Development of Emissions-Estimating Methodologies for Broiler Operations

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Executive Summary

In 2005, the EPA offered animal feeding operations (AFOs) an opportunity to participate in a voluntary consent agreement referred to as the Air Compliance Agreement (Agreement) (70 FR 4958). Under the Agreement, participating AFOs provided the funding for the National Air Emissions Monitoring Study (NAEMS) – a two-year, nationwide emissions monitoring study of animal confinement structures and manure storage and treatment units in the broiler, egg-layer, swine, and dairy industries. The purpose of this study was to gather baseline uncontrolled emissions data that would be used to develop by the EPA to develop emission estimating methodologies (EEMs). The NAEMS began in the summer of 2007 and consisted of 25 monitoring sites located in 10 states. At the animal confinement sites, the study collected process and emissions data for ammonia (NH_3), hydrogen sulfide (H_2S), total suspended particulate matter (TSP), particulate matter (PM) with aerodynamic diameters less than 10 micrometers (PM_{10}), PM with aerodynamic diameters less than 2.5 micrometers ($PM_{2.5}$) and volatile organic compounds (VOCs).

In accordance with the Agreement, the EPA developed EEMs for animal housing structures and manure storage and treatment units using the emissions and process data collected under the NAEMS and other relevant information submitted to the EPA in response to its Call for Information (76 FR 3060). The EEMs will be used by the AFO industry to estimate daily and annual emissions for use in determining their regulatory responsibilities under the Clean Air Act (CAA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Emergency Planning and Community Right-to-Know Act (EPCRA).

This report presents the background information, data collected, data analyses performed, statistical approach taken and the EEMs developed by the EPA for confinement structures used in the broiler industry. The EEMs provide emissions estimates of the following pollutants for grow-out and decaking/full litter clean-out periods: NH_3, H_2S, PM_{10}, $PM_{2.5}$, TSP and VOCs.

The EPA developed the EEMs using emissions and process information collected from one broiler operation in California (site CA1B) and from two broiler operations in Kentucky (sites KY1B- and KY1B-2). At the CA1B site, monitoring was conducted in two houses from 2007 to 2009. At the Kentucky sites, monitoring was conducted in a single house at each location from 2006 to 2007. Monitoring at site CA1B was conducted under the NAEMS while monitoring at the Kentucky sites was sponsored by Tyson Foods. Because the quality assurance project plan (QAPP) and site monitoring plans for the Tyson study were developed to be consistent with the NAEMS, the EPA considered the data collected under the Tyson study to be an integral part of the NAEMS.

For broiler grow-out periods, the EPA used the emissions and process parameter data collected at the California and Kentucky sites and SAS statistical software to develop the EEMs. To accommodate varying levels of available input data, the EPA developed three EEMs for grow-out periods: EEMs that uses bird inventory data as input parameters (I EEMs); EEMs that uses bird inventory and ambient parameters (IA EEMs) and EEMs based on bird inventory, ambient and confinement parameters (IAC EEMs). For the I EEMs, the input parameters are total bird inventory in the house and their average weight which are typically recorded manually by growers. For the IA EEMs, the input parameters include the bird inventory parameters and ambient temperature and relative humidity. The ambient data can be obtained by either a monitoring system installed at the farm or from a representative local meteorological station. For the IAC EEMs, the input parameters include the bird inventory, ambient meteorological parameters and confinement parameters (i.e., house temperature and relative humidity). A monitoring system that recorded confinement parameters would have to be installed in the broiler house if the IAC EEM is used to determine emissions.

For litter decaking and clean-out periods, the EPA developed emissions factors that relate pollutant emissions to the mass of birds raised on the litter since the previous decaking or full litter clean-out activity and to the duration of the decaking or clean-out period. The EPA considered using regression analyses to develop separate methods for litter decaking and clean-out periods, but rejected this approach due to the relatively small number of emissions and process parameter data values collected during these periods. Also, applying the regression analyses to litter decaking and clean-out periods was further complicated because the data did not fully represent the manner in which the house doors and openings were managed and the specific activities undertaken during these periods while gas and PM sampling were conducted.

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1.0 INTRODUCTION

There are approximately 1 million livestock and poultry farms in the United States. About one-half of these farms raise animals in confinement, which qualifies them as Animal Feeding Operations (AFOs) (USDA, 2007 Census of Agriculture). AFOs are potential sources of the following emissions: ammonia (NH_3), hydrogen sulfide (H_2S), total suspended particulate matter (TSP), particulate matter with aerodynamic diameters less than 10 micrometers (PM_{10}), PM with aerodynamic diameters less than 2.5 micrometers ($PM_{2.5}$) and volatile organic compounds (VOCs).

This report presents emissions-estimating methodologies (EEMs) for determining uncontrolled emissions from a broiler confinement barn. The EEMs were developed based on data collected in the National Air Emissions Monitoring Study (NAEMS) and other relevant information obtained through the EPA's January 19, 2011, Call for Information (see Section 4.0).

The EPA's previous effort to quantify potential emissions from this source sector and the evolution of the Air Compliance Agreement, are described in Section 1.1. Section 1.2 outlines the requirement for the NAEMS established by the Air Compliance Agreement. Section 1.3 describes how the data collected during the NAEMS was used to develop the EEMs.

1.1 EPA's Consent Agreement for Animal Feeding Operations

In August 2001, the EPA published methodologies for estimating farm-level emissions from AFOs in the beef, dairy, swine and poultry (broilers, layers and turkeys) animal sectors (*Emissions from Animal Feeding Operations*, Draft, August 2001). To develop the methodologies, the EPA: (1) identified the manure management systems typically used by AFOs in each animal sector, (2) developed model farms, (3) conducted literature searches to identify emission factors related to model farm components (e.g., confinement, manure handling and treatment system) and (4) applied the emission factors to the model farms to estimate annual mass emissions.

After publication of the EPA's 2001 report, the EPA and the United States Department of Agriculture (USDA) jointly requested that the National Academy of Science (NAS) evaluate the current knowledge base and the approaches for estimating air emissions from AFOs. In its 2003 report (*Air Emissions From Animal Feeding Operations: Current Knowledge, Future Needs*, National Research Council), the NAS concluded the following: reliable emission factors for AFOs were not available at that time; additional data were needed to develop estimating methodologies; current methods for estimating emissions were not appropriate; and the EPA should use a process-based approach to determine emissions from an AFO.

In January 2005, the EPA announced the voluntary Air Compliance Agreement with the AFO industry. The goals of the Air Compliance Agreement were to reduce air pollution, monitor AFO emissions, promote a national consensus on methodologies for estimating emissions from AFOs and ensure compliance with the requirements of the Clean Air Act (CAA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Emergency Planning and Community Right-to-Know Act (EPCRA).

To develop the Air Compliance Agreement, the EPA worked with industry representatives, state and local governments, environmental groups and other stakeholders. Approximately 2,600 AFOs, representing nearly 14,000 facilities that included broiler, dairy, egg layer and swine operations, received the EPA's approval to participate in the Air Compliance Agreement. Participating AFOs paid a civil penalty, ranging from $200 to $100,000, based on the size and number of facilities in their operations. They also contributed approximately a total of $14.6 million to fund the NAEMS.

As part of the Air Compliance Agreement, the EPA agreed not to sue participating AFOs for certain past violations of the CAA, CERCLA and EPCRA, provided that the AFOs comply with the Air Compliance Agreement's conditions. However, the Air Compliance Agreement does not limit the EPA's ability to take action in the event of imminent and substantial danger to public health or the environment. The Air Compliance Agreement also preserves state and local authorities' ability to enforce local odor or nuisance laws. After the EPA publishes the final emissions-estimating methodologies (EEMs) for the broiler, swine, egg layer and dairy sectors, participating AFOs must apply the final methodologies for their respective sectors to determine what actions, if any, they must take to comply with all applicable CAA, CERCLA and EPCRA requirements. If a participating facility ***does not*** trigger CAA, CERCLA or EPCRA permitting or release notification requirements based on the data collected, the facility will have 60 days from the publication date of the final EEMs to submit a written certification to EPA confirming compliance with current applicable requirements under these regulations. If a participating facility ***does*** trigger CAA, CERCLA or EPCRA permitting or release notification requirements, the facility will have 120 days from the publication date of the final EEMs to apply for any required permits under the CAA, or submit any required release notifications under CERCLA or EPCRA. Finally, AFOs that did not participate in the Air Compliance Agreement can use the appropriate EEMs for their sectors to determine what, if any, measures they must take to comply with applicable CAA, CERCLA and EPCRA requirements.

1.2 National Air Emissions Monitoring Study for AFOs

1.2.1 Overview of Emissions and Process Parameters Monitored

In the early planning stages of the NAEMS, representatives from the EPA, USDA, AFO industry, state and local air quality agencies and environmental organizations met to discuss and define the parameters that would be collected by the study. The goal was to develop a comprehensive list of parameters that must be monitored to provide a greater understanding and accurate characterization of emissions from AFOs. By monitoring these parameters, the EPA would have the necessary information to develop EEMs for uncontrolled emissions of particulate matter, ammonia, hydrogen sulfide and volatile organic compounds from animal feeding operations.

The Air Compliance Agreement provided guidance on the emissions and process parameters to be monitored under the NAEMS and the specific components that were to be included in the emissions monitoring plans. In addition, the Air Compliance Agreement identified the technologies and measurement methodologies to be used to measure emissions and process parameter data at each of the broiler, dairy, egg layer and swine monitoring sites. The Air Compliance Agreement required that an on-farm instrument shelter (OFIS) for housing monitoring equipment be located at each site and that the following parameters be monitored for 24 months:

- NH_3 concentrations using a chemiluminescence or photoacoustic infrared gas analyzer.
- CO_2 concentrations using a photoacoustic infrared gas analyzer, or equivalent.
- H_2S concentrations using a pulsed fluorescence gas analyzer.
- $PM_{2.5}$ concentrations using a gravimetric, federal reference method for $PM_{2.5}$ for at least one month per site.
- PM_{10} concentrations using a tapered element oscillating microbalance (TEOM).
- TSP concentrations using an isokinetic, multipoint gravimetric method.
- VOC concentrations using a sampling method that captures a significant fraction of the 20 analytes determined by an initial characterization study of confinement VOC emissions to be the greatest contributors to total VOC mass.
- Animal activity, manure handling, feeding and lighting operation.
- Total nitrogen and total sulfur concentrations determined by collecting and analyzing feed, water, and manure samples.
- Environmental parameters (heating and cooling operation, floor and manure temperatures, inside and outside air temperatures and humidity, wind speed and direction and solar radiation).

- Feed and water consumption, manure production and removal, animal mortalities and production rates.

The Air Compliance Agreement also required that sites estimate the ventilation air flow rate of mechanically ventilated confinement structures by continuously measuring fan operational status and building static pressure and applying field-tested fan performance curves and by directly measuring selected fan air flows using anemometers.

There were some variations in process parameters collected, as not all were applicable to each animal type or site. Additionally, some of the sites may have opted to collect more than required by the Air Compliance Agreement. Table 1-1 lists the process parameters monitored at the NAEMS broiler sites. Section 4.0 discusses the data submitted to EPA, including the amount of data received, in more detail.

Table 1-1. Process Parameters Monitored at the NAEMS Broiler Sites

Parameter		Units
Confinement conditions	Temperature	^{o}C
	Relative humidity	%
	Activity (personnel and bird)	Volts DC
	Light operation	On/off
	Feeder operation	On/off
	Brood heater operation	On/off
Ventilation rate estimation	Fan operation[a]	On/off
	House differential static pressure[a]	Pascals (Pa)
Meteorological conditions	Ambient temperature	^{o}C
	Ambient relative humidity	%
	Barometric pressure	kPa
	Solar radiation	Watts/m^2
	Wind speed	ft/sec
	Wind direction	Degrees
Bird population	Bird age	Days
	Bird inventory	No. of birds
	Average bird mass	kg
Nitrogen mass balance	Feed consumption rate	lb
	Water consumption	gal
	Feed nitrogen content	mg/g
	Water nitrogen content	mg/liter
	Incoming bedding addition rate	lb
	Incoming bedding nitrogen content	mg/g
	Litter volume	ft^3
	Litter nitrogen content	mg/g

[a] Fan operation, differential static pressure and fan performance curves were used to calculate the ventilation flow rate of the broiler house.

1.2.2 NAEMS Monitoring Sites

The EPA provided oversight for the NAEMS and the team of researchers assembled from the following eight universities: Purdue University, Iowa State University, University of California-Davis, Cornell University, University of Minnesota, North Carolina State University, Texas A&M University and Washington State University. Table 1-2 lists the monitoring sites that were established under the NAEMS. The researchers conducted monitoring at 25 different sites in 9 states (California, Indiana, Iowa, New York, North Carolina, Oklahoma, Texas, Washington and Wisconsin). Consistent with the NAEMS Monitoring Protocol, the monitoring sites selected for the NAEMS provided representative samples of typical broiler, egg-layer, swine and dairy operations.

For the broiler sector portion of the NAEMS, monitoring was conducted at the California site (CA1B) from 2007 to 2009. Tyson Foods sponsored an earlier monitoring study at the Kentucky sites (KY1B-1 and KY1B-2) from 2006 to 2007. However, the quality assurance project plan (QAPP) and site monitoring plans for the Tyson study were developed to be consistent with the NAEMS. Therefore, for the purposes of developing methodologies for estimating emissions from broiler operations, the EPA considers the data collected at the Tyson study sites to be an integral part of the NAEMS.

Table 1-2. NAEMS Monitoring Sites

State	County	Site Name	Type of Operation Monitored
California	Stanislaus	CA1B	Broiler (2 Houses)
California	San Joaquin	CA2B	Egg-Layer (2 High-Rise Houses)
California	San Joaquin	CA5B	Dairy (2 Barns)
Iowa	Marshall	IA4B	Swine Sow (2 Barns, 1 Gestation Room)
Iowa	Jefferson	IA3A	Swine Finisher (1 Lagoon)
Indiana	Wabash	IN2B[a]	Egg-Layer (2 Manure-Belt Houses)
		IN2H[a]	Egg-Layer (2 High-Rise Houses)
Indiana	Carroll	IN3B	Swine Finisher (1 "Quad" Barn)
Indiana	Clinton	IN4A	Swine Sow (1 Lagoon)
Indiana	Jasper	IN5B[b]	Dairy (2 Barns, 1 Milking Center)
Indiana	Jasper	IN5A[b]	Dairy (1 Lagoon)
North Carolina	Nash	NC2B	Egg-Layer (2 High-Rise Houses)
North Carolina	Duplin	NC3B	Swine Finisher (3 Barns)
North Carolina	Bladen	NC3A	Swine Finisher (1 Lagoon)
North Carolina	Duplin	NC4A[c]	Swine Sow (1 Lagoon)
		NC4B[c]	Swine Sow (2 Barns, 1 Gestation Room)
New York	Onondaga	NY5B	Dairy (1 Barn, 1 Milking Center)
Oklahoma	Texas	OK3A	Swine Finisher (1 Lagoon)
Oklahoma	Texas	OK4A[c]	Swine Sow (1 Lagoon)
		OK4B[c]	Swine Sow (2 Barns, 1 Gestation Room)
Texas	Deaf Smith	TX5A	Dairy (Corral)[d]

Table 1-2. NAEMS Monitoring Sites

State	County	Site Name	Type of Operation Monitored
Washington	Yakima	WA5A[c]	Dairy (1 Lagoon)
		WA5B[c]	Dairy (2 Barns)
Wisconsin	Saint Croix	WI5A[c]	Dairy (2 Lagoons)[e]
		WI5B[c]	Dairy (2 Barns)
Kentucky	Union	KY1B-1	Broiler (1 House)
	Hopkins	KY1B-2	Broiler (1 House)

[a] Two different types of barns located at the same site were monitored.
[b] Monitoring occurred on two separate dairy farms in Jasper County, IN.
[c] Barns and lagoons were located at the same site.
[d] The reported emission estimates represent the entire corral.
[e] Instrumentation was deployed around two of the lagoons in the three-stage system. The emissions from the two lagoons were reported as a combined value.

1.3 Emission Estimating Methodology Development

Consistent with the Air Compliance Agreement, the EPA developed methodologies for estimating air pollutant emissions from broiler confinement operations using the emissions and process data collected under the NAEMS and other relevant information obtained through the EPA's January 19, 2011, Call for Information (see Section 4.0). Based on the results of the its analysis of emissions trends (see Section 6.0), the EPA developed separate EEMs for broiler grow-out periods and for periods when litter on the confinement house floor was decaked or fully removed from the house (see Section 2.0 for a description of the broiler industry and production processes).

The EPA developed grow-out and decaking/litter clean-out period EEMs for the following pollutants: NH_3, H_2S, PM_{10}, $PM_{2.5}$, TSP and VOCs. Section 7 describes the statistical methodology used to analyze the data and develop the EEMs. Due to issues related to the performance of the gas analyzer at site CA1B and the procedures used to develop speciation profiles for VOC components, the EEM for VOCs is based only on the data from the two Kentucky sites.

For broiler grow-out periods, the EPA used the emissions and process parameter data collected under the NAEMS and SAS statistical software to develop the EEMs. Process data was divided into the following three groups: inventory data (e.g. number of birds and bird weight), ambient data (e.g. ambient temperature, pressure and relative humidity), and confinement data (e.g. building temperature, pressure and relative humidity). All of the process parameters were statistically evaluated to determine if they were predictor variables. In addition, the EPA evaluated whether the predictor variable process data was readily available to the growers, state and local agencies and other interested parties. Based on the results of the EPA's predictor

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variable evaluation process, three EEMs were developed using various process parameters. The three EEMs are as follows and are explained below: an EEM based on bird inventory parameters (I EEMs); an EEM based on bird inventory and ambient parameters (IA EEMs) and an EEM based on bird inventory, ambient and confinement parameters (IAC EEMs).

- I EEMs - The input parameters are data that characterize the bird population in the house (i.e., total bird inventory in the house and their average weight). These parameters are typically recorded manually by the grower without the need for an automated monitoring system.
- IA EEMs - The input parameters are the bird inventory, average bird weight and ambient meteorological parameters (i.e., ambient temperature and relative humidity). The ambient data can be obtained by either a monitoring system installed at the farm or from a representative local meteorological station in the National Weather Service (NWS) Automated Surface Observing System (ASOS) network. Recent data from NWS ASOS sites are readily available through the NWS website (http://www.nws.noaa.gov/asos/). Historical data is also available through the National Climate Data Center (NCDC) website (http://www.ncdc.noaa.gov/oa/ncdc.html), regional climate center websites (http://www.wrcc.dri.edu/rcc.html), state climate office websites (http://stateclimate.org/), and some university websites (e.g., http://mesonet.agron.iastate.edu/ASOS/).
- IAC EEMs - The input parameters are the bird inventory, average bird weight, ambient meteorological parameters and confinement parameters (i.e., house temperature, relative humidity and ventilation rate) collected by a monitoring system installed in the house.

For litter decaking and clean-out periods, the EPA developed emissions factors that relate pollutant emissions to the mass of birds raised on the litter since the previous decaking or clean-out activity and the duration of the decaking or clean-out period. The EPA considered applying the regression analyses to develop separate methods for litter decaking and clean-out periods, but rejected this approach due to the relatively small number of emissions and process parameter data values collected during these periods. Also, applying the regression analyses to litter decaking and clean-out periods was further complicated because the data did not fully represent the manner in which the house doors and openings were managed and the specific activities undertaken during these periods while gas and PM sampling were conducted.

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2.0 OVERVIEW OF BROILER INDUSTRY

Broiler production is the raising of chickens of either sex for meat. A broiler is a young chicken that is characterized as having tender meat, flexible breastbone cartilage and soft, pliable smooth-textured skin. Section 2.1 describes the typical business structure and the size and scale of broiler operations. Section 2.2 explains the production cycle, outlining the practices of growing hatched chicks to market weight, followed by a description of typical confinement houses in Section 2.3. Section 2.4 describes typical manure management practices. Section 2.5 provides a brief overview of the emissions from broiler production.

2.1 Industry Overview

Broiler production is a highly vertically-integrated industry, wherein a common owner or parent company is involved in several phases of the supply chain. For example, a parent company, or integrator, typically operates or contracts every aspect of the broiler production process (e.g., hatcheries, production houses, slaughterhouses, meat packing plants, feed production facilities and food distributors).

For broiler production operations, the integrator typically provides the birds, feed, medicines, transportation and technical support, under contract, to growers who provide the labor and the production facilities to raise the birds from hatchlings to market weight. The contract grower receives a minimum guaranteed price for the birds moved for market. More than 90 percent of all chickens raised for human consumption in the United States are produced by growers working under contract with integrators (USEPA, 2001). Because of this vertical integration, management strategies at the facility level tend to be more uniform than in other sectors of AFOs.

Based on the information reported in the USDA's 2007 Census of Agriculture (http://www.agcensus.usda.gov/Publications/2007/Full_Report/usv1.pdf), 27,091 broiler operations produced 8.9 billion birds for market in 2007. Larger operations dominate broiler production, based on the 2007 Census data. In 2007, approximately 76 percent of the total broiler operations had a confinement capacity of 90,900 birds or less. However, operations with confinement capacities greater than 90,900 birds (approximately 24 percent of the total number of broiler operations) accounted for approximately 67 percent of the total annual bird production. The EPA estimated the confinement capacity by dividing the 2007 bird sales by the 5.5 flocks raised per year (this value for the typical flock turnover rate was obtained from the USDA National Agriculture Statistics Service). In addition to being dominated by large producers, the broiler industry is concentrated in several states. Alabama, Arkansas and Georgia are the largest broiler producing states followed by Mississippi, North Carolina and Texas. California and Kentucky rank 7th and 14th, respectively, in terms of broiler production.

2.2 Production Cycle

The length of the grow-out period ranges from 28 to 63 days, depending on the size of the bird desired. The grow-out period includes a brooding phase that begins when day-old chicks are placed in a heated section of a broiler house known as the brood chamber. The brood chamber is initially maintained at an elevated temperature (e.g., 85 to 95 °F), which is gradually decreased during the first few weeks of the birds' growth. As the growing birds need floor space, the remainder of the house is opened and the chicks are grown to market weight.

Broilers are produced to meet specific requirements of customers, which can be retail grocery stores, fast-food chains or institutional buyers. For broilers, the typical grow-out period is 49 days, resulting in an average bird weight of 4.5 to 5.5 pounds. The grow-out period may be as short as about 28 days to produce a 2.25 to 2.5 pound bird, commonly referred to as a Cornish game hen. For producing roasters weighing 6 to 8 pounds, the grow-out period is may take as long as 63 days.

Broiler houses are operated on an "all in-all out" basis and require time between flocks when the house is empty litter removal (either decaking or full litter cleanout), cleaning (e.g., pressure washing fans), and repair and maintenance. For broilers, five to six flocks per house per year is typical. However, the number of flocks raised per year is dependent on final bird weight, so is lower for roasters and higher for Cornish game hens. Female broilers grown to lay eggs for replacement stock are called broiler breeders and are usually raised on separate farms. These farms produce only eggs for broiler replacements. A typical laying cycle for hens is about 1 year, after which the hens are sold for slaughter.

2.3 Animal Confinement

The most common type of housing for broilers, roasters and breeding stock is enclosed housing with a compacted soil floor covered with dry bedding. Dry bedding can be sawdust, wood shavings, rice hulls, chopped straw, peanut hulls or other products, depending on availability and cost. The bedding absorbs moisture from the manure excreted by the birds, which forms litter (mixture of bedding and manure). Mechanical ventilation is typically provided using a negative-pressure system, with exhaust fans drawing air out of the house, and fresh air returning through ducts around the perimeter of the roof. The ventilation system uses exhaust fans to maintain acceptable housing conditions year round. Advanced systems use thermostats and timers to control exhaust fans.

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2.4 Manure Management

Broiler houses are cleaned between flocks to remove some (i.e., decaking) or all of the accumulated litter. In decaking operations, the upper layer of cake (i.e., the compacted mixture of bedding and manure) that typically accumulates on the house floor near waterers and feeders is removed from the house. The litter remaining after decaking may be "top dressed" with an inch or so of new bedding material before the new flock is placed in the house. When the broiler house is completely cleaned out, the litter is typically removed using a front-end loader. After all litter and organic matter (e.g., feathers adhering to building surfaces) is removed, the house is disinfected.

Litter removed from the house is either immediately applied to cropland and/or pastureland or it is stored for later land application. Water quality concerns have led to the increased use of storage structures known as litter sheds, which are typically partially enclosed pole type structures, to store the cake. Water quality concerns also have prompted the recommendation that cake not stored in litter sheds be placed in well-drained areas and covered to prevent contaminated runoff and leaching. Litter sheds generally are sized only to provide capacity for cake storage because of cost. Thus, because of the larger volume of litter involved with a total facility clean-out, litter is often stored in temporary outdoor stockpiles when manure storage containment structures are at capacity, and/or immediate land application is not possible.

Broiler operations may add litter amendments, such as alum or sodium bisulfate, between the flocks to acidify the litter and reduce NH_3 levels in the houses. However, amendments were not used on the houses monitored as part of the NAEMS.

2.5 Emissions from Broiler Operations

There are three primary sources of emissions associated with broiler operations: (1) the bird confinement house, (2) manure storage and (3) manure land application site. The NAEMS measured emissions from the confinement house and manure storage facility but did not measure emissions resulting from manure land application.

Gaseous emissions (NH_3, H_2S and VOC) from broiler confinement houses are predominately generated by microbial decomposition of bird manure and other materials (e.g., bedding, waste feed) that accumulate on the house floor. Ammonia and VOC emissions are generated under aerobic or anaerobic conditions while an anaerobic environment (e.g., around bird watering stations in confinement houses) is necessary to form H_2S. Emissions of PM from bird confinement houses are primarily due to the entrainment of dry materials (e.g., feed, litter and feathers) caused by movement of birds and personnel in the confinement house.

3.0 NAEMS MONITORING SITES

This section describes the broiler operations monitored under the NAEMS. Section 3.1 explains the site selection criteria and an overview of the sites selected for monitoring. Section 3.2 describes the facility design and animal management practices followed at each site. Section 3.3 summarizes the instrumentation, measurement methods and sampling frequency specified in the site monitoring plans (SMPs).

3.1 Site Selection

Three broiler farms were selected for the NAEMS based on factors specified in the Agreement. In general, these factors focused on the farm's location, configuration, relative size, participation in the Agreement and whether it was representative of the broiler industry. Two houses were monitored at the California farm, designated as CA1B, and a single house was monitored at each of the Kentucky sites. Table 3-1 provides an overview of the sites and their characteristics, based on the information contained in the Quality Assurance Project Plans (QAPPs), SMPs, and site final reports. More detailed descriptions of each site are provided in the following sections.

Table 3-1. NAEMS Broiler Sites Information

Parameter	Site			
	CA1B H10	CA1B H12	KY1B-1 H5	KY1B-2 H3
Site type	Litter on Floor			
House ventilation type	Mechanically ventilated (MV) (tunnel)			
House capacity (no. of birds per flock)	21,000[a]		24,400 (summer) 25,800 (winter)	
Bird type	60% Cobb, 40% Ross		100% Cobb (mixed sex)	
Average animal residence time, days	47		53	
Average bird weight	2.63 kg (5.8 lb)		2.75 kg (6.1 lb)	
Frequency of full litter clean-out	After three flocks		Annually	
Decaking	After each flock		After each flock	
No. of buildings at site	16		8	24
Year of construction	1960s/2002		1992	1991
Ridgeline orientation	East-West		North-South	
House width	12.2 m (40 ft)		13.1 (43 ft)	
House length	125 m (410 ft)		155.5 m (510 ft)	
House area	1,524 m^2 (16,400 ft^2)		2037 m^2 (21,930 ft^2)	
House spacing	12.2 m (40 ft)		18.3 m (60 ft)	
Ridge height	4.2 m (13.8 ft)		5.2 m (17.2 ft)	
Sidewall height	2.3 m (7.5 ft)		2.1 m (7 ft)	
No. of air inlets	60 sidewall/2 tunnel		52 sidewall	

Table 3-1. NAEMS Broiler Sites Information

Parameter	Site			
	CA1B H10	CA1B H12	KY1B-1 H5	KY1B-2 H3
Type of inlet	Baffled eave inlet, 0.18 x 1.32 m (0.6 x 4.3 ft)		Box air inlets 0.15 x 0.66 m (0.5 x 2.17 ft)	
Inlet control basis	Static pressure		Automatic (based on air flow rate)	
No. of ventilation fans	12		14	
Largest fan diameter	1.22 m (48 in)		1.22 m (48 in)	
Smallest fan diameter	0.91 m (36 in)		0.91 m (36 in)	
No. of large fans	10		10	
No. of small fans	2[b]		4	
Spacing between large fans	0.2 m (8 in)		0.2 m (8 in)	
Spacing between small fans	125 m (410 ft)[c]		36.6 m (120 ft)[d]	
No. of ventilation stages	17		12	13
Fan manufacturer	Chore-Time (48 in), Aerotech (36 in)		CanArm	Euroemme
Controls vendor	Chore-Time (48 in), Aerotech (36 in)		Chore-Time	Rotem
Artificial heating	LP Radiant brooders (14), 12.3 kW (42,000 Btu/h)		Pancake brooders (26), 8.78 kW (30,000 Btu/h)	
	LP heaters (3), 52.7 kW (180,000 Btu/h)		Space furnaces (3), 65.9 kW (225,000 Btu/h)	
Summer cooling	Tunnel/evaporative pads		Tunnel/evaporative pads	
Brooding section	East half of house		South half of house	
Monitoring Period	Sept. 27, 2007- Oct. 21, 2009		Feb. 14, 2006 – March 14, 2007	Feb. 20, 2006 – March 5, 2007
Length of monitoring (days)	756		394	379

[a] The NAEMS documentation for site CA1B did not indicate a difference in summer and winter bird placements.

[b] One of the small fans was inactive during the study.

[c] The small fans are located at opposite ends of each house.

[d] The small fans are located along one sidewall of each house.

3.2 Description of Sites Monitored

The NAEMS Monitoring Protocol specified that two broiler sites be monitored as part of the study, one on the west coast and the other in the Southeast to reflect the potential impact of climatic differences and geographical density of broiler production. Furthermore, the NAEMS Monitoring Protocol specified that the houses monitored should be mechanically ventilated with litter-on-the-floor manure handling systems. Final site selection was based on factors outlined in the NAEMS Monitoring Protocol and site-specific factors including facility age, size, design and operation practices and feed and bird genetics.

Both the California and Kentucky sites are representative of the broiler industry in the following aspects: the confinement house design (mechanically ventilated, tunnel), animal management practices (pancake brooder along with space heaters and half-house brooding), and the litter management and handling practices (decaking of houses between flocks with periodic full litter clean-outs).

3.2.1 Site CA1B

The California farm (CA1B) is a 16-house broiler ranch in Stanislaus County, California. Figure 3-1 shows the overall layout of the site, with the two monitored houses (Houses 10 and 12) highlighted. The houses are 125 m (410 ft) long x 12.2 m (40 ft) wide arranged in an east-to-west orientation and are spaced 12.2 m (40 ft) apart. The house roofs have a 4:12 slope with sidewall heights of 2.3 m (7.5 ft).

Each house contains 21,000 birds (per flock) for a total farm capacity of 336,000 birds. Six to seven flocks of birds are raised in each house every year, and all houses are operated on the same grow-out and litter clean-out cycles. The birds housed at the facility over the course of the NAEMS were a 60/40 split between Cobb and Ross genetic varieties and were raised from approximately 0.05 to 2.41 kg (1.1 to 5.3 lb) with an average grow-out period of 47 days. The birds were concentrated in the east (front) end of the houses during the first 10 days of each brooding phase of the grow-out period.

Birds were fed a pelleted diet consisting of corn, soybeans, protein, and poultry fat. Four feed rations were used, specially formulated for weeks 1 and 2, weeks 3 and 4, week 5, and week 6. Feed was delivered to the birds by auger and water consumption was recorded by an automatic water meter. The house lights were turned off for several hours each night. A standby generator supplied power for critical systems during power outages.

Ventilation air entered the house through pressure-adjusted, baffled air inlets at the house eaves (Figure 3-2). The building air was withdrawn from the house using 10, 122-cm (48-inch) diameter belted exhaust fans located in banks of five on both the north and south sidewalls (Figure 3-3). The fans within each bank were spaced 20 cm (8 inches) apart. In addition, a single 91-cm (36-inch) diameter belted exhaust fan was located on the west wall at the back of the house. The fan operation in each house was configured into 8 stages to provide temperature control over the grow-out period. Each house was equipped with six sensors to monitor temperature.

During cooler weather, 14 radiant brood heaters [12.3 kW (42,000 Btu/hr) each] heated the front (east) half of the house, while three liquid propane heaters [52.7 kW (180,000 Btu/hr) each] heated the rest of the house. During warmer conditions, evaporative pads located at the east ends of the houses provided supplemental cooling (Figure 3-4). The evaporative pads were made of a paper product and were 1.2 m (3.9 ft) high, 0.2 m (7.9 inches) deep and 0.3 m (11.8 inches) wide.

