Steinbach et al., 1950). The outliers were not included in the 24 hour average concentrations used to produce the PM_{10} emission factors from the TEOM sampler data.

Methodology

TEOM samplers were used by Auvermann (2010) to measure PM_{10} concentrations upwind and downwind at a cattle feedyard (CFY) in Panhandle, Texas. The data for this research were 5-minute PM_{10} concentrations measured by TEOM samplers from September 2010 through December 2010. The 5-minute concentrations were averaged on a daily basis to obtain the 24-hour concentrations of PM_{10} in the cattle feedyard. Necessary corrections were provided to remove invalid concentrations and measurements that were considered as outliers. The sampler located on the north side of the yard was designated the downwind sampler due to the prevailing wind direction. The cattle feedyard had dimensions of 1100 m x 850 m.

Two TEOM samplers were located on opposite sides of the rectangular cattle feedyard to measure concentrations upwind and downwind based on the prevailing wind direction. The dimensions of the cattle feedyard were 1100 m x 850 m (See Figure 1). The wind direction during sampling was not always in the prevailing wind direction. Five minute PM_{10} concentrations measured by TEOM samplers, with meteorological data collected on the cattle feedyard site which were provided by Faulkner (2010) were used to estimate the daily 24-hour concentrations.

Figure 1. Cattle feedyard sampling layout.

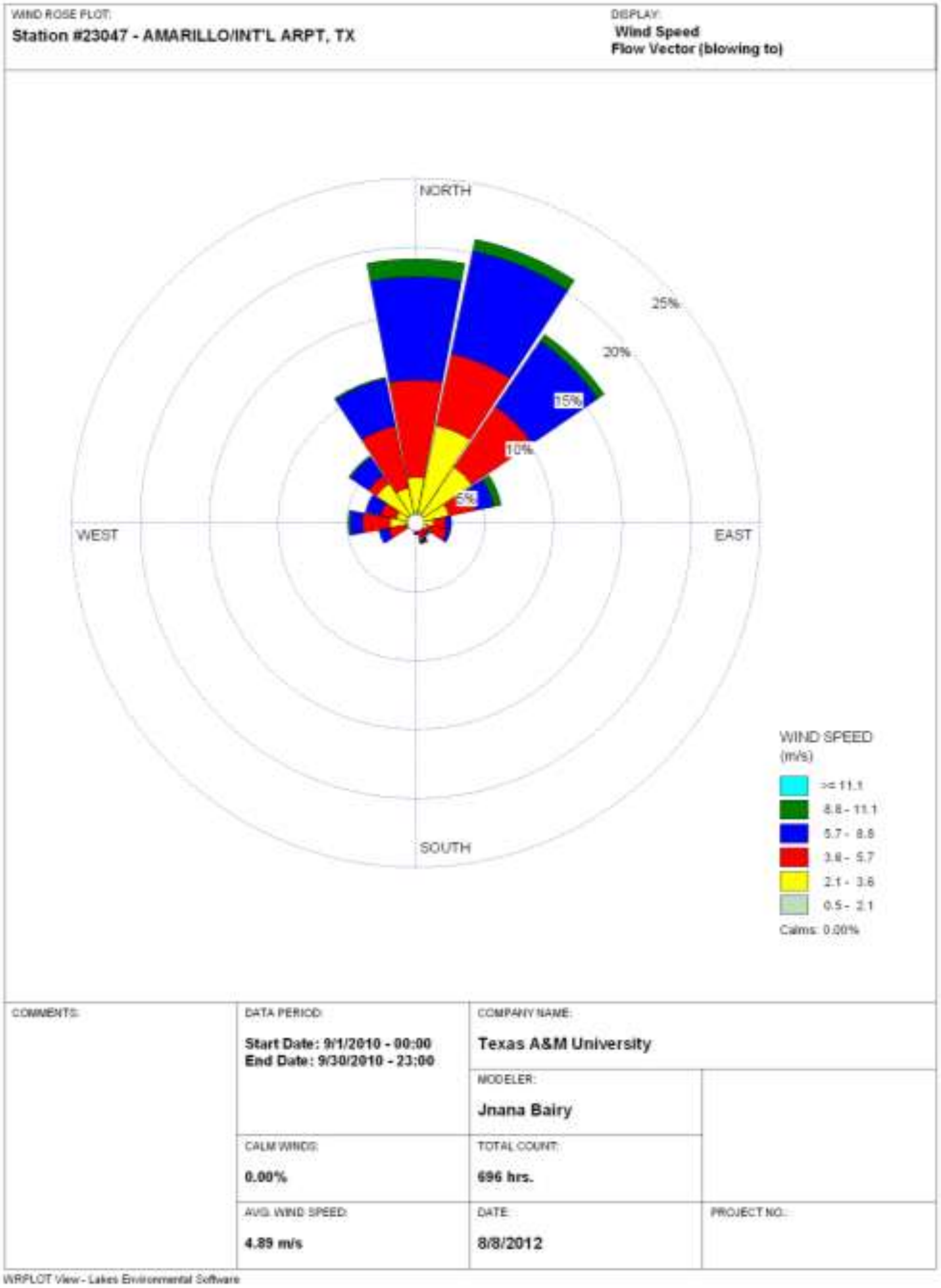
The combined factor for both over-sampling and FRM/TEOM correction would be 0.5 * 0.6 = 0.3. Hence all TEOM measurements used to determine emission factors in this study were adjusted by multiplying the raw TEOM PM_{10} concentrations by 0.3 (Table 2). AERMOD was used with the meteorological data and a 4.54 kg/ 1000 head-day (kg/1000 head-day) or 10 pound per 1000 head-day (lb/1000 head-day) emission factor to determine the 24-hour concentration. Each of the five minute TEOM sampler downwind concentrations were adjusted by applying the FRM/TEOM and over-sampling corrections. 5-minute concentrations greater than mean ± 3 SD were considered as outliers and were excluded. The TEOM concentrations measurements that were not within ± 45 degrees of the prevailing wind direction were also excluded. The remaining TEOM concentrations were averaged and assumed to be equal to the 24-hour concentration for that day. This procedure was followed for the months of September, October, November and December 2010.

Table 2. Adjustments (corrections) of measured TEOM five-minute PM_{10} concentrations to obtain 24-hour average concentrations.

No.	***Concentrations ($\mu g/m^3$)***	***TEOM vs. FRM***	***Ave TEOM 5-min PM_{10} Corrections***
1	Upwind	-	TEOM ave = TEOM meas.
2	Upwind/Downwind	Invalid and outliers	Removed invalid data and mean ± 3 SD
3	Downwind	TEOM meas. for wind outside of ± 45 deg.	Excluded
4	Downwind	FRM/TEOM bias	TEOM ave = 0.6*TEOM meas.
5	Downwind	Oversampling	TEOM ave = 0.5*TEOM meas.

AERMOD was used with the pre-processor AERMET to predict the 24-hour downwind PM_{10} concentrations at the TEOM receptor locations. The meteorological data provided by Faulkner (2010) were processed using AERMET to generate boundary layer parameters. Figure 2 shows the wind rose for the month of September at the cattle feedyard. The wind speeds were recorded in m/s. This wind rose plot is the direction towards which the wind was blowing, which was the prevailing wind direction in the cattle feedyard.

TCEQ recommended values for the particular location were chosen for surface roughness, albedo and Bowen ratio (TCEQ, 2011). Accordingly, values of 0.18 for albedo, 1.5 for bowen ratio and 0.01 for surface roughness, were adopted. USEPA provided the missing data for cloud cover for that particular county (USEPA, 1992).



WIND ROSE PLOT:
Station #23047 - AMARILLO/INT'L ARPT, TX

DISPLAY:
Wind Speed
Flow Vector (blowing to)

COMMENTS:

DATA PERIOD:
Start Date: 9/1/2010 - 00:00
End Date: 9/30/2010 - 23:00

COMPANY NAME:
Texas A&M University

MODELER:
Jnana Bairy

CALM WINDS:
0.00%

TOTAL COUNT:
696 hrs.

AVG. WIND SPEED:
4.89 m/s

DATE:
8/8/2012

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Figure 2. Wind rose for September 2010 generated from AERMOD pre-processor AERMET, showing the prevailing wind direction towards North.

The CAAQES protocol was used for developing emission factors using AERMOD. An emission factor of 4.54 kg/1000 head-day (10 lb/1000 head-day); equivalent to a flux (Q_1) of 3.77 μ g/m^{2}s was used along with the test meteorological data in AERMOD to obtain the flux concentration C_1 (See Figure 3). The corrected measured concentrations C_2 were divided by C_1 to obtain flux required to match measured concentrations. Emission factors for PM_{10} were developed from this protocol, from Sep to Dec, 2012 (Figure 3).

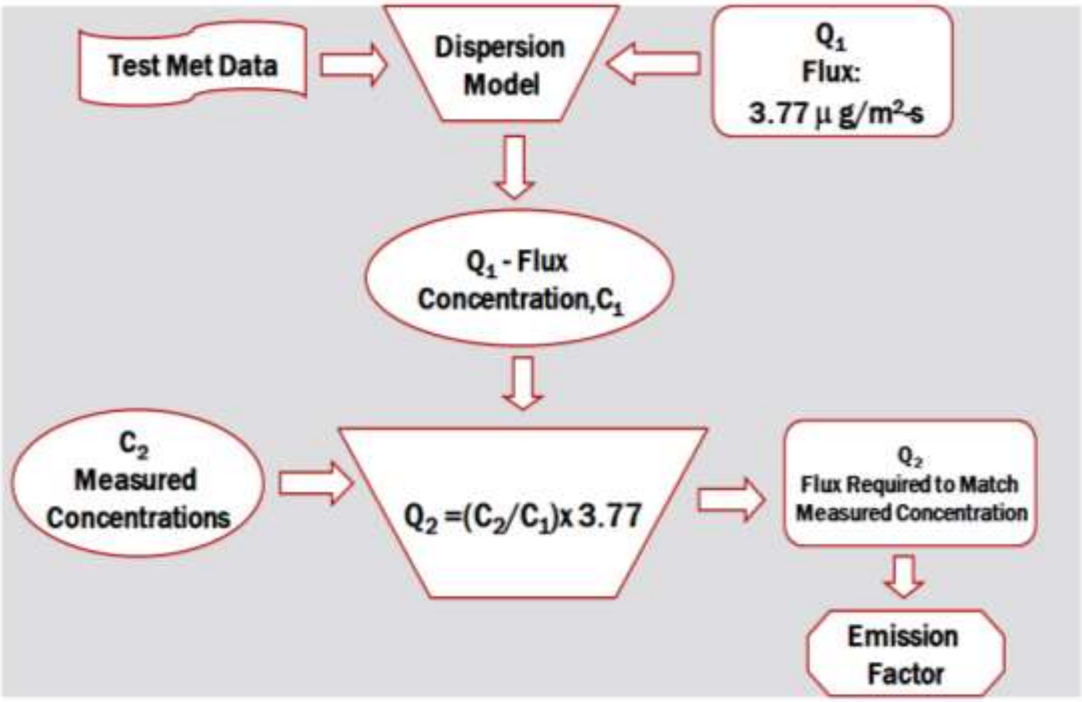


Figure 3. CAAQES protocol for deriving emission factor using the dispersion model, AERMOD.

Results and Discussion

To obtain PM_{10} emission factors for cattle feedyards, TEOM concentrations measured for PM_{10} were adjusted with correction factors for TEOM vs. FRM concentrations and for oversampling of the FRM PM_{10} pre-collector. On analyzing the corrected TEOM concentration data, it was found that certain 5-minute concentrations were abnormally high. To remove the bias to the daily concentrations from these dust peaks, the 5 minute concentrations which exceeded the mean ± 3 SD were removed from the study (Steinbach et al., 1950). The 5-minute TEOM concentrations that were considered to be outliers (downwind and upwind concentrations) and their percentages are recorded in Table 3.

Figure 4 is the plot of 5-minute TEOM sampler measurements of raw upwind and downwind concentrations, and the corrected TEOM concentrations for a 24-hour period on Sep 4, 2010. The 24-hour average PM_{10} concentration after applying the necessary corrections for that day was 202 $\mu g/m^3$.

Table 3. The 5-minute downwind and upwind PM_{10} concentrations at the cattle feedyard measured by TEOM samplers and the corresponding outliers.

Month	*Wind Direction*	*Total 5-min TEOM measurements*	*Invalid*		*3 SD*	
			5-min measurements	*%*	*5-min measurements*	*%*
Sep	DW[(a)]	8520	1086	13	198	2
	UW[(b)]	8520	1189	14	23	0
Oct	DW	8928	468	5	146	2
	UW	8928	1250	14	401	4
Nov	DW	8640	719	8	127	1
	UW	8640	332	4	134	2
Dec	DW	8928	451	5	149	2
	UW	8928	269	3	60	1

(a) DW: Downwind concentrations
(b) UW: Upwind concentrations

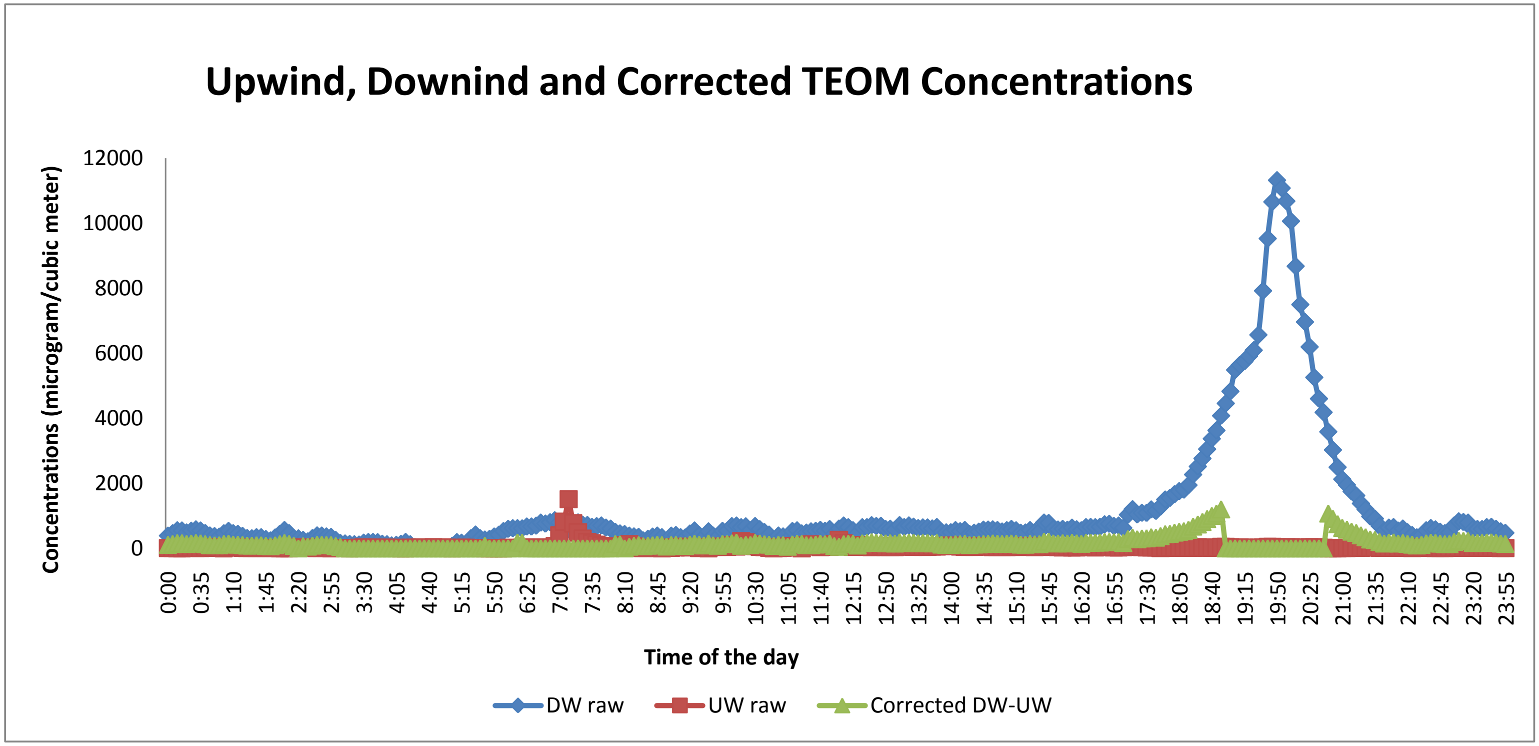


Figure 4. Plot of 5-minute TEOM sampler measurements of PM_{10} collected at the cattle feedyard for raw downwind concentrations, raw upwind concentrations, and the corrected concentrations for Sep 4, 2010.