Between each flock, the top 20 to 25 percent of the litter was removed from the entire length of the house (i.e., decaking) using a commercial poultry litter removal machine. After decaking, the remaining litter at the front (east end) of the house was moved to the back (west end) of the house and 34.4 m^3 (1,214.8 ft^3) of rice hulls were placed in the front of the house. After three flocks, all litter from the houses was removed (i.e., full litter clean-out). Litter removed from the houses during decaking and full litter clean-out activities was placed in short-term storage piles for two to three days before being taken off site to a fertilizer plant.

Other potential emissions sources near site CA1B were a chick hatchery located approximately 1.6 km (0.99 miles) west of the farm, a 10-house broiler farm located approximately 1.2 km (0.75 miles) to the north-northwest, and a large dairy located approximately 0.8 km (0.5 miles) to the northwest.

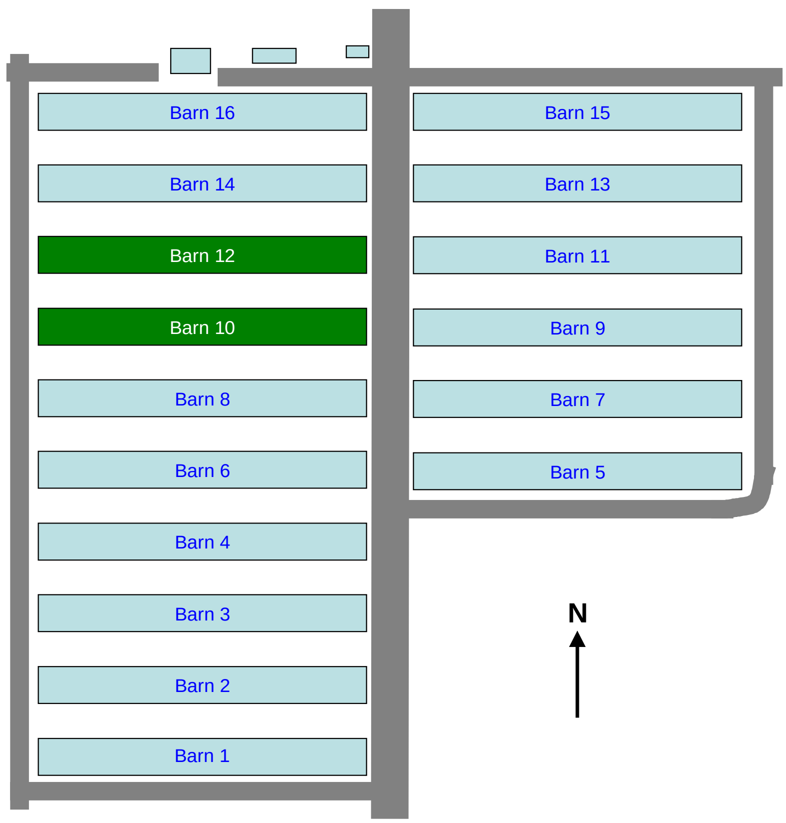


Figure 3-1. California Broiler Site Layout

Figure 3-2. Example House Air Inlet

Figure 3-3. Bank of 122-cm (48-inch) Fans (left, view from inside of house) and (right, view from outside of house)

Figure 3-4. Evaporative Cooling Pads

3.2.2 Sites KY1B-1 and KY1B-2

The two broiler farms, designated as KY1B-1 and KY1B-2, are located in western Kentucky. The KY1B-1 farm has 8 broiler houses and has a total maximum winter capacity of 206,400 birds. The KY1B-2 farm has 24 broiler houses and a total maximum winter capacity of 619,200 birds. Figure 3-5 shows the location of the monitored facilities within Kentucky. The aerial photographs in Figure 3-6 show the locations of the monitored houses at each site.

One broiler confinement house at each farm (designated as KY1B-1 House 5 and KY1B-2 House 3) was monitored. Built in the early 1990s, the two houses each measured 13.1 m x 155.5 m (43 ft x 510 ft). The birds housed during the monitoring period were Cobb-Cobb straight-run (mixed sex) broilers. During the winter, the houses were stocked with an initial placement of 25,800 birds. The initial placement during the summer was 24,400 birds. Typically, the birds were grown to 53 days of market age and an average bird weight of 2.75 kg (6.1 lb).

Each house had insulated drop ceilings, 26 box air inlets [15 x 66 cm (6 x 26 inch)] along each sidewall (see Figure 3-7), 26 pancake brood heaters [8.8 kW (30,000 Btu/hr) each], three space furnaces [65.9 kW (225,000 Btu/hr) each], four 91-cm (36-inch) diameter sidewall exhaust fans spaced approximately 36.6 m (120 ft) apart, and 10, 123-cm (48-inch) diameter tunnel fans. A single 91-cm (36-inch) fan (SW1) used for minimum ventilation was located in the brooding end of each house. Two evaporative cooling pads (24-m (80-ft) sections) were located in the opposite end of the houses from the tunnel fans. The houses were also equipped with foggers for additional cooling, if needed. Rice hulls were used as litter bedding in both houses. Each house was decaked and topped off with fresh litter after every flock, with a full litter clean-out occurring once per year.

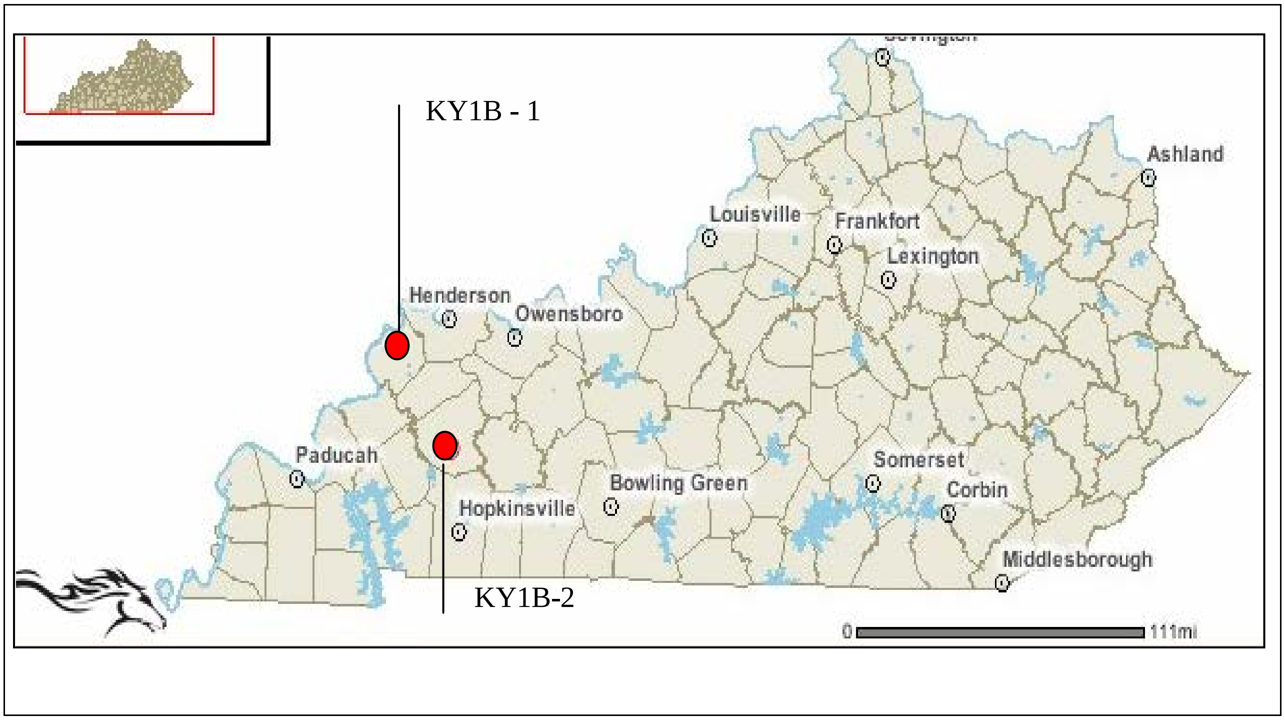
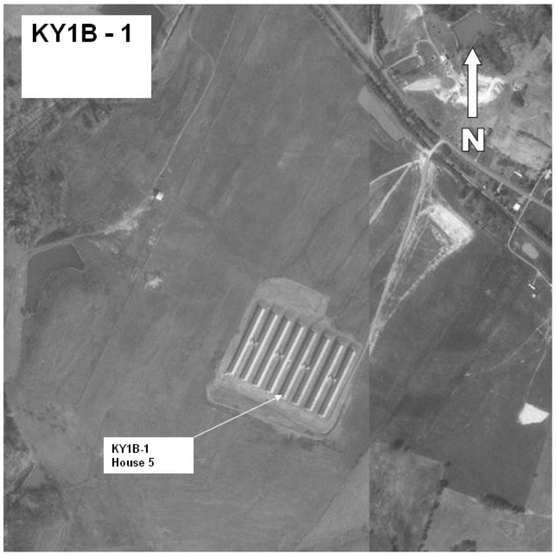


Figure 3-5. Locations of Kentucky Measurement Sites



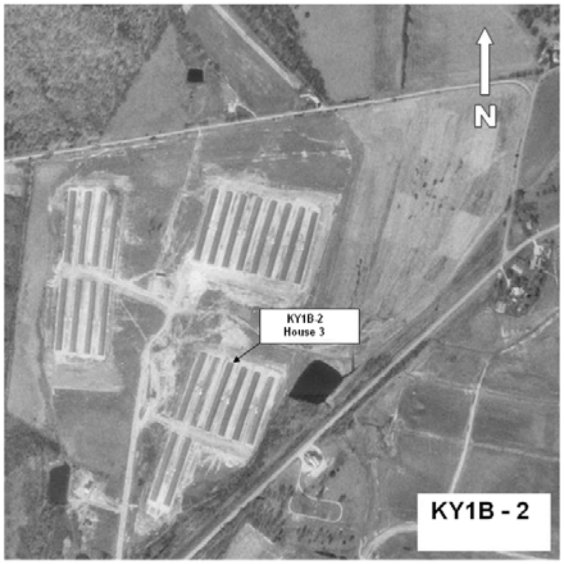


Figure 3-6. Aerial Photographs of Kentucky Monitoring Sites

Figure 3-7. Tunnel Fans and Box Air Inlets

3.3 Site Monitoring Plans

This section provides a summary of the monitoring conducted at each of the broiler sites. Detailed descriptions of the monitoring program, including monitoring equipment specifications and calibration procedures and frequencies, are provided in Appendix A (QAPPs), Appendix B (SMPs), Appendix C [standard operating procedures (SOPs)], and Appendix D (final site reports).

3.3.1 Site CA1B Monitoring Plan

Figure 3-8 shows the configuration of the house monitoring equipment. Installation and preliminary testing of the monitoring equipment was conducted from May 29, 2007 through September 27, 2007. Monitoring of emissions and process parameters began on September 27, 2007 and was completed on October 21, 2009. Table 3-2 lists the sampling locations by analyte.

The on-farm instrument shelter (OFIS) was positioned between houses 10 and 12 at the far west end houses, with a north/south orientation to minimize interference with vehicle traffic along the driveway west of the houses. The OFIS was positioned somewhat off-center in between the houses to leave enough space on one side for vehicle access.

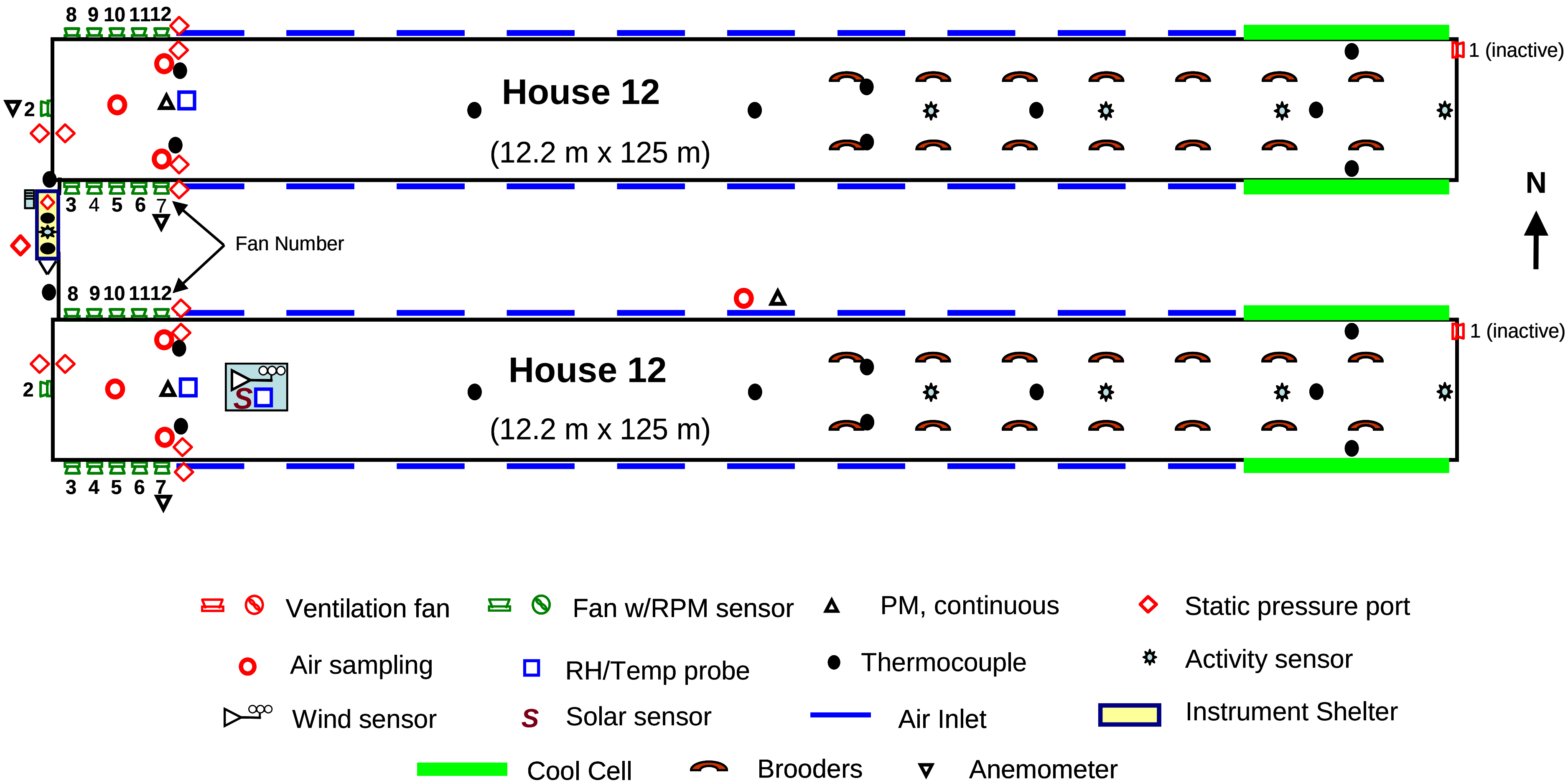


Figure 3-8. Overhead View of Sensor and Air Sampling Locations

Table 3-2. Analyte Sampling Locations at Site CA1B

Analyte	Sampling Location[a]
Gases (continuous measurements for NH_3, H_2S and CO_2)	GSL-A: Directly in front of the inlet of fan 2, along a line connecting fans 5 and 10
	GSL-B: 1 m E of fan 12 and 3 m from N wall
	GSL-C: 1 m E of fan 7 and 3 m from S wall
	INLET: In front of the 5th ventilation inlet from the E end of barn 10 on N sidewall
PM (continuous measurements for $PM_{2.5}$, PM_{10} and TSP)	TEOM: Located 2 m in front of Fan 7
	INLET: Beta-Gage in front of the 5th ventilation inlet from the E end of barn 10 on N sidewall
VOC (grab samples)	1 m E of fan 7 and 3 m from S wall, at fan hub level (GSL-C)

[a] Gas sampling probes were located at fan hub height, suspended from the ceiling. GSL = Gas sampling location.

3.3.1.1 Gas Sampling

A custom-designed gas sampling system (GSS) collected air samples for continuous gas measurements from multiple gas sampling probes located in and near the monitored houses. Each probe was connected to the GSS with Teflon tubing. Tubular raceways between the OFIS and the monitored houses protected the sampling lines and data signal cables. The sampling lines were wrapped with insulation and heated inside the raceways and at other locations vulnerable to cold air to prevent condensation inside the tubes.

The house exhaust emissions were measured using three gas sampling probes (A, B and C) placed in the west end of each house near the exhaust fans at a height equal to the fan hubs (Figure 3-8). Gas sampling probe A was located in front of the inlet of fan 2 and between fans 5 and 10. Two sampling probes (B and C) were located three meters from each sidewall in a cross-sectional plane approximately 1 meter east of fans 7 and 12. Incoming air for both houses was sampled near the air inlet of House 12 at approximately the midpoint (lengthwise) of the house. Other than the exhaust from other houses, the occasional two- to three-day stockpile of litter just outside the far end of the houses was the only on-farm emissions source that could contribute to the concentrations on the inlet air for Houses 10 and 12.

Each exhaust location was sampled and measured continuously for 10 minutes. The inlet air location was monitored for 20 minutes twice daily. After approximately four months of data collection, the gas concentration data were evaluated at each sampling location to determine whether equilibrium occurred within the sampling periods. A statistical analysis confirmed that 10 minutes was sufficient for the exhaust GSLs, but that 30 minutes was required for the house inlet. Consequently, the sampling period for the inlet air was increased from 20 minutes to 30 minutes. Additional detail on the collection method is provided in Appendix A (NAEMS QAPP) and Appendix C (SOP G1). At each sampling location, the gas was analyzed for NH_3, H_2S, non-methane hydrocarbons (NMHC) and CO_2 and the gas analyzer provided concentration readings every second. The average concentration values were recorded every 15 and 60 seconds.

One set of gas analyzers in the OFIS measured gas concentrations as the GSS sequenced through all of the GSLs. A personal computer collected all site monitoring data using a data acquisition and control program (AirDAC). AirDAC averaged the signals (after conversion to engineering units) over 15-second and 60-second intervals and recorded the means into two separate computer files. All real-time data were displayed in tabular and graphic forms for on-site or remote viewing. Measurement alarms, data collection notifications, data files, graphs and statistics of the daily data sets and modified configuration and field note files were automatically emailed to the site investigator and engineer and to the Purdue Agricultural Air Quality Laboratory after midnight each night.

3.3.1.2 PM Sampling

A tapered element oscillating microbalance (TEOM) was placed in each house approximately 6 meters (19.7 ft) in front of fan 7. A Beta Gauge attenuation PM monitor continuously measured the PM concentration of the ambient air. The Beta Gauge was enclosed in a protective outdoor enclosure and was located at the air inlet of House 10. The PM_{10} size-cut heads on the TEOM and Beta Gauge were replaced with $PM_{2.5}$ heads for two, two-week periods over the course of the study, and with TSP heads for one week every 8 weeks (beginning with the first week of data collection).

As shown in Table 3-3, $PM_{2.5}$ emissions were measured in February and July of 2008 and January and September of 2009 continuously for 12 to 18 days each time. The TSP concentrations were measured continuously for six 7- to 14-day periods. Emissions of PM_{10} were measured continuously at all other times. Additional detail on the collection method is provided in Appendix A (NAEMS QAPP) and Appendix C (SOP P1).

Table 3-3. PM Sampling Schedule

Time and Day (mm/dd/yy)		Test Duration (days)		
Start	Stop	PM_{10}	TSP	$PM_{2.5}$
9/28/07	12/10/07	73.6	NS	NS
12/10/07	12/19/07	NS	8.9	NS
12/19/07	2/1/08	44.0	NS	NS
2/1/08	2/19/08	NS	NS	18.1
2/19/08	2/20/08	NS	NS	0.3[a]
2/19/08	2/20/08	0.3[b]	NS	NS
2/20/08	5/15/08	85.7	NS	NS
5/15/08	5/28/08	NS	12.8	NS
5/28/08	7/9/08	42.0	NS	NS
7/9/08	7/25/08	NS	NS	16.0
7/25/08	11/17/08	115.1	NS	NS
11/17/08	11/24/08	NS	7.1	NS
11/24/08	1/5/09	41.9	NS	NS
1/5/09	1/20/09	NS	NS	15.0
1/20/09	4/9/09	79.0	NS	NS
4/9/09	4/20/09	NS	11.0	NS
4/20/09	6/25/09	66.1	NS	NS
6/25/09	7/8/09	NS	12.9	NS
7/8/09	9/26/09	80.1	NS	NS
9/26/09	10/7/09	NS	NS	10.9
10/7/09	10/21/09	NS	14.1	NS
10/21/09	10/22/09	0.4	NS	NS
Totals		628.3	66.7	60.3

NS = Not sampled.
[a] For this sampling episode, ambient concentration data were not collected.
[b] For this sampling episode, only ambient concentration data were collected.

3.3.1.3 VOC Sampling

An initial characterization study of VOCs was conducted during the first quarter after site setup at site CA1B. While NMHC were continuously monitored using photoacoustic infrared spectroscopy along with building air-flow rate, periodic grab samples of VOCs were taken at the primary representative exhaust fan location (as defined in the SMPs) of Houses 10 and 12. The purpose of the VOC grab sampling was to obtain data to speciate the NMHC measurements.

During the initial study, three sampling methods were evaluated to determine which method would be used for the remainder of the broiler study: sorbent tubes and Silcosteel canisters for general VOCs, and all-glass bubblers for amines. Each sorbent tube or canister sample was evaluated using gas chromatography – mass spectrometry (GC-MS); amines collected in bubblers were analyzed by ion chromatography (IC). The results of this initial study were used to identify the top 20 analytes by mass. After consulting to determine which of these analytes were present in sufficient quantities to warrant further monitoring, the EPA and the NAEMS researchers determined that canisters would be use to collect periodic VOC samples over the remainder of the broiler monitoring period.

Grab samples of VOCs were collected at fan 7 in Houses 10 and 12 using techniques based on EPA Methods TO-15 and TO-17. Samples were collected using 6-liter (0.2-ft^3) stainless-steel canisters, equipped with 0.64 cm (0.25 in) bellows valves and 207-kPa (30 psi) vacuum gauges. Sampling trains contained flow controllers with 2- to 4-standard cubic centimeters per minute (sccm) (0.12- to 0.24-cubic inches per minute) critical orifices and 7-µm (2.76E-04 in) in-line stainless steel filters. Flow controllers were pre-set to a constant flow rate of 3.4 mL/min (1.2E-04 ft^3/min). Canister sampling was conducted for a 24-hour period, with canister pressures recorded at the beginning and end of each sampling period to calculate total sample volumes. Seven 24-hour sampling episodes were conducted between July 14, 2009 and October 7, 2009, with duplicate samples typically collected at each exhaust location. All canisters were cleaned and passed a quality control inspection before sample collection.

Purdue University's Trace Contaminant Laboratory analyzed the canister samples. The canisters were pressurized to +207 kPa (30 psi) with ultrapure nitrogen and transferred to sorbent tubes. The pressurized canisters initially yielded sample flows of 50 mL/min (1.8E-03 ft^3/min) during sample transfer to tubes. The canisters were heated when a canister pressure decreased to 13.8 kPa (2 psi) to ensure maximum transfer of nonvolatile components.

Canister samples were analyzed on a thermo-desorption GC-MS, consisting of a GC coupled with a Model 5795 MS detector and equipped with a thermal desorption system and a cooled injection system. The GC-MS passed a leak check prior to analyzing each set of samples. Compounds were separated on a 60 m x 0.32 mm x 1 µm column. The detector utilized the full scan mode covering masses from 27-270 Daltons in 8 scans/second. The MS's quad hold temperature was 150ºC, and the MS source hold temperature was 230ºC. ChemStation evaluated the analytical results, which manually checked all integrations. This method used an external standard compound for instrument monitoring and quality assurance to avoid losses of low-molecular-weight analytes that would occur when purging solvent used with internal standard(s). All thermal desorption system tubes were cleaned with a conditioning system for 3.5 hour at 350ºC prior to each use.

Response curves were generated at both the beginning and the end of the VOC analysis period. The response curves of all chemical standards reach good linearity as 55 percent of the response curves had $R^2 > 99$ percent and over 98 percent had $R^2 > 95$ percent. Toluene was used as an external standard that was analyzed during each batch of samples to ensure quality. The relative bias and standard deviation of 97 toluene checks were -4.3 percent and 18.8 percent, respectively. The uncertainty of the mean of duplicate field samples was calculated as 27 percent, based on the toluene checks.

3.3.1.4 Building Air Flow

The ventilation air flow for each monitored house was calculated as the sum of the volumetric flow rates for all fans operating over a given time interval. The baseline air flow curves of each type of fan were obtained from the Bioenvironmental and Structural Systems (BESS) Laboratory at the University of Illinois, Urbana-Champaign (Appendix C, SOP A1). Each performance record used to develop the fan curves consisted of air flow measurements (Q1) at several static pressure values (P1), and at relatively constant rotational speeds (N1 = 779 and 550 rpm for small and large fans, respectively). For each fan type, the BESS fan curve was adjusted to the mean speed (N2) of the fan tests (530 and 749 rpm for the large and small fans, respectively). The new, speed-indexed baseline curves were derived using the first ($Q_2 = Q_1(N_2/N_1)$) and second ($\Delta P_2 = \Delta P_1(N_2/N_1)^{0.5}$) fan laws, where Q_2 is the speed-adjusted BESS fan curve at speed N_2. The speed-corrected air flow prediction model is $Q_4 = (a\Delta P_4 + b)\cdot(N_4/N_2)\cdot Q_2$, where ΔP_4 and N_4 are measured fan static pressure and speed.

Rotational speed and operational status of the fans installed in each house were monitored using a magnetic Hall-effect sensors (speed sensor) installed on each fan (except for fan 1 which was inactive). The speed sensors were mounted to detect the rotational speed in revolutions per minute (rpm) of either the fan shaft or the fan pulley. The digital signal from the speed sensor was converted into a frequency measurement with a counter module in the data acquisition system. Additionally, impeller anemometers were installed on the outlet of fans 2 and 7 in House 12 and fan 7 in House 10. The differential static pressure was measured across the north, south and west walls of each house using pressure transducers. The outside port was located against the outside wall near the ventilation fans of the north, south and west walls. Additional detail regarding the air flow calculations is provided in Appendix A (NAEMS QAPP) and Appendix C (SOP A4).

The air flow rate of installed fans was measured using a Fan Assessment Numeration System (FANS). The FANS consists of a housing containing five impeller anemometers mounted horizontally. To measure the flow rate of an individual fan, the housing is centered vertically and horizontally on the exhaust side of the fan to be tested and the anemometer readings provide the average air velocity across a known cross-sectional area. Additional detail on the FANS analyzer is provided in Appendix A (NAEMS QAPP) and Appendix C (SOP A2).

The field data obtained from the FANS were used to develop equations that calculated air flow as a function of differential pressure and fan rotational speed and to assess the uncertainty in air flow predictions. A total of 237 FANS tests with replication were conducted during April and June of 2008 and April, July and September of 2009. Each fan was tested at least once during three or more of the five testing periods. The fan belts had been recently replaced prior to the tests in June 2008. For a given test using the FANS, the model is $Q_4 = (a \cdot \Delta P_3 + b) \cdot (N_3/N_2) \cdot Q_2$, where ΔP_3 and N_3 are the measured fan static pressure and speed during the fan test, and the fan degradation factor $k = a \cdot \Delta P_3 + b$. The values for the coefficients a and b were those that minimized the sum of square differences between Q_4 and Q_3 for all the valid fan tests within a speed regime. Table 3-4 shows the resulting fan models.

Table 3-4. Fan Air Flow Models

Fan Type	Reference Speed (N_2)	Polynomial Coefficients of $Q_2=f(\Delta P_2)$ at Speed N_2				Coefficients of k	
		a3	a2	a1	a0	b1	b0
Large	530	2.943E-06	-2.304E-04	4.368E-02	9.412	8.213E-04	0.887
Small	749	1.474E-05	5.108E-04	3.908E-02	5.617	4.196E-03	0.697

3.3.1.5 Meteorological and Confinement Data

At site CA1B, the following meteorological data were continuously recorded: ambient temperature, ambient relative humidity, atmospheric pressure, solar radiation, wind direction, and wind speed. The meteorological instruments (i.e., a capacitance-type relative humidity and temperature probe (RH/T), a pyranometer, and a cup anemometer) were mounted on a 1-meter aluminum tower located on the ridge of House 10 near the OFIS.

To measure the building environmental conditions, RH/T sensors were located at the center of the west end of each house. Type-T thermocouples (TCs) were used to measure temperatures at each sampling point not already monitored with a RH/T probe and were also equally spaced along the center of each house. The TCs were attached to the support posts that ran down the center of the house at 3-meter intervals. Two TCs were located next to the two brooders closest to the OFIS, and two were located at the center of the evaporative pads. A TC was added on April 9, 2009, to monitor the manure temperature in House 12 at floor level.

Thermocouples were also located in the heated raceway between the houses and OFIS. Two TCs were located in the OFIS to measure the temperature of the OFIS and the air-conditioning system. One TC monitored the temperature in the ambient PM monitor enclosure. Additional detail on the collection method is provided in Appendix A (NAEMS QAPP) and Appendix C (SOPs E1 and E2).

3.3.1.6 Animal Husbandry and Building Systems

Infrared motion detectors (activity sensors) were mounted to roof support posts along the center axis of the house to monitor movements of birds and workers. An activity sensor was also used to monitor researcher presence in the OFIS.

The producer recorded data on animal inventory and mortalities manually on a daily basis and provided this information to the NAEMS site personnel. The average mass of the birds between 1 and 47 days old was measured at least weekly during three consecutive cycles of birds. For each measurement period, 25 or 50 birds of each gender (50 or 100 total) were measured in each house and the average mass reported.

The relays that controlled lights, brooders and feeders were monitored in each house using auxiliary contacts in 5V-DC circuits in conjunction with the digital inputs of the data acquisition system.

3.3.1.7 Biomaterials Sampling Methods and Schedule

An independent laboratory, Midwest Laboratories, Omaha, NE, performed all analyses of biomaterials (e.g., litter, bedding). The water provided to the birds in August 2009 was analyzed to evaluate the nitrogen content of the water. Samples of feed and fresh bedding (rice hulls) were collected in duplicate from each house and analyzed for nitrogen and solids. Additional detail regarding the biomaterial sample handling and analyses is provided in Appendix A (NAEMS QAPP) and Appendix C (SOP M1).

On April 15, 2008, the manure mass removed during a full litter clean-out, estimated from the square area and average mass of manure per unit area, was 88,000 kg (97 tons) in House 10 and 79,000 kg (87 tons) in House 12. The total volume of fresh bedding brought into each house on April 18, 2008 after a full litter clean-out was 118 m^3, based on measured litter density.

The estimated volume of litter removed by the decaking procedure was 30 to 45 m^3 (1,059 to 1589 ft^3), based on the volume of manure removed from a house on December 31, 2007, and the average volume of litter removed from multiple houses on January 2, 2008. The amount of bedding used to replenish litter volume after decaking operations was not specified in the final reports submitted to EPA. The density of decaked litter (474 g/m^3, 0.03 lb/ft^3) was determined from a 15.3-liter (0.54-ft^3) sample.

Three types of manure samples were collected: surface litter, decaked litter and litter removed during full clean-out. Surface litter samples were collected over the grow-out period from 16 random locations per house, including 8 samples from the front of the house with relatively fresh litter and 8 from the back of the house with the older litter. The two groups were considered representative of the house litter. At each sampling point, all litter within a 0.6-m radius was brought to the center of the sampling location and mixed thoroughly. Composite samples from the mixtures were analyzed for pH, solids and NH_3. Decaking and complete litter clean-out samples were collected from the blended litter pile before it was removed from the site. A total of 12 samples were collected for each litter decaking and clean-out event and analyzed for ash (after December 2, 2008), nitrogen and solids content.

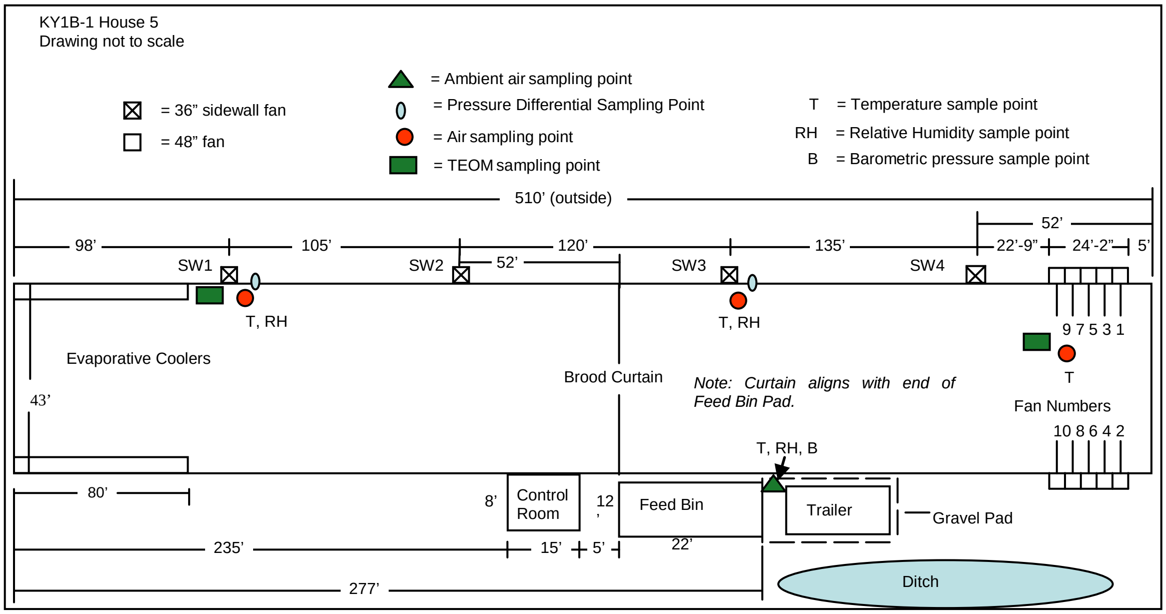
3.3.2 Sites KY1B-1 and KY1B-2

Figure 3-9 and Figure 3-10 show the schematics of the monitoring plan for the Kentucky sites, and Table 3-5 lists the locations at which the various samples were collected. Equipment was installed by January 06, 2006, and preliminary testing was completed on February 10, 2006. The monitoring periods ran from February 14, 2006, through March 14, 2007, for KY1B-1, and from February 20, 2006, through March 5, 2007, for KY1B-2.

Each broiler house has its own Mobile Air Emissions Monitoring Unit (MAEMU) that contains the air pollutant and fan flow monitoring systems and provides an environmentally-controlled instrument area. Locations of the MAEMU are noted in Figure 3-9 as the “trailer.” Figure 3-10 shows a cross-section view of monitor placement. Heated raceways connected the MAEMU to each house to avoid condensation in the sampling lines during cold weather.

Table 3-5. Analyte Sampling Locations at Sites KY1B-1 and KY1B-2

Analyte	Sampling Location
Gases (continuous measurements for NH_3, H_2S, NMHC, CO_2)	SW1: near the primary minimum ventilation (36-in) sidewall fan (SW1); 1.2 m (4.0 ft) away from the fan in the axial direction, 2.3 m (7.5 ft) in the radial direction, and 1 m (3 ft) above the floor
	SW3: fourth sidewall (36-in) exhaust fan (SW3) (non-brooding end); 1.2 m (4.0 ft) away from the fan in the axial direction, 2.3 m (7.5 ft) in the radial direction, and 1 m (3 ft) above the floor
	TE: tunnel end (TE); at the center across the house (for example, 6.6 m or 21.5 ft from each sidewall) and 7.3 m (24.0 ft) from the end wall
	A: ambient sample location (A) is between the inlet boxes opposite of the sidewall with the exhaust fans
PM (continuous measurements for $PM_{2.5}$, PM_{10}, TSP)	TEOM: During the brooding period, the TEOMs are placed at SW1 sampling location. When the brood curtain is open, the TEOMs are moved to the TE sampling location.



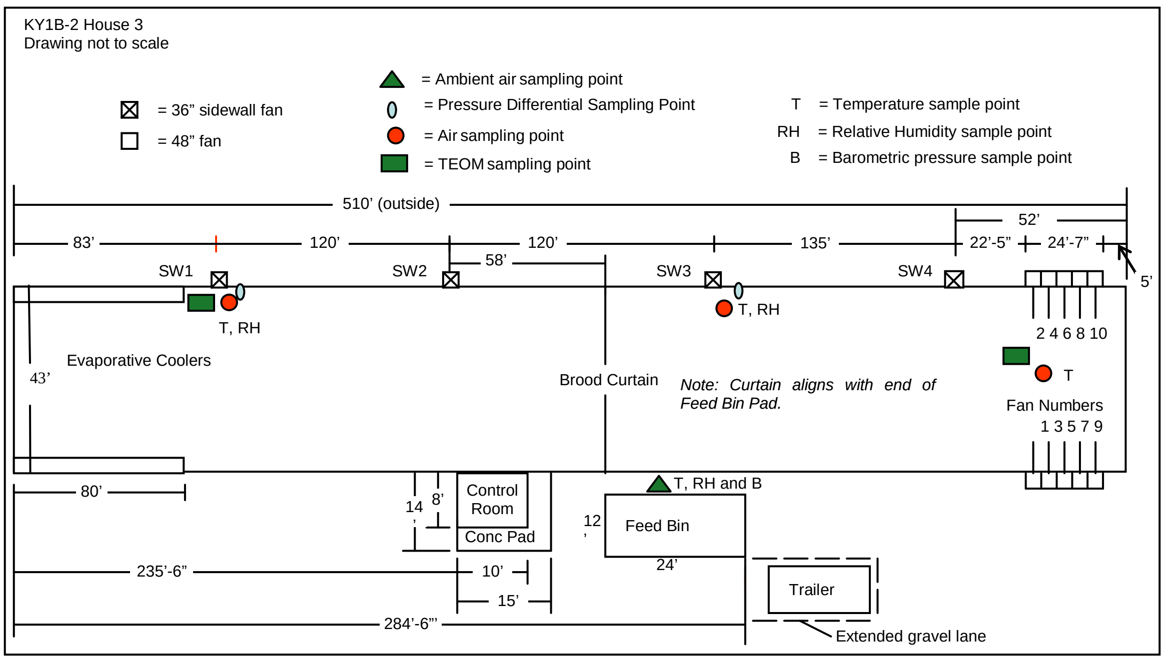


Figure 3-9. Schematic of KY1B-1 (top) and KY1B-2 (bottom)

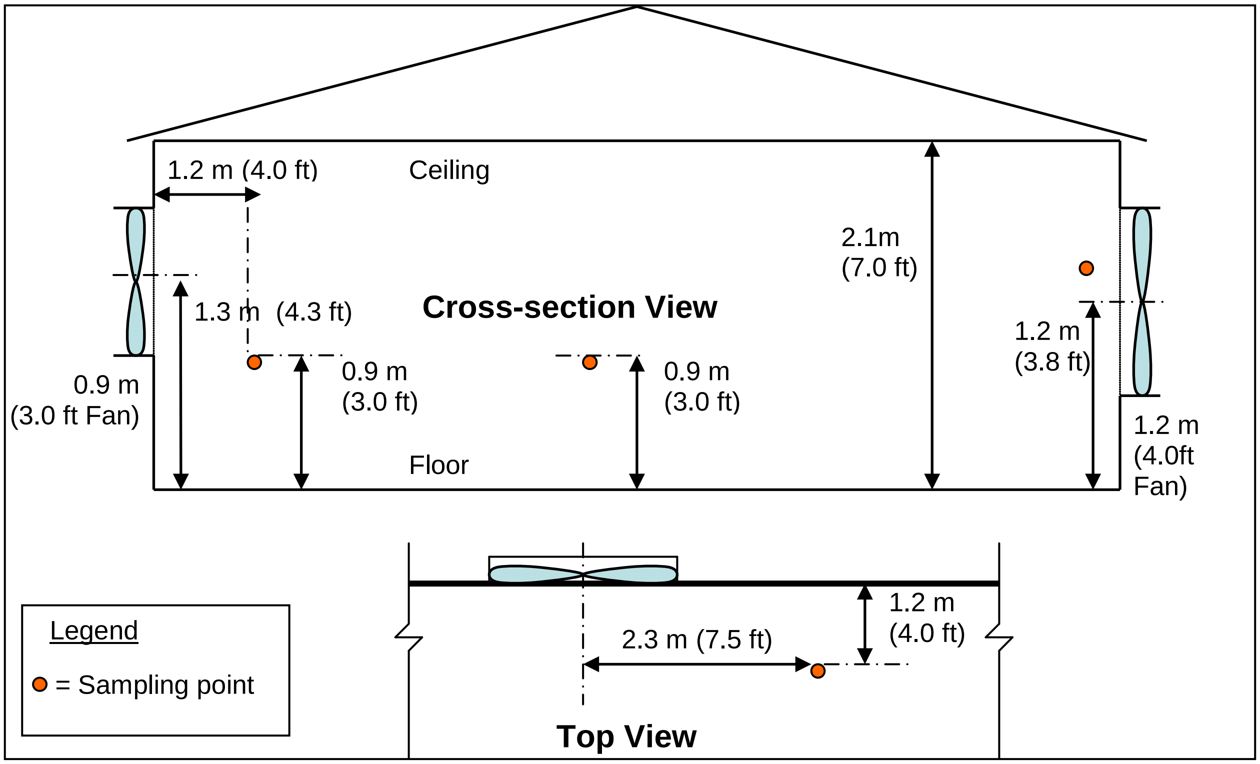


Figure 3-10. Cross-sectional View of Sidewall Sampling Locations

3.3.2.1 Gas Sampling

Individual air samples for both in-house and background locations were collected using a GSS that was designed to collect samples from four locations on a cyclical basis. Gases and PM were sampled when the house ventilation system was in operation. Gaseous emissions were sampled continuously on a 120-second interval (i.e., samples were continuously collected and analyzed every 30 seconds, with every fourth concentration value used to calculate emissions). A real-time data acquisition (DAQ) system program developed with LabView 7 was used to acquire data, automate sampling location control, display real-time data and deliver data and system operation status.

Air samples moving from the broiler house sampling points (representing the exhaust air streams) to the instrument trailer/analyzers were protected against in-line moisture condensation with insulation and temperature-controlled resistive heating cable. The samples were pumped into the GSS with pumps on its inlet side, making it a positive-pressure system. Using this approach ensured that the integrity of the gas sample was not compromised if a leak developed at any connection point on the GSS.

Three sampling points were located inside each broiler house at two sidewall fans and at the tunnel end. The fourth sampling point was located outside of the broiler house and was used as the ambient measurement point for background concentration determination. Figure 3-9 shows the location of the sampling points in KY1B-1 and KY1B-2. One sampling location was near the primary minimum ventilation sidewall fan (SW1) used for cold weather ventilation (in the brooding half of the house). The second sampling location was near the third sidewall fan (SW3, nonbrooding end). The third location was at the tunnel end (TE). The ambient sample location (A) was between the inlet boxes opposite of the sidewall with the exhaust fans. The mass of pollutant in the background (inlet) air was subtracted from that in the exhaust air when calculating aerial emissions from the house.

Hydrogen sulfide was measured by ultraviolet (UV) pulsed fluorescence analyzer. Concentrations of NMHC were measured with a methane/nonmethane/total hydrocarbon analyzer using column technology to separate methane and nonmethane from total hydrocarbons and a dual flame ionization detector (FID) to measure each component in the air sample. Concentrations of NH_3 and CO_2 for the ambient (or incoming air) and exhaust air were measured with an advanced photoacoustic multigas analyzer.

Every two hours, air samples from the ambient location were collected and analyzed for 8 minutes. The longer sample analysis time for the ambient point was to account for the longer response time of the instrument when measuring a potentially large step change in gas concentration. The 2-hour interval for the analysis of the ambient concentrations was selected because the ambient conditions remained relatively constant compared to the in-house conditions.

3.3.2.2 PM Sampling

Each of the Kentucky sites was equipped with a TEOM monitor to measure the PM mass concentration of the exhaust air. Three different inlet heads were used on the TEOMs to simultaneously measure TSP, PM_{10} and $PM_{2.5}$ continuously over the study period. The TEOM 1400a is a gravimetric instrument that draws ambient air through a filter at a constant flow rate, continuously weighing the filter and calculating near real-time mass concentrations. The mass concentration was recorded at 1-second intervals and the average readings, which were correlated to the INNOVA 1412 sampling interval, were used for the PM emissions calculation provided in the final report for the Kentucky sites.

Due to concerns that the TEOMs might not function properly under high-velocity conditions near the exhaust fan, an in-house evaluation of the TEOM performance was conducted to determine the optimal placement of the instruments. The first phase of testing consisted of assessing the TEOM performance in air velocities ranging from 1.3 to 6 $m \cdot s^{-1}$ (250 to 1200 feet per minute) and revealed that the TEOM readings are unaffected by the tested air velocity range. In the second phase of testing, the TEOMs were placed near the center of the house. Comparison of TEOM readings taken near the house center versus near the exhaust location revealed that concentrations near the exhaust were generally lower than concentrations near the center of the house. Because velocity showed no impact on the concentration measurement and the goal of the NAEMS was to quantify the emissions going out of the house, the TEOMs were located near the exhaust fan(s).

During the half-house brooding period, the TEOMs were placed near SW1, 0.6 m (2 ft) from the fan in the axial direction. The individual monitors were located at different distances in the radial direction: the TSP TEOM was located 1.1 m (3.5 ft) to the left of the fan, the PM_{10} TEOM was 1.1 m (3.5 ft) to the right of the fan, and the $PM_{2.5}$ TEOM was located 2.2 m (7 ft) to the right of the fan. After the birds were released into the full house (between 10-14 days old), the TEOMs were moved to the tunnel end sampling location: 4.9 m (16 ft) from the tunnel fan in the axial direction. The TSP TEOM was located 11 m (36 ft) from the tunnel end of the house, the PM_{10} TEOM was located 9.8 m (32 ft) from the tunnel end of the house, and the $PM_{2.5}$ TEOM was located 8.5 m (28 ft) from the tunnel end of the house. Figure 3-9 shows the TEOM sampling locations. Additionally, the TEOMs were placed outside the broiler houses to measure the ambient background PM concentrations at KY1B-1 from March 22 to April 21, 2007.

3.3.2.3 VOC Sampling

The NAEMS Monitoring Protocol specified using EPA TO-15 to speciate NMHC emitted from these facilities. Stainless steel canisters were used to collect the air samples from the two broiler houses; a GC-MS method was used to speciate the NMHC compounds. A solid sorbent method (TO-17) was used simultaneously to collect the air samples on glass sorbent tubes. Sample collection and speciation trials were conducted on April 19, 2006, at KY1B-2 (empty house) and on February 6, 2007, at KY1B-1 (with birds in house). The air samples were collected from nine different locations throughout the whole house, including each air sampling location (Figure 3-11). The top 25 compounds were speciated with the TO-15 and TO-17 methods.

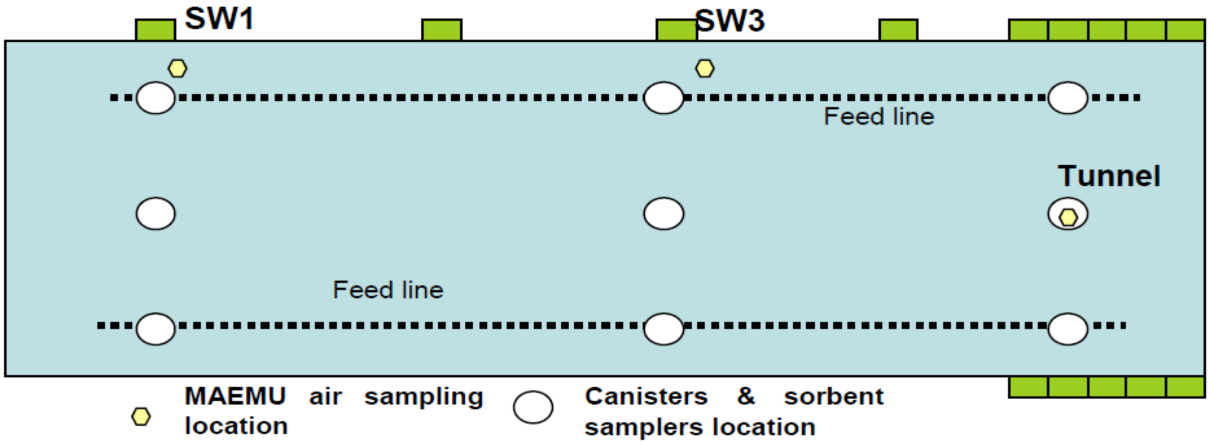


Figure 3-11. Analyte Sampling Locations

3.3.2.4 Building Air Flow

The running time of each fan was monitored continuously using an inductive current switch (with analog output) attached to the power supply cord of each fan motor. The voltage signal from induction current switches attached to the fan power cords were sampled every second and recorded every 30 seconds as the average or duty cycle of the time interval.

Static pressure was measured continuously at SW1 and SW3 locations with a differential pressure transducer. These locations provided building static pressure measurements in both brooding and nonbrooding portions of the production houses.

Ventilation rates of the houses were measured using the following procedure. First, all exhaust fans were calibrated in situ, using a FANS unit to obtain the actual ventilation curves (air flow rate versus static pressure). The FANS measured the total air flow rate of a ventilation fan by integrating the intake velocity field obtained from an array of five propeller anemometers used to perform a real-time traverse of the air flow entering ventilation fans of up to 122 cm (48 in) diameter.

At the beginning of the study, all 14 ventilation fans in each house were calibrated by FANS and fan curves were developed. Three to four fans in each house (at least 20 percent of the total fans) were randomly chosen and calibrated at the beginning of each flock for retesting. If differences in the fan flow rate from the previous calibration were greater than 10 percent, all fans were recalibrated.

Fan ventilation rates (cfm) for each running fan were determined using the building static pressure difference (SP, Pa) and the calibration equation for the fan, as follows:

$$Q_{FAN} = A*(\text{Static pressure, inch})^2 + B*(\text{Static pressure, inch}) + C$$

The parameters A, B and C are fan-specific and were obtained from regression of the FANS calibration data (see Table 3-6 and Table 3-7).

Summing air flows from the individual fans during each monitoring cycle or sampling interval produces the overall house ventilation rate, $Q'_{o.}$ When large spatial variations were noted, the building ventilation rate was broken into representative amounts near each sampling location, typically two values in the broiler house (e.g., $Q'o_1$ and $Q'o_2$).

Table 3-6. Fan Air Flow Models for KY1B-1

Fan ID	Ventilation Rate, cfm = A * (Static Pressure, inch)^2 + B * (Static Pressure, inch) + C											
	September 2005			December 1, 2005			February 11, 2006			April 11, 2006		
	A	B	C	A	B	C	A	B	C	A	B	C
Fan 1	11719	-27449	10948	-125719	239.9	9866.7	-16193	-16591	10708	-16193	-16591	10708
Fan 2	-74375	-12522	10800	-70156	-11629	11127	Not Tested	Not Tested	Not Tested	-52411	-16095	10832
Fan 3	-35469	-21136	9937	43670	-34956	11246	-51604	-13056	10257	-816.07	-20832	9627.9
Fan 4	-53750	-18508	10279	-47062	-14441	10175	Not Tested	Not Tested	Not Tested	59937	-39618	11259
Fan 5	-73750	-61360	17624	-5010469	11666	16847	-145497	-53723	18821	-191642	-41800	17382
Fan 6	102500	-112015	19647	-109817	-54465	17997	-5190.3	-76587	19018	-65045	-71060	18277
Fan 7	-98750	-81440	19707	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-33831	-66266	17584
Fan 8	2578.1	-96907	20675	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-561449	10225	16769
Fan 9	48984	-96008	19035	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	265002	-112655	18225
Fan 10	215885	-132748	21203	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-248939	-26295	17682
Fan 11	-42266	-82438	18652	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	96907	-99875	18616
Fan 12	-26562	-83028	20131	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-48248	69382	18460
Fan 13	109609	-117881	20425	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	306517	-143433	20552
Fan 14	79219	-94836	18649	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	212523	-122196	19134

Table 3-7. Fan Air Flow Models for KY1B-2

Ventilation Rate, cfm = A * (Static Pressure, inch)^2 + B * (Static Pressure, inch) + C												
Fan ID	**July 2005**			**December 5, 2005**			**February 24, 2006**			**May 15, 2006**		
	A	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Fan 1	6403.3	-29082	9642.3	-7821.1	-15676	9297.3	-29807	-10340	9111.9	-60966	-8426.1	9398.9
Fan 2	-47858	-14388	9846.4	-114105	9241	8425.6	Not Tested	Not Tested	Not Tested	-40028	-14290	9866.8
Fan 3	42656	-28816	9237.6	21546	-21872	9493.6	43247	-31819	9871.6	-19403	-22317	9747.8
Fan 4	-3342	-24017	10554	8613	-25464	9858.8	Not Tested	Not Tested	Not Tested	47951	-31092	9314.6
Fan 5	253372	-96967	20933	Not Tested	Not Tested	Not Tested	-85076	-9593.1	19509	-78261	-9195.9	19489
Fan 6	-253576	-17841	21085	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-1244.4	-40277	23232
Fan 7	-152966	-26838	18408	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-139947	-9577.2	18517
Fan 8	-44395	-38509	19075	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-114366	-13120	19272
Fan 9	82765	-51069	17839	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-160782	-6965.8	18436
Fan 10	-117396	-17837	17937	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-237136	8013.3	17526
Fan 11	-634085	42869	16708	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-69097	-24168	19206
Fan 12	6932	-30806	22119	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-29634	-18754	21888
Fan 13	-20851	-21422	17939	-66950	-21004	19478	Not Tested	Not Tested	Not Tested	7527	-17373	16694
Fan 14	48860	-41344	17014	-96405	-11609	16430	982.46	-30137	17273	-76565	-38454	20420

Table 3-8. Fan Air Flow Models for KY1B-2 (continued)

Ventilation Rate, cfm = A * (Static Pressure, inch)^2 + B * (Static Pressure, inch) + C												
Fan ID	**July 18, 2006**			**September 28, 2006**			**December 11, 2006**			**February 8, 2007**		
	A	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Fan 1	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-56437	-6311.5	9349.2
Fan 2	-145370	5525	8548.6	-5730.9	-21492	9959.2	-41252	-13429	9946.1	34189	-24934	10124
Fan 3	-46087	-11251	8220.3	Not Tested	Not Tested	Not Tested	2252.3	-23655	9707.6	-43170	-13533	9322.3
Fan 4	Not Tested	Not Tested	Not Tested	-41312	-13038	8456.6	-1771	-23136	9631.9	49357	-30704	9771.2
Fan 5	Not Tested	Not Tested	Not Tested	-18949	-24356	20541	-66110	-7306.8	19526	Not Tested	Not Tested	Not Tested
Fan 6	90002	-63514	23180	Not Tested	Not Tested	Not Tested	-30536	-24754	22502	Not Tested	Not Tested	Not Tested
Fan 7	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested
Fan 8	Not Tested	Not Tested	Not Tested	-118262	-8942.8	17835	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested
Fan 9	3095	-39533	19275	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested
Fan 10	Not Tested	Not Tested	Not Tested	-210356	16026	16108	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested
Fan 11	Not Tested	Not Tested	Not Tested	-86591	-21761	19710	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested
Fan 12	47400	-37407	21819	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested
Fan 13	-120124	-14919	19103	-89008	-18498	19600	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested
Fan 14	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-86552	-9773	15676	Not Tested	Not Tested	Not Tested

3.3.2.5 Meteorological and Confinement Data

Ambient and confinement temperature and relative humidity were measured type-T TCs and electronic relative humidity transmitters that were connected to the PC-based DAQ. In addition, portable RH/T loggers were used as back-ups. Ambient air samples were taken near the MAEMU (see Figure 3-9). Building temperature and relative humidity probes were placed adjacent to the SW1, SW3 and TE air sampling points (see Figure 3-9).

3.3.2.6 Animal Husbandry and Building Systems

The study conducted at the Kentucky sites did not track animal activity with infrared motion sensors. The only activity information regarding animal movement in and out of the house was recorded by the producer.

Farm personnel at the Kentucky sites manually recorded the daily animal inventories and mortalities and provided the data to the NAEMS site personnel. Similarly, farm personnel were to provide information regarding the operation of the lights and feeders within the monitored houses; however, this information has not yet been submitted to EPA.

3.3.2.7 Biomaterials Sampling Methods and Schedule

Biomaterial sampling for the Kentucky portion of the study was limited to litter sampling. All litter samples were processed by the Agricultural Waste Management Laboratory in the Department of Agricultural and Biosystems Engineering at Iowa State University.

Litter from the production houses was sampled after the removal of each flock and analyzed for pH, moisture content, NH_3 and total Kjeldahl nitrogen. Analyzed samples, in conjunction with litter mass removed during clean-out, were used to estimate nongaseous nitrogen movement in and out of the house.

Two types of litter samples were collected: total litter and caked litter. For total litter sampling, the broiler house was divided into nonbrooding and brooding zones. Each zone was then subdivided into three sections: sidewall, waterer and feeder and central. Twenty random samples were collected from each section and pooled together to form one composite sample per section (three composite samples per zone). Figure 3-12 illustrates the zone and section for the house and an example sampling scheme to demonstrate the distribution of samples through the zones. Caked litter samples were also collected by taking shovel samples from each load of removed cake and combining them to form two 20-L samples.

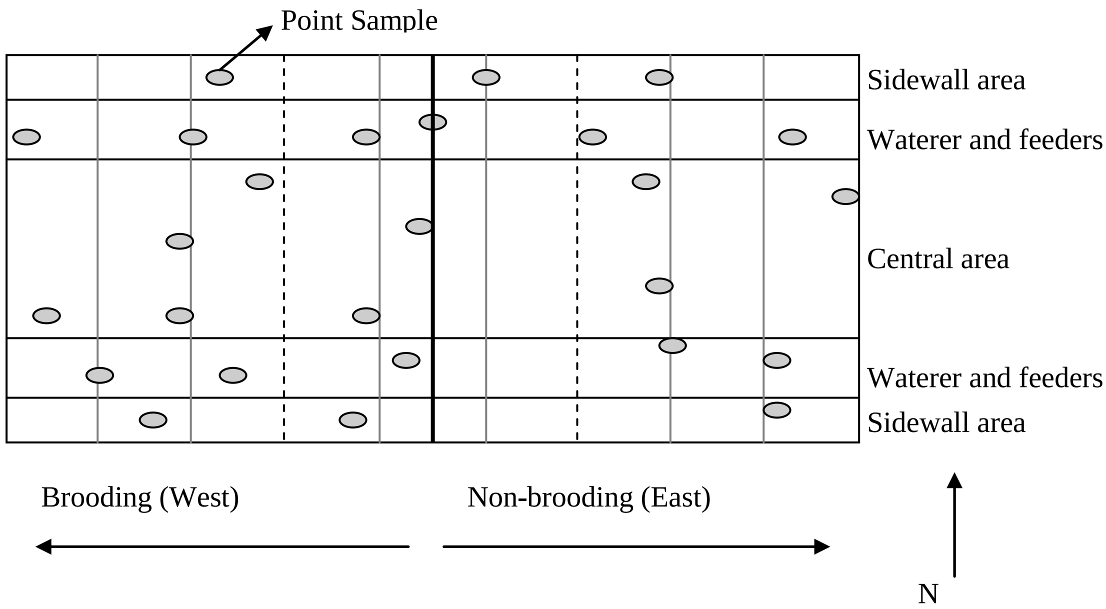


Figure 3-12. Schematic of Litter Sampling Locations

4.0 DATA AVAILABLE FOR EEM DEVELOPMENT

In the Air Compliance Agreement, the EPA committed to developing EEMs for estimating daily and annual emissions from broiler confinement operations using the emissions and process data collected under the NAEMS and any other relevant data and information that are available. Section 4.1 summarizes the NAEMS emissions and process data for broiler confinement operations. Section 4.2 discusses the other relevant data that the EPA has gathered both under a Call for Information (CFI) that was issued by the EPA on January 19, 2011, and through previously-conducted literature searches.

4.1 NAEMS Data

4.1.1 Data Received

The EPA received final reports and data spreadsheets for the CA1B, KY1B-1, and KY1B-2 monitoring sites. In general, the final reports for each site describe the monitoring locations and sampling methods and present the results of the emissions measurements expressed in various units (e.g., annual average emissions in kg NH_3/bird, maximum daily emissions in kg NH_3/bird). For site CA1B, the final report also contained the results of the chemical composition analyses of materials (e.g., nitrogen content of feed) conducted to support the nitrogen mass balance, as well as notes of significant events and modifications to farm practices that occurred over the monitoring period. Appendix D contains the final reports submitted for each monitoring site. The data spreadsheets submitted for each site contains the emissions and process parameter values calculated from continuous measurements. Table 4-1 identifies the information and data submittals for each monitoring site.

Table 4-1. Information and Data Submitted

Site	Description	Submitting Entity
CA1B	Microsoft Excel® spreadsheet containing: daily average values for NH_3, H_2S, PM_{10}, $PM_{2.5}$ and TSP emissions; confinement parameters; meteorological parameters; bird inventory and bird weight and periodic VOC sampling results	Purdue University
	Final report (PDF file)	
KY1B-1 and KY1B-2	Microsoft Excel® spreadsheets containing: 1-second and 30-second sampling data; bird performance data; individual ventilation fan calibration curves and containing daily average data for inventory and weight and pollutant emissions per house and per animal unit	Iowa State University
	Microsoft Excel® spreadsheets containing: daily average values for NH_3, H_2S, PM_{10}, $PM_{2.5}$, TSP and VOC emissions; building ventilation rate; bird inventory and bird weight	
	Final report (PDF file)	

Draft

To increase public involvement and maintain transparency throughout the EEMs development process, the EPA has made information and data relating to the NAEMS available at http://www.epa.gov/airquality/agmonitoring/. This website provides links to background information regarding the Air Compliance Agreement, the NAEMS (including information describing the monitoring sites, site-specific data files and final reports), and the CFI. Additionally, the EPA has included all information received pertaining to the NAEMS in the public docket (EPA Docket ID No. EPA-HQ-OAR-2010-0960), which is available at: http://www.regulations.gov.

Table 4-2 summarizes the emissions and process data elements that were required to be monitored by either the NAEMS Monitoring Protocol, the QAPPs, the SMPs or the SOP documents submitted to the EPA. The NAEMS Monitoring Protocol was developed in a collaborative effort by representatives from the EPA, USDA, AFO industry representatives, agricultural researchers, state and local air quality agencies and environmental organizations. The NAEMS Monitoring Protocol identified the parameters to be monitored during the study and, for some parameters, specific measurement methodologies and frequencies. For those parameters for which either or both the measurement methodology and frequency was not specified, the information was provided in the study's QAPP (Appendix A). Table 4-2 also provides specific information regarding data availability that is based upon the EPA's review of the final reports and data spreadsheets. During its review of the final reports and data spreadsheets, the EPA identified missing emissions and process data. Section 5 summarizes the issues and discrepancies identified by the EPA's review.

The EPA's review of the data spreadsheets also identified negative daily average emissions values for H_2S and PM_{10} for certain days at site CA1B (see Section 5). After discussion with the study's Science Advisor, it was determined the negative values were a result of instrumentation drift, and are considered to be valid values. To avoid possible complications with EEM development (e.g., the EEM predicting negative emissions), the negative values were withheld from the data sets used for EEM development. The amount of measured negative values is low (less than 1.7 percent) compared to the total number of emissions records for H_2S and PM_{10}, which indicates that the steps taken to calibrate and maintain instrumentation and to minimize the influence of other on-site sources on ambient H_2S and PM_{10} emissions were reasonably effective. Because of their relatively small number, excluding the negative values does not compromise the EEM data sets for H_2S and PM_{10}.

The EPA's review of the data spreadsheets also identified daily average emissions and parameter values that were exactly zero. After further review and discussion with the study's Science Advisor, it was determined the values were valid reported values and were used for EEM development.