The daily average concentrations for PM_{10} at the cattle feedyard from the corrected TEOM data were 158 $\mu g/m^3$ for September, 95 $\mu g/m^3$ for October, 50 $\mu g/m^3$ for November and 53 $\mu g/m^3$ for December. The 24-hour average downwind concentrations of PM_{10} predicted by AERMOD were 67 $\mu g/m^3$ for September, 86 $\mu g/m^3$ for October, 114 $\mu g/m^3$ for November and 110 $\mu g/m^3$ for December for CFY. The AERMOD-predicted 24-hour PM_{10} concentrations are compared to the adjusted TEOM sampler daily average PM_{10} concentrations for September in Figure 5. The average PM_{10} emission factor for September was 10.9 kg/1000 head-day (24 lb/1000 head-day).

The measured concentrations of PM_{10} exceeded the NAAQS at the property line for September, after adjusting the TEOM concentrations. The concentrations did not exceed the PM_{10} NAAQS for the months of October, November and December. The concentrations predicted by AERMOD did not exceed the PM_{10} NAAQS limits for all the four months. The daily average TEOM concentrations were higher compared to the predicted 24-hour AERMOD concentrations for September. The modeled PM_{10} concentrations for October, November and December were higher than measured concentrations provided with corrections. There were certain predicted concentrations that were similar to spikes. These were especially due to low wind speeds in night times causing higher predicted concentrations during those days. There were some days for which there were no sufficient 5-minute concentrations from the TEOM samplers. These data points were excluded from the study since they did not represent the daily average concentration for that particular day.

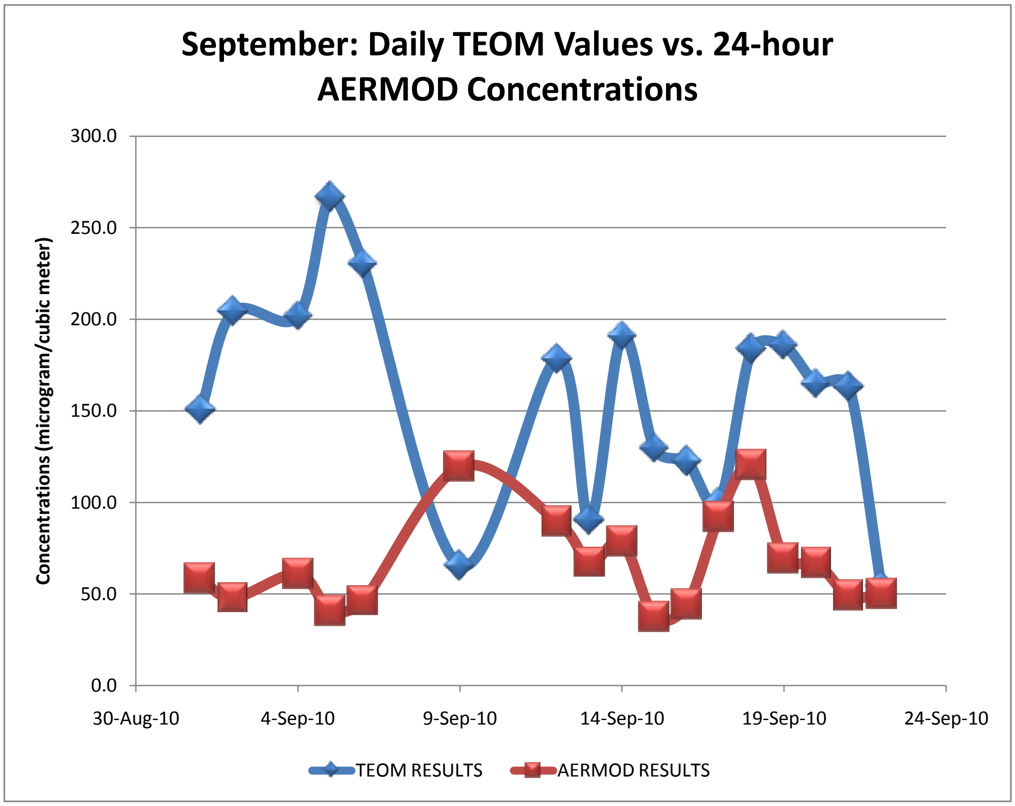


Figure 5. AERMOD predicted 24-hour PM_{10} concentrations compared to adjusted TEOM daily average PM_{10} concentrations for September 2010.

Figure 6 illustrates the comparision between the daily average TEOM 24-hour PM_{10} concentrations and the 24-hour PM_{10} concentrations predicted by AERMOD for October 2010. The average PM_{10} emission factor for October was 5 kg/1000 head-day (11 lb/1000 head-day).

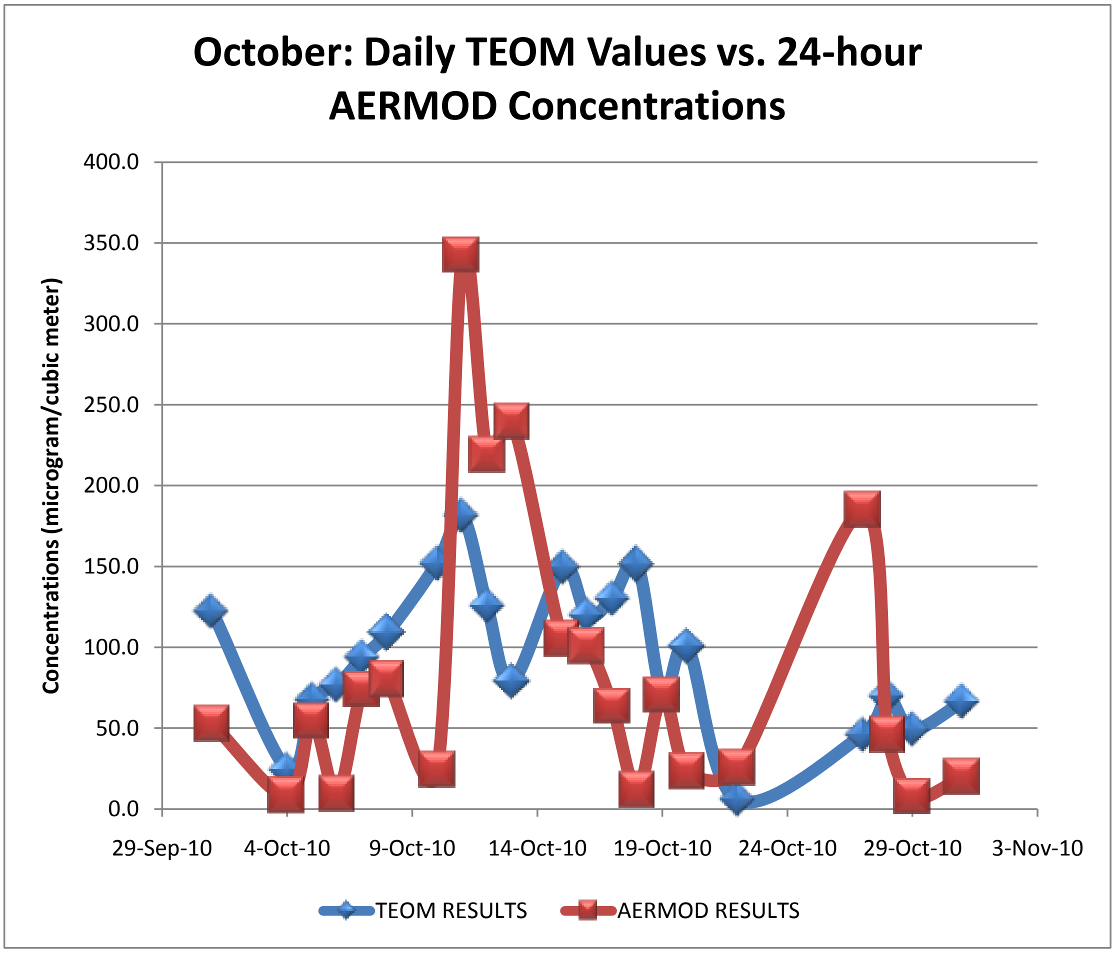


Figure 6. AERMOD predicted 24-hour PM_{10} concentrations compared to adjusted TEOM daily average PM_{10} concentrations for October 2010.

Figure 7 shows the plot of the daily average TEOM 24-hour PM_{10} concentrations vs. AERMOD predicted 24-hour PM_{10} concentrations for November 2010. The average PM_{10} emission factor for November was 3.18 kg/1000 head-day (7 lb/1000 head-day).

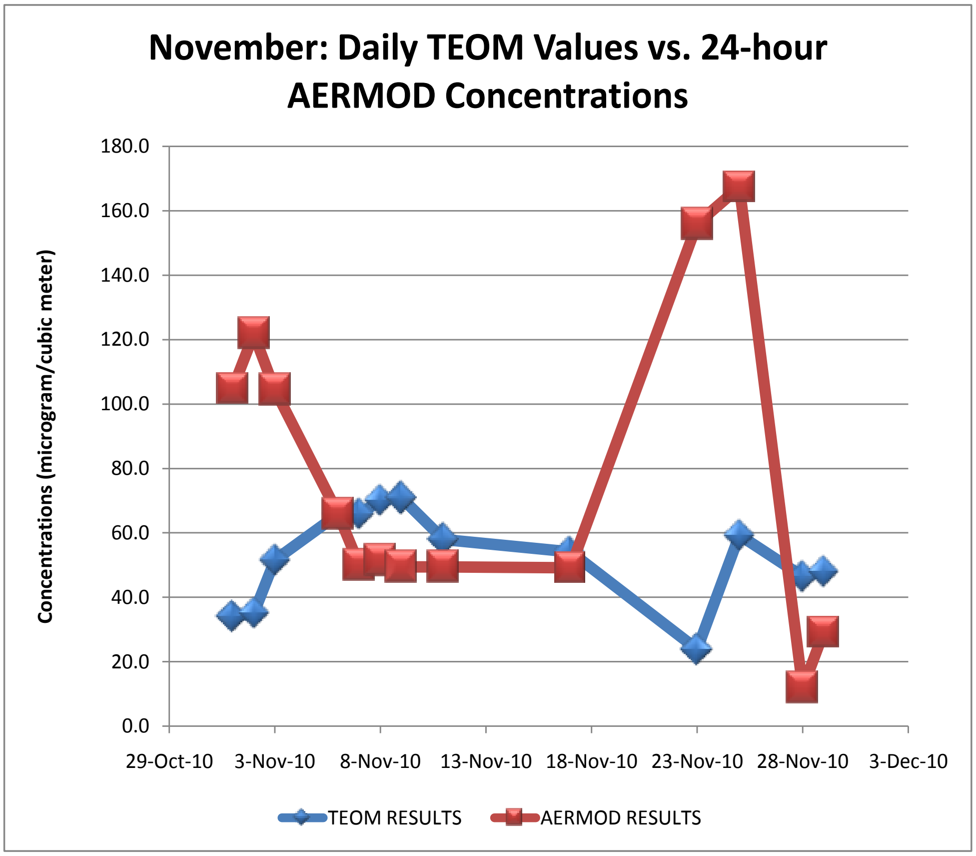


Figure 7. AERMOD predicted 24-hour PM_{10} concentrations compared to adjusted TEOM daily average PM_{10} concentrations for November 2010.

Figure 8 shows the plot of the daily average TEOM 24-hour PM_{10} concentrations vs. the AERMOD predicted 24-hour PM_{10} concentrations for December 2010. The average PM_{10} emission factor for December was 1.82 kg/1000 head-day (4 lb/1000 head-day).

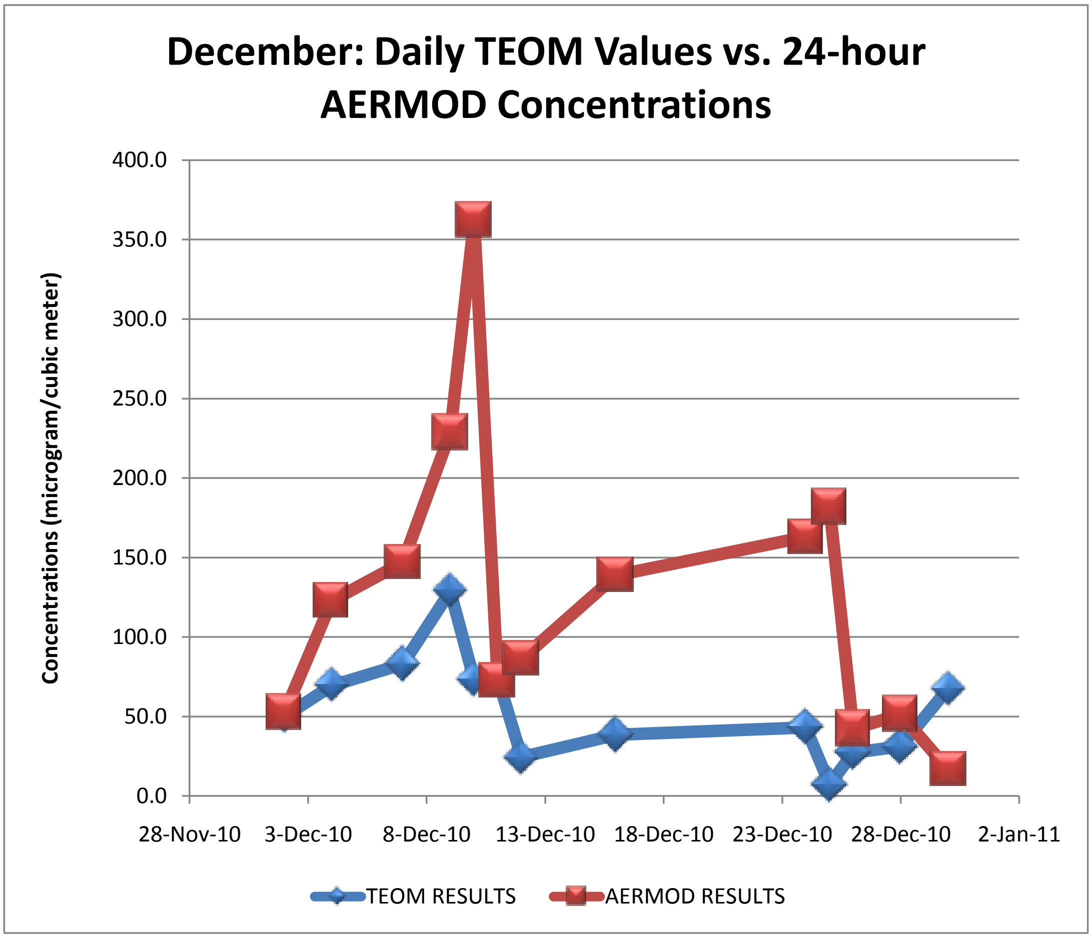


Figure 8. AERMOD predicted 24-hour PM_{10} concentrations compared to adjusted TEOM daily average PM_{10} concentrations for December 2010.