Draft

Table 4-2. NAEMS Emissions and Process Parameter Data Received

Parameter Information				NAEMS Data					
Parameter	Required by the NAEMS Monitoring Protocol	Measurement Methodology	Measurement Frequency	CA1B (Houses 10 and 12)			KY1B – 1 House 5 and KY1B – 2 House 3		
				Data Description	Measurement Methodology	Measurement Frequency	Data Description	Measurement Methodology	Measurement Frequency
Emissions									
NH_3	Yes	Chemiluminescence or photoacoustic infrared	24 months with data logged every 60 seconds	Average measured concentration values and average calculated emission rate values	Photoacoustic infrared	Logged every 15 & 60 seconds, for 24 months; daily averages provided	Average measured concentration values and average calculated emission rate values	Photoacoustic infrared	Sampled continuously at 120-second intervals for 12 months; daily averages provided
H_2S	Yes	Pulsed fluorescence	24 months with data logged every 60 seconds	Average measured concentration values and average calculated emission rate values	Pulsed fluorescence	Logged every 15 & 60 seconds, for 24 months; daily averages provided	Average calculated emission rate values	UV Pulsed fluorescence	Sampled continuously at 120-second intervals for 12 months; daily averages provided
TSP	Yes	Isokinetic multipoint gravimetric method	24 months with data logged every 60 seconds	Average measured concentration values and average calculated emission rate values	TEOM for representative exhaust locations in the house, and the TFS FH62-C-14 Beta Monitor for inlet air locations	Logged every 15 & 60 seconds, for six 7- to 14-day periods; Daily average provided	Average calculated emission rate values	TEOM, Reference Method number EQPM-1090-79	Recorded at 300-second intervals for 12 months; daily averages provided
PM_{10}	Yes	Real-time measurements using the TEOM at representative exhaust locations in the house and ambient air	24 months with data logged every 60 seconds	Average measured concentration values and average calculated emission rate values	TEOM for representative exhaust locations in the house, and the TFS FH62-C-14 Beta Monitor for inlet air locations	Logged every 15 & 60 seconds. Daily average provided.	Average calculated emission rate values	TEOM, Reference Method number EQPM-1090-79	Recorded at 300-second intervals for 12 months; daily averages provided
$PM_{2.5}$	Yes	Gravimetrically with a federal reference method for $PM_{2.5}$	Measured at least for 1 month per site; data logged every 60 seconds	Average measured concentration values and average calculated emission rate values	TEOM for representative exhaust locations in the house, and the TFS FH62-C-14 Beta Monitor for inlet air locations	Logged every 15 & 60 seconds for February and July, 2008, and January and September, 2009 for 12 to 18 days each time; daily averages provided	Average calculated emission rate values	TEOM, Reference Method number EQPM-1090-79	Recorded at 300-second intervals for 12 months; daily averages provided
CO_2	Yes	Photoacoustic infrared or equivalent	24 months with data logged every 60 seconds	Data not available[a]	Photoacoustic infrared	Logged every 15 & 60 seconds, for 24 months;	Average calculated emission rate values	Photoacoustic infrared	Sampled continuously at 120-second intervals for 12 months; daily averages provided

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Table 4-2. NAEMS Emissions and Process Parameter Data Received

Parameter Information				NAEMS Data					
				CA1B (Houses 10 and 12)			KY1B – 1 House 5 and KY1B – 2 House 3		
Parameter	**Required by the NAEMS Monitoring Protocol**	**Measurement Methodology**	**Measurement Frequency**	**Data Description**	**Measurement Methodology**	**Measurement Frequency**	**Data Description**	**Measurement Methodology**	**Measurement Frequency**
Non-methane hydrocarbons (NMHC) emissions (continuous)	Yes	NMHC – dual channel FID analyzer (Method 25A)	24 months with data logged every 60 seconds at one site	Data not available[a]	Photoacoustic infrared	Logged every 15 & 60 seconds, for 24 months; daily averages provided	Average calculated emission rate values	Dual-channel flame ionization detector (FID)	Daily for 12 months
VOC (Charac-terization Study)	Yes	Total nonmethane hydrocarbons (NMHC) – Dual-channel FID analyzer (Method 25A) VOC - concurrent gas chromatography-mass spectrometry (GC-MS) and GC/FID for TO 15 and other FID-responding compounds	Conducted on 1 day during the first month at the first site	Target VOC compounds for subsequent continuous monitoring and speciation	Canisters, sorbent tubes and glass impingers used to collect VOC samples	One sampling episode using canisters, sorbent tubes and glass impingers, and one sampling episode using sorbent tubes	Target VOC compounds for subsequent continuous monitoring and speciation	EPA TO-15 EPA TP-17	Two sampling events (9 locations in each house)
VOC (grab samples)	Yes	VOC – concurrent GC-MS and GC/FID for TO 15 and other FID-responding compounds.	Continuous for 24 months with data logged every 60 seconds Quarterly samples using selected VOC sampling method at all sites	Concentration and emissions for each day that the VOC samples were taken and the overall averages	Canisters	24 hour canister samples taken every 3 months	Data not collected[b]		
Confinement Parameters									
Bird activity	Yes	Not specified		Data not received[c]	Passive infrared detector	Logged every 15 & 60 seconds for 24 months	Data not collected[b]		
Manure handling	Yes	Not specified		Not applicable (litter periodically removed using manual methods)		End of grow-out periods	Not applicable (litter periodically removed using manual methods)		End of grow-out periods
Lighting	Yes	Not specified		Data not received[c]	Relays for recording on/off status	Logged every 15 & 60 seconds for 24 months	Data not received[c]	Not specified	Not specified
Heating/cooling operation	Yes	Not specified		Data not received[c]	Relays for recording on/off status	Logged every 15 & 60 seconds for 24 months	Data not collected[b]		

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Table 4-2. NAEMS Emissions and Process Parameter Data Received

Parameter Information				NAEMS Data					
				CA1B (Houses 10 and 12)			KY1B – 1 House 5 and KY1B – 2 House 3		
Parameter	**Required by the NAEMS Monitoring Protocol**	**Measurement Methodology**	**Measurement Frequency**	**Data Description**	**Measurement Methodology**	**Measurement Frequency**	**Data Description**	**Measurement Methodology**	**Measurement Frequency**
Floor and manure temperatures	Yes	Not specified		Data not received[c]	Thermocouple	Logged every 15 & 60 seconds for 24 months	Data not collected[b]		
Bird production & mortality (inventory)	Yes	Monitored with producer assistance (Methodology not specified)	Not specified	Daily average number of birds and bird age	Producer records	Daily	Daily average number of birds and bird age	Producer records	Daily
Animal weight gain/loss	Yes	Not specified		Daily average weight	Portable livestock scale	Daily	Daily average weight	Automatic scale	Daily
House ventilation air flow	Yes	Measure fan operational status and static pressure to calculate fan air flow from field-tested fan performance curves and by directly measuring air flow of selected fans using anemometers.	Continuous	Daily average ventilation rate	Measure fan operational status and static pressure to calculate fan air flow from field-tested fan performance curves and by directly measuring selected fan air flows using anemometers	Logged every 30 seconds, for 24 months	Daily average ventilation rate	Measure fan operational status and static pressure to calculate fan air flow from field-tested fan performance curves and by directly measuring selected fan air flows using anemometers	Logged every 30 seconds for 12 months
House temperature	Yes	Not specified		Daily average values	Type T thermocouples	Logged every 15 & 60 seconds for 24 months; daily averages provided	Daily average values	Type T thermocouples	Logged every second
House relative humidity	Yes	Not specified		Daily average values	Capacitance-type RH/T probes	Logged every 15 & 60 seconds for 24 months; daily averages provided	Daily average values	Relative humidity probe	Logged every second
Wind speed	Yes	Not specified		Daily average values	Cup anemometer	Logged every 15 & 60 seconds for 24 months; daily averages provided	Data not collected[b]		
Wind direction	Yes	Not specified		Daily average values.	Cup anemometer	Logged every 15 & 60 seconds for 24 months; daily averages provided	Data not collected[b]		
Solar radiation	Yes	Not specified		Daily average values.	Pyranometer	Logged every 15 & 60 seconds for 24 months; daily averages provided	Data not collected[b]		

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Table 4-2. NAEMS Emissions and Process Parameter Data Received

Parameter Information				NAEMS Data					
				CA1B (Houses 10 and 12)			KY1B – 1 House 5 and KY1B – 2 House 3		
Parameter	**Required by the NAEMS Monitoring Protocol**	**Measurement Methodology**	**Measurement Frequency**	**Data Description**	**Measurement Methodology**	**Measurement Frequency**	**Data Description**	**Measurement Methodology**	**Measurement Frequency**
House differential static pressure	Yes	Not specified		Daily average values.	Pressure transducer	Logged every 15 & 60 seconds for 24 months; daily averages provide.	30-second average values	Pressure transducer	Logged every second
Ambient temperature at site	Yes	Not specified		Daily average values	Solar radiation shielded capacitance-type RH/T probe	Logged every 15 & 60 seconds for 24 months; daily averages provided	Daily average values	Type T thermocouples	Logged every second
Ambient relative humidity at site	Yes	Not specified		Daily average values	Solar radiation shielded capacitance-type RH/T probe	Logged every 15 & 60 seconds for 24 months daily averages provided	Daily average values	RH probe	Logged every second
Nitrogen Mass Balance									
Water consumption rate	Yes	Monitored with producer assistance (methodology not specified)	Not specified	Data not received[c]	Automatic water meter	Not specified	Daily average values	Producer records	Daily
Water Total Kjeldahl Nitrogen (TKN) content	Yes	Not specified		Data not received[c]	Micro-Kjeldahl/ titrimetric	Not specified	Data not collected[b]		
Feed consumption rate	Yes	Monitored with producer assistance (methodology not specified)	Not specified	Data not received[c]	Not specified	Daily	Data not received[c]	Producer records	Each flock
Feed TKN content	Yes	Not specified		Data not received[d]	Micro-Kjeldahl/ titrimetric	Not specified	Data not received[c]	Producer records	Each flock
Feed sulfur content	Yes	Not specified		Data not collected[b]			Data not collected[b]		
Incoming bedding addition rate	No	Not applicable		Volume of litter (m^3)	Producer estimate	Single value	Data not received[c]	Producer records	Each flock
Incoming bedding TKN content	No	Not applicable		Two daily average values per house (wet weight basis, %)	Micro-Kjeldahl/ titrimetric	4 sampling events over course of study	Daily average value ("as is" and dry matter basis, %); Two values for KY1B-1 and a single value for KY1B-2.	Titration	Taken at least once during the study period after full litter removal

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Table 4-2. NAEMS Emissions and Process Parameter Data Received

Parameter Information				NAEMS Data					
				CA1B (Houses 10 and 12)			KY1B – 1 House 5 and KY1B – 2 House 3		
Parameter	**Required by the NAEMS Monitoring Protocol**	**Measurement Methodology**	**Measurement Frequency**	**Data Description**	**Measurement Methodology**	**Measurement Frequency**	**Data Description**	**Measurement Methodology**	**Measurement Frequency**
pH of manure and litter (in house)	No	Not applicable		Data not received[b]	Electrochemical pH meter	6 events/yr	16 values taken over 8 sampling events distributed over the grow-out period	Electrochemical pH meter	8 events
Sulfur content of manure and litter (in house)	Yes	Not specified		16 daily average values per house (wet weight basis, %)	Not specified	32 sampling events over course of study	Data not collected[b]		
NH_3 content of manure and litter (in house)	Yes	Not specified		16 daily average values per house (wet weight basis, %)	Kjeldahl/ titrimetric	6 events/yr	16 values taken over 8 sampling events distributed over the grow-out period	Electrochemical pH meter	8 events
Solids content of manure and litter (in house)	No	Not applicable		16 daily average values per house (wet weight basis, %)	Gravimetric	6 events/yr	16 values taken over 8 sampling events distributed over the grow-out period	Gravimetric	8 events
TKN content of manure and litter (decaking)	Yes	Not specified		8 daily average values per house (wet weight basis, %)	Kjeldahl/ titrimetric	3 events over duration of study	6 daily average values per site ("as is" and dry matter basis, %)	Titration	Samples taken after bird removal and just prior to decaking activities; Decaking occurred 6 times during the study period
Solids content of manure and litter (decaking)	No	Not applicable		8 daily average values per house (wet weight basis, %)	Gravimetric		6 daily average values per site ("as is" and dry matter basis, %)	Not specified	
pH of manure and litter (de-caking)	No	Not applicable		Data not received[c]	Electrochemical pH meter		6 daily average values per site	Electrochemical pH meter	
TKN content of manure and litter (cleanout)	Yes	Not specified		Four daily average values per house (wet weight basis, %)	Kjeldahl/ titrimetric	During each full cleanout (2nd or 3rd brood); 3 events in the 1st year, 2-3 events in the 2nd year	One daily average value per site	Titration	During each full litter removal (occurred once per year)
pH of manure and litter (cleanout)	No	Not applicable		Data not received[c]	Electrochemical pH meter		One daily average value per site	Electrochemical pH meter	
Solids content of manure and litter (cleanout)	No	Not applicable		Four daily average values per house (wet weight basis, %)	Gravimetric		One daily average value per site	Not specified	

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Table 4-2. NAEMS Emissions and Process Parameter Data Received

Parameter Information				NAEMS Data					
				CA1B (Houses 10 and 12)			KY1B – 1 House 5 and KY1B – 2 House 3		
Parameter	Required by the NAEMS Monitoring Protocol	Measurement Methodology	Measurement Frequency	Data Description	Measurement Methodology	Measurement Frequency	Data Description	Measurement Methodology	Measurement Frequency
Manure removed	Yes	Monitored with producer assistance (Methodology not specified)	Not Specified	Average estimated mass (metric tons)[e]	Producer estimate	Beginning and end of growth period	Data not collected[b]		
Volume of manure produced	Yes	Monitored with producer assistance (Methodology not specified)	Not Specified	Average estimated mass (metric tons)[e]	Producer estimate	Beginning and end of growth period	Data not collected[b]		

[a] Section 3.6 of the final report (p. 12) states that, due to irreconcilable interferences by water vapor and other gases, the CO_2 and VOC-related gas emissions measured by the INNOVA are not available.
[b] Data not expected. This parameter is not referenced in the QAPP or final report.
[c] The QAPP mentions this parameter was measured; however, these data are not provided in the final report(s).
[d] Section 4.2 of the final report (p. 23) provides the range of feed nitrogen content but does not provide the test values. Also, the report is unclear if the range is for nitrogen or TKN.

[e] Section 3.4 of the final report (p. 11) states that on 4/15/08, the manure mass removed during a complete load-out, estimated from the square area and average mass of manure per unit area, was 88 metric tons in House 10 and 79 metric tons in House 12.

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4.1.2 Emissions Levels Reported in the NAEMS Final Reports

The final reports for the California and Kentucky sites indicate that emissions from a broiler confinement house increases over the grow-out period with the lowest emissions occurring at the beginning of the period, when the birds are very small and floor litter is fresh, and the greatest emissions occurring near the end of the grow-out period before the birds are sent to market. Spikes in emissions occur during house litter clean-out periods, which are likely due to increased activity of personnel and cleaning equipment during these periods. The spikes in PM emissions during litter clean-out periods are not as pronounced as gaseous emissions; however, this may be due to the limited number of PM data values available for these periods.

Table 4-3 summarizes the average and maximum emissions cited in the final reports and data spreadsheets for each monitoring site. The average and maximum daily values were reportedly based on all valid monitoring days and include measurements at the beginning, middle and end of the grow-out and full litter clean-out periods (i.e., when the litter in houses is decaked or fully removed from the house between flocks). A valid monitoring day is one in which 75 percent of the hourly average data values used to calculate the daily value were valid measurements. An hourly average is considered valid if 75 percent of the data recorded during that hour were valid. Data were invalidated due to special events (e.g., audits, calibrations, and maintenance), failure of quality control limits (e.g., unreasonably low or high compared with normal ranges combined with supporting evidence that the values are not correct) or when a sample is contaminated. A summary of the major data invalidation events identified for site CA1B is provided in the final site report (see Appendix D). None of the data values submitted to EPA for site CA1B were considered by the EPA to be invalid. For the Kentucky sites, a summary of the major data invalidation events was not provided to the EPA. However, the data spreadsheets submitted to the EPA for the Kentucky sites contained emissions values that were estimated based on a regression analysis, rather than directly measured. The EPA did not use these estimated emissions values in developing the EEMs.

The average daily emissions values obtained during the NAEMS include a small number (less than 1.7 percent) of negative values for H_2S and PM_{10} (see Section 4.1.1). The EPA did not include negative emission values in the development of the EEMs. However, to maintain consistency with the values contained in the final reports, the values shown in Table 4-3 include negative daily emissions values. Section 5 contains data summaries that exclude the negative daily emission values.

For site CA1B, the average and maximum daily emissions data for VOCs were estimated using grab samples that were obtained periodically over the course of the NAEMS; however, continuous measurements were not available due to interference from water vapor encountered in the field by the continuous gas analyzer. Data collection at the Kentucky sites included

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continuous NMHC sampling. Periodic VOC grab samples were not collected at the Kentucky sites.

Table 4-3. Reported Emission Rates for NAEMS Broiler Houses

Site	Average House Inventory[a] (no. of birds)	Average Market Weight[a] (lbs)	Average Daily Emissions (lb/d-house)[b]					
			NH_3	H_2S	NMHC	PM_{10}	$PM_{2.5}$	TSP
CA1B, H10	21,000	5.81	22.49	0.12	3.92[b]	1.92	0.22	5.84
CA1B, H12	21,000	5.83	19.82	6.87	6.87[b]	1.94	0.27	5.00
KY1B-1, H5	23,000	6.00	26.76	0.11	1.58	2.03	0.20	4.78
KY1B-2, H3	24,500	6.12	27.29	0.12	0.99	2.30	0.21	5.34
			Maximum Daily Emissions (lb/d-house)[b]					
CA1B, H10	21,000	5.81	112.22	0.40	8.68[c]	7.85	7.85	7.85
CA1B, H12	21,000	5.83	77.60	0.40	12.56[c]	7.63	7.63	7.63
KY1B-1, H5	23,000	6.00	98.59	0.57	5.24	9.95	0.89	22.8
KY1B-2, H3	24,500	6.12	78.23	0.41	3.84	9.43	0.85	16.3

[a] The average bird inventory and market weight values were calculated based on the daily values submitted to the EPA.
[b] The emissions (e.g., kg/d-house, mg/d-house) provided in the final reports were converted to lb/d-house to provide a common basis for all pollutants.
[c] The emissions values are based on periodic grab samples of VOC.

4.2 Other Relevant Data

Since 2001, the EPA conducted several literature searches and a CFI to identify data and information that were relevant to support a preliminary investigation into air pollution from large AFOs (see the EPA's *Emissions From Animal Feeding Operations* (draft, August 15, 2001)). The EPA evaluated all of the articles and publications received through its own literature searches and obtained through the CFI to identify data and information that could be useful in developing EEMs for broiler confinement operations. In conducting this evaluation, the EPA retained for further consideration those resources that satisfied each of the following conditions:

- The resource pertained to monitoring conducted on broiler confinement structures at commercial sites.
- The resource contained emissions rates (e.g., mass/time, mass/animal) for NH_3, H_2S, PM_{10}, $PM_{2.5}$, TSP or VOC, or data to characterize the inputs or outputs necessary to construct a nitrogen mass balance across the confinement house.
- The resource used methods to measure the emissions concentrations, estimate the ventilation flow rate and characterize mass balance parameters that were consistent with the NAEMS procedures.

The EPA excluded data that were related to litter storage piles and land application sites because the Air Compliance Agreement does not cover these processes.

The EPA then evaluated the resources that satisfied the EPA's initial review to determine if the data were appropriate for consideration in either developing the EEMs or assessing the predictive accuracy of the EEMs. Section 4.2.1 summarizes the EPA's CFI and the review of the resources obtained. Section 4.2.2 summarizes the EPA's review of the resources obtained by previous EPA literature searches.

4.2.1 CFI

The EPA issued a CFI on January 19, 2011, seeking peer-reviewed, quality-assured emissions and process data relevant to developing EEMs for animal feeding operations. The CFI was designed to help ensure that the EPA would obtain the broadest range of scientific data available. All data and information received by the EPA is contained in the public docket for the Air Compliance Agreement (EPA Docket ID No. EPA-HQ-OAR-2010-0960) and is available online at http://www.regulations.gov.

In the CFI, the EPA requested emissions and process data for AFOs in the broiler, swine, egg-layer, dairy, beef and turkey industries. Although the EPA is interested in all air pollutants emitted from animal confinement, litter storage and treatment and litter land applications sites associated with AFOs, the CFI specifically requested emissions data and related process information for NH_3, H_2S, PM_{10}, $PM_{2.5}$, TSP and VOC.

To ensure compatibility with the NAEMS data, the CFI requested that, to the extent possible, the emissions and related process data provided to the EPA be accompanied by documentation that addresses the following parameters:

General information:

- Description of AFO process measured (e.g., animal confinement structure).
- Location of AFO process measured (e.g., physical address, latitude/longitude coordinates of facility).
- Beginning and ending dates of the monitoring period.

Monitoring data:

- Plan for quality assurance and quality control procedures.
- Site-specific monitoring plan.
- Test methods, instrumentation and SOPs used to collect emissions and process data measurements.

- Results of audits conducted on instruments and procedures.
- Field notes and associated documentation collected during the study.
- Emissions data (unanalyzed or analyzed) and associated process data.
- Meteorological data, including average ambient temperature, relative humidity, pressure, wind speed, wind direction and insolation (solar radiation) for each day that the study was conducted.
- Production data (e.g., number of eggs produced per day or quantity of milk produced per day or number of chickens or swine produced).
- Calculations and assumptions used to convert concentration data (e.g., ppmv) into mass emissions (e.g., lb/hr).

Animal confinement structures:

- Dimensions of structures monitored.
- Designed and permitted animal capacity.
- Type, age, number and weight of animals contained in the confinement structure over the duration of the monitoring period.
- Manure management system (e.g., pull-plug pit, scrape).
- Manure removal activities over the duration of the monitoring period.
- Ventilation method (i.e., natural or mechanical).
- Calculations and assumptions used to estimate the ventilation rate of the monitored confinement structure.
- Calibration procedures for instruments (e.g., flow meters, fan relays) used to collect data for calculating ventilation rate of the monitored confinement structure.
- Nitrogen content of process inputs and outputs (e.g., feed, water, bedding, eggs, milk).
- Nitrogen content of manure excreted.
- Description of any control device or work practice used in the monitored structure to reduce emissions.

Manure storage and treatment processes:

- Type, age, number, and weight of animals contributing manure to the storage and treatment process over the monitoring period.
- Dimensions of storage/treatment unit monitored (e.g., storage pile, tank, lagoon).
- Depth of settled solids in storage/treatment unit.
- Temperature, pH and reduction/oxidation potential of manure contained in the storage/treatment unit.

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- Moisture, total solids, volatile solids, total Kjeldahl nitrogen and ammoniacal nitrogen content and pH of manure entering storage and treatment process over the monitoring period.

Manure land application sites:

- Type, age, number, and weight of animals contributing manure to the land application site.
- Method used to apply manure (e.g., direct injection, broadcast spreading and frequency of application).
- Area (e.g., acres, square feet) used for manure application over the monitoring period.
- Quantity and moisture content of manure applied.

Table 4-4 lists the articles and publications received by the EPA in response to the CFI that pertained to broiler operations and their possible application for the NAEMS. As shown in the table, most of the articles and publications submitted to the EPA did not contain emissions or process data that met the EPA's initial review criteria (e.g., the measurement methods differed from the NAEMS methods). However, a few resources contained material composition data that could be used to supplement the nitrogen mass balance data collected by the NAEMS.

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Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2000	*Atmospheric Transport and Wet Deposition of Ammonium in North Carolina* - Walker, Aneja, Dickey	This study analyzes transport and deposition of ammonium (NH_4^+) by precipitation using regression analysis.	None	Not applicable	None. Wet deposition is typically conducted by collecting water and analyzing anions. Consequently, this article is not applicable to NAEMS.
2001	*Ammonia Emissions from Animal Feeding Operations* - Arogo, Westerman, Heber, Robarge, Classen	This article provides a compilation of several studies.	Range of poultry confinement emissions factors: 0.5 – 10 g NH_3-N/hr-animal unit (AU) Composite poultry emissions factors: 0.18 – 0.24 kg NH_3-N/yr-animal	Not applicable	None. The article presents ranges of NH_3 emissions factors for livestock operations but the resource does not identify the specific types of poultry or process to which the emissions factors apply.
2002	*Ammonia Losses, Evaluations, and Solutions for Poultry Systems* - Gates, Xin, Wheeler	This study describes an ongoing, multistate effort toward collecting data on emissions rates or emissions factors from selected U.S. poultry houses and the efficacy of certain management practices on emissions rates.	Confinement NH_3 concentrations (ppmv) Ventilation flow rate	Electrochemical sensors (unspecified vendor and model no.) Relationship between carbon dioxide (CO_2) production and metabolic rate of the birds, and FANS unit	None. Although the electrochemical sensor was compared to EPA chemiluminescence reference method with good results, the preliminary data presented in this paper are not useful for developing a emission estimating methodology. Additionally, the methodology for deploying the FANS unit to estimate total building air flow was not specified.

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Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2002	*Emission Factors for Broiler Production Operations: A Stochastic Modeling Approach* - Lacey, Redwine, Parnell	This article describes development of linear regressions for NH_3 and PM_{10} from measurement data collected at a commercial-scale broiler houses at a farm in Texas. The article also compares emissions factors developed using the regression equations to other published emissions factors.	PM Emissions Factors (mg/hr-500 kg live weight): Inhalable PM – 5,000; 8,500; 6,218; 4,984; 1,856; and 2,805 Respirable PM – 600, 850, 706, 725, 245, and 394 TSP – 2,214 PM_{10} – 131.5 NH_3 Emissions Factors: 7.4, 8.5, 8.3, 4.2, 2.2, 7.5, 1.9, 6.2, and 8.2 g/hr-500 kg live weight 19.8, 11.2, 8.9, 18.5, and 16.8 mg/hr-bird 0.179, 0.19, 0.2, and 0.02 kg/bird	Confinement NH_3 concentrations: electrochemical sensors (Drager Chip Measurement System) TSP: Hi-vol sampler PM10: Beckman Coulter Multisizer Building flow rate: vane anemometers on fans, scaled-up to whole-house flow rate	None. The NH_3 concentrations were taken at a single location (center of house, 1 meter above the litter surface) rather than at the house exhaust locations. Also, the Coulter particle sizing methodology is not consistent with the federal reference method for measuring PM_{10} emissions.
2002	*The Scientific Basis for Estimating Emissions from Animal Feeding Operations* - Hagenstein, Flocchini	This interim report from the National Academy of Science provides findings regarding identification of the scientific criteria needed to ensure that estimates of air emission rates are accurate, the basis for these criteria in the scientific literature, and the associated uncertainties.	None	Not applicable	None. The report cites studies that developed emissions factors; however, the report does not contain empirical data that could be used to supplement the NAEMS data.

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Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2003	*Particulate Matter and Ammonia Emission Factors for Tunnel-Ventilated Broiler Production Houses in the Southern U.S.* - Lacey, Redwine, Parnell	This commercial-scale study measured NH_3 and PM_{10} emission from four tunnel–ventilated broiler production facilities in central TX. The data were used to develop linear regression equations.	Confinement NH_3 concentrations Confinement PM_{10} concentrations Ventilation flow rate	Electrochemical sensors (Drager Chip Measurement System) Hi-Vol TSP sampler and Beckman Coulter Multisizer Vane anemometers and FANS unit	None. Particulate counting by Coulter technique is not equivalent to NAEMS aerodynamic particulate sampling. EPA could not evaluate the comparability of NH_3 measurements because the Drager apparatus used for the study was not specified. Additionally, the daily emissions and flow rate estimates were not explicitly quantified and several of the houses that participated in the study used litter amendments to suppress NH_3 emissions.
2003	*Progress Towards the Development of an Integrated Management System for Broiler Chicken Production* - Frost, Parsons, Stacey, Robertson, Welch, Filmer, Fothergill	The article presents previous research conducted to develop a prototype closed-loop, model-based, real time, system for the integrated control of broiler growth and pollutant emissions.	Confinement NH_3 concentrations	Ammonia concentration in the air was measured by converting the ammonia into nitric oxide which was fed to a chemiluminescence nitrogen oxides analyzer.	None. Animal feed was altered in this study when measurements were taken. Because the NAEMS was designed to focus on baseline or uncontrolled emissions, this study is not relevant for EEM development.
2004	*A Comparison of Ammonia Emission Rates from an Agricultural Area Source Using Dispersion Modeling: Gaussian Versus Backward-Lagrangian Stochastic* - Price, Lacey, Shaw, Cole, Todd, Capareda, Parnell	This research-scale study compared the emissions rates generated using the Industrial Source Complex (Guassian) model and the WindTrax (backward Lagrangian Stochastic)	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2004	*Ammonia Emissions from Animal Housing Facilities* - Gay	This article provides background information regarding NH_3 emissions from animal confinement facilities.	NH_3 Emissions Factors (g/bird-d): 0.043 (new bedding) 0.61 (reused litter) NH_3 Emissions Factors (g/bird): 0 – 336 (U.S.) 78 – 174 (European)	Not applicable	None. This article summarizes recent research findings regarding quantification of ammonia emissions from animal confinement in general. However, there is not sufficient information on the duration of the studies and/or the specific measurement technologies used to determine how comparable the results are to the NAEMS data.

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Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2005	*CARB Memo: Poultry Emissions VOC Sampling and Analysis Audit* - Goodenow	This memorandum documents an audit of the independent contractor and laboratory responsible for the collection and analysis of VOC emissions samples from a poultry house in Livingston, California.	None	Not applicable	None. The audit does not contain emissions or process data.
2005	*Final Report: Quantification of Gaseous Emissions from California Broiler Production Houses* - Summers, Mattos, Gaffney, FitzGibbon, Duke, Marnatti, Kim, Stabelfeld, Clutter, Ernst, Humbert	This commercial-scale study measured NH_3 and organic compound emissions from a fabricated duct at tunnel-ventilated broiler house in California.	Confinement NH_3 concentrations (ppmv)	BAAQMD Method ST-1B (impinger train w/0.1 N HCl)	While this study does not use measurement methods that are identical to the NAEMS, the data is still relevant and may be useful in assessing the EEMs after they have been developed.
			Confinement total hydrocarbon (THC) concentrations as propane	EPA Method 25A	
			Stack flow rate (dscfm)	CARB Methods 2 and 4	
			C1, C2 and C4 hydrocarbon concentrations	EPA Method 18 (Tedlar bag samples w/GC FID)	The speciated VOC data may be used to supplement the periodic VOC measurements taken under the NAEMS.
			Speciated organic compound concentrations (ppbv)	EPA Method TO-15 (Summa canisters w/GCMS)	
2005	*Nitrogen Emissions from Broilers Measured by Mass Balance Over Eighteen Consecutive Flocks* - Coufal, Chavez, Niemeyer, Carey	This large research-scale evaluated a nitrogen mass balance and partitioning in broiler houses.	Total nitrogen content of birds, feed and litter	Combustion method using LECO FP-428 Nitrogen Determinator	The nitrogen content data may be used to supplement NAEMS mass balance data.
2006	*Dietary Modifications to Reduce Air Emissions from Broiler Chickens* - Powers, Zamzow, Angel, Applegate	This research-scale study investigated the effects of changes to diet on NH_3 emissions.	Ammonia emissions (mg/kg-day)	TEI Model 17C ammonia/NOx chemiluminescence analyzer	Results from the control group in this study may be useful in assessing the EEMs after they have been developed.

Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2006	*Ammonia Emissions from Twelve U. S. Broiler Chicken Houses* - Wheeler, Casey, Gates, Xin, Zajaczkowski, Topper, Liang, Pescatore	Commercial-scale study of broiler farms in KY and PA to measure NH_3 emissions from house operated under different climatic conditions.	Confinement NH_3 concentrations	Portable electrochemical sensor (Drager Polytron)	None. Several of the houses that participated in the study used litter amendments to suppress NH_3 emissions. The flocks with and without litter treatment were grouped together in this study. Because the NAEMS was designed to focus on baseline or uncontrolled emissions, this study is not relevant for EEM development. Additionally, the results in this study are not explicitly quantified.
			Ventilation flow rate	Estimated using differential static pressure, temperature, relative humidity, and fan operation measurements	
			Bird inventory	Manual records	
			Bird weight	Estimated using regression equations in terms of bird age developed under a different study	
2006	*A Review of Emission Models of Ammonia Released from Broiler Houses* - Liu, Want, Beasley	This paper summarizes the scientific basis of and the major factors that may influence NH_3 emissions from broiler litter. The theoretical principles and the structures of the models are generalized. According to the study, these models improved understanding of NH_3 releases and can be useful to improve the accuracy and simplicity in emissions estimates. The paper also discusses current technical challenges and future direction of developments.	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2006	*Quality Assured Measurements of Animal Building Emissions: Odor Concentrations* - Jacobson, Hetchler, Schmidt, Nicolai	This study focuses on the methodology for collecting and analyzing samples for odor concentrations.	None	Not applicable	None. The article addresses odor measurement and does not contain emissions or process data that could be used to supplement the NAEMS data.
2006	*Quality Assured Measurements of Animal Building Emissions: Gas Concentrations* - Heber, Ni, Lim, Tao, Schmidt, Koziel, Beasley, Hoff, Nicolai, Jacobson, Zhang	This study focuses on the methodology of measuring gas concentration and the difficulty in achieving the desired results for livestock houses due to their unique traits.	None	Not applicable	None. The article provides an overview of the emissions monitoring system and instrumentation but does not contain emissions or process data.

Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2007	*Determination of Ammonia Emission Rates From a Tunnel Ventilated Chicken House Using Passive Samplers and a Gaussian Dispersion Model* - Siefert, Scudlark	This study provided NH_3 emissions data from tunnel-ventilated houses.	Mean EF = 0.13 g NH_3–N/bird-day Range of EFs = 0.0053 g NH_3–N /s to 0.037 NH_3–N g/s	Emissions of NH_3 were back-calculated from concentration measurements made using a sampling array (Ogawa passive samplers) positioned downwind of broiler house and Gaussian plume model.	None. The use of different sampling methods (passive vs. active) and modeling limit the applicability of the study for direct comparison or use in the NAEMS.
2007	*Effect of Moisture Content on Ammonia Emissions from Broiler Litter: A Laboratory Study* - Liu, Wang, Beasley, Oviedo, Munilla, Baughman, Williams	The research study evaluated the effect of moisture content on NH_3 emissions from litter samples using dynamic flow-through chambers.	None	Ammonia emissions from litter samples of varying moisture content placed in dynamic flow-through chambers were measured simultaneously using a chemiluminescence analyzer and a boric acid scrubber combined with gas chromatography of the scrubber solution.	None. Because this study used flux chambers to measure ammonia emissions, this study is not relevant for EEM development.
2007	*Modeling Atmospheric Transport and Fate of Ammonia in North Carolina—Part I: Evaluation of Meteorological and Chemical Predictions* - Wu, Krishnan, Zhang, Aneja	This study discusses the application of EPA's Community Multiscale Air Quality (CMAQ) modeling system to study the deposition and fate of NH_3 emissions from activities. Part I of the study describes the model configurations, evaluation protocols, databases and the operational evaluation for meteorological and chemical predictions.	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2007	*Modeling Atmospheric Transport and Fate of Ammonia in North Carolina—Part II: Effect of Ammonia Emissions on Fine Particulate Matter Formation* - Wu, Hu, Zhang, Aneja	This study discusses the application of EPA's CMAQ model to study the deposition and fate of NH_3 emissions from agricultural activities. Part II of the study describes the sensitivity simulations applied to various emission scenarios.	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.

Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2008	*Ammonia Assessment from Agriculture: U.S. Status and Needs* - Aneja, Blunden, James, Schlesinger, Knighton, Gilliam, Jennings, Niyogi, Cole	This article summarizes recent research on agricultural air quality and describes best management practices for reducing NH_3 emissions.	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2008	*Auditing and Assessing Air Quality in Concentrated Feeding Operations* - Cole, Todd, Auvermann, Parker	This paper discusses AFO emissions and the current air quality regulations and techniques for measuring and quantifying emissions.	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2008	*Commentary: Farming Pollution* - Aneja, Schlesinger, Erisman	This article provides commentary on the U.S. efforts to regulate farms. It provides general information related to agricultural emissions and the state of knowledge of processes and a comparison to of U.S. regulations to European regulations.	None	Not applicable.	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2008	*Comparison of Ammonia Emission Rates from Three Types of Broiler Litters* - Atapattu, Senaratna, Belpagodagamage	This research-scale study compared the emissions of NH_3 from three kinds of broiler bedding: refused tea, sawdust and paddy husk.	Confinement NH_3 emissions	NH_3 emissions volatilized from litter samples in conical flasks were trapped in 100 mL of 0.32 *N* H_3SO_4 solutions. The trap was titrated with 0.1 *N* HCl to determine the NH_3 emissions.	None. The NH_3 concentrations were taken from litter samples analyzed under laboratory conditions. Additionally, data are not available to determine how the concentration measurements made using the titration method compare to the measurements made using the NAEMS methodology (i.e., chemiluminescence analyzer).
2008	*Instrumentation for Evaluating Differences in Ammonia Volatilization from Broiler Litter and Cake* - Miles, Owens, Moore, Rowe	The research-scale study evaluated a chamber acid trap (CAT) technique for measuring NH_3 losses from broiler litter samples.	None	Ammonia concentrations from litter samples contained in 1-liter containers were measured using boric acid traps followed by titration with hydrochloric acid.	None. This study specifically looked at emissions from litter samples. Emissions from litter samples are not directly comparable to emissions from broiler houses. Additionally, no data was provided to relate the litter samples to a specific bird inventory.

Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2008	*Modeling Ammonia Emissions from Broiler Litter at Laboratory Scale* - Zifei	Laboratory-scale study to develop an NH3 emissions model using broiler litter samples. Emissions were measured using a wind tunnel and a flux chamber.	Confinement NH_3 concentrations	Chemiluminescence gas analyzer	The nitrogen and moisture content and pH of litter may be used to supplement the mass balance data collected under the NAEMS. Regarding the NH3 concentrations, although the measurements were made using a chemiluminescence gas analyzer (which is consistent with the NAEMS), the measurements were taken from litter samples placed in laboratory flux chambers and a wind tunnel. Also, data were not provided to relate the NH3 emission to the size of the litter sample or bird inventory.
			Total ammoniacal nitrogen content of broiler litter (manure and wood shavings)	Extraction with 1.25 N K_2SO_4	
			Total N and total C content of broiler litter (manure and wood shavings)	Thermal conductivity detection (Leco C/N 2000 analyzer)	
			TKN content of broiler litter (manure and wood shavings)	Catalytic digestion (using K_2SO_4, $CuSO_4$, H_2O and pumice) w/H_2SO_4	
			Moisture content of broiler litter (manure and wood shavings)	Gravimetric (before and after drying)	
			pH of broiler litter (manure and wood shavings)	Not specified	
2008	*Winter Broiler Litter Gases and Nitrogen Compounds: Temporal and Spatial Trends* - Miles, Rowe, Owens	Commercial-scale study of two broiler houses in Mississippi. Data specifically relate to spatial/temporal variation in gases emitted from litter at different locations.	NH_3, N_2O and CO flux emission rates	Flux chamber w/photoacoustic multigas analyzer (Innova 1312)	None. Because this study used flux chambers to measure emissions, this study is not relevant for EEM development.
			Total NH_4, NO_3 and TKN content of litter	NH_4 and NO_3: water extraction (QuikChem 8000) TKN: block digestion and distillation/titration (2300 Kjeltec Analyzer)	The nitrogen content data may be used to supplement NAEMS mass balance data.
2009	*Ammonia Emissions and Animal Agriculture* - Gay, Knowlton	This article provides general information regarding AFO emissions and the effects of farming on pollution.	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2009	*Does Animal Feeding Operation Pollution Hurt Public Health? A National Longitudinal Study of Health Externalities Identified By Geographic Shifts In Livestock Production* - Sneeringer	This article discusses an epidemiological study that assessed the relationship between livestock farming and infant mortality.	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.

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Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2009	*Effects of Agriculture upon the Air Quality and Climate: Research, Policy, and Regulations* - Aneja, Schlesinger, Erisman	This article describes the state of the science and how research can be improved.	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2009	*Efficacy of Urease Inhibitor to Reduce Ammonia Emission from Poultry Houses* - Singh, Casey, King, Pescatore, Gates, Ford	The study addresses the use of urease inhibitors to reduce NH_3 emissions from broiler litter.	None	Flux chambers and a photoacoustic infrared gas analyzer.	None. The litter samples used in the study were subjected to amendments that suppressed NH_3 emissions. Also, because this study used flux chambers to measure emissions, this study is not relevant for EEM development.
2010	*Ammonia Emission Factors from Broiler Litter In Houses, in Storage, and After Land Application* - Moore, Miles, Burns, Pote, Berg, Choi	Commercial-scale study to measure NH_3 emissions from four confinement houses for 1 year and to construct a N mass across the houses.	Confinement NH_3 concentrations	Electrochemical sensors (Drager Polytron)	These data may be used to supplement the NAEMS data.
			Building ventilation rates	Anemometers (R.M. Young) located at fan outlets	
			Bird inventory, final average weight (kg), Final total house bird weight (kg)	Counts of initial chick placement and birds caught for market (methods used to determine bird weight not specified).	These data may be used to supplement the NAEMS data.
			Nitrogen content of birds, feed, bedding and litter	Feed and litter: total N analysis (method not specified); KCl-extractable NH_4 (Moore et al., 1995) Bedding: Elementar Variomax N analyzer (combustion w/thermal conductivity) Birds: Elementar N analyzer	These data may be used to supplement the NAEMS N mass balance data.
			NH_3, N_2O, CH_4 and CO flux measurements from litter on floor	Flux chamber and photoacoustic multigas analyzer (Innova 1412)	None. Because this study used flux chambers to measure emissions, this study is not relevant for EEM development.
			NH_3, N_2O, CH_4 and CO flux measurements from litter storage piles	Flux chamber and photoacoustic multigas analyzer (Innova 1412)	None. The EPA is not assessing emissions from broiler litter storage piles at this time.
			NH_3, N_2O, CH_4 and CO flux measurements from land application site	Lab-scale wind tunnels, phosphoric acid traps and wire anemometers	None. The EPA is not assessing emissions from broiler litter land application sites at this time.

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Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2010	*Effect of Atmospheric Ammonia on Growth Performance and Immunological Response of Broiler Chickens* - Wang, Meng, Guo, Wang, Wang, Yao, Shan	Experimental study to assess the effects of NH_3 concentrations on growth and immune response of broilers.	None	Not applicable	None. The study subjected birds to varying levels of NH_3 concentrations provided in a controlled environment.
2011	*Comparing Ammonia Emissions from Poultry Barns Using Two Techniques* - Flesch, Harper, Wilson	This commercial-scale study compared the NAEMS NH_3 emissions rates for CA1B to emissions determined using backward Lagrangian Stochastics (bLS)	None	Not applicable	None. The bLS emissions estimates were determined based on upwind and downwind NH_3 concentrations and inverse dispersion modeling rather than direct measurement of confinement concentrations and ventilation flow rate.
2011	*Spatial Contrasts of Seasonal and Intraflock Broiler Litter Trace Gas Emissions, Physical and Chemical Properties* - Miles, Brooks, Sistani	Commercial-scale study of two broiler houses in Mississippi. Data showed the litter chemical/physical properties, and flux values were specific to the litter surface and not necessarily to the broiler house as a whole.	NH_3, N_2O and CO litter flux emission rates	Flux chamber w/photoacoustic multigas analyzer (Innova 1312)	None. Because this study used flux chambers to measure emissions, this study is not relevant for EEM development.
			Litter total N, NH_4 and total carbon content	Max CN analyzer (Elementar)	The litter composition data could be used to supplement the NAEMS N mass balance data.

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4.2.2 Previous Literature Searches

Beginning in 2001, the EPA conducted several literature searches using the Agricultural Online Access (AGRICOLA) bibliographic database to identify data and information that were relevant to support a preliminary investigation into air pollution from large AFOs (see the EPA's *Emissions From Animal Feeding Operations* (draft, August 15, 2001)). The EPA also conducted literature searches to support development of the EPA's National Emissions Inventory (NEI) for NH_3 emissions from animal agricultural operations.

Table 4-5 lists additional articles and publications pertaining to broiler operations that the EPA identified through literature searches it conducted prior to the CFI. Articles that were common to both the CFI and previous literature searches are reported in the Table 4-4 only. As result, articles with a publication date after 2002 are not shown in Table 4-5. As shown in the Table 4-5, none of the articles previously obtained by the EPA to support emissions factor development were applicable for EEM development.

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Table 4-5. Review of Broiler Articles Obtained by Previous EPA Literature Searches

Date	Title	Author	Possible Application for NAEMS
1965	*Dust Problems in Poultry Environments*	Grub, Rollo, Howes	None. This study focuses on collecting dust samples and does not provide particle-sizing data for PM_{10} or $PM_{2.5}$. Consequently, these data were not considered for use in EEM development.
1987	*Quantification of Odour Problems Associated with Liquid and Solid Feedlot and Poultry Wastes*	du Toit	None. This study focuses on the methodology for collecting and analyzing samples for odor concentrations. Consequently, these data were not considered for use in EEM development.
1988	*Controlling Ammonia Emission from Poultry Manure Composting Plants*	Bonazzi, et al.	None. This study evaluated emissions of odor and NH_3 and litter characteristics from two composting plants in Italy. The EPA is not assessing emissions from broiler litter composting sites at this time. Consequently, these data were not considered for use in EEM development.
1988	*Concentration and Size Distribution of Airborne Particles in a Broiler House*	Gupta, Sandhu, Harter-Dennis, Khan	None. This study evaluated PM concentrations inside of a broiler house. However, PM emissions from the house were not quantified. Consequently, these data were not considered for EEM development.
1988	*Ammonia Emission from Poultry Housing Systems*	Kroodsma, Scholtens, Huis	None. This study presents European farming practices and did not provide data for bird age, weight or inventory. Consequently, these data were not considered for EEM development.
1988	*Ammonia Emissions from Cattle, Pig and Poultry Wastes Applied to Pasture*	Lockyer, Pain, et al.	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1988	*Available Nitrogen in Broiler and Turkey Litter*	Westerman, et al.	None. This study evaluated nitrogen availability in poultry litter under aerobic and anaerobic conditions. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1989	*Poultry Manure Composting: Design Guidelines for Ammonia*	Hansen, Keener, Hoitink	None. The EPA is not assessing emissions from composting of broiler litter at this time. Consequently, these data were not considered for use in EEM development.

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Table 4-5. Review of Broiler Articles Obtained by Previous EPA Literature Searches

Date	Title	Author	Possible Application for NAEMS
1989	*Dust and Odour Relationships in Broiler House Air*	Williams	None. According to the author, the dust emissions measured during the study were likely increased due to a separate study that was being conducted at the same time that involved catching and weighing the birds. Consequently, these data were not considered for use in EEM development.
1990	*Empirical Models to Determine Ammonia Concentrations from Broiler Chicken Litter*	Carr, et al.	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
1990	*Batch Digester Studies on Biogas Production from Cannabis Sativa, Water Hyacinth and Crop Wastes Mixed with Dung and Poultry Litter*	Mallik, et al.	None. The EPA is not assessing the performance of anaerobic digestion of broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1991	*Odour Emissions from Broiler Chickens*	Clarkson, Misselbrook	None. This study focuses on the methodology for collecting and analyzing samples for odor. Consequently, these data were not considered for use in EEM development.
1991	*Odor Control from Poultry Manure Composting Plant Using a Soil Filter*	Sweeten, Childers, Cochran, Bowler	None. The EPA is not assessing emissions from composting of broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1992	*Effect of Surface-Applied Poultry Waste Source on Infiltration and Runoff*	Daniel, Edwards	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1992	*Gaseous Pollutants Produced by Farm Animal Enterprises*	Tamminga	None. This resource was used to develop emissions factors for broiler operations for the EPA's Emissions From Animal Feeding Operations (draft, August 15, 2001). However, data describing the number, size and weight of the birds associated with the emissions data were not provided. Consequently, these data were not considered for use in EEM development.
1992	*Potential Environmental Effects of Long-Term Land Application of Broiler Litter*	Kingery, et al.	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1992	*Physical and Chemical Characteristics of Pine Shavings Poultry Litter*	Koon, et al.	None. This study presents the chemical composition and particle size distribution of litter samples collected over four broiler grow-out periods.

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Table 4-5. Review of Broiler Articles Obtained by Previous EPA Literature Searches

Date	Title	Author	Possible Application for NAEMS
1993	*Nitrogen Transformations in Surface-Applied Poultry Litter: Effect of Litter Physical Characteristics*	Cabrera, Chiang, Merka, Thompson, Pancorbo	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1993	*Testing of Broiler Litter and its Effect on Land Application*	Nordstedt	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1993	*Mineral Levels of Broiler House Litter and Forages and Soils Fertilized with Litter*	Smith, Britton, Enis, Barnes, Lusby	None. The EPA is not currently assessing the mineral concentrations in broiler litter and soils treated with broiler litter, and thus these data were not considered in this study.
1993	*Use of Mineral Amendments to Reduce Ammonia Losses from Dairy-Cattle and Chicken-Manure Slurries*	Termeer, Warman	None. The EPA is not assessing the performance of litter amendments for broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1994	*Volatile Fatty Acids as Indicators of Process Imbalance In Anaerobic Digestors*	Ahring, et al.	None. The EPA is not assessing the performance of anaerobic digestion of broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1994	*Chemical and Microbiological Characteristics of Poultry Processing By-Products, Waste and Poultry Carcasses During Lactic Acid Fermentation*	Cai, Pancorbo, Barnhart	None. The EPA is not assessing waste composition during composting at this time. Thus these data were not considered for use in EEM development.
1994	*Stabilization of Poultry Processing By-Products and Waste and Poultry Carcasses Through Lactic Acid Fermentation*	Cai, Pancorbo,Merka, Sander, Barnhart	None. The EPA is not assessing emissions from composting of broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1994	*Land Application of Livestock and Poultry Manure*	Hammond, Segars, Gould	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1994	*Impact of Long-Term Land Application of Broiler Litter on Environmentally Related Soil Properties*	Kingery, et al.	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1994	*Changes in Physical and Chemical Characteristics of Poultry Litter Due to Rotary Tilling*	Koon, et al.	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.

Table 4-5. Review of Broiler Articles Obtained by Previous EPA Literature Searches

Date	Title	Author	Possible Application for NAEMS
1994	*Losses and Transformation of Nitrogen During Composting of Poultry Manure with Different Amendments: An Incubation Experiment*	Mahimairaja, et al.	None. The EPA is not assessing emissions from composting of broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1994	*Poultry Waste Management: Agricultural and Environmental Issues*	Sims, Wolf	None. This article reviews general information regarding issues related to poultry waste. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
1994a	*Nitrogen Mineralization and Ammonia Volatilization from Fractionated Poultry Litter*	Cabrera, et al.	None. This study evaluates mineralization of nitrogen in poultry litter and the effects of water content on mineralization, NH_3 volatilization and respiration. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
1994b	*Ammonia Volatilization and Carbon Dioxide Emission from Poultry Litter: Effects of Fractionation and Storage Time*	Cabrera, et al.	None. The EPA is not assessing emissions from broiler litter storage sites at this time. Consequently, these data were not considered for use in EEM development.
1995a	*Poultry Manure Management: Environmentally Sound Options*	Moore, et al.	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1995b	*Effect of Chemical Amendments on Ammonia Volatilization from Poultry Litter*	Moore, et al.	None. The EPA is not assessing the performance of litter amendments for broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1995	*Measuring Air-Borne Microbial Contamination of Broiler Cabinets*	Berrang, Cox, Baily	None. This study compares methods for measuring airborne bacteria. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
1995	*Exposure to Excessive Carbon Dioxide: Risk Factor for Early Poultry Mortality*	Donaldson, Christensen, Garlich, and McMurtry	None. The EPA is not assessing the effects of post-hatch stressors on newly hatched turkeys at this time. Consequently, these data were not considered for use in EEM development.
1995	*Ammonia Quick Test and Ammonia Dosimeter Tubes for Determining Ammonia Levels in Broiler Facilities*	Skewes, Harmon	None. The study measured NH_3 concentrations above the litter surface over a short period (10 hours). However, the concentration data were not converted to a mass emissions rate. Also, the data for the bird inventory were not provided in this article. Consequently, these data were not considered for use in EEM development.

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Table 4-5. Review of Broiler Articles Obtained by Previous EPA Literature Searches

Date	Title	Author	Possible Application for NAEMS
1995	*Addition of Different Sources and Levels of Amino Acids and Sugars to Broiler Litter Before Deep-Stacking*	Wang, et al.	None. The EPA is not assessing the use of additives in broiler manure at this time. Consequently, these data were not considered for use in EEM development.
1996	*Trace Element characterization of Composted Poultry Manure*	Ihnat, Fernandes	None. The EPA is not assessing emissions from composting of broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1996	*Changes During Processing in the Organic Matter of Composted and Air-Dried Poultry Manure*	Mondini, et al.	None. The EPA is not assessing the effects of manure drying and composting on emissions at this time. Consequently, these data were not considered for use in EEM development.
1997	*Land Application of Poultry Lagoon Effluent*	Aldrich, et al.	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1997	*A Farm-Scale Study on the Use of Clinoptilolite Zeolite and De-Odorase® for Reducing Odour and Ammonia Emissions from Broiler Houses*	Amon, Dobeic, Sneath, Phillips, Misselbrook, Pain	None. The EPA is not assessing the performance of litter amendments for broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1997	*Mineralizable Nitrogen in Broiler Litter: I. Effect of Selected Litter Chemical Characteristics*	Gordillo, Cabrera	None. This study assessed the kinetics of nitrogen mineralization in broiler litter samples to evaluate the supply of nitrogen to land application sites. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1997	*Reduction of Poultry Ventilation Fan Output Due to Shutters*	Simmons, Lott	None. This study evaluates the effects of fan shutters on air flow rates of poultry house fans. Emissions and the overall ventilation flow rate data for the house were not provided. Consequently, these data were not considered for use in EEM development.
1997	*Concentrations and Emission Rates of Aerial Ammonia, Nitrous Oxide, Methane, Carbon Dioxide, Dust and Endotoxin in UK Broiler and Layer Houses*	Wathes, Holden, Sneath, White, Phillips	None. Emissions in this study were measured over a very short sampling period (24 hours during summer and winter). Consequently, these data were not considered for use in EEM development.
1998	*Nitrogen: Some Practical Solutions for the Poultry Industry*	Chambers, Smith	None. This article discusses general options for reducing nitrogen emissions in the poultry industry. The article does not contain emissions or process data that could be used to supplement the NAEMS data.

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Table 4-5. Review of Broiler Articles Obtained by Previous EPA Literature Searches

Date	Title	Author	Possible Application for NAEMS
1998	*Litter Production and Nutrients from Commercial Broiler Chickens*	Patterson, Lorenz, Weaver	This study analyzed the moisture, total nitrogen, ammoniacal nitrogen, phosphorous pentoxide and potassium oxide content of broiler litter samples and the crude protein, total phosphorous, and total potassium content of feed. The nitrogen content data could be used to supplement NAEMS mass balance data.
1998	*Field-Scale Nitrogen and Phosphorus Losses From Hayfields Receiving Fresh and Composted Broiler Litter*	Vervoort, et al.	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1998	*Aerial Emissions from Poultry Production*	Wathes	None, This article discusses the potential control mechanisms for pollutants from broiler operations. Emissions values presented were from other articles and the article does not provide descriptions of monitoring methodologies used to measure emissions.
1998	*Estimating Ammonia Emission Factors in Europe: Summary of the Work of the UNECE Ammonia Expert Panel*	Van der Hoek	None. This resource was used to develop emissions factors for broiler operations for the EPA's Emissions From Animal Feeding Operations (draft, August 15, 2001). However, the resource does not provide the underlying data (e.g., daily values for bird inventory, bird mass, pollutant emissions) for the emissions factors cited. Consequently, these data were not considered for use in EEM development.
1998	*Concentrations and Emissions of Ammonia in Livestock Buildings in Northern Europe*	Groot Koerkamp, Metz, Uenk, Phillips, Holden, Sneath, Short, White, Hartung, Seedorf, Schroder, Linkert, Pederson, Takai, Johnsen, Wathes	None. This resource was used to develop emissions factors for broiler operations for the EPA's *Emissions From Animal Feeding Operations* (draft, August 15, 2001). However, data describing the number, size and weight of the birds associated with the emissions data were not provided. Consequently, these data were not considered for use in EEM development.
1999	*In Situ Measurement of Ammonia Volatilization from Broiler Litter Using an Enclosed Air Chamber*	Brewer, Costello	None. The study measured NH_3 emissions from litter using flux chambers. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2002	*Efficient Feed Nutrient Utilization to Reduce Pollutants In Poultry and Swine Manure*	Nahm	None. The EPA is not assessing the effects of dietary changes on emissions at this time, and this study evaluates outcomes not addressed by the NAEMS (such as odor and manure characteristics).

Table 4-5. Review of Broiler Articles Obtained by Previous EPA Literature Searches

Date	Title	Author	Possible Application for NAEMS
2002	*Continuous Monitoring of Ammonia, Hydrogen Sulfide and Dust Emissions From Swine, Dairy and Poultry Barns*	Schmidt, Jacobson, Janni	None. This study does not contain broiler data.
NA	*Ammonia Emissions from Field Applications of Poultry Litter*	Meisinger, et al.	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.

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5.0 NAEMS DATA PREPARATION

This section provides an overview of the data assessment procedures followed by the NAEMS in collecting the emissions and process parameter data from the broiler monitoring sites and the procedures followed by the EPA in preparing the data for use in development of EEMs for broiler confinement operations.

Section 5.1 discusses the Quality Assurance/Quality Control (QA/QC) procedures outlined in the NAEMS QAPP and implemented by the researchers to ensure collection of high-quality emissions and process data. Section 5.2 summarizes the steps the EPA followed to process and review the data submitted to the EPA prior to developing the broiler EEMs. Section 5.3 compares the design and operating parameters and reported emissions of each site.

5.1 NAEMS Data Assessments

5.1.1 QA/QC Procedures

The NAEMS followed strict QA/QC procedures throughout the data collection and preliminary data analyses processes of the NAEMS. The investigators developed QAPPs, SOPs for sampling systems and monitoring instruments and site-specific monitoring plans and provided extensive training for on-site operators and producers. Appendix A contains the QAPPs, Appendix B contains the SMPs for each monitoring site and Appendix C contains the SOPs.

Monitoring instruments underwent initial and periodic calibration, bias and precision checks and were corrected if they failed the QC checks. The frequency of each check/calibration event was dependent on the type of instrument and on the site investigator. For example, the NH_3 gas analyzer was checked with calibration gases weekly or semi-weekly for the Kentucky sites, while the calibration checks were conducted every two months at site CA1B. The investigators also implemented external system audits conducted by independent personnel and maintained supporting documentation (e.g., field logs, instrument calibration records).

All of the monitoring sites were equipped with data acquisition (DAQ) systems that allowed on-site operators, and other authorized personnel via high-speed Internet connection, to view the measured data and parameter values daily through real-time computer displays. The DAQ systems also generated email notifications for project personnel when monitored parameter values were outside of preset ranges.

The NAEMS also used control charts extensively in QA/QC procedures to assess data quality and measurement variability and to evaluate long-term trends in the instrument/equipment performance. The control charts provided a graphical means of determining whether the measured parameters were within acceptable upper and lower control limits. Data values outside the control limits triggered corrective actions by site operators to maintain data quality. The control charts were generated on site using Microsoft ® Excel templates to provide a real-time assessment of the data quality.

Measurement data recorded at each site were uploaded to the respective researchers (Purdue University for site CA1B and Iowa State University for the Kentucky sites) each day for review and evaluation. The researchers used custom-designed software to apply flags to measurement data that were considered invalid or outliers and to calculate emissions rates for the monitored houses. The researchers used the Calculation of Air Pollutant Emissions from Confined Animal Buildings (CAPECAB) program for site CA1B and the Mobile Air Emissions Monitoring Unit (MAEMU v1.2) program for the Kentucky sites.

5.1.2 Data Validation

In general, the researchers invalidated measurement data (e.g., concentration, differential static pressure, temperature) if the data values were:

- Unreasonably low or high when compared to normal ranges if there was supporting evidence that the data value is not correct (e.g., unresponsive relative humidity sensor inside a house producing a reading of less than 10 percent).
- Obtained during system installation, testing or maintenance during which uncorrectable errors might be introduced.
- Obtained when a sensor or instrument was proven to be malfunctioning (e.g., unstable).
- Obtained during calibration or precision check of a sensor or instrument and before the sensor or instrument reached equilibrium after the check.
- Obtained when the data acquisition and control hardware and/or software were not functioning correctly.

Data that the researchers deemed invalid were retained in the preprocessed data sets. However, the EPA did not use the flagged data to calculate pollutant emissions rates.

For averaged data, data were invalidated to avoid errors introduced into calculated mean values due to partial-data days (e.g., only a few hours of valid data) that would result in biased time weights:

- Hourly averages were invalidated if less than 75 percent of the data recorded during that hour were valid.

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- Daily means were invalidated if less than 75 percent of the hourly average data recorded during that day were valid.
- Monthly averages were invalidated if less than 75 percent of the individual days recorded during that month were valid.
- Average daily means (ADM) were invalidated if less than 75 percent of the daily average data recorded during all measurement days were valid.

5.1.3 Data Completeness

Consistent with the EPA's *Guidance for Quality Assurance Project Plans* (EPA QA/G-5), data completeness is the measure of the amount of valid data obtained from a measurement system, compared with the amount of data that was expected to be obtained under normal conditions. Data completeness is expressed as the percentage of valid data obtained from the measurement system. For data to be considered valid, they must meet all the acceptance criteria. The researchers calculated data completeness during data processing.

The goal of the NAEMS was to continuously monitor emissions and process parameters over a long period to characterize uncontrolled emissions from broiler confinement houses. The long monitoring period was intended to capture the variations in pollutant emissions due to the bird grow-out and litter clean-out cycles, and diurnal and seasonal variations. Emissions and process parameters were monitored at site CA1B from September 27, 2007, to October 21, 2009, and at site KY1B-1 from February 14, 2006, to March 14, 2007, and at site KY1B-2 from February 20, 2006, to March 5, 2007.

Table 5-1 presents the total number of days that the monitoring instrumentation systems were operational and the number of valid emissions days submitted to EPA for each site. According to the criteria established in the NAEMS QAPPs, a valid day for a pollutant or process parameter was one in which more than 75 percent of the measurement values recorded were valid (i.e., the data passed all QA checks). The NAEMS also established an overall completeness goal of 75 percent for the number of valid days of data that were recorded versus the number of scheduled sampling days. Table 5-2 presents the data completeness percentages for each site by pollutant. In the development of EEMs, the EPA considered all valid data days regardless of whether the NAEMS completeness goal was achieved.

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Table 5-1. Reported Number of Valid Emissions Days for Required Data from NAEMS Broiler Operations

Site	Monitoring Period	Total Monitoring Days[a]						Number of Valid Emissions Days[a]					
		NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP	NMHC	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP	NMHC
CA1B, H10	9/27/2007 – 10/21/2009	756	756	628	60	67	756	467	592	352	53	37	NA[b]
CA1B, H12	9/27/2007 – 10/21/2009	756	756	628	60	67	756	466	590	376	43	39	NA[b]
KY1B-1, H5	2/14/2006 – 3/14/2007	394	394	394	394	394	394	381	342	295	279	304	268
KY1B-2, H3	2/20/2006 – 3/5/2007	379	379	379	379	379	379	337	274	301	299	298	203

[a] In the final report for the Kentucky sites, the number of total monitoring days and valid emissions days were prorated to represent a monitoring period of 365 days. The values shown in the table are the actual number of days.
[b] Not available. The final report for the CA1B site states that the NMHC data were questionable due to irreconcilable interferences caused by water and other gases.

Table 5-2. Data Completeness for Daily Emissions Data from NAEMS Broiler Operations

Site	Data Completeness (%)					
	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP	NMHC
CA1B, H10	61.8	78.3	56.1	88.3	55.2	NA[a]
CA1B, H12	61.6	78.0	59.9	71.7	58.2	NA[a]
KY1B-1, H5	96.7	86.0	74.9	70.8	77.0	68.5
KY1B-2, H3	88.9	71.2	79.4	78.9	80.8	55.1

[a] Not available. The final report for the CA1B site states that the NMHC data were questionable due to irreconcilable interferences caused by water and other gases.

At site CA1B, the completeness goal of 75 percent was achieved only for H_2S (at Houses 10 and 12) and $PM_{2.5}$ (only at House 10). The completeness goal was not met for NH_3, PM_{10} and TSP emissions by either house at site CA1B due to delays in receiving monitoring equipment at the beginning of the study and calibration and maintenance issues with the gas analyzer.

At site CA1B, a single instrument (TEOM) and different inlet sampling heads were used to measure PM_{10}, $PM_{2.5}$ and TSP emissions. Because a single instrument was used, each PM component was sampled on an intermittent schedule. The goal of the NAEMS over the study period was to collect emissions data for seven weeks out of every eight weeks for $PM_{10;}$ two weeks of summertime data and two weeks of wintertime data for $PM_{2.5}$; and data for one week out of every eight weeks for TSP.

Table 5-3 shows the operating times for the TEOM instrument and the total number of measurement days at each particle size. The number of valid PM emissions days was limited due to TEOM failures. Emissions of $PM_{2.5}$ were sampled in periods ranging from 12 to 18 days in February and July 2008 and in January and September 2009, with the goal of obtaining data under both cold (winter) and hot (summer) conditions. For TSP, sampling was conducted during six measurement events, each lasting from 7 to 14 days. Emissions of PM_{10} were measured at all other times over the course of the monitoring study at site CA1B. The length of the monitoring period for each PM size cut was varied, where possible, to accommodate the completeness requirements. For example, TSP sampling was allowed to run for up to two weeks to meet the 75 percent completeness requirement of 5.25 emissions days. However, if this requirement was not met by the end of the two-week period, the TEOM was reconfigured for the next particle size cut to be monitored.

Table 5-3. Particulate Matter Monitoring Schedule for CA1B

Date		Test Duration (days)		
Start	**Stop**	**PM_{10}**	**TSP**	**$PM_{2.5}$**
9/28/07	12/10/07	73.6	NS	
12/10/07	12/19/07	NS	8.9	NS
12/19/07	2/1/08	44	NS	
2/1/08	2/19/08	NS		18.1
2/19/08	2/20/08	NS		0.3[a]
2/19/08	2/20/08	0.3[b]	NS	
2/20/08	5/15/08	85.7	NS	
5/15/08	5/28/08	NS	12.8	NS
5/28/08	7/9/08	42	NS	
7/9/08	7/25/08	NS		16
7/25/08	11/17/08	115.1	NS	
11/17/08	11/24/08	NS	7.1	
11/24/08	1/5/09	41.9	NS	
1/5/09	1/20/09	NS		15
1/20/09	4/9/09	79	NS	
4/9/09	4/20/09	NS	11	NS
4/20/09	6/25/09	66.1	NS	
6/25/09	7/8/09	NS	12.9	NS
7/8/09	9/26/09	80.1	NS	
9/26/09	10/7/09	NS		10.9
10/7/09	10/21/09	NS	14.1	NS
10/21/09	10/22/09	0.4	NS	
	Totals	628.3	66.7	60.3

NS - Not sampled.
[a] Ambient data were not collected during this sampling period.
[b] Only ambient data were collected during this sampling period.

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At the Kentucky sites, the completeness goal of 75 percent was achieved for all pollutants except for H_2S (at KY1B-2 H3), PM_{10} (at KY1B-1 H5) and $PM_{2.5}$ (at KY1B-1 H5). The final report for the Kentucky sites did not provide explanations for the missing data days.

5.2 EPA Assessments

5.2.1 Data Processing

The data collected under the NAEMS were provided to the EPA in the form of final site reports (pdf format) and Microsoft Excel® spreadsheets that contained the emissions and process data. For site CA1B, separate worksheets were used to present the daily values for each pollutant. In addition, the data within each worksheet were further divided into tables that presented the daily values and summary statistics (i.e., number of data points, averages, standard deviations, minimums and maximums) for each month of the study period.