Figure 9 is the plot of the daily average measured TEOM PM_{10} concentrations vs. AERMOD predicted 24-hour PM_{10} concentrations for months September 2010 to December 2010.

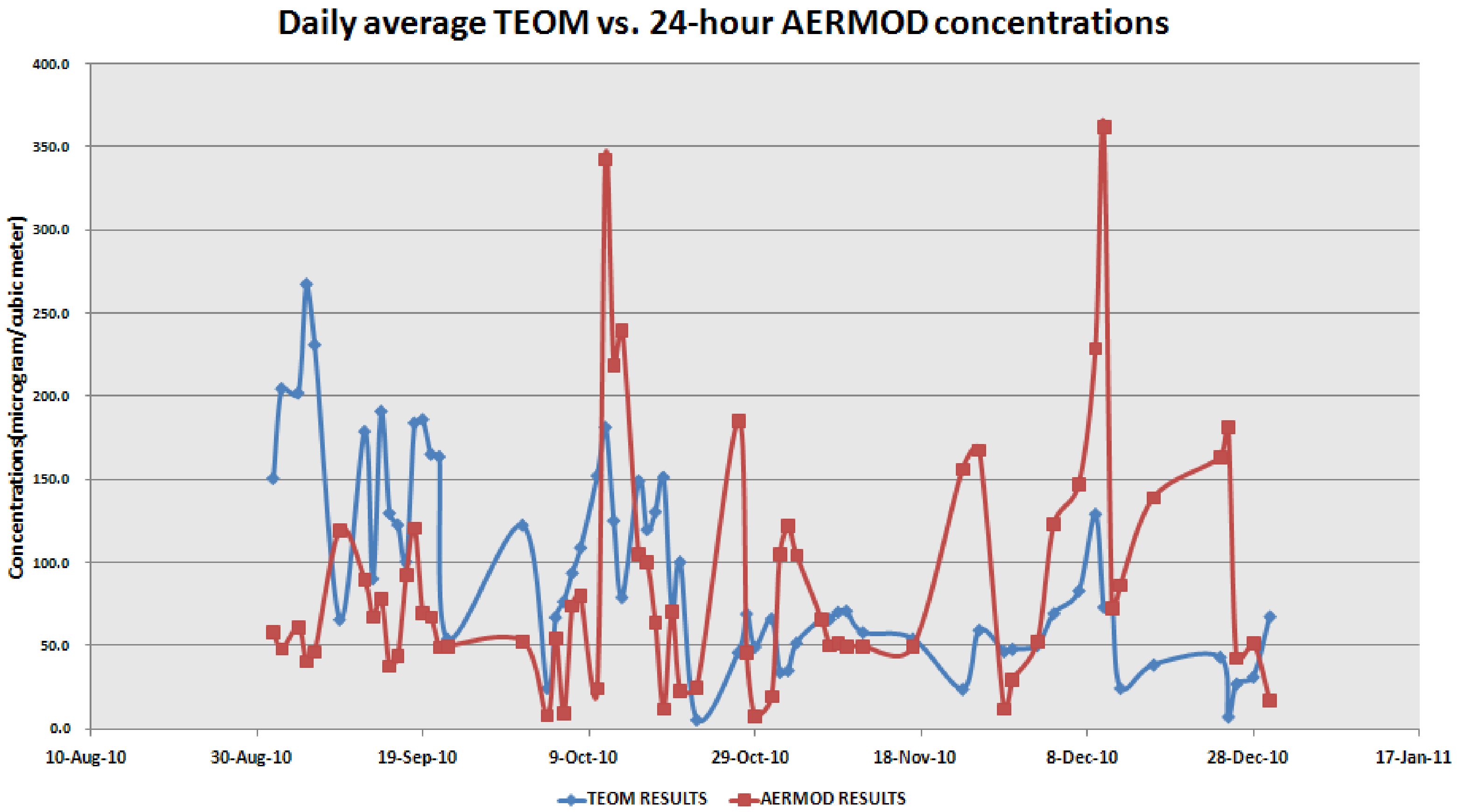


Figure 9. AERMOD predicted 24-hour PM_{10} concentrations compared to adjusted TEOM daily average PM_{10} concentrations for September to December, 2010.

The emission factors for PM_{10} for cattle feedyard were computed from the 24-hour AERMOD and daily-TEOM average concentrations for the months of September to December. The low, high and average PM_{10} emission factors for every month are recorded in Table 4.

Table 4. PM_{10} emission factors for cattle feedyard using TEOM samplers and the CAAQES protocol.

Month	***N***	***Range***	***PM_{10} Emission Factor kg/1000 head-day (lb/1000 head-day)***
SEP	17	Low	2.72 (6)
		High	30 (66)
		Expected average	**12.3 (27.2)**
OCT	21	Low	0.91 (2)
		High	59 (130)
		Expected average	**13 (28.7)**
NOV	13	Low	0.91 (2)
		High	18.2 (40)
		Expected average	**4.81 (10.6)**
DEC	13	Low	0.18 (0.4)
		High	18.2 (40)
		Expected average	**3.86 (8.5)**

The emission factors for PM_{10} for cattle feedyard were obtained using the CAAQES protocol for the months of September to December. The expected average emission factor for each month was obtained using discrete probability distribution. The low, high and average PM_{10} emission factors for every month are recorded in Table 3.

The emission factors ranged from 2.72 to 30 kg/1000 head-day (6 to 66 lb of PM_{10}/1000 head-day) for the month of September; 0.91 to 59 kg/1000 head-day (2 to 130 lb of PM_{10}/1000 head-day) for the month of October; 0.91 to 18.2 kg/1000 head-day (2 to 40 lb of PM_{10}/1000 head-day) for the month of November and 0.18 to 18.2 kg/1000 head-day (0.4 to 40 lb of PM_{10}/1000 head-day) for the month of December. The average PM_{10} emission factors were 12.3, 13, 4.81 and 3.86 kg/1000 head-day (27.2, 28.7, 10.6 and 8.5 lbs of PM_{10}/1000 head-day) for the months of September, October, November and December, respectively. The average emission factor for the four months was 5.45 ± 8.5 kg/1000 head-day (18.8 ± 10.7 lb of PM_{10}/1000 head-day). The relatively lower PM_{10} emission factors in November and December could be due to subdued cattle activity as a consequence of the colder climatic conditions. In general, the PM_{10} emission factors were in congruence with the emission factor of 6.81 kg/1000 head-day (15 lb of PM_{10}/1000 head-day) used by the TCEQ for PM_{10} regulation. The emission factors for PM_{10} were also in comparison with the PM_{10} emission factors developed by previous researchers at CAAQES (S. Parnell, 1994; McGee, 1997; Parnell et al., 1999).

Conclusions

- PM_{10} concentrations measured using TEOM samplers should be adjusted with scientifically proven corrections. The CAAQES has developed a factor of 0.3 to be applied to TEOM measured downwind concentrations for PM_{10}. There should be adjustments provided for TEOM vs. gravimetric concentrations, oversampling due to PM_{10} pre-collectors and removal of invalid concentrations and dust peaks.
- The adjusted daily concentrations measured using TEOM at cattle feedyard C exceeded the 24-hour NAAQS for the month of September 2010, and were below the PM_{10} NAAQS for October, November and December 2010.
- The daily average TEOM concentrations were higher compared to the predicted 24-hour AERMOD concentrations for September. October had daily average TEOM concentrations similar to the predicted 24-hour AERMOD concentrations. The modeled concentrations for October, November and December for PM_{10} were higher than measured concentrations provided with corrections, mainly due to the low wind velocities especially during night times.
- The average PM_{10} emission factors were 12.3, 13, 4.81 and 3.86 kg/1000 head-day (27.2, 28.7, 10.6 and 8.5 lbs of PM_{10}/1000 head-day) for the months of September, October, November and December, respectively. The average emission factor for the four months was 5.45 ± 8.5 kg/1000 head-day (18.8 ± 10.7 lb of PM_{10}/1000 head-day), which was in congruence with published emission factors.

CHAPTER III

PREDICTION OF PROPERTY LINE CONCENTRATIONS OF PM_{10} AND $PM_{2.5}$ AT COTTON GINS USING AERMOD

Introduction

The implementation of the Clean Air Act by the SAPRAs involves permitting of agricultural and industrial facilities. The special use of the NAAQS requires that the facility being permitted has to demonstrate that the property-line concentrations do not exceed the NAAQS. Dispersion modeling and/or on-site measurements are used for this purpose. Fritz et al. (2002), conducted studies on a cotton gin in New Mexico and concluded that using only modeling or only on-site measurements can lead to differing property line concentrations. There is a need to compare both dispersion modeling and measurement methods and analyze the data to avoid inappropriate regulations in agricultural operations. The objective of this study was to estimate the 24-hour PM_{10} and $PM_{2.5}$ concentrations as a function of distances from the source to receptor, using AERMOD.

Methodology

A hypothetical study was conducted to predict the 24-hour average concentrations of PM_{10} and $PM_{2.5}$ emitted from cotton gins in Amarillo, Texas. Three sizes of cotton gins were considered: 20 bales/hour, 40 bales/hour and 60 bales/ hour. The detailed emission factors adopted for the three sizes of cotton gins are shown in Table 5. The documented TSP emission factor of 1.4 kg/bale (3.1 lb/bale) was used in this study (USEPA, 1996). Agricultural dust typically has a MMD of 20 μm and a GSD of 2.0 (Buser, 2007). For a PSD defined by a MMD of 20 μm and a G.S.D of 2.0, 20% of TSP is comprised of PM_{10} and 5% of TSP consists of $PM_{2.5}$ (Vanderlick et al., 2011). Hence the emission factors for PM_{10} and $PM_{2.5}$ were estimated to be 0.27 kg/bale (0.6 lb/bale) and 0.07 kg/bale (0.15 lb/bale), respectively. There were four receptors located at east, west, north and south of the 50 m and 100 m property lines each. The meteorological data was obtained from Amarillo, Texas. The cotton gin stack data were used from the guidelines provided by the North Carolina Department of Air Quality (NCDAQ, 2003). Accordingly, the stack height was 30 feet, inside diameter of stack was 4.3 feet, and temperature of exit gases was 70^{o} F. The volumetric flow rate was 3600 acfm and this flow rate was used to calculate the velocity of exit gases. The 24-hour concentrations of PM_{10} and $PM_{2.5}$ were predicted using AERMOD, at the property line of two distances, 50 m and 100 m. These predicted concentrations were checked for compliance with the PM_{10} and $PM_{2.5}$ NAAQS.

Table 5. PM_{10} and $PM_{2.5}$ emission factors for cotton gins.

Cotton Gin Emission Rate bales/hr	*PM_{10} Emission Rate*		*$PM_{2.5}$ Emission Rate*	
	lbs/hr	*g/s*	*lbs/hr*	*g/s*
20	12.4	1.6	3.1	0.4
40	24.8	3.1	6.2	0.8
60	37.2	4.7	9.3	1.2

Results and Discussion

Concentrations of PM_{10} and $PM_{2.5}$ were predicted using AERMOD for cotton gins for three different sizes. Based on the assumed emission factors and the fence line distances, the results obtained are discussed below.

Predicted PM_{10} emissions at 50 m property line distance

For the property line at 50m, it was observed that the maximum 24-hour PM_{10} concentrations for September, October, November and December did not exceed the NAAQS for the 20 bales/hour (bph) cotton gin. The emissions from 40 bph and 60 bph sources exceeded the PM_{10} NAAQS at 50 m for all the months.

Predicted PM_{10} emissions at 100 m property line distance

The 24-hour maximum emissions of PM_{10} exceeded the NAAQS for 20 bph, 40 bph and 60 bph cotton gins, for all the four months in the study.

Predicted PM$_{2.5}$ emissions at 50 m property line distance

The predicted maximum concentrations did not exceed the 24-hour PM$_{2.5}$ NAAQS for the 20 bph source, through the months of September to December. The gins operating at 40 bph and 60 bph had PM$_{2.5}$ emissions that were exceeding the 24-hour NAAQS, from September to December.

Predicted PM$_{2.5}$ emissions at 100 m property line distance

AERMOD predicted PM$_{2.5}$ emissions exceeded the 24-hour NAAQS at the 100 m property line for all the three sized gins, studied from September through December.

Figure 10 represents the predicted PM$_{10}$ emission concentrations for September to December, from the three cotton gins.

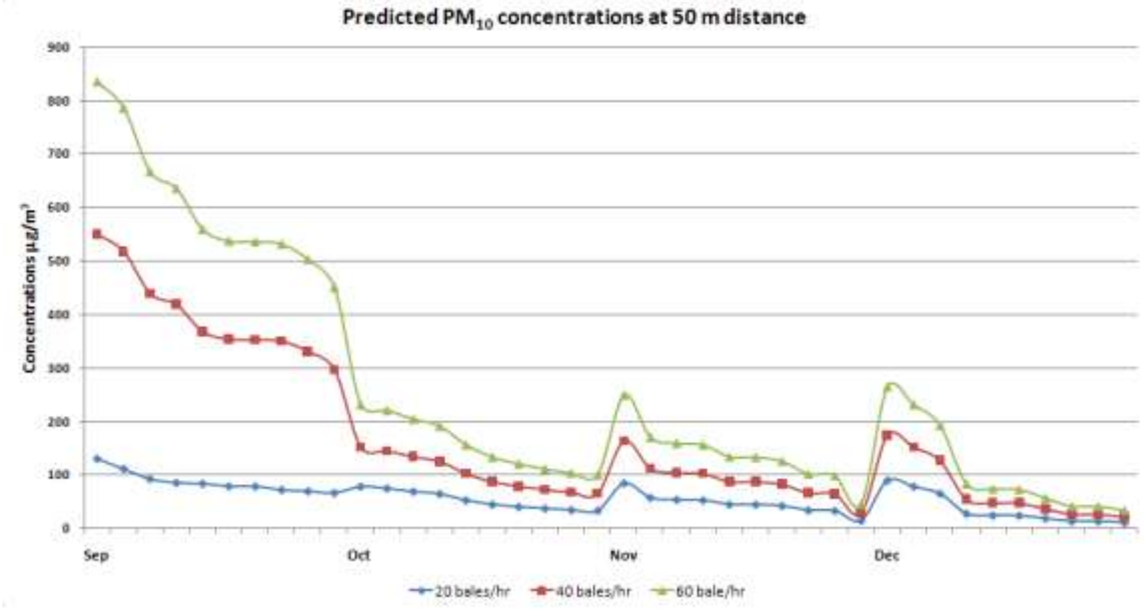


Figure 10. The range of AERMOD predicted concentrations of PM$_{10}$ in μg/m^3 for three different sized cotton gins of 20, 40 and 60 bales/hour, at 50 m property line distance.