To facilitate analyses of the emissions and process data for site CA1B, the EPA reformatted and converted the files to a Microsoft Access® database containing all of the data elements provided by the investigators in the summary spreadsheets. To reformat the spreadsheets received, the EPA removed the summary statistics and the blank spaces between data tables that presented the data for each month. Merged cells were removed and the data headers for each month were consolidated and rearranged, as necessary, to create an input file for uploading into Microsoft Access®. The EPA performed QA checks to verify that the conversion from spreadsheets to database tables was performed correctly and that data were not lost or transposed in the conversion. Additionally, the EPA randomly selected three dates during the study period and compared all of the values contained in the database on those dates to the original spreadsheets to ensure the data were properly transferred to the new file format.

The EPA reformatted and converted the spreadsheets submitted for the Kentucky sites to Microsoft Access® data tables. The EPA performed QA checks of the uploaded Kentucky data and then the Kentucky data were combined with the data for site CA1B to create a comprehensive database of the NAEMS broiler data.

5.2.2 Data QA

The EPA developed a comprehensive list of the emissions and confinement operating parameter, meteorological condition and mass balance data that were expected to be submitted to the EPA based on the EPA's review of the QAPPs, SOPs and SMPs. As the final reports and data spreadsheets were received, the EPA compared the information received to the comprehensive list to identify missing information. After determining whether the data submittals to the EPA were complete and identifying missing data elements, the EPA verified

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that the units of measurement for the emissions and supporting data were consistent between the final reports and spreadsheet data files. In addition, the EPA assessed whether the units of measurement and the magnitude of emissions were consistent across the monitoring sites. The EPA prepared and provided summaries of the missing data elements to the researchers.

The EPA's review identified that a small number (less than 1.7 percent) of the daily average emissions for H_2S and PM_{10} at site CA1B were reported as negative values. After discussion with the study's Scientific Advisor, it was determined the negative emission values occurred due to drift in the instrument readings between calibrations. The EPA included the negatives values when graphing the data to visualize emission trends but did not include the negative values when developing EEMs for broiler houses, to avoid possible complications with EEM development (e.g., the EEM predicting negative emissions) the negative values were withheld from the data sets used for EEM development. The EPA's review also identified a few instances (less than 2 percent) of zero emission values (i.e., instances where the ambient and confinement concentrations were the same). However, because the zero values were not the result of instrument drift, the EPA included the zero emissions values in the data sets used in the development of the EEMs for broiler confinement houses.

As specified in the QAPPs developed for the CA1B and Kentucky sites, the daily emissions values submitted to the EPA did not include measurements that were considered to be outliers by the NAEMS researchers. However, the EPA compared the emissions values calculated for each day of the grow-out, decaking and litter clean-out periods for each flock to the average daily emissions for all flocks to identify anomalies in the reported data. Daily emissions values that were higher or lower than ± two standard deviations and ± twice the average flock emission for that day were noted for further evaluation. For these values, the EPA prepared graphical overlays of the pollutant emissions and the average ambient and confinement parameter values (e.g., air temperature, house temperature, ventilation flow rate) recorded for that day to determine if the anomalous emission value could be attributed to an irregular condition (e.g., an abnormally high ambient temperature or house ventilation flow rate). This analysis identified several anomalies (e.g., spikes in NH_3 emissions during litter clean-out periods); however, the analysis suggested that other activities (e.g., high/low ventilation rates) could account for these anomalies. Additionally, the field note summaries in the final reports for the CA1B and Kentucky sites did not suggest abnormal conditions that would warrant excluding the emissions values from EEM development.

5.2.3 Data Completeness Assessment

The EPA assessed the data completeness of the average daily emissions values to verify the completeness calculations presented in the final reports. Based upon its analysis, the EPA confirms that the completeness goal of 75 percent was achieved at site CA1B only for H_2S (at Houses 10 and 12) and $PM_{2.5}$ (only at House 10) and was not achieved for $PM_{2.5}$ at KY1B-1 H5. Additionally, the EPA looked at the seasonal distribution of the data to determine if any pollutant was under-represented during a particular season (see Table 5-4 and Table 5-5). The NAEMS QAPP for barn sources defined the seasons as follows:

- Spring: March 1 through May 31.
- Summer: June 1 through August 31.
- Fall: September 1 through November 30.
- Winter: December 1 through February 28.

Table 5-4. Number of Valid Emissions Days in the Spring and Summer

Site	Spring					Summer				
	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP
CA1B, H10	160	161	76	0[a]	8	130	169	104	15	10
CA1B, H12	160	160	113	0[a]	15	129	167	90	15	12
KY1B-1, H5	103	103	87	89	89	90	54	55	46	63
KY1B-2, H3	89	49	67	67	67	87	64	79	79	79

[a] Per the study design, $PM_{2.5}$ data was not scheduled for collection during the spring and fall.

Table 5-5. Number of Valid Emissions Days in the Fall and Winter

Site	Fall					Winter				
	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP
CA1B, H12	49	88	78	0[a]	5	128	175	95	28	7
CA1B, H10	51	89	88	10	12	126	173	84	28	7
KY1B-1, H5	87	87	69	57	69	98	98	90	94	94
KY1B-2, H3	88	84	77	75	77	72	94	81	79	77

[a] Per the study design, $PM_{2.5}$ data was not scheduled for collection during the spring and fall.

For site CA1B, the least number of days of valid NH_3 and H_2S emissions were collected during the fall, most likely a function of the partial fall seasons captured at the start and end of the study. The seasonal distributions of PM_{10} and TSP emissions days were relatively consistent. Emissions data for $PM_{2.5}$ were collected during the summer and winter for both houses and only for House 10 in the fall.

At the Kentucky sites, the seasonal distributions of the emissions data were relatively consistent across pollutants. However, the amount of H_2S emissions data collected was

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somewhat lower during the spring at site KY1B-2 H3 and during the summer at both Kentucky sites. For PM_{10}, less data were collected during the summer at site KY1B-1 H5. Fewer $PM_{2.5}$ data values were collected during the summer and fall at site KY1B-1 H5 and fewer TSP data were collected during the fall at site KY1B-1 H5.

5.3 Comparison of Broiler Monitoring Sites

Table 5-6 shows the NAEMS data available for the grow-out and litter removal periods at each site. The EPA developed comparative statistics and graphs of emissions data for each site to determine if there were any notable differences or data anomalies among the sites at the process, location or emissions level. Each of these comparisons is discussed in more detail in the following sections. Based upon this assessment, the EPA determined that the NAEMS data are appropriate and consistent with the requirements of the Air Compliance Agreement.

Table 5-6. NAEMS Data for Broiler Confinement Operations

Process Description		
Confinement	**Period**	**NAEMS Data**
Broiler on litter, mechanically ventilated (tunnel) houses	Grow-out	CA1B (Houses 10 and 12), KY1B-1 H5 and KY1B-2 H3
	Decaking	
	Full litter clean-out	

5.3.1 Process-Level Comparison

Table 5-7 summarizes the design and operating parameters for the CA1B and Kentucky sites. All of the broiler confinement houses monitored under the NAEMS are comparable at the process level. All sites use mechanically-ventilated tunnel houses with litter (rice hulls) on the floor and periodically conducted decaking and full litter clean-out operations. In each of the houses, birds are raised to an approximate final weight of 5 to 6 pounds over the grow-out periods covered by the study.

The houses differed in the types of birds raised and length of the litter clean-out periods. The flocks at site CA1B comprised a 60/40 percent mix of Cobb and Ross broilers while the flocks at the Kentucky sites were all Cobb broilers. The differences in growth rate, feed conversion and emissions due to bird type are expected to be negligible. Regarding duration of the litter clean-out periods, the clean-out operations at the Kentucky sites tended to last an average of 8 days longer than at site CA1B (see Table 5-8). This apparent difference could be caused by a longer idle period (i.e., the period after litter has been cleaned out but before a new flock is placed in the house) for the Kentucky houses compared to the CA1B site.

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Additionally, the Kentucky sites conducted full litter clean-outs once per year, while the CA1B houses cleaned out litter after three consecutive grow-out periods. Table 5-9 specifies the dates of the litter clean-outs for each broiler confinement house during the study and the type of clean-out activity performed.

Table 5-7. Design and Operating Parameters of the NAEMS Broiler Sites

Monitoring Site		House Capacity (no. of birds)	Bird Type	Final Bird Weight[a] (kg)		Design	Ventilation Type
				Average	Range		
CA1B	H10	21,000[b]	60 percent Cobb, 40 percent Ross	2.64	2.48 – 2.75	Litter (rice hulls) on floor	Mechanical (tunnel)
CA1B	H12	21,000[b]	60 percent Cobb, 40 percent Ross	2.65	2.55 – 2.76	Litter (rice hulls) on floor	Mechanical (tunnel)
KY1B-1	H5	25,800 (summer) 24,400 (winter)	100 percent Cobb[c]	2.74	2.53 – 2.89	Litter (rice hulls) on floor	Mechanical (tunnel)
KY1B-2	H3	25,800 (summer) 24,400 (winter)	100 percent Cobb[c]	2.78	2.47 – 2.97	Litter (rice hulls) on floor	Mechanical (tunnel)

[a] Bird weight at the end of the grow-out period.
[b] The CA1B site did not vary stocking numbers during the year.
[c] Described in the final report text as "Cobb-Cobb-straight-run (mixed sex)."

Table 5-8. Duration of Grow-out and Clean-out Periods

Monitoring Site		Grow-Out Periods			Clean-Out Periods					
					Decaking			Full Litter Clean-Out		
		Frequency	Average (days)	Range (days)	Frequency	Average Duration (days)	Range of Duration (days)	Frequency	Average Duration (days)	Range of Duration (days)
CA1B	H10	~ 7 flocks per year	47	45 - 49	~ 5 time per year	7.75	6 – 11	Every third flock (~2 times per year)	12.6	6 – 21
CA1B	H12	~ 7 flocks per year	47	45 - 49	~ 5 time per year	7.25	3 – 11	Every third flock (~2 times per year)	12.8	6 – 23
KY1B-1	H5	~ 6 flocks per year	51	50 - 54	~4 times per year	15.5	12 – 22	Once per year	25	NA[a]
KY1B-2	H3	~ 6 flocks per year	52	50 - 54	~4 times per year	22	15 – 41	Once per year	9	NA[a]

[a] Not applicable. Only one full litter clean-out event was monitored during the study.

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Table 5-9. Summary of Flock and Litter Clean-out Operations

Monitoring Site		Flock	Start and End Dates	Season[a]	Type of Litter[b]	Type of Clean-Out[c]
CA1B	H10	1[d]	9/20/07 - 11/3/07	F	Built-up litter	Full litter
		2	11/15/07 - 12/31/07	F/W	New bedding	Decake
		3	1/7/08 - 2/21/08	W	Built-up litter	Decake
		4	2/28/08 - 4/15/08	Sp	Built-up litter	Full litter
		5	4/22/08 - 6/6/08	Sp	New bedding	Decake
		6	6/14/08 - 8/1/08	Su	Built-up litter	Decake
		7	8/11/08 - 9/27/08	Su/F	Built-up litter	Full litter
		8	10/20/08 - 12/4/08	F	New bedding	Decake
		9	12/12/08 - 1/28/09	W	Built-up litter	Decake
		10	2/9/09 - 3/27/09	W/Sp	Built-up litter	Full litter
		11	4/10/09 - 5/27/09	Sp	New bedding	Decake
		12	6/5/09 - 7/21/09	Su	Built-up litter	Decake
		13	7/30/09 - 9/14/09	Su	Built-up litter	Full litter
		14[d]	9/26/09 - 11/10/09	F	New bedding	NA[e]
	H12	1[d]	9/20/07 - 11/3/07	F	Built-up litter	Full litter
		2	11/15/07 - 1/1/08	F/W	New bedding	Decake
		3	1/5/08 - 2/21/08	W	Built-up litter	Decake
		4	2/28/08 - 4/15/08	Sp	Built-up litter	Full litter
		5	4/22/08 - 6/6/08	Sp	New bedding	Decake
		6	6/14/08 - 8/1/08	Su	Built-up litter	Decake
		7	8/11/08 - 9/26/08	Su/F	Built-up litter	Full litter
		8	10/20/08 - 12/4/08	F	New bedding	Decake
		9	12/12/08 - 1/28/09	W	Built-up litter	Decake
		10	2/9/09 - 3/27/09	W/Sp	Built-up litter	Full litter
		11	4/10/09 - 5/27/09	Sp	New bedding	Decake
		12	6/4/09 - 7/21/09	Su	Built-up litter	Decake
		13	7/30/09 -9/14/09	Su	Built-up litter	Full litter
		14[d]	9/26/09 - 11/10/09	F	New bedding	NA[e]
KY1B-1	H5	1	2/14/20 - 4/4/06	W/Sp	Built-up litter	Decake
		2	4/21/06 - 6/9/06	Sp	Built-up litter	Decake
		3	6/22/06 - 8/10/06	Su	Built-up litter	Full litter
		4	9/5/06 - 10/25/06	F	New bedding	Decake
		5	11/17/06 - 1/9/07	F/W	Built-up litter	Decake
		6	1/22/07 - 3/14/07	W	Built-up litter	NA[e]
KY1B-2	H3	1	2/20/06 - 4/10/06	W/Sp	Built-up litter	Decake

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Table 5-9. Summary of Flock and Litter Clean-out Operations

Monitoring Site		Flock	Start and End Dates	Season[a]	Type of Litter[b]	Type of Clean-Out[c]
		2	5/22/06 - 7/11/06	Su	Built-up litter	Decake
		3	7/28/06 - 9/19/06	Su	Built-up litter	Decake
		4	10/5/06 - 11/27/06	F	Built-up litter	Decake
		5	12/14/06 - 2/2/07	W	Built-up litter	Full litter
		6[d]	2/12/07 - 3/5/07	W	New bedding	NA[e]

[a] Season of the year: Su = Summer, Sp = Spring, F = Fall, W = Winter.
[b] Denotes the type of litter on which the flock was raised. Built-up litter is litter that was decaked after removing the previous flock and partially replenished with fresh bedding (typically, 20 – 25 percent of the bedding material is new). New bedding is the complete replenishment of bedding material after full litter clean-out operations.
[c] Clean-out process occurs after the flock has been removed from the confinement house.
[d] Partial data.
[e] Clean-out occurred after study period concluded. No data were collected.

5.3.2 Comparison of Local Meteorological Conditions

Table 5-10 summarizes the site-specific ambient and confinement conditions for each site. Ambient temperature and relative humidity are the same for both CA1B broiler houses because a single sampling point was used to represent the ambient conditions for both houses. The minimum ambient temperature at the Kentucky farms tended to be lower than at the CA1B site, but the average ambient temperatures are very similar to those at CA1B. Ambient relative humidity conditions are very similar for all the broiler sites, as are temperature and relative humidity conditions in the broiler houses.

Table 5-10. Site-Specific Ambient and Confinement Conditions

Monitoring Site		Ambient				Confinement			
		Temperature (°C)		Relative Humidity (%)		Temperature (°C)		Relative Humidity (%)	
		Average	Range	Average	Range	Average	Range	Average	Range
CA1B	H10	16.69	3.30 - 31.10	61.53	32.70 - 94.90	24.99	11.40 - 32.60	57.66	35.70 - 89.20
	H12					24.99	10.80 - 33.70	55.48	36.60 - 88.10
KY1B-1 H5		13.02	-9.94 - 29.78	71.82	37.44 - 97.46	23.03	10.25 - 30.27	58.24	29.41 - 80.24
KY1B-2 H3		13.37	-6.96 - 29.94	72.97	37.8 - 97.43	24.09	8.04 - 31.92	59.7	33.49 - 83.10

5.3.3 Emissions-Level Comparison

Table 5-11, Table 5-12, Table 5-13, Table 5-14 and Table 5-15 summarize the emissions values from each of the broiler confinement houses monitored during the NAEMS, for each

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phase of production. The data presented in the tables include all non-negative, daily average values.

As shown in Table 5-11, the average and range of daily emissions for all periods (i.e., grow-out, decaking and full litter clean-out) are comparable across the three monitoring sites, although the average NH_3 and PM_{10} emissions tended to be slightly higher for sites KY1B-1 H5 and KY1B-2 H3 than site CA1B.

Table 5-12 presents the emissions for grow-out periods in terms of pollutant mass per day. The average NH_3 emissions were somewhat higher at the Kentucky sites. Emissions of H_2S and PM_{10} were also higher at KY1B-2 H3. Table 5-13 presents the emissions for grow-out periods in terms of pollutant mass per day per bird. The average per-bird emissions rates for all pollutants were comparable across the monitoring sites, although $PM_{2.5}$ emissions at the KY1B-1 H5 were slightly higher than the other sites.

Table 5-14 and Table 5-15 show the emissions for decaking and full litter clean-out periods. For both types of clean-out activities, NH_3 emissions tended to be higher at site KY1B-1 H5 than the other broiler houses. Emissions of H_2S during decaking periods tended to be higher at site CA1B while H_2S during litter clean-out periods were higher at site KY1B-2 H3. The Kentucky sites tended to have higher PM_{10} emissions during decaking and litter clean-out periods.

The average emissions for gaseous pollutants during the grow-out period are higher than during the decaking or full litter clean-out periods, as fresh manure is constantly deposited by the birds to contribute to the chemical reactions responsible for the emissions. Although PM emissions data during the clean-out periods are limited (the TEOMs at site CA1B were removed to prevent damage by the cleaning operations), the available data show that PM emissions also tend to be higher during grow-out periods. This difference is likely attributable to contributions from bird feathers and dander and the agitation of the litter by the birds.

With the exception of PM_{10}, all pollutant emissions during full litter clean-out periods were lower than during decaking periods. Decaking events are expected to have higher emissions than full litter clean-out events because of litter remaining in the house continues to contribute to gaseous emissions.

Table 5-11. Average Daily Emissions for All Periods

Pollutant	Parameter	Site[a]			
		CA1B (H10)	CA1B (H12)	KY1B-1 H5	KY1B-2 H3
NH_3 (g/d)	No. of values	467	466	378	336
	Average	10,197.05	8,950.20	12,136.80	12,376.33
	Range	0 – 50,900	0 – 35,200	0 – 44,721.02	0 – 35,484.91
H_2S (g/d)	No. of values	583	580	342	291
	Average	53.72	51.24	47.84	53.5
	Range	0 - 181.00	0 - 181.00	0 - 259.46	0 - 186.34
PM_{10} (g/d)	No. of values	349	375	301	304
	Average	880.67	881.64	919.7	1,043.47
	Range	0 - 3,560.00	1.2 - 3,460.00	0 - 4,513.85	0 – 4,146.87
$PM_{2.5}$ (g/d)	No. of values	53	43	286	300
	Average	98.8	124.41	89.61	97.32
	Range	1.3 - 243.00	45.1 - 235.00	0 - 405.16	0 - 383.82
TSP (g/d)	No. of values	37	39	315	330
	Average	2,652.16	2,269.77	2,166.50	2,421.74
	Range	0 - 4,760.00	0 - 6,220.00	0 - 10,340.87	0 – 7,472.53

[a]The daily emissions values presented in the table do not include negative data points (i.e., measurements where the ambient concentration was greater than the confinement concentration).

Table 5-12. Average Daily Emissions During Grow-Out Periods (mass per day)

Pollutant	Parameter	Site[a]			
		CA1B (H10)	CA1B (H12)	KY1B-1 H5	KY1B-2 H3
NH_3 (g/d)	No. of values	390	389	299	246
	Average	11,072.25	9,719.26	12,230.00	14,562.90
	Range	56.0 – 35,900	71.0 – 29,700	332.65 – 28,587.85	143.24 – 35,484.91
H_2S (g/d)	No. of values	511	509	276	216
	Average	59.79	56.97	56.84	69.56
	Range	0.0 – 181.00	0.0 – 181.00	1.41 – 259.46	1.36 – 186.34
PM_{10} (g/d)	No. of values	335	366	299	243
	Average	919.88	903.11	969.94	1,234.79
	Range	9.8 – 3,560	3.1 – 3,460	20.9 – 4,513.85	24.56 – 4,146.87
$PM_{2.5}$ (g/d)	No. of values	53	43	290	256
	Average	98.80	124.41	95.11	113.56
	Range	0 – 243	0 – 235	2.55 – 405.16	3.89 – 383.82
TSP (g/d)	No. of values	37	39	215	166
	Average	2,652.16	2,269.77	2,347.02	2,830.54
	Range	0 – 4,760	0 – 6,220	43.53 – 10,340.87	44.47 – 7472.53

[a]The daily emissions values presented in the table do not include negative data points (i.e., measurements where the ambient concentration was greater than the confinement concentration).

Table 5-13. Average Daily Emissions During Grow-Out Periods (mass per day per bird)

Pollutant	Parameter	Site[a]			
		CA1B (H10)	CA1B (H12)	KY1B-1 H5	KY1B-2 H3
NH_3 (g/d-bird)	No. of values	386	390	299	246
	Average	1.37	1.22	1.19	1.31
	Range	0.01 – 42.20	0.01 – 39.90	0.03 – 3.35	0.01 – 3.27
H_2S (g/d-bird)	No. of values	511	509	276	216
	Average	3.02E-03	2.89E-03	2.52E-03	2.84E-03
	Range	3.06E-6 – 2.07E-02	5.47E-05 - 1.18E-02	5.47E-05 – 1.18E-02	5.57E-05 – 7.80E-03
PM_{10} (g/d-bird)	No. of values	335	366	299	243
	Average	4.46E-02	4.37E-02	4.33E-02	5.05E-02
	Range	4.61E-04 – 1.17E-01	3.39E-04 – 1.68E-01	8.01E-04 – 2.07E-01	9.83E-04 – 1.74E-01
$PM_{2.5}$ (g/d-bird)	No. of values	53	43	290	256
	Average	4.78E-03	6.00E-03	4.30E-03	4.66E-03
	Range	6.74E-05 – 1.19E-02	2.15E-03 – 1.14E-02	1.29E-04 – 1.86E-02	1.08E-04 – 1.53E-02
TSP (g/d-bird)	No. of values	37	39	215	166
	Average	1.28E-01	1.09E-01	1.05E-01	1.16E-01
	Range	6.80E-02 – 2.28E-01	1.61E-04 – 2.98E-01	1.74E-03 – 4.22E-01	1.82E-03 – 3.09E-01

[a]The daily emissions values presented in the table do not include negative data points (i.e., measurements where the ambient concentration was greater than the confinement concentration).

Table 5-14. Average Daily Emissions During Decaking Periods (mass per day)

Pollutant	Parameter	Site[a]			
		CA1B (H10)	CA1B (H12)	KY1B-1 H5	KY1B-2 H3
NH_3 (g/d)	No. of values	51	48	58	82
	Average	7,534.51	6,208.75	12,675.34	6,773.21
	Range	0 – 50,900	0 – 35,200	0 – 44,721.02	0 – 34,974.74
H_2S (g/d)	No. of values	55	52	57	67
	Average	18.21	15.1	12.09	6.9
	Range	0 – 98.60	0 – 68.0	0 – 76.44	0 – 56.39
PM_{10} (g/d)	No. of values	6	4	11	45
	Average	4.5	3.98	24.79	22.92
	Range	0 .10 – 11.8	1.50 – 8.9	0 – 55.36	0 – 171.52
$PM_{2.5}$ (g/d)	No. of values	b		19	45
	Average			17.24	12.39
	Range			0 – 40.33	0 – 153.18
TSP (g/d)	No. of values	b		20	41
	Average			85.02	41.34
	Range			0 – 361.23	0 – 321.37

[a]The daily emissions values presented in the table do not include negative data points (i.e., measurements where the ambient concentration was greater than confinement concentration).
[b] Emissions data for this pollutant were not collected during decaking periods.

Table 5-15. Average Daily Emissions During Full Litter Clean-Out Periods (mass per day)

Pollutant	Parameter	Site[a]			
		CA1B (H10)	CA1B (H12)	KY1B-1 H5	KY1B-2 H3
NH_3 (g/d)	No. of values	30	30	21	8
	Average	3,459.60	3,390.07	9,322.43	2,571.25
	Range	57.0 – 23,100	17.0 – 24,000	0 – 30,569.63	129.78 – 10,024.84
H_2S (g/d)	No. of values	23	23	8	8
	Average	5.36	7.23	4.62	10.16
	Range	0.06 – 31.30	0.05 – 63.50	0.84 – 20.01	1.81 – 30.72
PM_{10} (g/d)	No. of values	9	5	5	3
	Average	9.66	12.86	24.86	23.13
	Range	0 - 30.50	1.20 – 35.80	0 - 71.29	7.18 – 55.72
$PM_{2.5}$ (g/d)	No. of values	b		1	3
	Average			0	6.83
	Range			0	0 – 13.76
TSP (g/d)	No. of values	b		5	3
	Average			21.86	69.97
	Range			0 – 61.12	10.83 – 161.71

[a] The daily emissions values presented in the table do not include negative data points (i.e., measurements where the ambient concentration was greater than the confinement concentration).

[b] Emissions data for this pollutant were not collected during litter clean-out periods.

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6.0 MEASURED EMISSIONS FROM BROILER OPERATIONS

The EPA prepared graphs of the NAEMS daily emissions values to identify general and seasonal trends or cycles in pollutant emissions over the monitoring period. Section 6.1 describes the data processing steps used to prepare the graphs of daily emissions values. Sections 6.2 through 6.6 present the daily and seasonal graphs and discuss any trends seen for NH_3, H_2S, PM_{10}, $PM_{2.5}$, TSP and VOC emissions, respectively. For the trend discussions, the EPA related the emissions trends identified for specific process operations based upon its review of the field note summaries in the final reports for the monitoring sites and its general understanding of broiler operations.

In general, the emissions of all pollutants from broiler confinement houses tend to:

- Increase over the grow-out period with the lowest emissions rate occurring at the beginning of the period (when the birds are small and floor bedding is fresh) and the highest emissions rate occurring near the end of the grow-out period before the birds are sent to market.
- Decrease during the decaking and full litter clean-out periods when the houses are empty.

6.1 Data Processing

This section describes the processing steps used by the EPA in preparing the emissions graphs. The graphs prepared by EPA include all of the valid measurements submitted to the EPA.

6.1.1 Daily Emissions Graphs

For the graphs of daily emissions, the emissions values were highlighted to designate whether the emissions values were associated with the grow-out, decaking or full litter clean-out periods. Unshaded values on the daily emissions figures correspond to grow-out periods. Light shading depicts the decaking periods (i.e., partial litter removal and replenishment with fresh bedding) and darker shading indicates full litter clean-out periods (i.e., complete removal of litter).

6.1.2 Seasonal Emissions Graphs

For this analysis, the EPA assigned each of the flocks monitored under the NAEMS a season using the same designations as specified in the NAEMS QAPP:

- Spring - March through May.

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- Summer - June through August.
- Fall - September through November.
- Winter - December through February.

Table 6-1 provides the average duration of the grow-out, decaking and full litter clean-out periods, along with the range of values in brackets. To simplify the seasonal assignments, if the grow-out period of the flock overlapped with another season by less than 15 days, the EPA assigned the flock to the season that had the majority of days. The EPA assigned flocks that overlapped the next season by more than 15 days as mixed-season flocks (e.g., Fall/Winter). Table 6-2 contains the start and end dates for each flock grow-out period and the seasonal designation assigned by EPA.

Table 6-1. Average Flock Duration by Site

Site	Average Duration and Range of Period (days) [min, max]							
	Grow-Out		Litter Removal Activity				Total Flock	
			Full Litter Clean-Out		Decaking			
CA1B H10	47.00	[45, 49]	12.60	[6, 22]	7.75	[6, 11]	56.69	[52, 70]
CA1B H12	47.21	[45, 49]	12.80	[6, 23]	7.25	[3, 11]	56.69	[51, 70]
KY1B-1 H5	51.17	[50, 54]	25.00		15.50	[12, 22]	72.40	[62, 86]
KY1B-2 H3	52.00	[50, 54]	9.00		22.00	[15, 41]	71.40	[60, 91]

Table 6-2. Flock Classified by Season

Site	Flock	Number of Days	Occupied Start	Occupied End	Season (Occupied)
CA1B H10	1	45	9/20/2007	11/3/2007	Fall
	2	47	11/15/2007	12/31/2007	Fall/Winter
	3	46	1/7/2008	2/21/2008	Winter
	4	48	2/28/2008	4/15/2008	Spring
	5	46	4/22/2008	6/6/2008	Spring
	6	49	6/14/2008	8/1/2008	Summer
	7	48	8/11/2008	9/27/2008	Summer/Fall
	8	46	10/20/2008	12/4/2008	Fall
	9	48	12/12/2008	1/28/2009	Winter
	10	47	2/9/2009	3/27/2009	Winter/Spring
	11	48	4/10/2009	5/27/2009	Spring
	12	47	6/5/2009	7/21/2009	Summer
	13	47	7/30/2009	9/14/2009	Summer
	14	46	9/26/2009	11/10/2009	Fall
CA1B H12	1	45	9/20/2007	11/3/2007	Fall
	2	48	11/15/2007	1/1/2008	Fall/Winter
	3	48	1/5/2008	2/21/2008	Winter

Table 6-2. Flock Classified by Season

Site	Flock	Number of Days	Occupied Start	Occupied End	Season (Occupied)
	4	48	2/28/2008	4/15/2008	Spring
	5	46	4/22/2008	6/6/2008	Spring
	6	49	6/14/2008	8/1/2008	Summer
	7	47	8/11/2008	9/26/2008	Summer/Fall
	8	46	10/20/2008	12/4/2008	Fall
	9	48	12/12/2008	1/28/2009	Winter
	10	47	2/9/2009	3/27/2009	Winter/Spring
	11	48	4/10/2009	5/27/2009	Spring
	12	48	6/4/2009	7/21/2009	Summer
	13	47	7/30/2009	9/14/2009	Summer
	14	46	9/26/2009	11/10/2009	Fall
KY1B-1 H5	1	50	2/14/2006	4/4/2006	Winter/Spring
	2	50	4/21/2006	6/9/2006	Spring
	3	50	6/22/2006	8/10/2006	Summer
	4	51	9/5/2006	10/25/2006	Fall
	5	54	11/17/2006	1/9/2007	Fall/Winter
	6	52	1/22/2007	3/14/2007	Winter
KY1B-2 H3	1	50	2/20/2006	4/10/2006	Winter/Spring
	2	51	5/22/2006	7/11/2006	Summer
	3	54	7/28/2006	9/19/2006	Summer
	4	54	10/5/2006	11/27/2006	Fall
	5	51	12/14/2006	2/2/2007	Winter
	6[a]	22	2/12/2007	3/5/2007	Winter

[a] Values for flock 6 at KY1B-2 H3 represent a partial flock. The study period concluded before the grow-out period ended.

Table 6-3 summarizes the seasonal distribution of flocks monitored during the course of the NAEMS. The table shows that each discrete season (i.e., spring, summer, fall, and winter) is well represented by the NAEMS data. Although most of the flocks monitored during the NAEMS occurred during a single season, the study also collected data for each transitional period with the exception of spring to summer.

Table 6-3. Flock Distribution by Season

Season	Number of Flocks
Spring	7
Spring/Summer	0
Summer	9
Summer/Fall	2
Fall	8
Fall/Winter	3
Winter	7
Winter/Spring	4

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To derive the values used in the seasonal graphs, the overall average emissions for each day of each flock was calculated. For example, the EPA determined the data point for the first day of a summer flock by averaging the emissions values for Day 1 for all flocks grown during the summer season.

6.2 NH_3 Emissions

6.2.1 General Trends

Figure 6-1and Figure 6-2 present the daily NH_3 emission rates calculated over the study period for the CA1B houses and the Kentucky sites, respectively. As reflected in these plots, the daily NH_3 emissions rate generally increased over the grow-out period and decreased during the decaking and full litter clean-out periods. These figures also show spikes and dips in emissions during these litter removal periods that are likely due to increased personnel and equipment activity associated with removing litter, disinfecting the house and replenishing or replacing bedding. Low emissions values during litter removal periods reflect the house sitting idle after cleaning before the next flock of birds arrives. The figures also indicate variation in the emissions levels at the beginning of flock placement and the early stages of the grow-out period. The relationship of this variance with litter condition (i.e., fresh bedding versus decaked litter) is discussed in Section 7.

The decrease in NH_3 emissions early in the grow-out periods shown in the graphs is likely due to management practices of the confinement space. Typically, the birds are confined to a portion of the house (e.g., using a dividing curtain) for the first few weeks of the grow-out period. As they grow larger, the full house is opened up, allowing emissions to diffuse across a larger volume.

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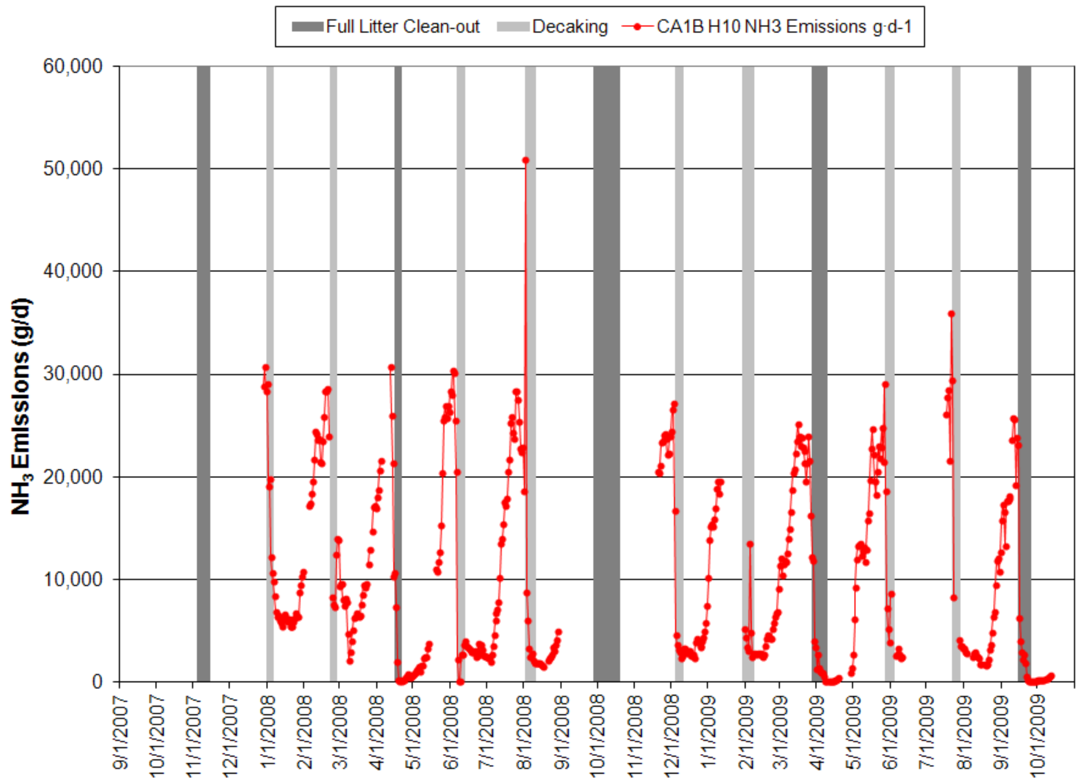


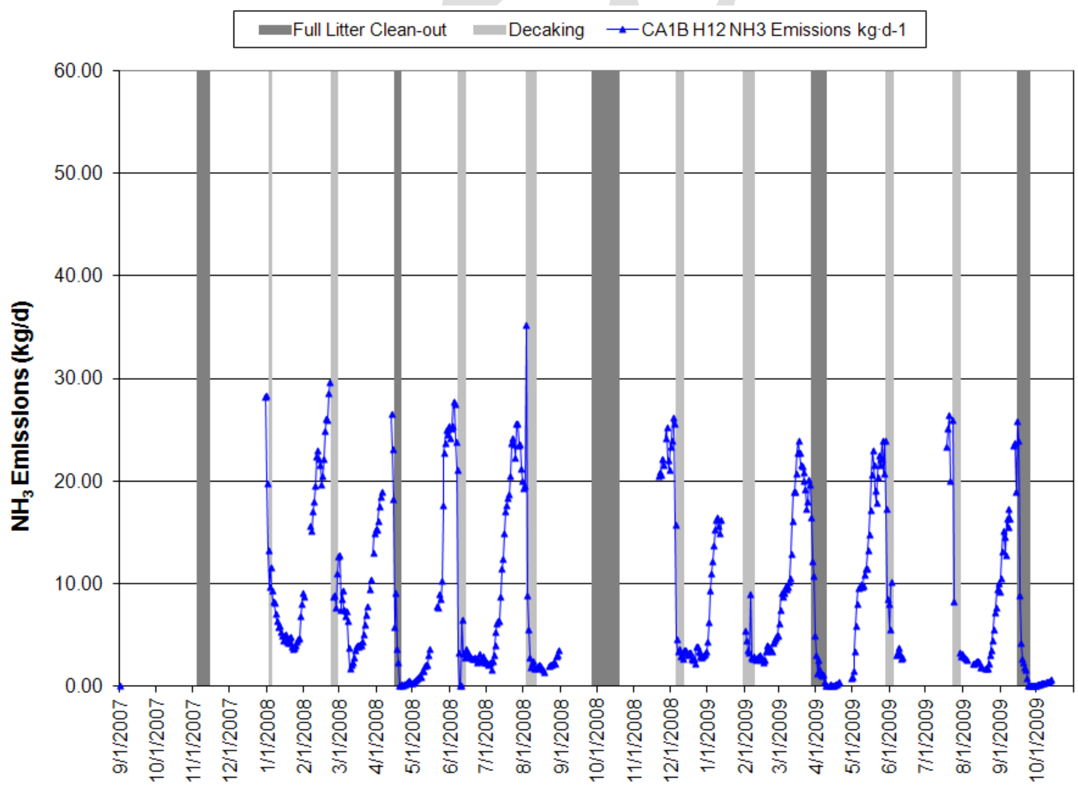
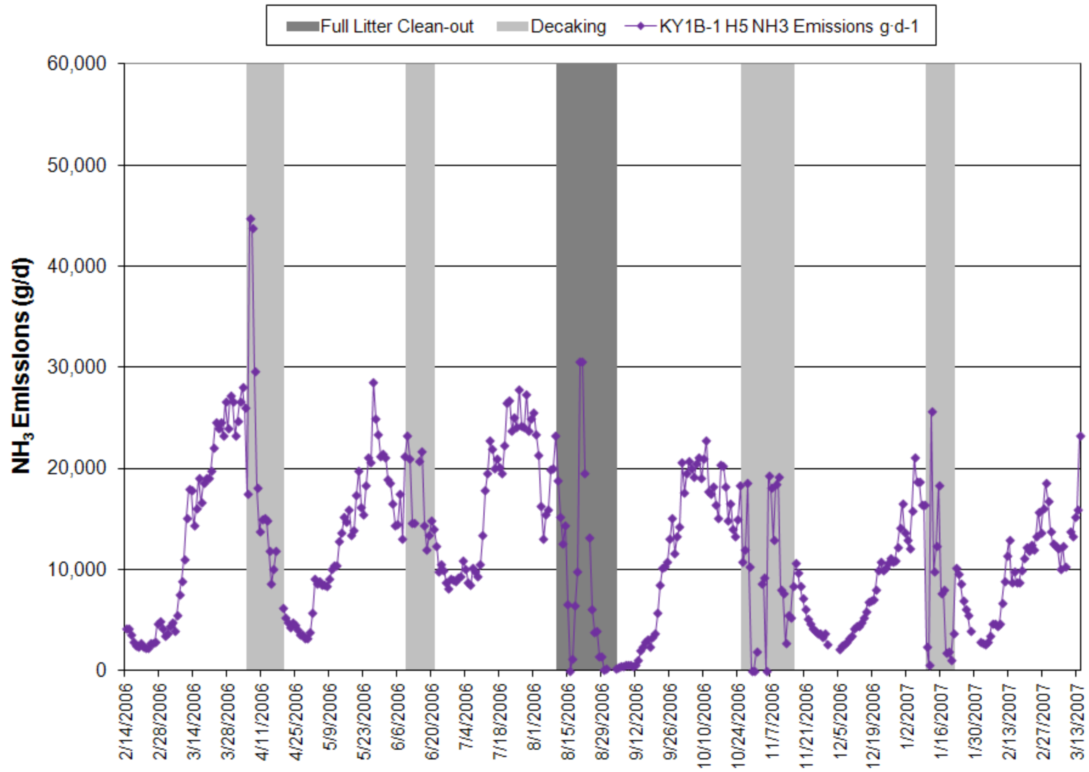


Figure 6-1. NH_3 Emission Rates from the CA1B Broiler Houses



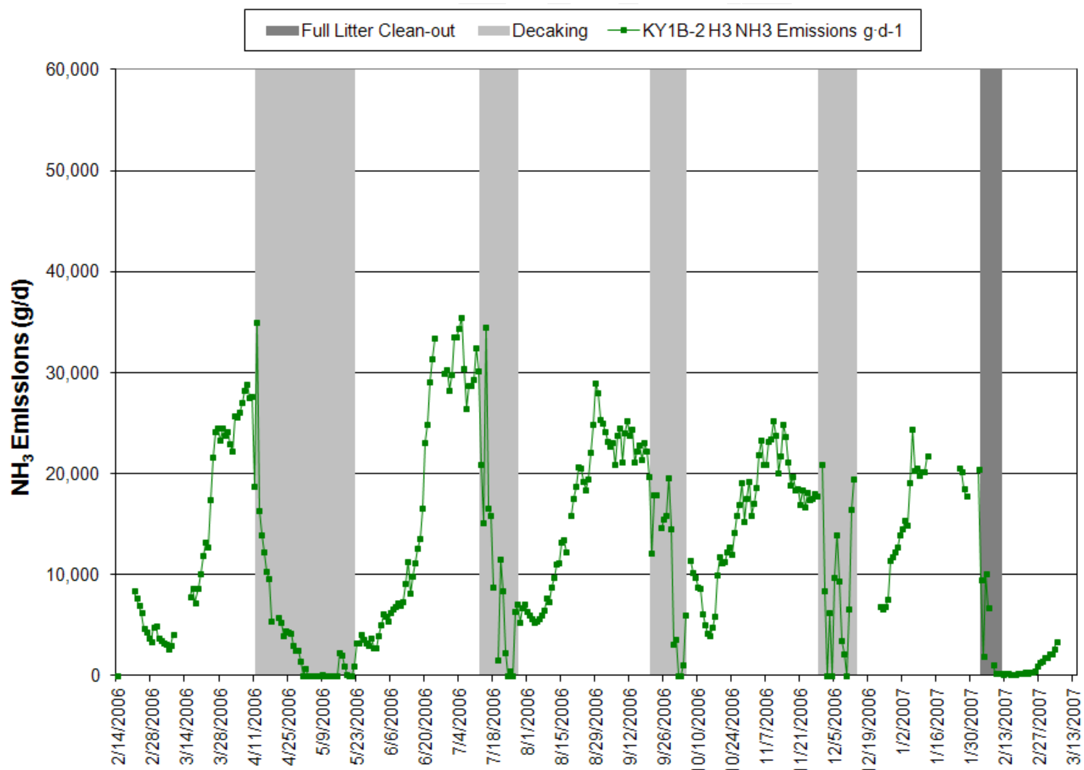


Figure 6-2. NH_3 Emission Rates from the Kentucky Broiler Houses

6.2.2 Seasonal Trends

Figure 6-3 presents the daily NH_3 emissions for the grow-out, decaking and full litter clean-out periods for all flocks monitored under the NAEMS, color coded by season. Figure 6-4, Figure 6-5. Figure 6-6 and Figure 6-7 present the same data shown in Figure 6-3, grouped by season and transitional periods between seasons. The black line on the figures represents the average NH_3 emissions for all flocks.

Based on the seasonal plots, NH_3 emissions from the grow-out, decaking and full litter clean-out periods tend to be higher than the average during the summer months and lower than average during the winter months. The plots for the seasonal classification (Figure 6-5. and Figure 6-6) also indicate NH_3 emissions in the fall season are slightly above average for most of the flock. Furthermore, the average emissions rates for the four seasons suggest that spring is representative of the average emissions rate across all the houses. The graphs show that summer flocks also tended to have the highest NH_3 emissions towards the end of the grow-out and litter removal periods. The only exception is the first monitored flock from KY1B-1 H5 that occurred in the transitional period from winter to spring (WI/SP).

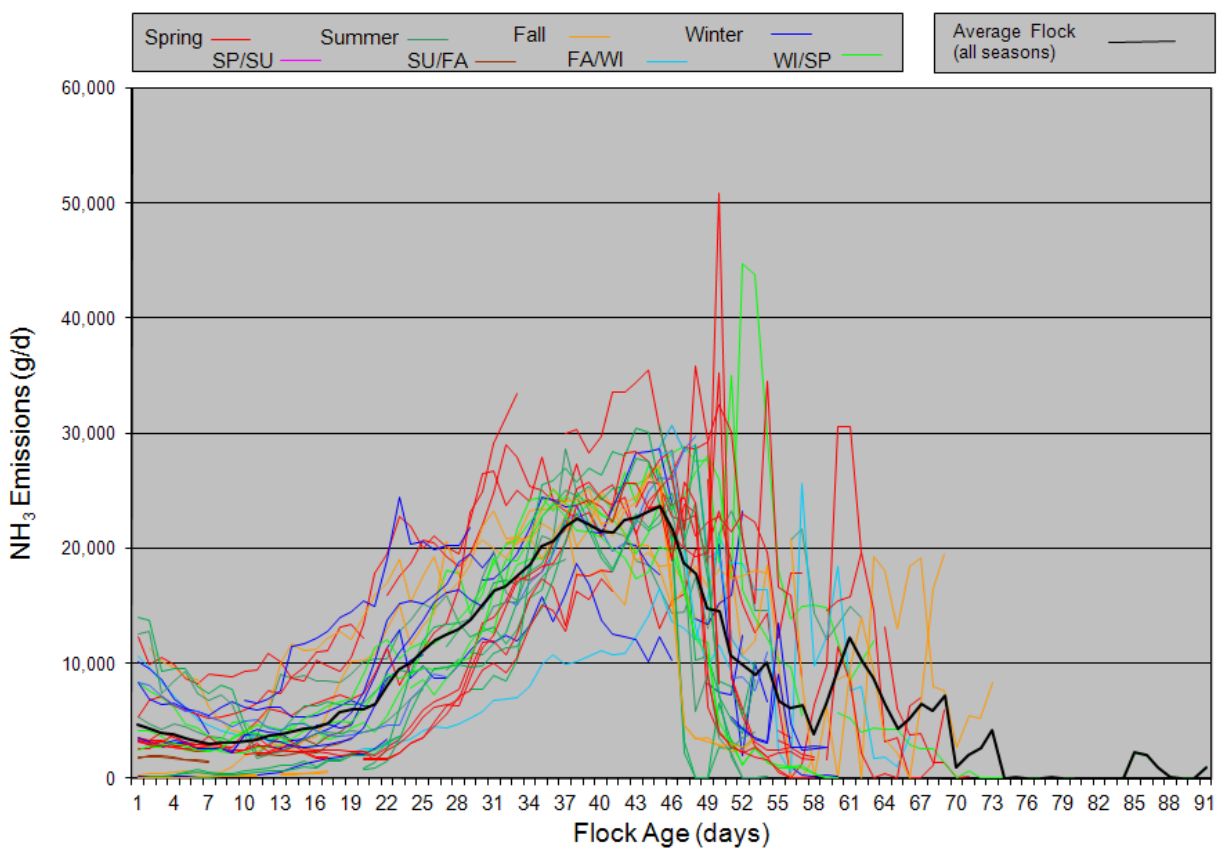


Figure 6-3. NH_3 Emissions by Flock, Color Coded by Season

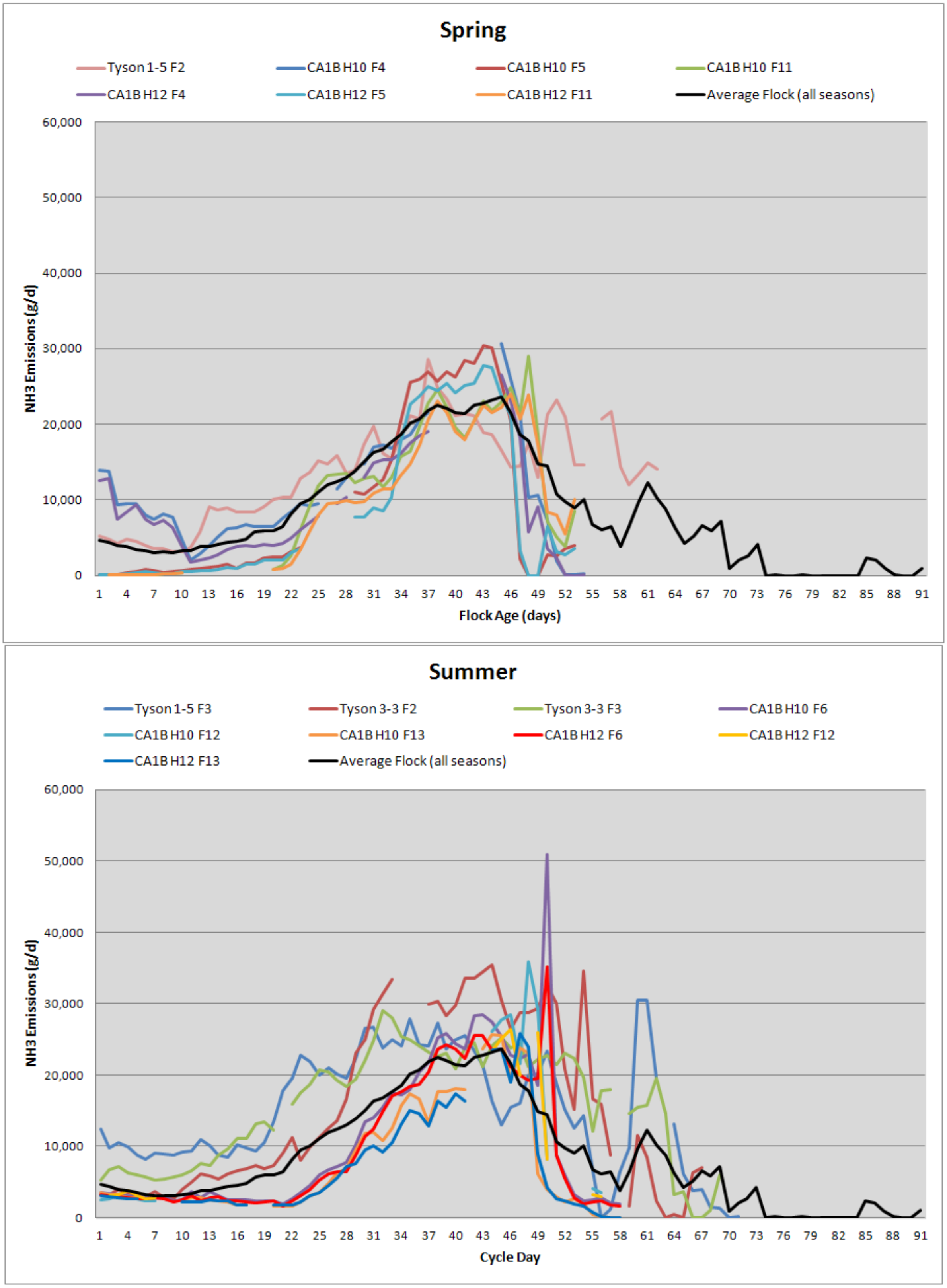


Figure 6-4. NH_3 Emissions from the Broiler Sites for Spring and Summer

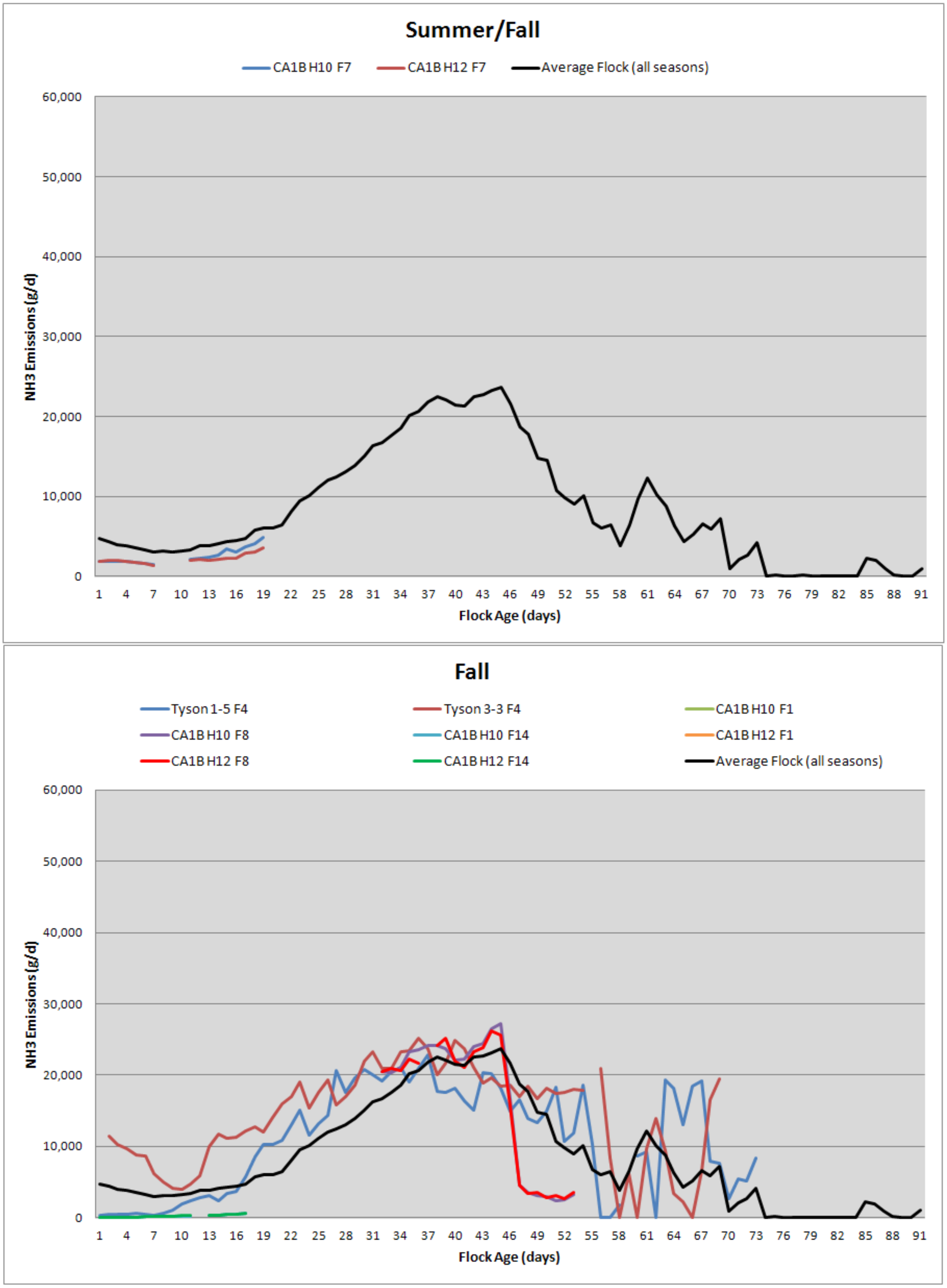


Figure 6-5. NH_3 Emissions from the Broiler Sites for Summer/Fall and Fall

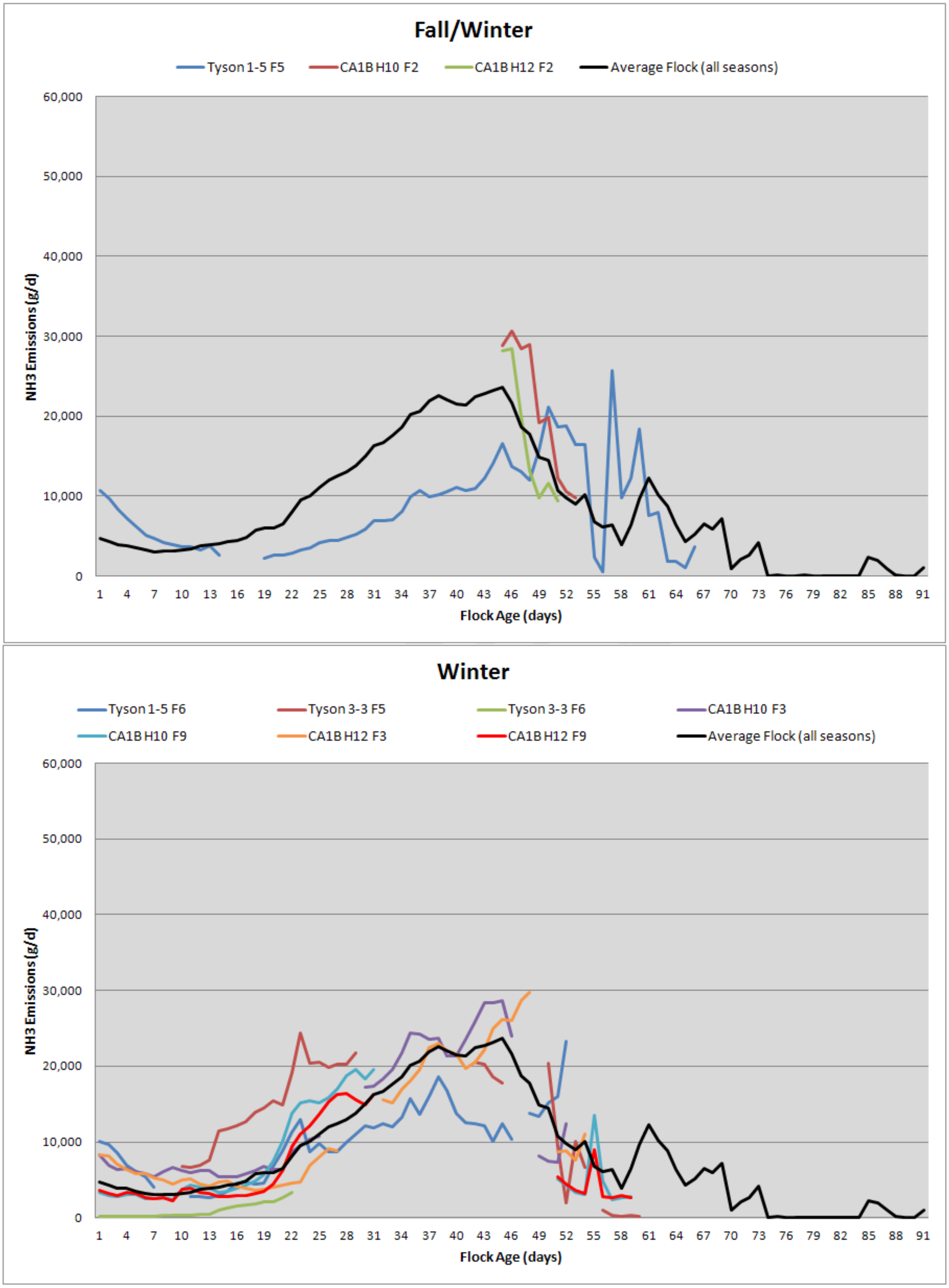


Figure 6-6. NH_3 Emissions from the Broiler Sites for Fall/Winter and Winter

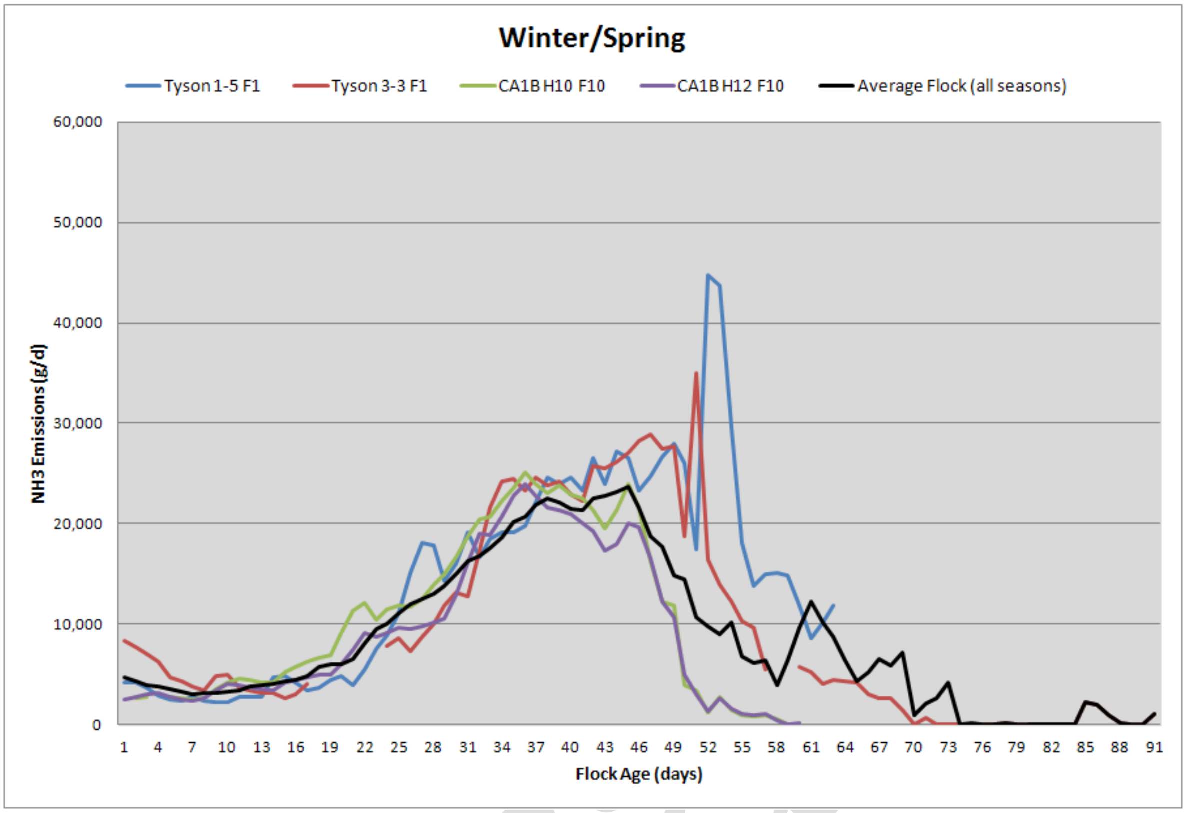


Figure 6-7. NH_3 Emissions from the Broiler Sites for Winter/Spring

6.3 H_2S Emissions

6.3.1 General Trends

Figure 6-8 and Figure 6-9 present the daily H_2S emission values calculated over the study period for the CA1B and Kentucky sites. The H_2S emissions follow the same general trend as NH_3 emissions (i.e., increasing emissions with bird age, with emissions dropping after birds are removed from the house). Figure 6-9 also shows that the H_2S emissions rates tended to spike at site KY1B-1 H5.