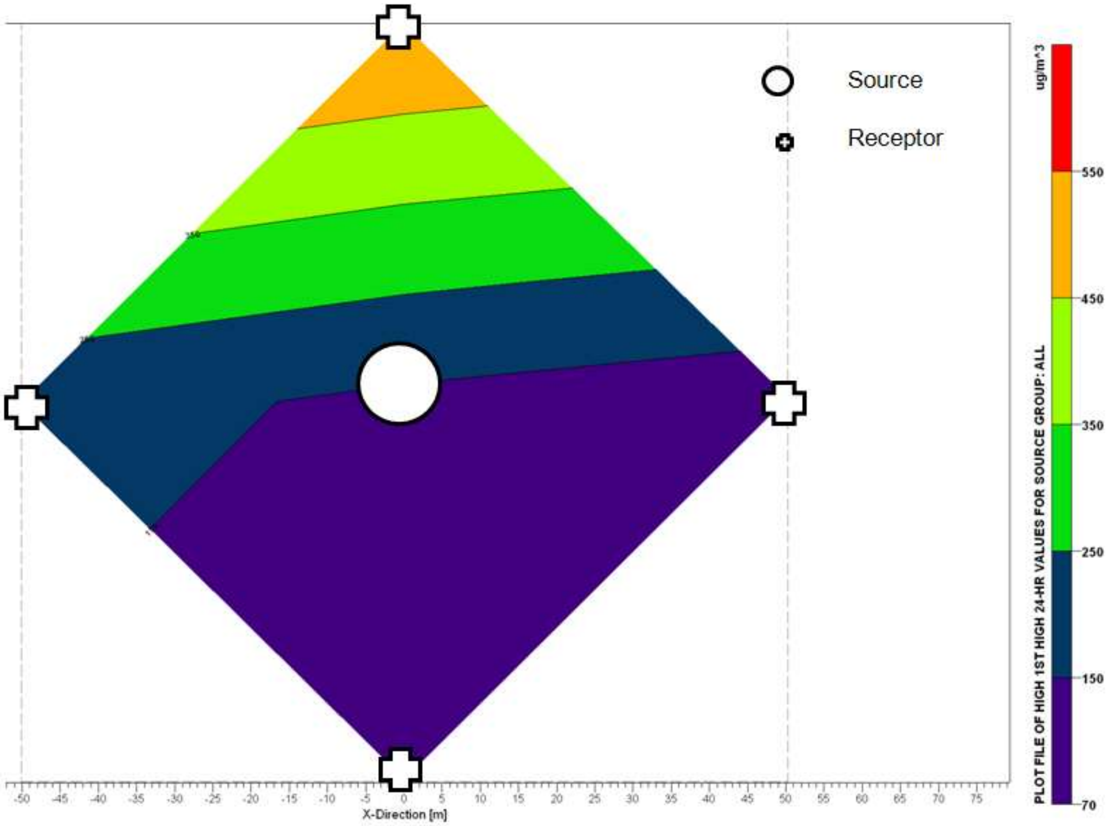


Figure 11. PM$_{10}$ concentrations predicted by AERMOD for the 40 bph source in September at 50 m distance.

Figure 11 is the plot of the PM_{10} concentrations emitted by the 40 bale/hr source at the property line distance of 50m. The source is at the center with four receptors placed at the property line of 50 m. The receptors estimated the concentrations of PM_{10} that were emitted from the source. The different colors represent the different ranges of concentrations of PM_{10} emitted by the cotton gin. The predicted concentrations were directed towards the north direction due the prevailing wind direction. The maximum PM_{10} concentration for the month of September was 551 $\mu g/m^3$. This exceeded the 24-hour PM_{10} NAAQS.

Figure 12 is the expanded plot of the PM_{10} concentrations emitted by the 40 bale/hr source at the property line distance of 50m. The effect of the prevailing wind direction towards north is clearly depicted in this figure. The 40 bph cotton gin required a distance of 330 m for its PM_{10} emissions to not exceed the 24-hour PM_{10} NAAQS.

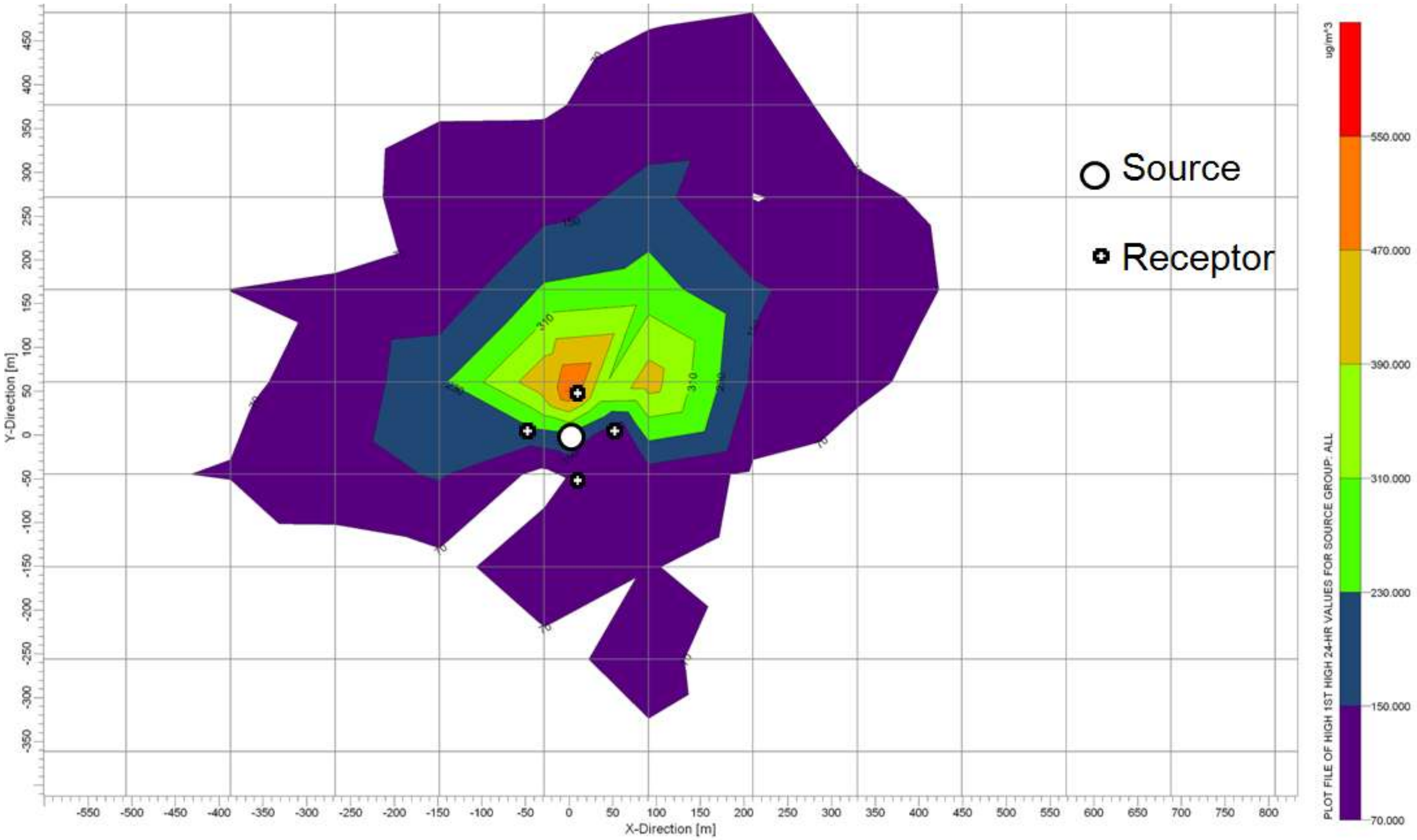


Figure 12. The plume of the PM_{10} concentrations predicted by AERMOD for the 40 bph source in September at 50 m distance.

The AERMOD generated plot of the $PM_{2.5}$ concentrations emitted by the 20 bale/hr source at 50m property line distance is shown in Figure 13. The maximum concentration for the month of September was 33 μg/m^3. This did not exceed the 24-hour NAAQS for $PM_{2.5.}$

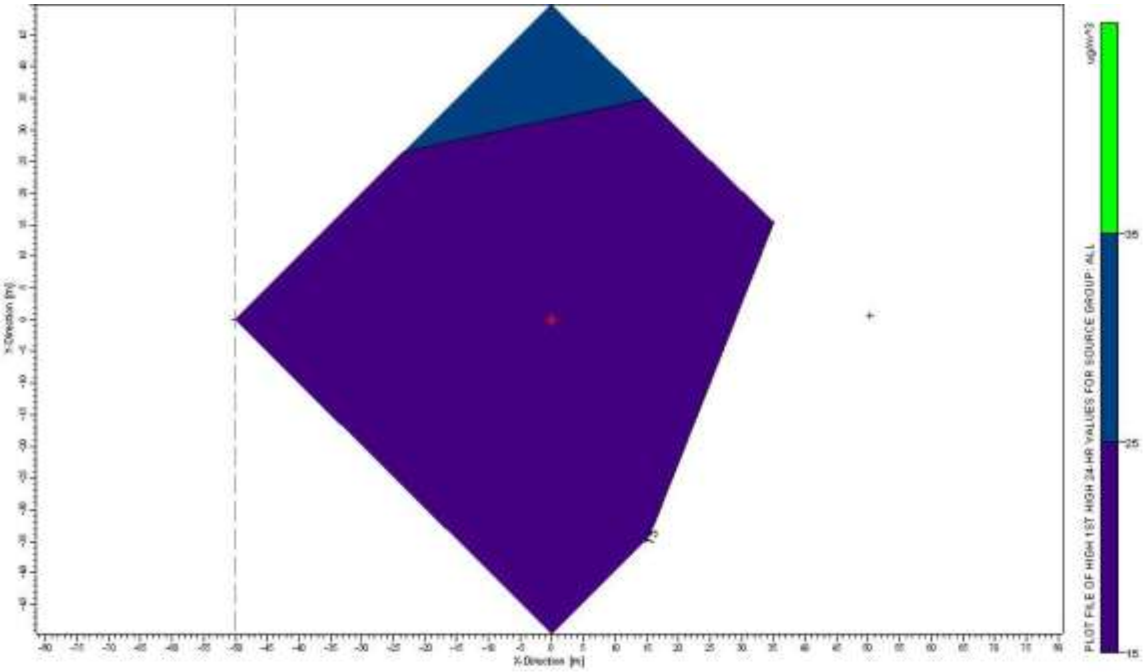


Figure 13. $PM_{2.5}$ concentrations predicted by AERMOD for the 20 bph source in September at 50 m distance.

The plot of the $PM_{2.5}$ concentrations emitted by the 40 bale/hr source at 100m property line distance is shown in Figure 14. The maximum concentration for the month of September was 65 μg/m^3. This exceeded the $PM_{2.5}$ NAAQS for a 24-hour period.

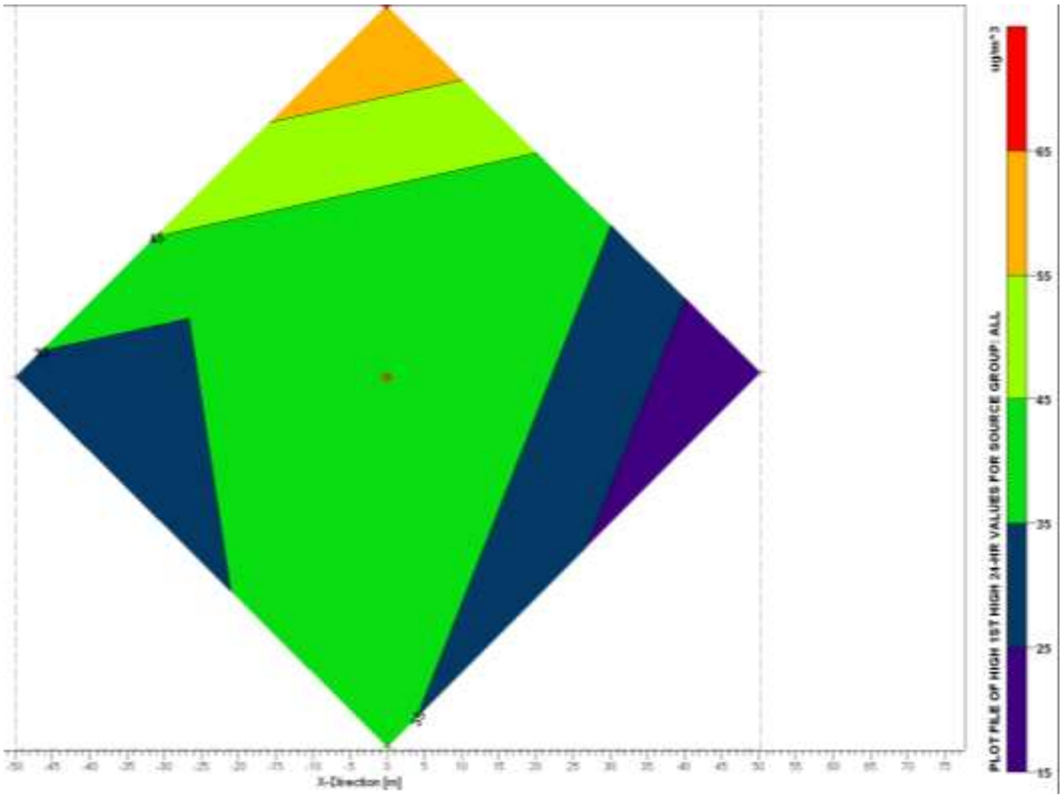


Figure 14. $PM_{2.5}$ concentrations predicted by AERMOD for the 40 bph source in September at 50 m distance.

Figure 15 depicts the maximum 24-hour concentrations of PM_{10} emissions for the months of September, October, November and December. The concentrations were obtained for the property lines at 50 m and 100 m from the cotton gins. Figure 15 also depicts the average 24-hour PM_{10} concentration for the four months.

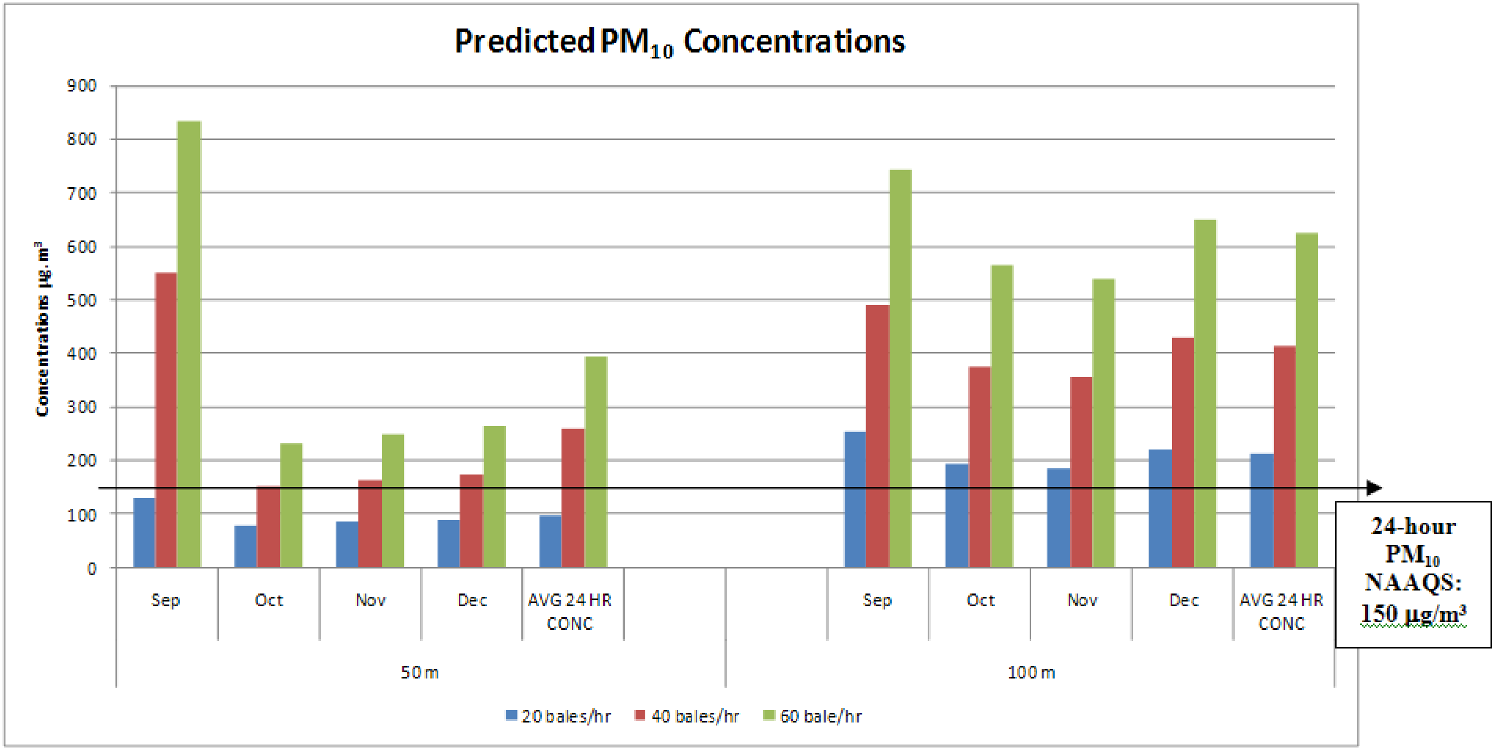


Figure 15. Predicted maximum concentrations of PM$_{10}$ in µg/m^3 for three different sized cotton gins of 20, 40 and 60 bales/hour, at 50 m and 100 m for the months of September to December.

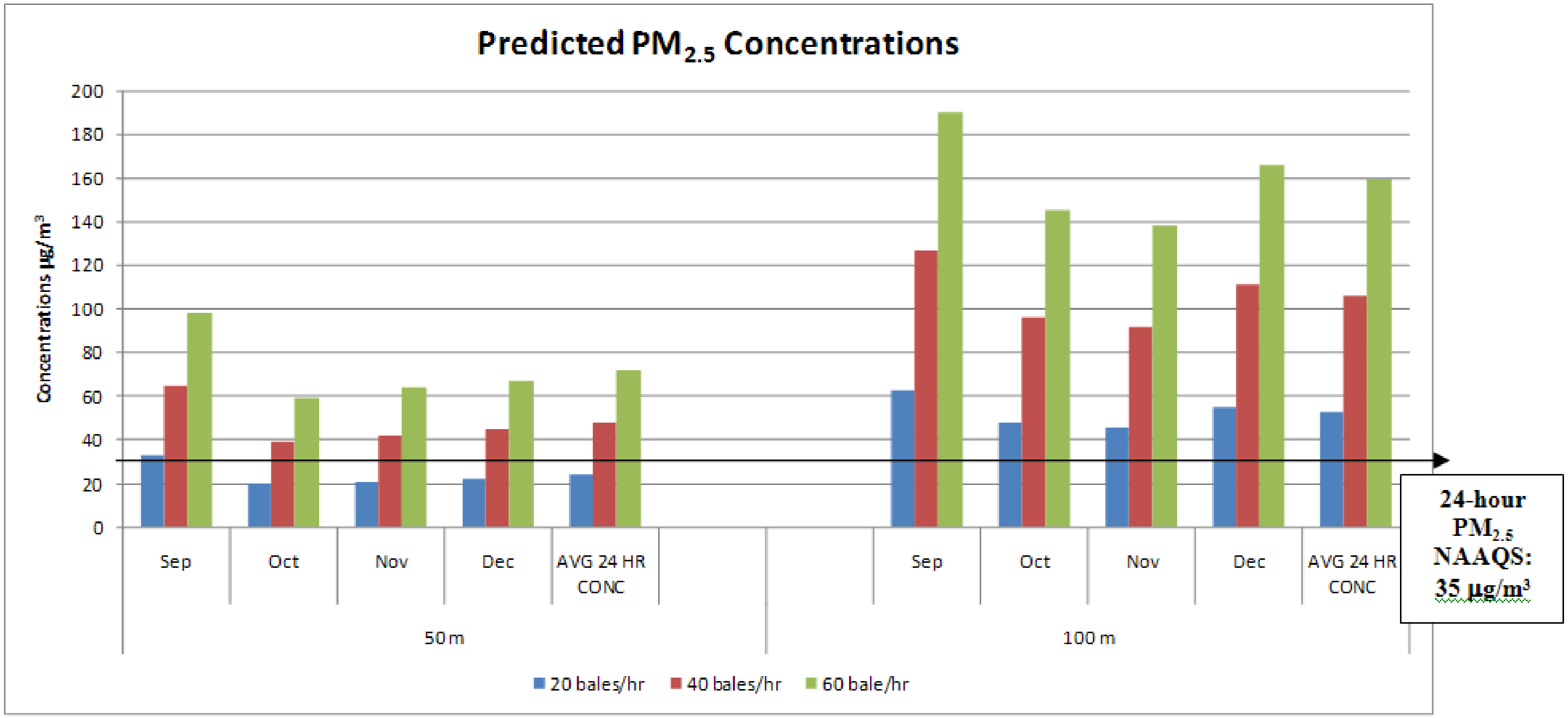


Figure 16. Predicted maximum concentrations of $PM_{2.5}$ in µg/m^3 for gins of 20, 40 and 60 bales/hour, at property lines of 50 m and 100 m.

Figure 16 represents the maximum 24-hour concentrations of $PM_{2.5}$ emissions for the months of September, October, November and December for the property lines at 50 m and 100 m.

Conclusions

- The maximum 24-hour PM_{10} concentrations did not exceed the NAAQS for the 20 bales/hour gin for all the months at 50 m property line distance. The emissions from 40 bales/hour and 60 bales/hour sources exceeded the 24-hour PM_{10} NAAQS for all the months at 50 m distance.
- All the three gins exceeded the NAAQS at the 100 m property line distance from September to December.
- Similar results were obtained for the predicted concentrations of $PM_{2.5}$ at both 50 m and 100 m property lines.

As a consequence of these results, the cotton gins may be in violation of their permits. The predicted 24-hour downwind concentrations for the cotton gins increased as the property line distances increased from 50m to 100m. This was most likely a consequence of the plume passing over the 50m distance. This shows that there is a need for careful observation of measured and modeled data when permitting cotton gins; else, facilities could be improperly regulated.

CHAPTER IV

ANALYSIS OF PM_{10} EMISSIONS AT LAYING HEN HOUSES

Introduction

Emission rates of PM_{10} from agricultural sources including layer hen facilities are regulated by the SAPRAS. Concentrations of PM_{10} at the property line or beyond must be less than the NAAQS for the facility to be in compliance with its permit conditions. If the NAAQS are exceeded (off property), the emitting source is subjected to enforcement actions including fines and requirements to reduce emission rates. The goal of this research was to develop and demonstrate a process for determining the property line distances from layer hen operations such that the concentrations off-property did not exceed the NAAQS. The objectives of this research were:

(1) Develop emission factors utilizing valid PM_{10} concentration data from inside a layer house obtained with TEOM and filter-based low-volume PM_{10} samplers

(2) Estimate the 24-hour PM_{10} concentrations at the property line and beyond using the emission factors in the AERMOD dispersion model

(3) Determine the distances to the property lines required for the layer house to maintain compliance with the PM_{10} NAAQS at property lines.

Title V permits, also known as Part 70 Federal Operating Permits, are federal operating permits for facilities that have the potential to emit large amounts of air pollutants. A major source that emits 100 tons per year (tpy) or more of a regulated air-pollutant is required to obtain a Title V permit. Prevention of Significant Deterioration permit applies to new major sources or major modifications at existing sources for pollutants with a threshold of 250 tpy or more of a regulated air-pollutant. The USEPA conducted studies on emissions of PM at Buckeye Egg Farm facilities in Ohio and concluded that the three facilities were emitting 740, 650 and 550 tpy of PM, with none of the facilities obtaining Title V and Prevention of Significant Deterioration permits. Consequently, the facilities were subjected to a civil penalty of $881,000 and were required to provide additional controls worth $1.4 million (USEPA, 2004).

CAAQES reviewed the findings of the USEPA's contractor and found several errors. The consultants had measured the TSP concentrations and assumed they were the same as PM_{10} concentrations, to determine the annual emissions. Based on the data reported by the contractor, Lange estimated the particle size distribution and reported that PM_{10} fraction was 10% of the TSP. The USEPA had calculated the PM emissions based on the assumption that all the fans were running throughout a 24-hour period, all days a year, at 396 cubic meter per minute (m^3/min) or 14000 cubic feet per minute (cfm), with no regard to ambient temperatures, which was inappropriate (Lange, 2008). Based on these findings, CAAQES reported that the PM_{10} emissions from the Buckeye laying facilities did not exceed the Title V and Prevention of Significant Deterioration thresholds, and that the facilities were improperly regulated (Lange, 2008). The protocol used by the USEPA to estimate the potential to emit (PTE) at the Buckeye facilities was used to estimate the emission rates and the tpy of PM_{10} emissions from the layer house, in this research.

Several researchers have published data on emission rates in laying hen houses and broiler operations the United States (Table 6). Lacey et al. (2003) in Texas reported an emission rate of PM_{10} of 536 mg/hr/500 kg-liveweight for broilers on litter. Lim et al. (2003) documented PM_{10} emissions of 525 to 808 mg/hr/500 kg-liveweight for mechanically ventilated battery-caged layers in Indiana. Jacobson et al. (2004) reported PM_{10} emissions 83 to 417 mg/hr/500 kg-liveweight for mechanically ventilated high-rise laying hen facility in four states in the U.S.

Table 6. Emission rates for laying hen facilities and broiler operations in U.S.

Reference	*Type of facility/climate*	*PM_{10} Emission Rates (mg/h/AU $^{(a)}$)*
Lacey et al.	Broilers	536
Lim et al.	Layer	525-808
Jacobson et al.	Layer	83-417

(a) AU: Animal unit where 1 AU = 500 kg liveweight

The particle size distribution of PM emitted by broiler operations is very different from the PSD of PM emitted by layer hen operations. Layer hen facilities have mass median diameters (MMDs) that are small relative to broiler facilities. As a consequence, the mass fraction of PM_{10} is much larger. Consequently, the property line distances at which the concentrations of PM_{10} would be below the 24-hour average PM_{10} standard for a broiler operation would be less than that needed for layer hen facility.

For several years, faculty in the Center for Agricultural Air Quality Engineering and Science (CAAQES) have reported that FRM sampling of PM_{10} in the presence of PM with large MMDs, results in concentrations that are 2 to 4 times higher than the true concentrations (Wang et al., 2005; Buser et al., 2007). This result was referred to as "over-sampling". The TEOM monitors use the same pre-collectors for PM_{10} sampling as the FRM samplers, thus share the same "over-sampling" problem as the FRM-PM_{10} sampler does.

The MMDs and the GSDs of PM particle size distributions in a high-rise laying hen house ranged from 16.8 ± 1.6 μm to 20.3 ± 3.5 μm, and 2.4 ± 0.2 to 2.8 ± 0.3, respectively (Wang-Li et al., 2012). Mean TSP concentrations ranged from 1.0 ± 0.5 mg/m^3 to 5.3 ± 0.4 mg/m^3 (Wang-Li et al., 2012).

In studies of PM concentrations emitted in cattle-feedyards, there were differences in concentrations of TSP and PM_{10} measured by collocated TEOM-PM_{10}/TSP and filter-based low-volume PM_{10} (FBLV-PM_{10}) and TSP (FBLV-TSP) samplers (Skloss, 2008). TEOM samplers measured concentrations that were 1.7 times the low-volume (FRM) sampler measurements, in the presence of higher concentrations and larger particle diameters (Vanderlick et al., 2011). In effect, a concentration of 1000 $\mu g/m^3$ measured by TEOM sampler would result in a FRM sampler concentration of 600 $\mu g/m^3$. This FRM *vs.* TEOM bias was separate from the oversampling of the FRM and TEOM PM_{10} pre-collectors. Hence, to account for oversampling of the pre-collectors in addition to the FRM *vs.* TEOM bias, a correction factor of 0.3 (obtained from 0.5 * 0.6) was adopted by Bairy et al. (2012), in estimating the 24-hour PM_{10} concentrations at cattle feedyards.

Methodology

The TSP and PM_{10} concentrations were measured in a high-rise tunnel ventilated laying hen house in North Carolina (Li et al., 2012). The house was 175 m long and 18 m wide, containing 95,000 hens. For this reported case study, each bird was assumed to be weighing 1.81 kg or 4 lb (Li et al., 2012). There were 276 hens in one animal unit (AU) where 1 AU = 500 kg liveweight. There were a total of 344 AU in this particular layer house. The PM concentrations were measured using co-located TEOM-PM_{10} and TEOM-TSP samplers, and filter-based low-volume PM_{10} and TSP samplers. TEOM-PM_{10} and LV-PM_{10} concentrations were measured between the months of October 2009 and December 2009. TEOM-TSP concentrations were recorded between February 2009 and December 2009 (Li et al., 2012). Thirty-minute TEOM-TSP/PM_{10} concentrations were measured using TEOM samplers, from which, 24-hour average concentrations were obtained. Fifteen 24-hour samples were measured by low-volume PM_{10} samplers to obtain the 24-hour concentrations based on the FRM sampling method (Li et al., 2012). Six co-located FBLV-TSP samplers were used to measure the TSP for four seasons in 2009 (Wang-Li et al., 2012). Table 7 shows the PM sampling events and the sampling time durations.

Table 7. PM sampling timetable and the sampling duration.

PM sampling time(a)	*TEOM-PM_{10}*	*FBLV-PM_{10}*	*TEOM-TSP*	*FBLV-TSP*(b)	*Data source*
Oct - Dec 2009	Co-located		---	---	Li et al., 2012
Feb - Dec 2009	---	---	Monitors	---	Li et al., 2012
Four seasons Sep 2009	---	---	---	6 Co-located LV-TSP samplers	Wang-Li et al., 2012

(a) TEOM-PM_{10}/TSP samplers measured concentrations at 30-minute time intervals. The sampling duration for the filter based low volume PM_{10} sampler was 24 hours.
(b) Four sampling seasons with 4 daytime and 3 nighttime sampling periods per season.

In the tunnel-ventilated layer house, there were 34 fans of 1.22 m (48”) diameter provided for house ventilation. During winter or nighttime, when the temperatures were generally lower, some of the fans were turned off. In order to estimate the emission rates, the 24-hour average concentration of PM_{10} was multiplied by the house ventilation flow rates. The monitored concentrations were analyzed to obtain the 24-hour TSP and the 24-hour PM_{10} concentrations. There were four scenarios considered for estimating emission rates and emission factors, based on the house ventilation flow rates, and accounting for oversampling of PM_{10} sampler pre-collectors. To account for the oversampling error, the 24-hour average concentrations of PM_{10} measured by the TEOM samplers were multiplied by an oversampling correction factor (OSC) of 0.5 in Cases 2 and 4. The Midwest Plan Services (MWPS) recommendations of ventilation flow rates were utilized to estimate PTE of the layer house.

Case 1. Emission rates were estimated assuming that all the fans were operating at a constant flow rate 390 m^3/min (13800 cfm), 24 hrs a day, 365 days a year. It must be noted that this situation followed the methodology adopted by the EPA in estimating the PTE of the Buckeye facilities without considering ventilation variations in response to ambient temperature changes (Lange, 2008).

Case 2. This procedure was adopting the minimum flow-rate recommendations as specified by the Midwest Plan Service (MWPS) standards for broiler operations (MWPS, 1990). Every bird was assumed to be weighing four pounds. The MWPS 1990 standards for ventilation flow rates were as follows:

- 0.006 m^3/min-kg-bird (0.1 cfm/lb-bird) for cold days
- 0.03 m^3/min-kg-bird (0.5 cfm/lb-bird) for mild days
- 0.06 to 0.09 m^3/min-kg-bird (1 to 1.5 cfm/lb-bird) for hot days

In order to estimate the emissions from a similar layer house, this hypothetical study was assumed to be based at Amarillo in Texas. Cold days were defined as days with average temperatures less than 13°C (55°F), mild days had temperatures between 13°C (55°F) and 21°C (70°F), and days with temperatures higher than 21°C (70°F) were considered as hot days. The weather data for the year 1988 from Weather Underground, Inc (2012) was utilized for this study. It was observed that there were 159 cold days, 105 mild days and 102 hot days. The flow rates generated following the MWPS 1990 flow rate recommendations were equivalent to each fan operating at 170 m^3/min (6000 cfm).

Case 3. The emission rates were estimated similar to Case 1 with correction for over-sampling of the PM_{10} pre-collectors of the FRM and TEOM samplers.

Case 4. Emission rates were obtained following the methodology of Case 2 with correction for over-sampling of the FRM and TEOM sampler pre-collectors.

The following equations were used to calculate the emission rates, emission factors and tons per year of emissions from this layer house.

$$ER = QC \tag{1}$$

Where, ER - Emission rate g/s (lb/day)

Q - Flow rate in cubic meter per second (cubic feet per day)

C - Concentration of PM_{10} in gram per cubic meter (pound per cubic feet)

$$EF = \frac{ER * 365 days}{N} \tag{2}$$

Where, EF - Emission Factor (g/bird/yr)

N - Number of birds

ER - Emission rate (g/day)

Emission factor was also calculated in terms of mg/h/AU, with each bird in the laying hen house approximately weighing 4 lb or 1.81 kg.

$$EF = \frac{ER * 500 kg}{N * w} \tag{3}$$

Where, EF - Emission Factor (mg/h/AU)

w - Weight of each bird in kg

$$tpy = \frac{Q * C_{24}}{907000g} \tag{4}$$

Where, tpy - tons per year of PM_{10} emissions

Q_A – Flow rate in cubic meter per year

C_{24} - 24-hour average concentration in gram per cubic meter

Thus, four emission factors were obtained, based on the ventilation flow rates in the laying hen facility and the average 24-hour emissions of PM_{10}. These emission factors were adopted in AERMOD to predict the downwind concentrations of PM_{10} from a hypothetical layer house for each of the four cases. There were 34 point sources representing the fans provided for ventilation at the facility. The point sources were divided into two groups of 17 fans, and each group was placed 180 m apart to reflect the positioning of fans in the layer house (Figure 17). The release height was ground level with differing ventilation flow rates for the four cases based on the PM_{10} emission rates.

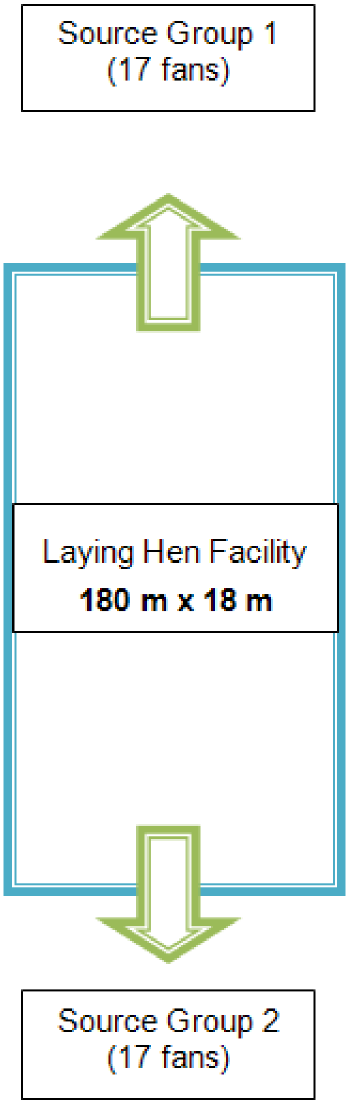


Figure 17. Representation of PM_{10} source groups 1 and 2 in AERMOD.

The meteorological data were obtained from Texas Commission on Environmental Quality (TCEQ, 2012). The terrain was assumed to be flat and no background concentrations were adopted for the modeling of PM_{10} concentrations. The atmospheric dispersion model predicted the average 24-hour PM_{10} concentrations downwind from the facility. These results were analyzed to obtain property line distances beyond which the facility's PM_{10} emissions would not exceed the 24-hour average PM_{10} NAAQS, on a case by case basis.

Results and Discussion

The 30-minute PM_{10} and TSP concentrations measured by the TEOM samplers inside the laying hen house were distributed in a non-uniform manner in a 24 hour period. There were high concentrations during daytime and low concentrations during nighttime (Figure 18). Estimating the 24-hour concentrations with due regard to this observation was necessary, since this average 24-hour concentration was a key factor in approximation of the emission rates of PM_{10} in the facility.

On analysis of the TSP concentrations on a 24-hour basis, it was observed that there were high concentrations from 3:00 h to 20:00 h and low concentrations from 20:00 h to 3:00 h. PM_{10} concentrations were high from 5:00 h to 20:00 h and low from 20:00 h to 5:00 h. Accordingly, the concentrations were divided into 17 hours of daytime and 7 hours of nighttime for TSP; 15 hours of daytime and 9 hours of nighttime for $PM_{10.}$

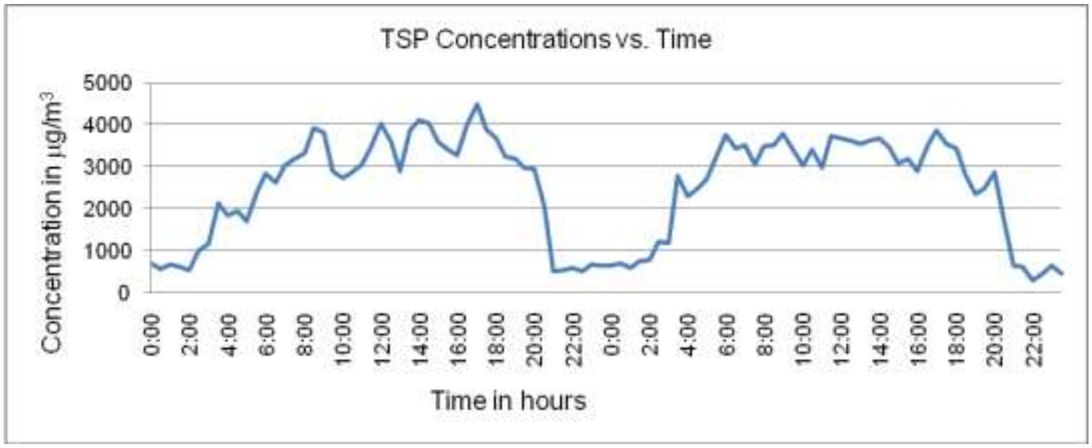
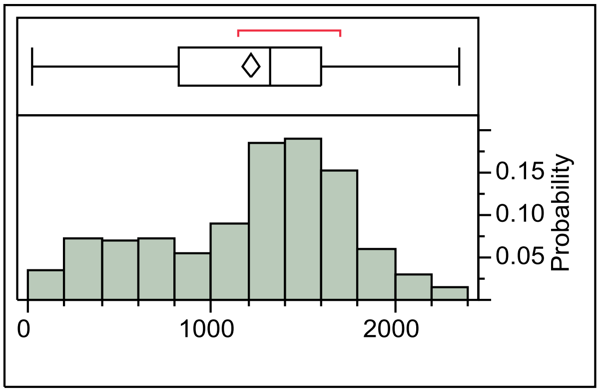


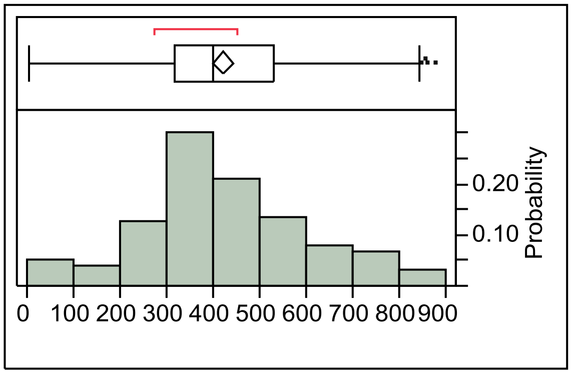
Figure 18. Thirty-minute TEOM concentrations of TSP distributed in 48-hour period (Feb 28-Mar 1, 2009) in the laying hen house.

The main cause for the varying concentrations was that the lights were turned on during the day (3:00 h to 20:00 h), and turned off during the nighttime (20:00 h to 3:00 h). There were certain TEOM-PM$_{10}$ and TEOM-TSP 30-minute concentrations that were zero and negative which were assumed to be invalid data and were hence not included in the study. All the 30-minute TEOM-PM$_{10}$ and TEOM-TSP concentrations that were beyond the 1st quartile - 1.5*(interquartile range) and the 3rd quartile + 1.5*(interquartile range) were considered outliers and were removed. The removal of outliers was the methodology adopted by JMP statistical software (SAS Institute Inc., 2012). This was similar to the protocol of removing concentrations which exceeded values that were mean ± 3 SD (Steinbach et al., 1950). This protocol was different than the methodology followed by Li et al. (2012). Of 748 TEOM-PM$_{10}$ measurements on a 30-minute basis, 21 negative and zero concentrations were removed. A total of 23 (nine negative and zero) measurements out of 575 measurements of 30-minute TEOM-TSP concentrations were removed.

Using discrete probability distribution, expected values were computed for the daytime and nighttime concentrations to obtain the weighted average 24-hour concentration (Figure 19). This protocol was followed to obtain the daily average TEOM-PM concentration for each day.



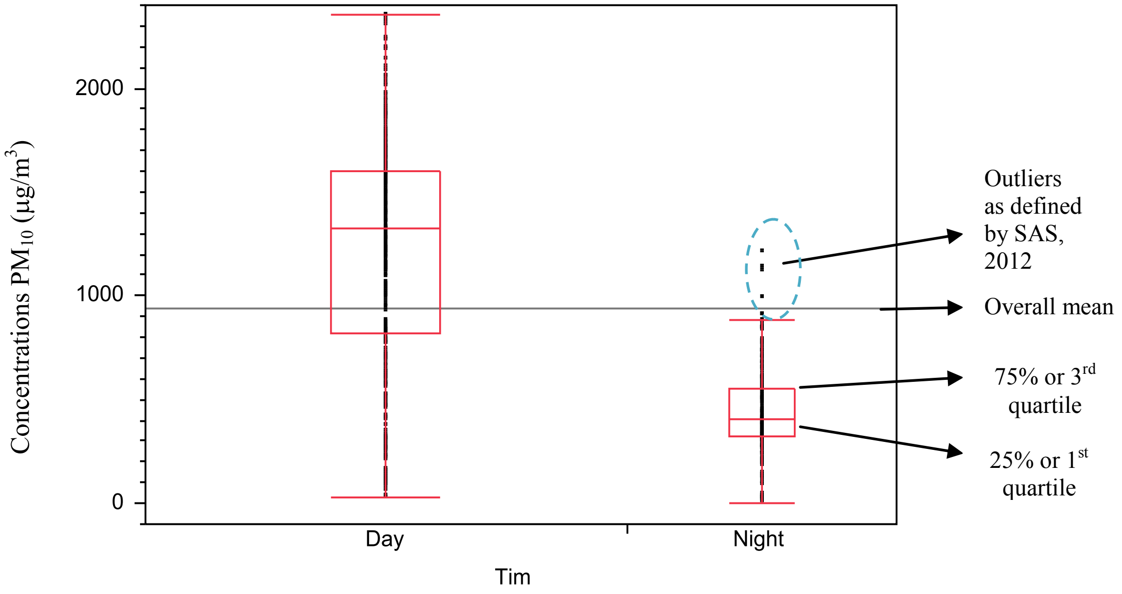
Daytime PM_{10} concentration distribution in µg/m^3



Nighttime PM_{10} concentration distribution in µg/m^3

Figure 19. Discrete probability distributions of 30-minute TEOM concentrations of PM_{10} measured during daytime and nighttime in the laying hen house, after removing outliers.

There was a statistically significant difference between the concentrations measured at day and night, as seen in Figure 20. The average 24-hour TEOM-PM_{10} concentration after computing the weighted average of the valid data was 953 ± 268 µg/m^3. From the observed TEOM measurements, the 24-hour average concentration of TSP was 1.39 ± 1.03 mg/m^3. The FBLV-PM_{10} sampler recorded an average 24-hour PM_{10} concentration of 968 ± 284 µg/m^3.



Outliers as defined by SAS, 2012

Overall mean

75% or 3rd quartile

25% or 1st quartile

Figure 20. Analysis of 30-minute TEOM concentrations of PM_{10} vs. time of the day.

The 95% confidence interval for TEOM-PM_{10} and LV-PM_{10} methods were 824–1080 µg/m^3 and 753–1066 µg/m^3, respectively. Paired t-test and nonparametric Wilcoxon signed rank tests were conducted to test the difference between TEOM-PM_{10}

and FBLV-PM_{10} methods (SAS Institute Inc., 2012). The paired t-test shows differences by means and assumes the observations are independent and identically normally distributed (Li et al., 2012). The Wilcoxon signed rank test is a nonparametric version of the paired t-test that compares the sizes of the positive differences to the sizes of the negative differences in medians. This test does not assume the data to be normally distributed (SAS Institute Inc., 2012). The p-values for the paired t-test and the nonparametric tests were 0.28 and 0.23 respectively at 95% ($p < 0.05$) confidence. This shows that the TEOM-PM_{10} concentrations had no statistically significant difference when compared to the FBLV-PM_{10} concentrations.

This was an important finding, as previous studies at cattle feedyards had reported the 24-hour average concentrations measured by TEOM samplers to be 1.7 times the 24-hour average values measured by co-located FBLV samplers for $PM_{10,}$ in the presence of higher concentrations and larger particle diameters (Skloss, 2008; Vanderlick et al., 2011). It must be noted that the concentrations of PM were measured indoors in the layer house, where there were no effects of the meteorological conditions, whereas, cattle feedyards involved collection of PM measurements outside, close to the property lines (Skloss, 2008; Vanderlick et al., 2011).

Based on the four case studies, the emission rates for the laying hen house ranged from 0.045 g/s to 0.21 g/s (8.5 lb/day to 40 lb/day). The emission factors were calculated in terms of grams of PM_{10} per bird per year and mg per hour of PM_{10} per 500 kg liveweight or AU. The 24-hour average TEOM-PM_{10} concentration of 930 $\mu g/m^3$ was used to estimate the PM_{10} emission rates and emission factors (Table 8). Ventilation flow rates adopted using recommendations of MWPS and accounting for oversampling of the pre-collectors of the samplers, resulted in PM_{10} emission factors that were similar to the PM_{10} emissions reported in previous research (Lim et al., 2003; Jacobson et al., 2004).

The PM_{10} emission factors ranged from 470 to 2200 mg/h/AU. High emission factors (1100 and 2200 mg/h/AU) were observed in Cases 3 and 1, where the ventilation fan flow rates were considered with no regard to ambient temperatures. When house ventilation rates with regard to minimum flow rate recommendations specified by the MWPS were adopted (Cases 4 and 2), the emission factors of PM_{10} ranged from 470 to 942 mg/h/AU. A typical commercial egg production operation would consist of about nine laying hen houses similar to the layer house considered in this study (Wang et al., 2012). On estimating the total emissions from the facility in tons per year, the maximum emissions of PM_{10} were 65 tpy. Thus, the PM_{10} emissions did not exceed the thresholds for Title V (100 tpy) and Prevention of Significant Deterioration (250 tpy) permits.

Table 8. Estimated emission rates, emission factors and tons per year of emissions of PM_{10} in the laying hen house based on the 4 scenarios.

Case	Emission Rate		Emission Factor		Tons per Year of Emissions
	g/s	*lb/day*	*g/bird/yr*	*mg/h/AU* [(c)]	*Tpy*
1. High Flowrate[(a)]	0.21	40	68	2200	7.2
2. MWPS 1990	0.09	17	32	942	3.1
3. High Flowrate with OSC[(b)]	0.105	20	34	1100	3.6
4. MWPS 1990 with OSC	0.045	8.5	16	470	1.55

[(a)] Assuming that all the fans were operating at all times of the year without regard to ambient conditions
[(b)] Oversampling correction, factor of 0.5.
[(c)] 1 AU=500 kg liveweight

The particle size distribution of PM emitted in a broiler operation was described by a log-normal distribution with an MMD of 25 μm and a GSD of 1.6, PM_{10} was 6% of TSP (Lacey et al., 2002). The emission factor in the broiler operation was 536 mg/h/AU, the average weight of the 27,500 birds being 1.03 kg. The emission factors in layer houses are recorded in Table 8. The MMD of TSP measured in the laying hen house ranged from 16.8 ± 1.6 μm to 20.3 ± 3.5 μm, whereas GSD ranged from 2.4 ± 0.2 to 2.8 ± 0.3 (Wang et al., 2012). Mean TSP concentrations ranged from 1.0 ± 0.5 mg/m^3 to 5.3 ± 0.4 mg/m^3. Mean PM_{10} fractions ranged from 23.4 ± 5.2% to 38.6 ± 3% (Wang et al., 2012).

Larger PM was emitted in broiler operation (25 μm) than in laying hen houses (18 μm). Higher PM_{10} fractions (23% to 39%) in the layer house were observed compared to broiler facilities (6%). Table 9 shows the MMDs, GSDs, PM_{10} fractions, PM_{10} emission factors, $PM_{2.5}$ emission factors and TSP emissions factor for laying hen houses and broiler operations. The PM_{10} and $PM_{2.5}$ emission factors were 536 and 0.03 mg/h/AU for broiler operations, and 942 and 105 mg/h/AU for laying hen houses (Case 2), respectively. The TSP emission factors were obtained by dividing the PM_{10} emission factors by the fraction of TSP that was PM_{10}. The corresponding TSP emission factors were 8930 mg/h/AU and 3490 mg/h/AU for broilers and layer facilities (Case 2) respectively. Thus, the PM_{10} and $PM_{2.5}$ emission factors were higher but the TSP emission factor was lower, in laying hen houses, compared to broiler operations. This followed the observation of the range of MMDs and the fractions of TSP that comprised of PM_{10} and $PM_{2.5}$, in the two types of facilities.

Table 9. Comparison of emission factors in layer and broiler operations.

Observations	*Broiler Operation (Lacey et al., 2002, 2003)*	*Laying hen house*
MMD (μm)	25	17 to 20
GSD	1.6	2.4 to 2.8
PM_{10} fraction	6%	23% to 39%
PM_{10} Emission Factor (mg/h/AU)	536	942(a)
$PM_{2.5}$ Emission Factor (mg/h/AU)	0.03(b)	105(c)
TSP Emission Factor (mg/h/AU)	8930(d)	3490(e)

(a) Emission factor estimated from PM_{10} concentration of 930 μg/m^3 and minimum flow rate recommendations in MWPS, 1990 (Case 2)
(b) Fraction of $PM_{2.5}$ – 0.00032%, MMD 25 μm, GSD 1.6
(c) Fraction of $PM_{2.5}$ – 3%, MMD 18 μm, GSD 2.6
(d) Fraction of PM_{10} - 6%
(e) Fraction of PM_{10} - 27%

Simulations of downwind PM_{10} concentrations were run using AERMOD for four different cases. Downwind concentrations of PM_{10} at a hypothetical layer house were predicted. The property-line dimensions, such that the emissions of PM_{10} would be lower than 150 μg/m^3 were recorded, by observing the contour levels of the AERMOD-predicted concentrations. A typical contour plot of 24-hour concentrations obtained from AERMOD is displayed in Figure 21. The source groups were marked in red. The concentrations of PM_{10} that were greater than 150 μg/m^3, were the colored region around the source. This case followed the flow rates provided when all the fans were assumed to be running at all times of the year, without regard to ambient temperatures (Case 1).

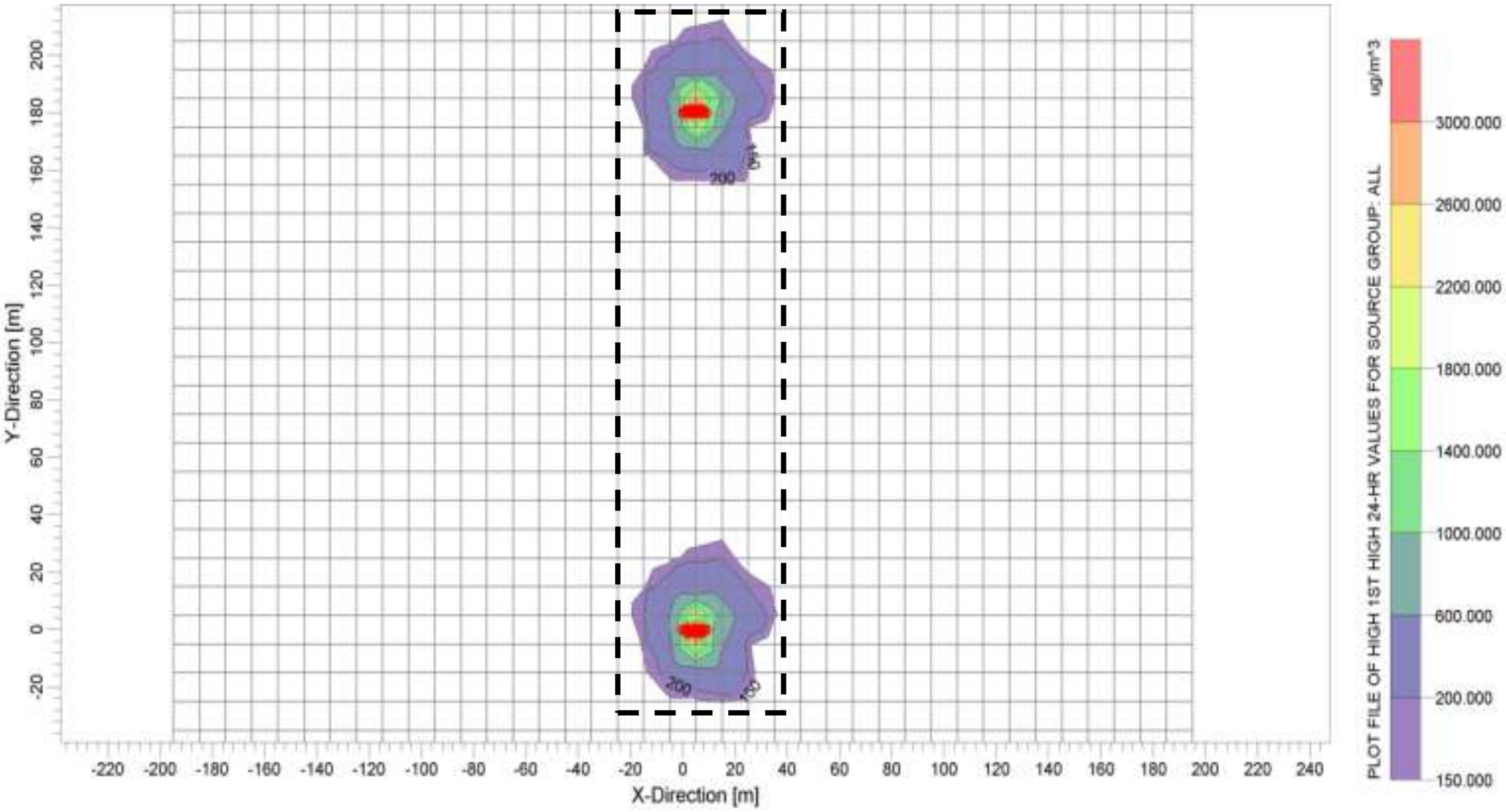


Figure 21. AERMOD prediction of PM_{10} concentrations at a laying hen house for Case 1.

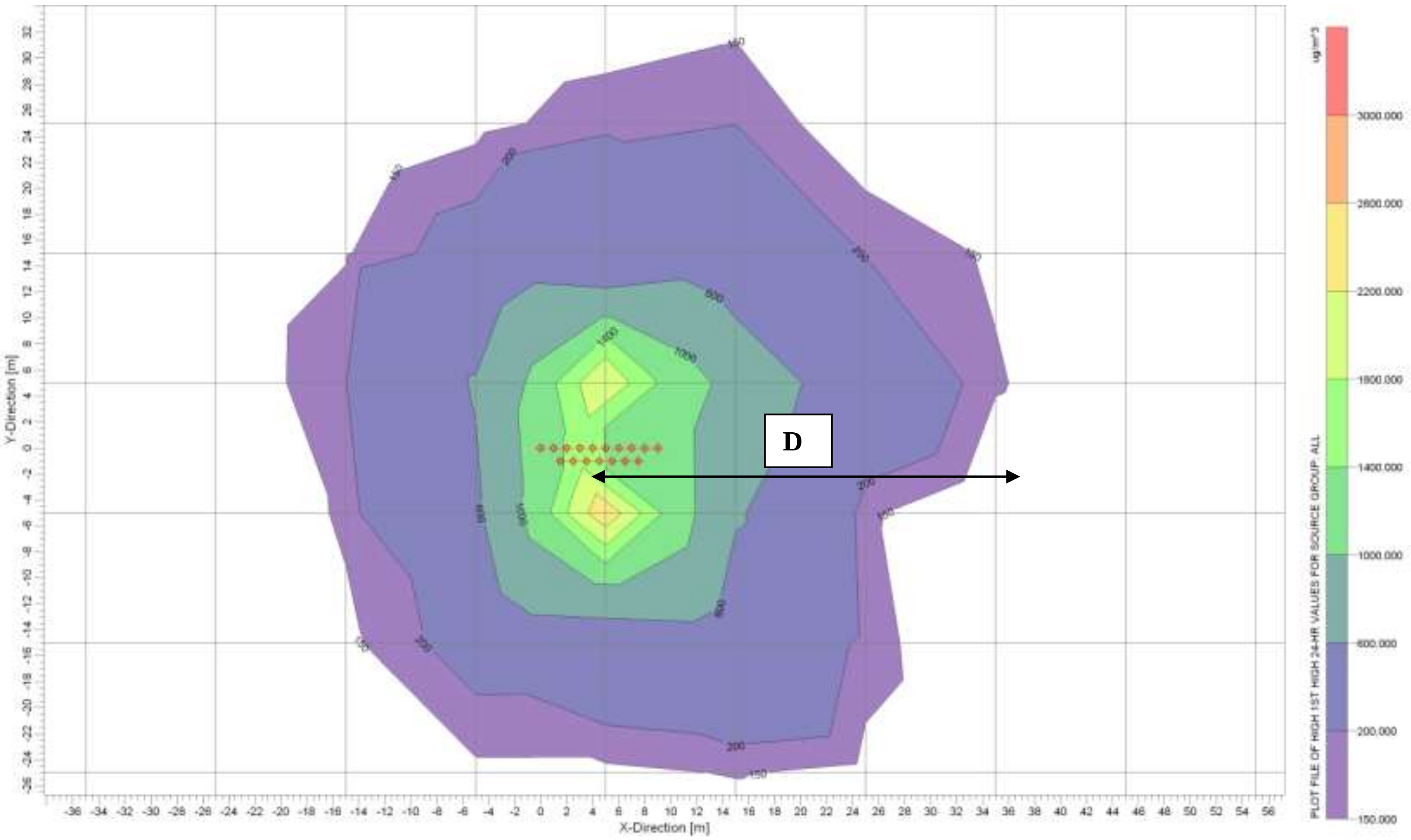


Figure 22. AERMOD prediction of the 24-hour PM_{10} concentrations at one of the two identical source groups in a laying hen house. The shortest distance (D) is the distance at which PM_{10} emission would be lower than NAAQS.

Figure 22 is the plot of 24-hour concentrations from the laying hen facility, focused on one of the two identical source groups for Case 1. The shortest distance from the source, such that its PM_{10} emissions would be lower than NAAQS, were interpreted from these results from AERMOD.

The results for the shortest distances from the sources of PM_{10} emissions such that the facility would be in compliance with the 24-hour average NAAQS for PM_{10} are shown in Table 10. The shortest downwind distance required ranged from 12 m to 40 m.

Table 10. Downwind concentrations of PM_{10} predicted using dispersion model AERMOD.

Scenario	***Property-lines/dimensions Required***		
	Dimensions	***Acres***	***D[c]***
1. High Flowrate[a]	250 m x 60 m (820 ft x 200 ft)	3.7	40 m (131 ft)
2. MWPS 1990	220 m x 30 m (720 ft x 100 ft)	1.6	18 m (60 ft)
3. High Flowrate with OSC[b]	240 m x 50 m (800 ft x 170 ft)	3.0	24 m (79 ft)
4. MWPS 1990 with OSC	200 m x 20 m (700 ft x 100 ft)	1.0	12 m (40 ft)

[a] Assuming that all the fans were operating at all times of the year without regard to ambient conditions

[b] Oversampling correction, factor of 0.5

[c] Shortest distance from each source group in the laying hen house such that the 24-hour average emissions of PM_{10} were lower than 150 $\mu g/m^3$

The property-line dimensions required for the laying hen facility ranged from measurements larger than 200 m x 20 m to 250 m x 60 m. Modeling the 24-hour PM_{10} emissions when all the fans were running at all times resulted in large property-line dimensions. The shortest distances such that the 24-hour average emissions of PM_{10} did not exceed the NAAQS, were large (24 m, 40 m), when maximum possible ventilation flow rates (Cases 3 and 1) were considered. Shorter distances were predicted (12 m, 18 m), when minimum flow rate recommendations (Cases 4 and 2) were considered. If the facility did not provide these distances from the source, it may be in violation of its permit for exceeding the 24-hour PM_{10} standards. Cases 1 and 3 did not take into account the ambient temperatures and hence should not be used to estimate the potential to emit. Care should be taken to consider the recommended or actual flow rates provided for ventilation in the laying hen house so that the PM_{10} emissions from the facility are not overstated, to avoid inappropriate regulation of the facility.

Conclusions

Analysis of TEOM and FBLV concentrations

- Concentrations of TSP and PM_{10} measured using TEOM samplers in a layer house showed a non-uniform distribution of in a 24-hour period. There were significantly high concentrations measured during daytime and low concentrations measured during nighttime. This followed the pattern in which the lights were turned on and off in the house.

- The 24-hour average PM_{10} concentration measured by TEOM samplers was 953 ± 268 μg/m^3. This was obtained from the weighted average of the expected values of daytime and nighttime concentrations.
- The FBLV-PM_{10} sampler measurements for 24-hour PM_{10} concentrations were not significantly different than 24-hour average concentrations obtained from the 30-minute concentrations measured by TEOM-PM_{10} samplers with exclusions of negative concentrations and concentrations 3 * SD higher than the means, inside the layer house. This was a significant finding as earlier studies had shown the concentrations by TEOM samplers to be higher than measurements by low-volume gravimetric concentrations based on the FRM method, in the presence of higher concentrations and larger particle diameters (Vanderlick et al., 2011).

Emission rates and emission factors in the layer house

- The PM_{10} emission factors ranged from 470 to 2200 mg/h/AU. High emission factors (1100 and 2200 mg/h/AU) were observed in cases where the fan flow rates were considered with no regard to ambient temperatures (Cases 3 and 1). When ventilation flow rates with minimum flow rate recommendations specified by the MWPS were adopted (Cases 4 and 2), the emission factors of PM_{10} ranged from 470 to 942 mg/h/AU.
- The assumption that the TSP emission factors of broiler operations would be higher than layer houses was found to be true. The TSP emission factors were 8930 mg/h/AU and 3490 mg/h/AU for broilers and layer facilities (Case 2),

respectively. But the PM_{10} and $PM_{2.5}$ emission factors were higher in layer houses when compared to broiler operations. The PM_{10} and $PM_{2.5}$ emission factors were 536 and 0.03 mg/h/AU for broiler operations, and 942 and 105 mg/h/AU for layer houses (Case 2), respectively.

- The annual emissions of PM_{10} from the layer house did not exceed the thresholds of Title V (100 tpy) and PSD permits (250 tpy). When an egg-production operation with nine layer houses similar to the layer house in this study were considered, the maximum emissions of PM_{10} were 65 tons per year, lower than the thresholds for Title V and Prevention of Significant Deterioration permits.

Predicting downwind concentrations and property lines using AERMOD

- Distances from the sources of PM_{10} emissions, for the layer house to be in compliance with the 24-hour average PM_{10} NAAQS ranged from 12 m to 40 m.
- Not utilizing recommended house ventilation rates and no correction for PM_{10} pre-collector oversampling resulted in large property lines. If a layer house did not have these distances as property lines, the layer house was likely to be in violation of its permit.

This research demonstrated a process for determining the property line distances from the emission source to be in compliance with its permit requirements. A protocol was developed to screen the measured concentrations and exclude invalid data and outliers. The special use of the NAAQS for permitting PM_{10} emissions from agricultural sources, irrespective of whether the off-property concentrations impact the public, can be problematic to agriculture. The particle size distribution of PM emitted by broiler operations was very different from the PSD of PM emitted by layer hen operations. Layer hen facilities had mass median diameters (MMDs) that were small relative to broiler facilities. As a consequence, the mass fraction of PM_{10} was much larger in layer houses. The results of this study were that layer hen operations emitted more PM_{10} than comparable broiler operations. Consequently, the property line distances at which the concentrations of PM_{10} would be below the 24-hour average PM_{10} standard for a broiler operation would be less than that needed for a layer hen facility. Property line distances were reduced when the PM_{10} concentrations were corrected for over-sampling of PM_{10}. If recommended house ventilation flow rates were not considered, higher distances to the property line were predicted. The consequences could be that the facilities be inappropriately regulated. The consequences of a permit violation could be enforcement action and a mandate that the emission rate of the layer house be reduced. Therefore, there is a need to develop PM_{10} emission factors that are representative of accurate emissions from layer houses.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The special use of the NAAQS for permitting PM_{10} emissions from rural agricultural sources, irrespective of whether the off-property concentrations impact the public, can be problematic to agriculture. In this research, a process was developed to determine distances from emitting sources to where concentrations of PM would not exceed the NAAQS. These distances were a function of emission rates of the sources and meteorological conditions at the source location. Dispersion modeling was conducted with the USEPA recommended dispersion model, AERMOD. In order to model the emissions, accurate emission factors are necessary. Different protocols were used to develop emission factors for cattle feedyards and layer houses.

Objective 1

Concentrations of PM_{10} measured using TEOM samplers at cattle feedyards, should be adjusted with scientifically proven corrections. There should be adjustments provided for TEOM vs. gravimetric concentrations, oversampling due to PM_{10} pre-collectors and removal of dust peaks. The corrected daily concentrations measured by TEOM samplers at the cattle feedyard were higher than the 24-hour NAAQS for the month of September 2010, and did not exceed the PM_{10} NAAQS for October, November and December 2010. The daily average TEOM concentrations were higher compared to the predicted 24-hour AERMOD concentrations for September. The AERMOD-predicted concentrations for October, November and December for PM_{10} were higher than measured concentrations provided with corrections. The average PM_{10} emission factors from the CAAQES protocol were 12.3, 13, 4.81 and 3.86 kg/1000 head-day (27.2, 28.7, 10.6 and 8.5 lbs of PM_{10}/1000 head-day) for the months of September, October, November and December, respectively. The average emission factor for the four months was 5.45 ± 8.5 kg/1000 head-day (18.8 ± 10.7 lb of PM_{10}/1000 head-day), which was in congruence with published emission factors. Analysis of PM_{10} emission factors for January to August is recommended for further research.

Objective 2

AERMOD predictions of PM_{10} and $PM_{2.5}$ concentrations from three cotton gins were observed for compliance with the 24-hour PM_{10} and $PM_{2.5}$ NAAQS at property lines. The maximum predicted 24-hour concentrations for PM_{10} and $PM_{2.5}$ did not exceed the NAAQS for the 20 bales/hour cotton gin, from September to December, at the 50 m property line. The emissions from 40 bales/hour and 60 bales/hour sources exceeded the PM_{10} and $PM_{2.5}$ NAAQS for all the months at 50 m distance. All the three gins exceeded the PM_{10} and $PM_{2.5}$ NAAQS at 100 m property line for September to December. As a result, the cotton gins may be in violation of their permit conditions. The predicted 24-hour downwind concentrations for the cotton gins increased as the property line distance increased from 50m to 100m. This was most likely an effect of the plume passing over the 50m distance. This shows that there is a need for careful observation of measured and modeled data when permitting cotton gins; else, the facilities could be inappropriately regulated.

Objective 3

TSP and PM_{10} concentrations measured using TEOM samplers in a layer houses showed a non-uniform distribution of during a 24-hour period. There were significantly high concentrations measured during daytime and low concentrations measured during nighttime. This followed the pattern in which the lights were turned on and off in the house. The 24-hour average PM_{10} concentration measured by TEOM samplers was 953 ± 268 $\mu g/m^3$. This was obtained from the weighted average of the expected values of the daytime and nighttime concentrations. The 24-hour FBLV-PM_{10} sampler measurements were not significantly different from the 24-hour average concentrations obtained from the 30-minute TEOM-PM_{10} concentrations measured inside the layer house. This was an important finding, as previous studies had shown the concentrations measured by TEOM samplers to be 1.7 times the measurements by FRM samplers.

There were four cases considered to estimate the emission rates and emission factors at the layer house. The emissions were based on the house ventilation flow rates and accounted for the oversampling of the PM_{10} sampler pre-collectors. The PM_{10} emission factors ranged from 470 to 2200 mg/h/AU. High emission factors (1100 and 2200 mg/h/AU) were observed in cases where the flow rates were considered with no regard to ambient temperatures (Cases 3 and 1). When ventilation flow rates with minimum flow rate recommendations specified by the MWPS were adopted (Cases 4 and 2), the emission factors of PM_{10} ranged from 470 to 942 mg/h/AU.

The assumption that the emission factors of broiler operations would be higher than laying hen houses was true for the TSP emission factors. The TSP emission factors were 8930 mg/h/AU and 3490 mg/h/AU for broilers and layer facilities (Case 2) respectively. The PM_{10} and $PM_{2.5}$ emission factors were 536 and 0.03 mg/h/AU for broiler operation, and 942 and 105 mg/h/AU for laying hen houses (Case 2), respectively. Thus, the PM_{10} and $PM_{2.5}$ emission factors were higher in the laying hen houses when compared to broiler operations. This was due to the larger PM emitted in broiler operation (25 μm) than in laying hen houses (18 μm), and the higher fraction of dust in the laying hen houses that was PM_{10} (23% to 39%), compared to broiler facilities (6%). Annual emissions of an egg-production operation with nine layer houses similar to the facility in this study were estimated to be 65 tons per year of PM_{10}. These emissions were within the thresholds for Title V and Prevention of Significant Deterioration permits (100 tpy and 250 tpy, respectively).

AERMOD was used to predict the downwind concentrations of 24-hour PM_{10} emitted from a layer house for four cases. The predicted concentrations were analyzed to obtain the distances beyond which the emissions from the facility would not exceed the 24-hour PM_{10} NAAQS. Shortest distances required for the laying hen house to be in compliance with the 24-hour average NAAQS for PM_{10} ranged from 12 m to 40 m. Large boundary lines were required if actual ventilation recommendations and oversampling correction were not provided. If a facility did not have these distances as property lines, the facility was likely to be in violation of its permit.

Conclusions

Objective 1

- A factor of 0.3 should be applied to the downwind TEOM sampler concentrations for PM_{10} measured at cattle feedyards. The 0.3 correction factor includes the correction for TEOM vs. FRM concentrations and the oversampling due to PM_{10} pre-collectors. The removal of invalid data and removal of dust peaks are required.
- The average PM_{10} emission factor for cattle feedyard, developed from the CAAQES protocol, was 5.45 ± 4.09 kg/1000 head-day (12 ± 9 lb of PM_{10}/1000 head-day).

Objective 2

- All the cotton gins exceeded the 24-hour PM_{10} and $PM_{2.5}$ NAAQS at 50 and 100 m, with the exception of the 20 bale/hr plant at 50 m. Both the measured and the modeled data should be carefully observed when permitting cotton gins, to avoid inappropriate regulation.

Objective 3

- TEOM-PM_{10} measurements inside layer hen houses should be corrected for oversampling due to the PM_{10} pre-collectors. The invalid data and the dust peaks should be removed.
- The 24-hour average PM_{10} concentration measured by TEOM samplers was 953 ± 268 $\mu g/m^3$. The 24-hour FBLV-PM_{10} sampler measurements inside the layer house were not significantly different from the 24-hour TEOM-PM_{10} average concentrations, obtained from the 30-minute TEOM-PM_{10} measurements after data smoothing.
- The PM_{10} emission factors in layer houses ranged from 470 to 2200 mg/h/AU. High emission factors (1100 and 2200 mg/h/AU) were observed in cases where the fan flow rates were considered with no regard to ambient temperatures (Cases 3 and 1). When ventilation flow rates with minimum flow rate recommendations specified by the MWPS were adopted (Cases 4 and 2), the emission factors of PM_{10} ranged from 470 to 942 mg/h/AU.
- The TSP emission factors were 8930 mg/h/AU and 3490 mg/h/AU for broilers and layer facilities (Case 2), respectively. The PM_{10} and $PM_{2.5}$ emission factors were 536 and 0.03 mg/h/AU for broiler operations, and 942 and 105 mg/h/AU for layer houses (Case 2), respectively.
- Distances from the sources of PM_{10} emissions, for the layer house to be in compliance with the 24-hour average PM_{10} NAAQS ranged from 12 m to 40 m. Not utilizing the recommended ventilation rates and no correction for PM_{10} pre-

collector oversampling, resulted in large property lines. If a layer house did not have these distances as property lines, the layer house was likely to be in violation of its permit.

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APPENDIX A

METEROLOGICAL DATA FOR MODELING

AERMOD modeling system consists of the main interface and a pre-processor AERMET. AERMET computes the boundary layer parameters generating two meteorological input files; a surface file and a profile file.

The parameters in the surface meteorological data file are as follows:

1. Year
2. Month (1 - 12)
3. Day (1 -31)
4. Julian day (1 - 366)
5. Hour (1 - 24)
6. Sensible heat flux (W/m^2)
7. Surface friction velocity, (m s^{-1})
8. Convective velocity scale, (m s^{-1})
9. Vertical potential temperature gradient above the PBL
10. Height of the convectively-generated boundary layer - PBL (m)
11. Height of the mechanically-generated boundary layer - SBL (m)

12. Monin-Obukhov length, (m)

13. Surface roughness length, (m)

14. Bowen ratio

15. Albedo

16. Wind speed (m/s)

17. Wind direction (degrees)

18. Reference height for wind speed and wind direction (m)

19. Temperature (K)

20. Reference height for temperature (m)

21. Precipitation code

22. Precipitation rate (mm/hr)

23. Relative humidity (%)

24. Station pressure (milli bars)

25. Cloud cover (tenths)

The contents of the profile meteorological data file are as follows:

1. Year

2. Month (1 - 12)

3. Day (1 -31)

4. Hour (1 - 24)

5. Measurement height (m)

6. Top flag = 1, if this is the last (highest) level for this hour, 0, otherwise

7. Wind direction for the current level (degrees)

8. Wind speed for the current level (m/s)

9. Temperature at the current level (C)

10. Standard deviation of the wind direction fluctuations (degrees)

11. Standard deviation of the vertical wind speed fluctuations (m/s)

APPENDIX B

MODELING OF CATTLE FEEDYARD

Parameters used from TCEQ guidance:

The following three parameters were assumed from TCEQ guidance for Swisher County in Amarillo, Texas (TCEQ, 2011).

- Albedo: The value of Albedo used for this data set was 0.18 which is the value prescribed by TCEQ for Swisher county.
- Bowen ratio: Bowen ratio has been assumed to be 1.5 as per TCEQ guidance for Swisher County.
- Surface roughness length: Considering the flat terrain, winter time, and rural category, a surface roughness of 0.01 was assumed for modeling.

The input provided to the pre-processor AERMET using measured meteorological data is shown in Table B-1 (Faulkner, Unpublished data, 2010; USEPA, 1992). The missing cloud cover data was adopted from USEPA published data.

Table B-1: Meteorological data input for AERMET

Year	Month	Day	Hour	Hourly avg Wind Speed m/s	Hourly avg Wind Directiin deg	Hourly avg Temp F	Hourly Relative Humidity %	Hourly Pressure mbar	Total Cloud cover	Opaque Cloud cover
10	10	01	01	2.8	112	59	68	900	0	0
10	10	01	02	2.6	103	55	73	900	0	0
10	10	01	03	2.4	118	56	72	900	0	0
10	10	01	04	2.2	117	55	72	900	0	0
10	10	01	05	2.7	122	55	71	900	0	0
10	10	01	06	2.7	124	54	71	900	0	0
10	10	01	07	2.9	134	54	70	901	0	0
10	10	01	08	3.6	134	56	66	901	0	0
10	10	01	09	6.4	152	62	53	901	0	0
10	10	01	10	6.0	165	67	45	901	0	0
10	10	01	11	5.8	174	71	42	901	0	0
10	10	01	12	5.9	186	75	41	900	0	0
10	10	01	13	6.0	196	78	37	899	0	0
10	10	01	14	5.6	196	81	34	898	0	0
10	10	01	15	5.5	203	82	32	897	0	0
10	10	01	16	5.2	184	83	32	897	0	0
10	10	01	17	5.3	176	83	33	896	0	0
10	10	01	18	5.2	164	82	35	896	0	0
10	10	01	19	4.6	147	77	41	897	1	0
10	10	01	20	5.8	139	72	49	897	1	0
10	10	01	21	4.6	130	69	54	898	1	0
10	10	01	22	4.2	118	66	58	899	0	0
10	10	01	23	3.7	106	63	60	899	0	0
10	10	01	24	3.6	117	61	62	899	0	0