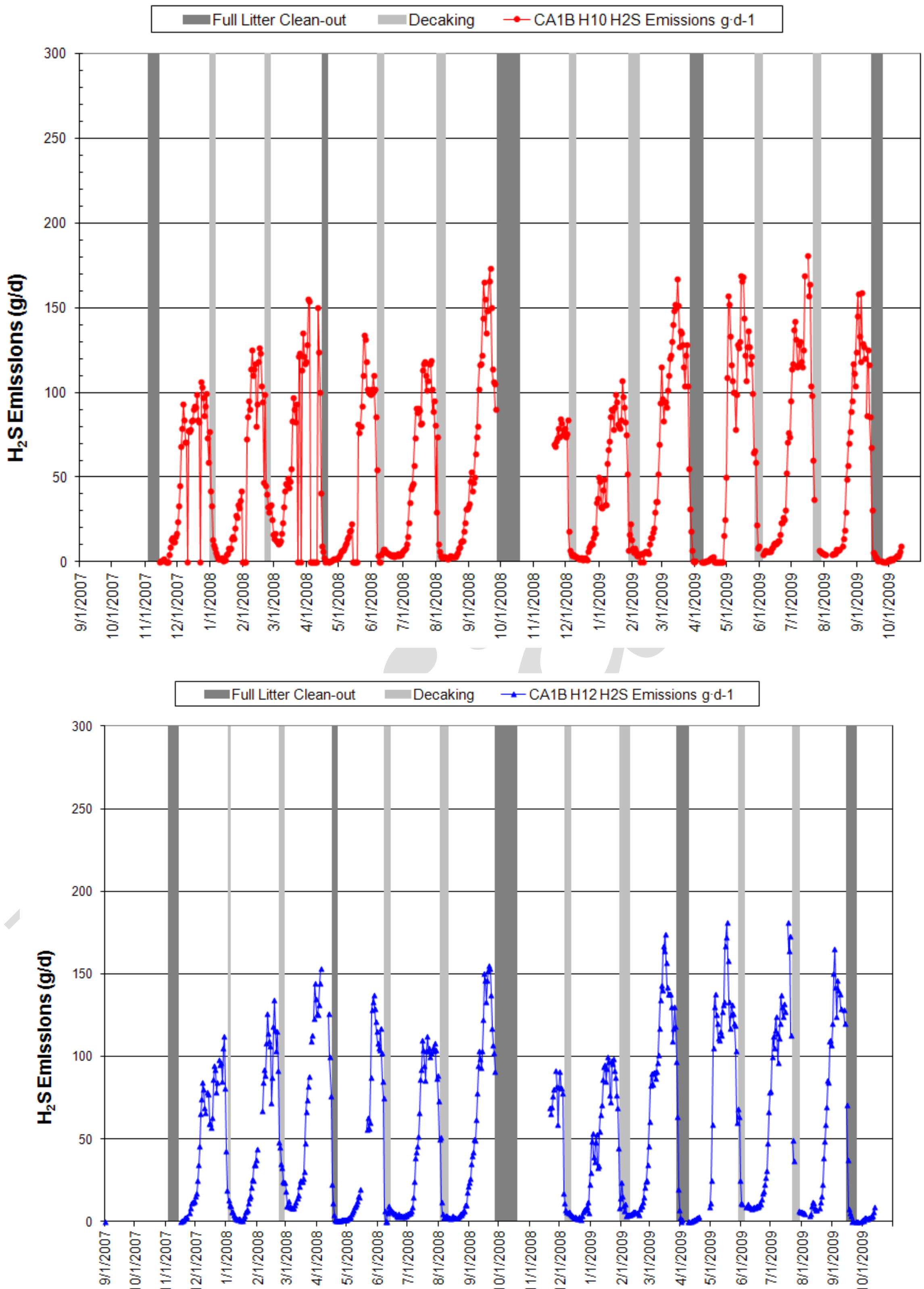
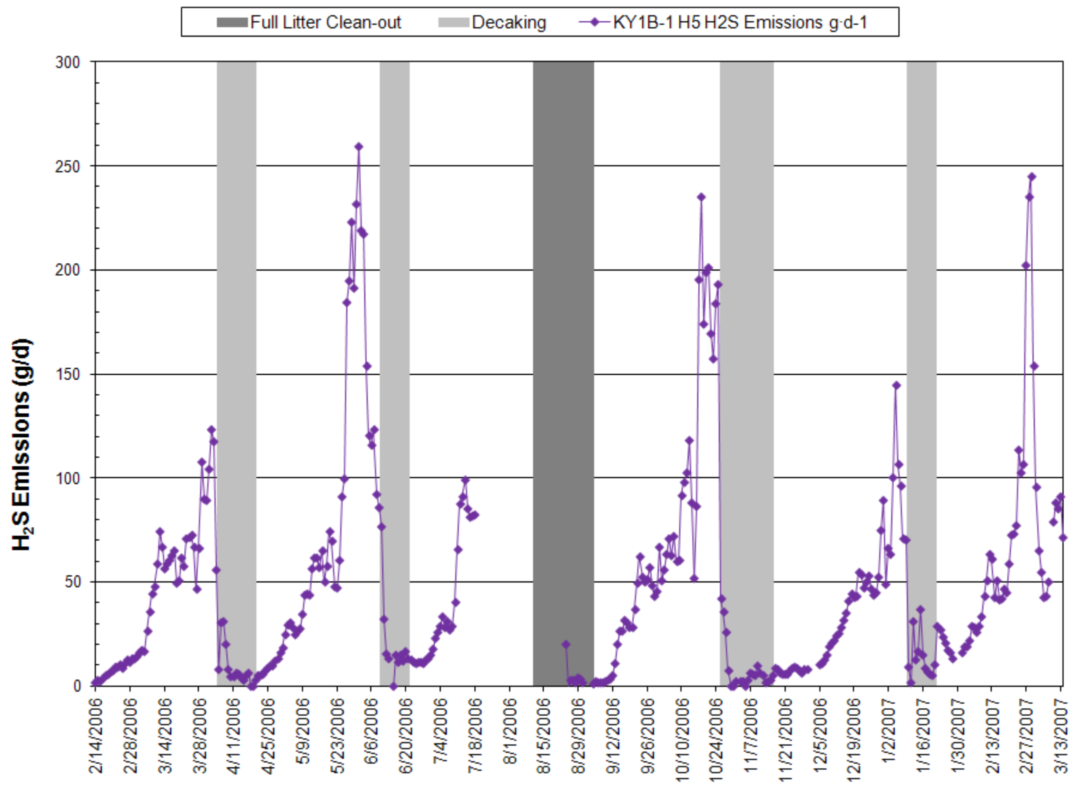


Figure 6-8. H_2S Emissions from the CA1B Broiler Houses



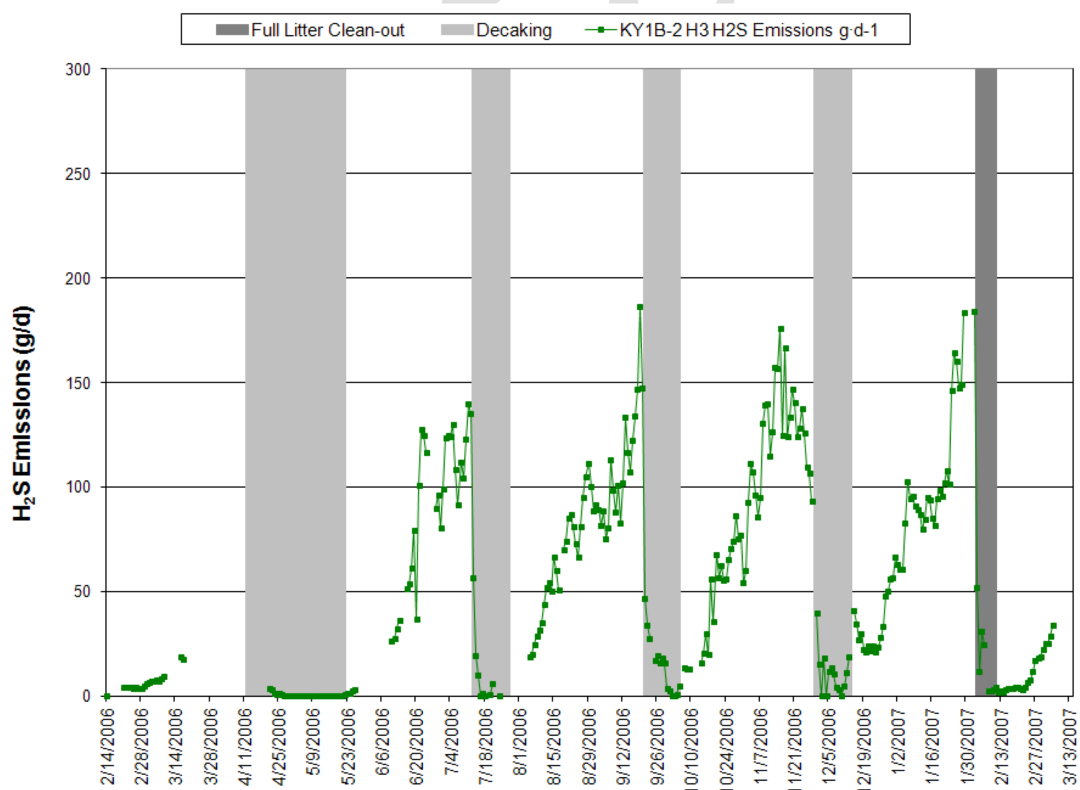


Figure 6-9. H_2S Emissions from the Kentucky Broiler Sites

6.3.2 Seasonal Trends

Figure 6-10 presents the daily H_2S emissions for the grow-out, decaking and full litter clean-out periods for all flocks monitored under the NAEMS, color coded by season. Figure 6-11, Figure 6-12, Figure 6-13 and Figure 6-14 present the same data shown in Figure 6-10, grouped by season and transitional period. The black line on the figures represents the average emissions for all flocks.

In general, emissions were slightly higher than average during grow-out periods in the spring and slightly higher during litter removal periods in the summer and fall. Figure 6-10 also shows that the variation in daily emissions rates from the overall average (black line) was minimal, with a few exceptions later in the period (days 35 through 55). As shown in Figure 6-11 and Figure 6-12, these late period anomalies occurred at KY1B-1 H5. The anomalies of two of these flocks from the summer (flock 3) and fall (flock 4) are largely explained by the change in emissions during litter removal activities. The anomalies of the remaining two flocks in the spring (flock 2) and winter (flock 6) that peak near day 40 appear to be due to higher ventilation rates for the house. Figure 6-12, Figure 6-13 and Figure 6-14 also show flocks raised during the transition between seasons had emissions near the overall average.

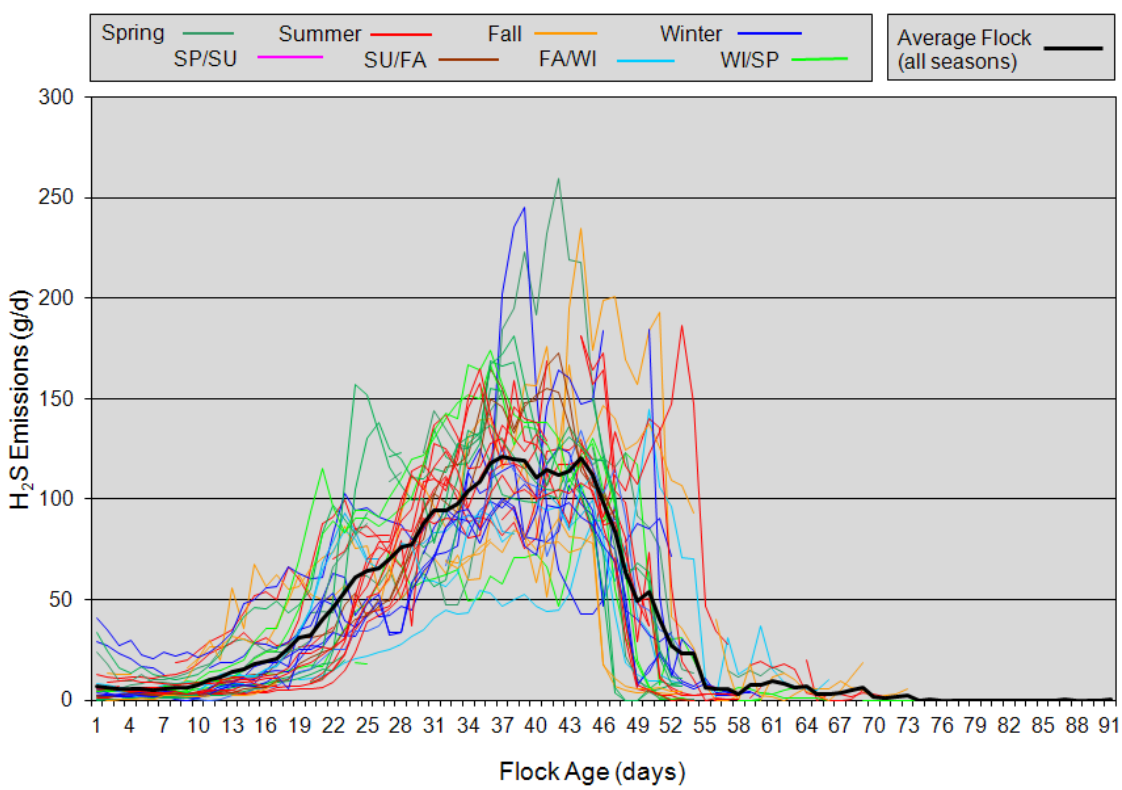


Figure 6-10. H_2S Emissions by Flock, Color Coded by Season

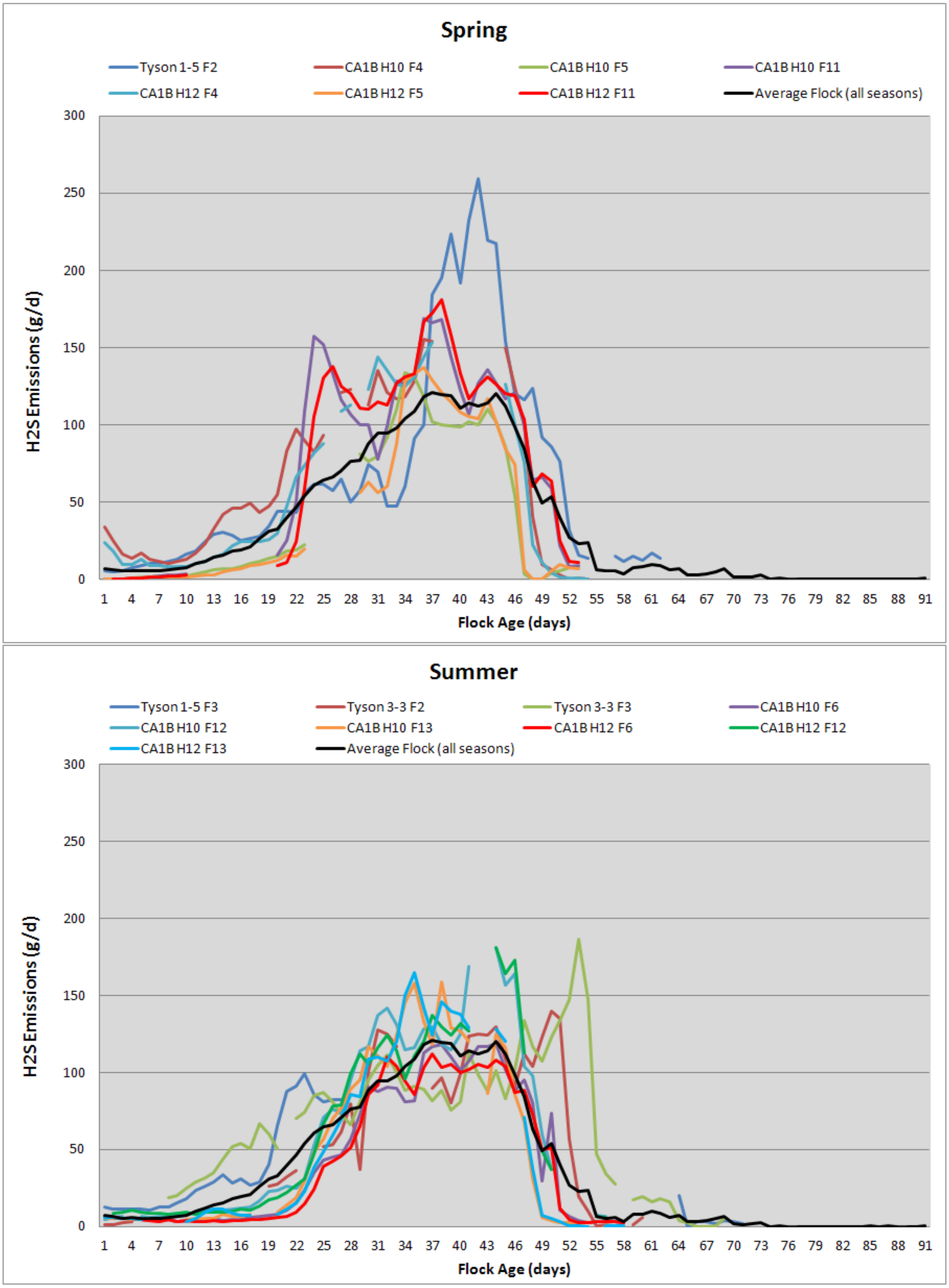
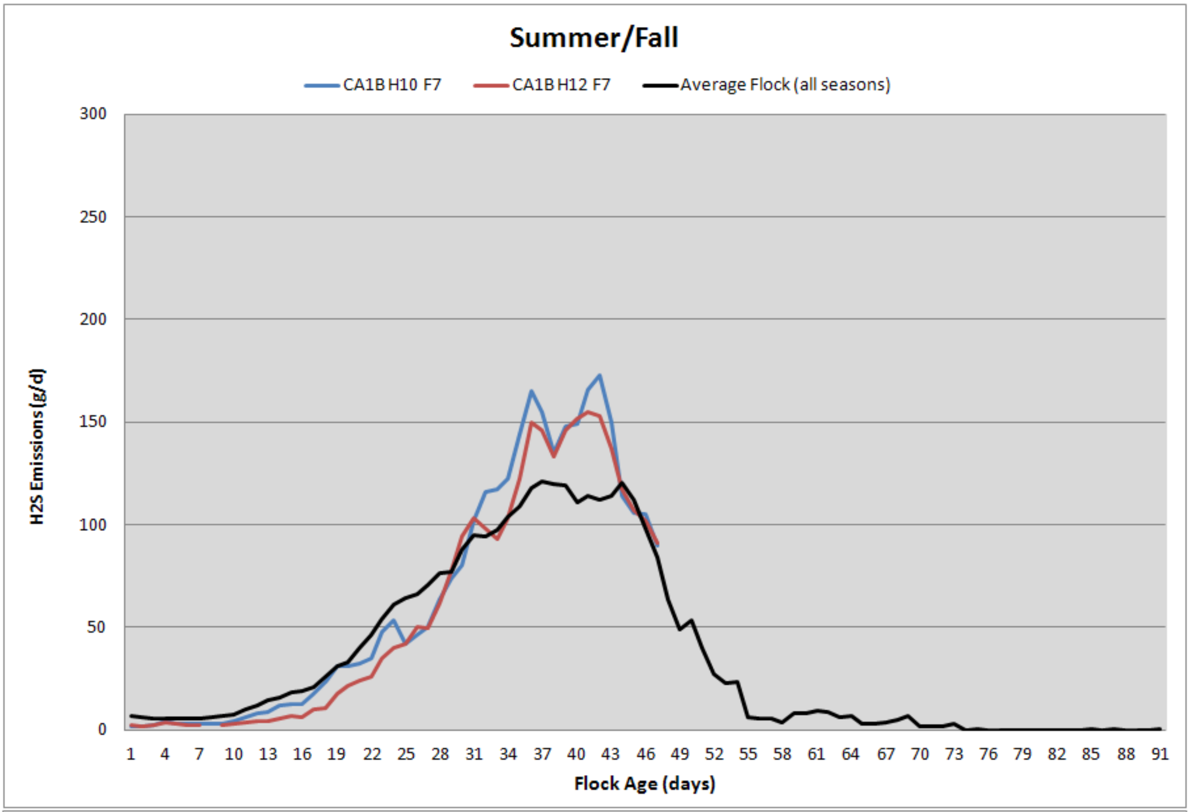


Figure 6-11. H_2S Emissions from the Broiler Sites for Spring and Summer



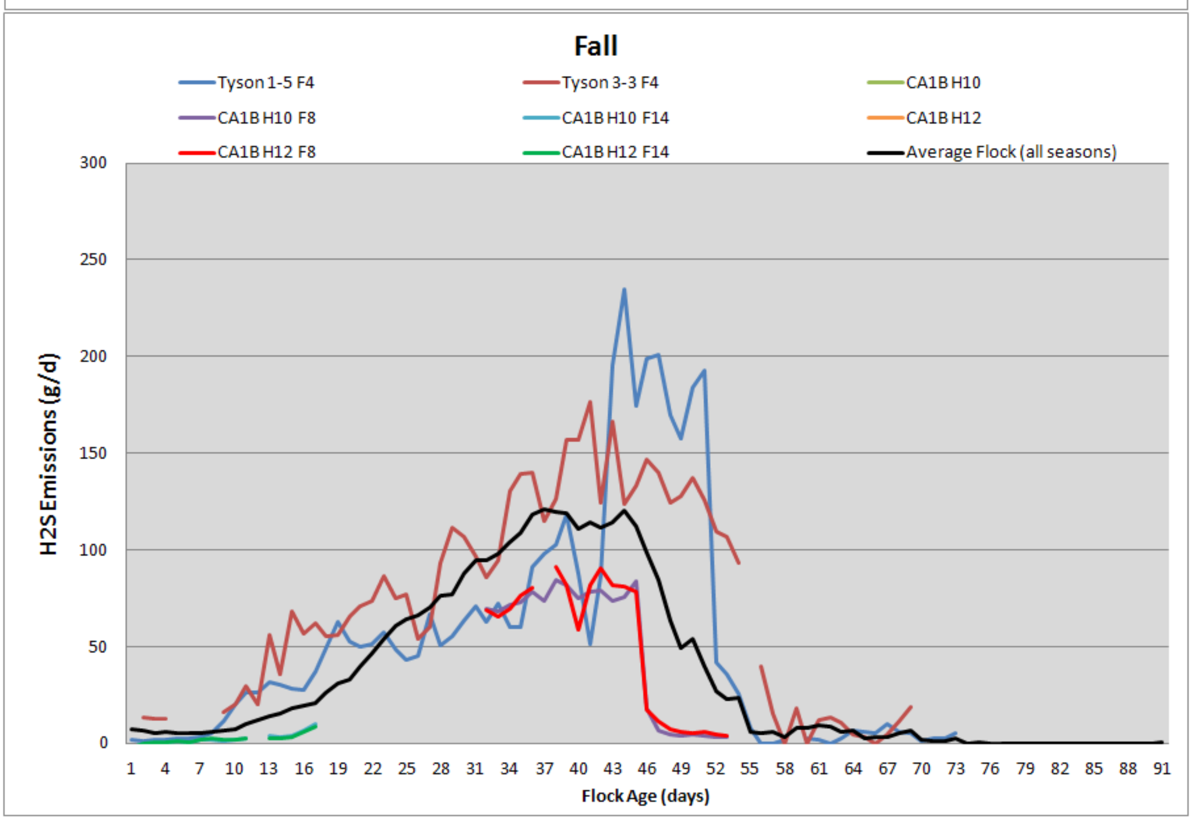


Figure 6-12. H_2S Emissions from the Broiler Sites for Summer/Fall and Fall

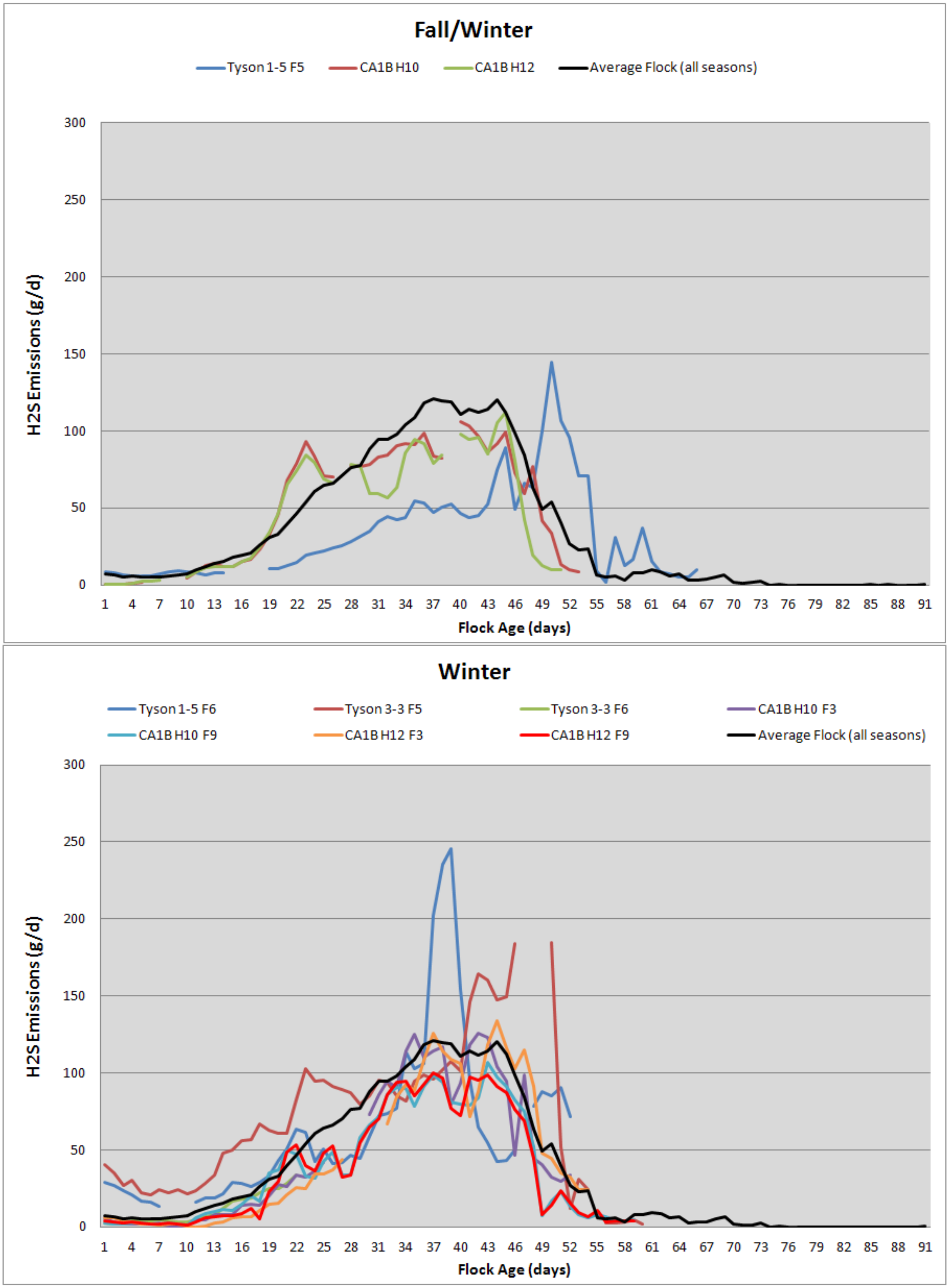


Figure 6-13. H_2S Emissions from the Broiler Sites for Fall/Winter and Winter

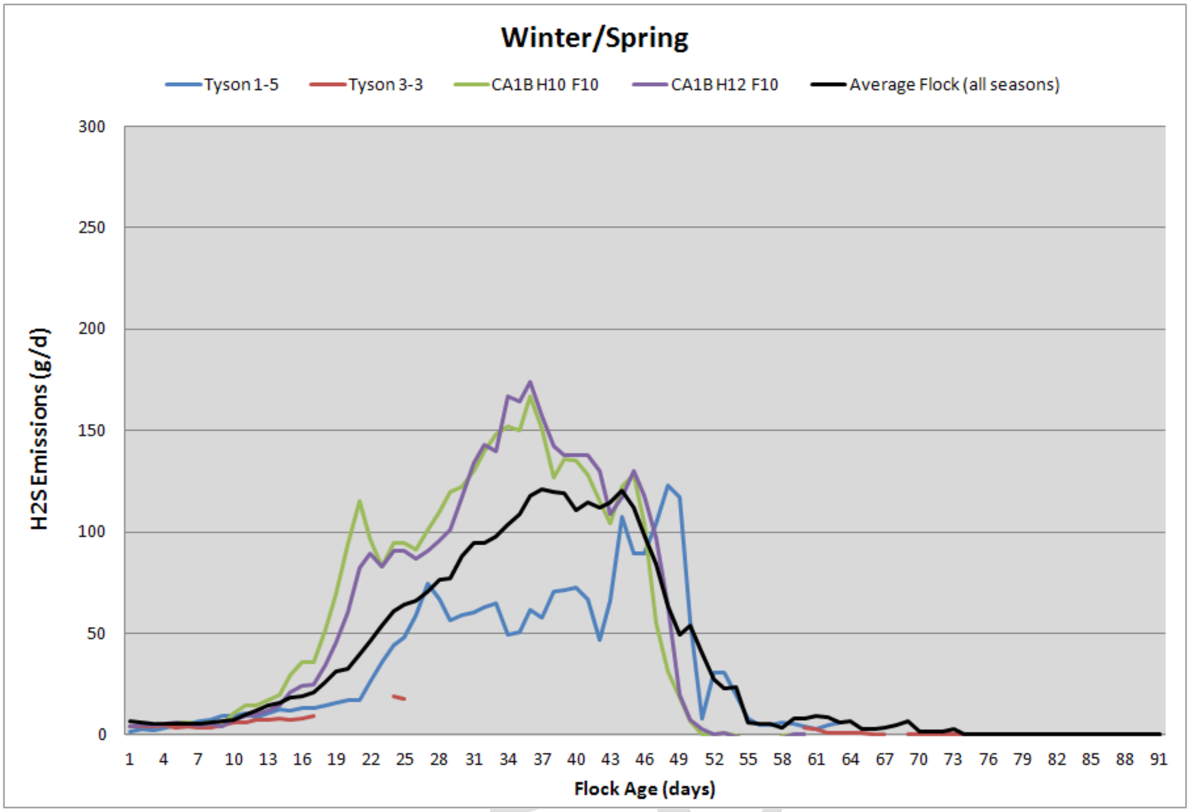
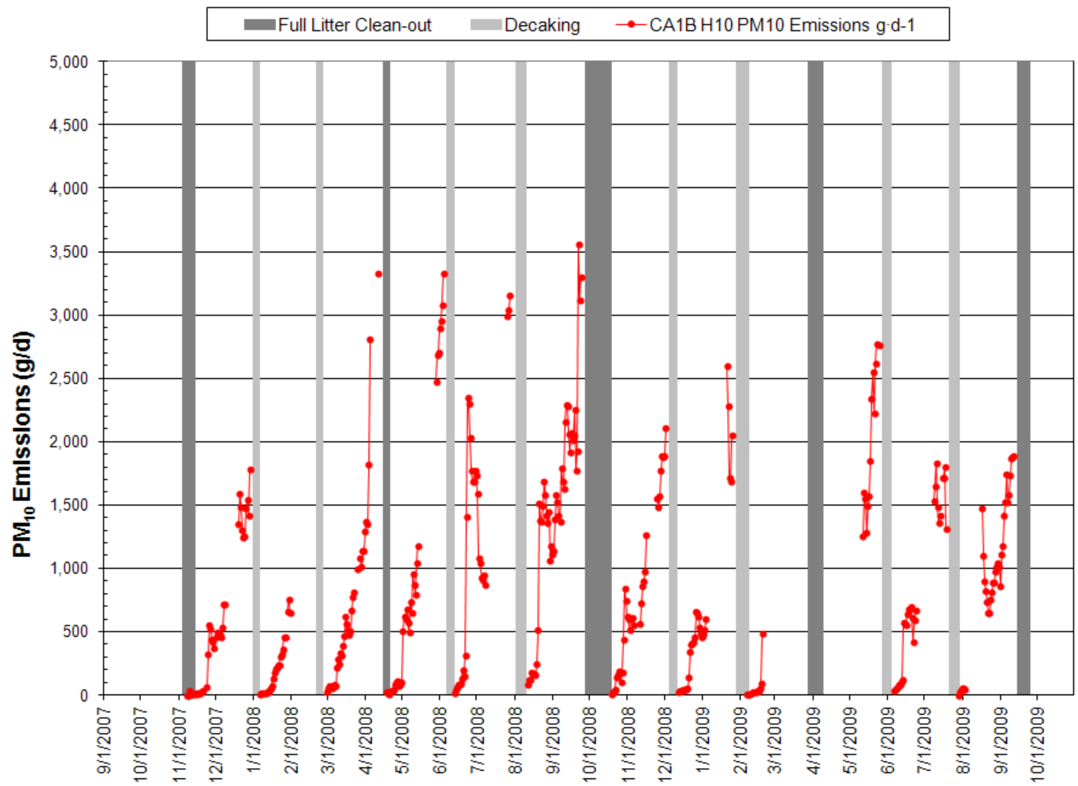


Figure 6-14. H_2S Emissions from the Broiler Sites for Winter/Spring

6.4 PM_{10} Emissions

6.4.1 General Trends

Figure 6-15 and Figure 6-16 present the daily PM_{10} emissions rates calculated over the study period for the CA1B and Kentucky sites, respectively. The figures show that emissions of PM_{10} tend to increase with bird age and weight and decrease during decaking and full litter clean-out periods (i.e., the same general trend as the other measured pollutants). However, the steep drop in PM_{10} emissions during litter removal periods is due to removal of the PM monitors for the first 4 to 9 days of the litter removal period. It is possible that spikes in PM_{10} emissions, similar to those seen for NH_3 and H_2S, occurred during these times; however, these spikes were not captured because the monitors were not operating. The PM_{10} measurements taken during litter removal periods reflect emissions from a clean house that is idle while waiting for the next flock of birds. The PM_{10} measurements do not reflect periods when the decaking or full litter clean-out activities were being conducted.



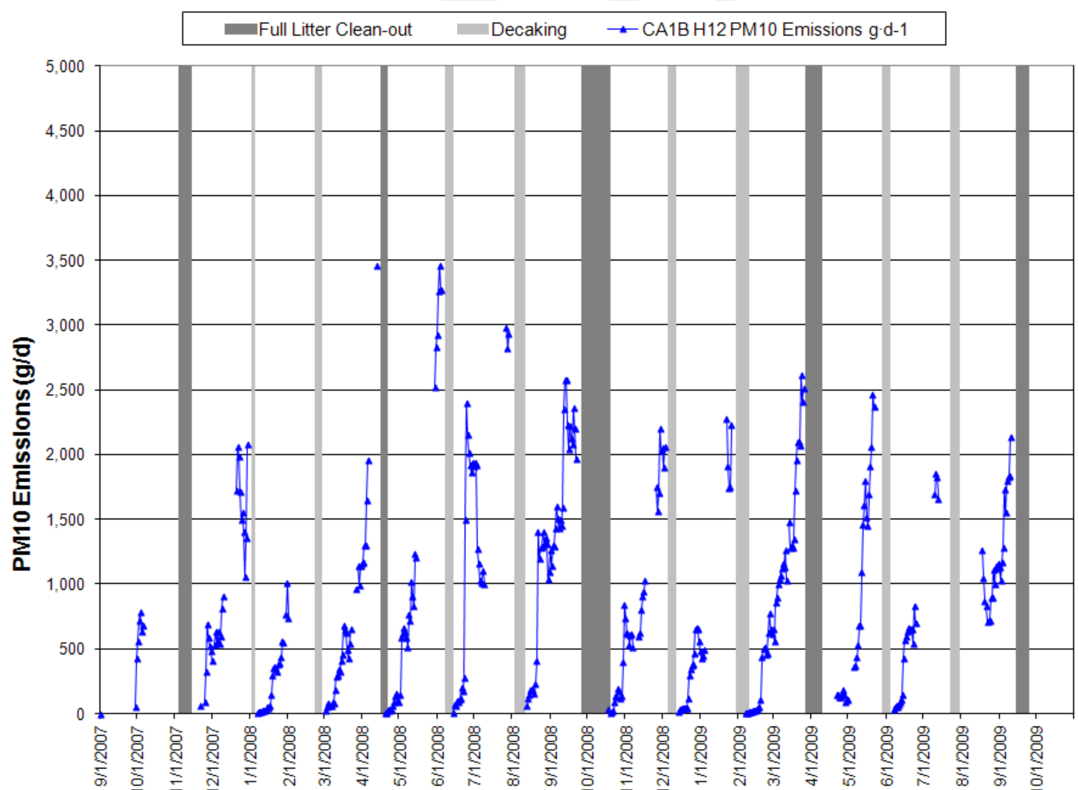


Figure 6-15. PM_{10} Emissions from the CA1B Broiler Houses

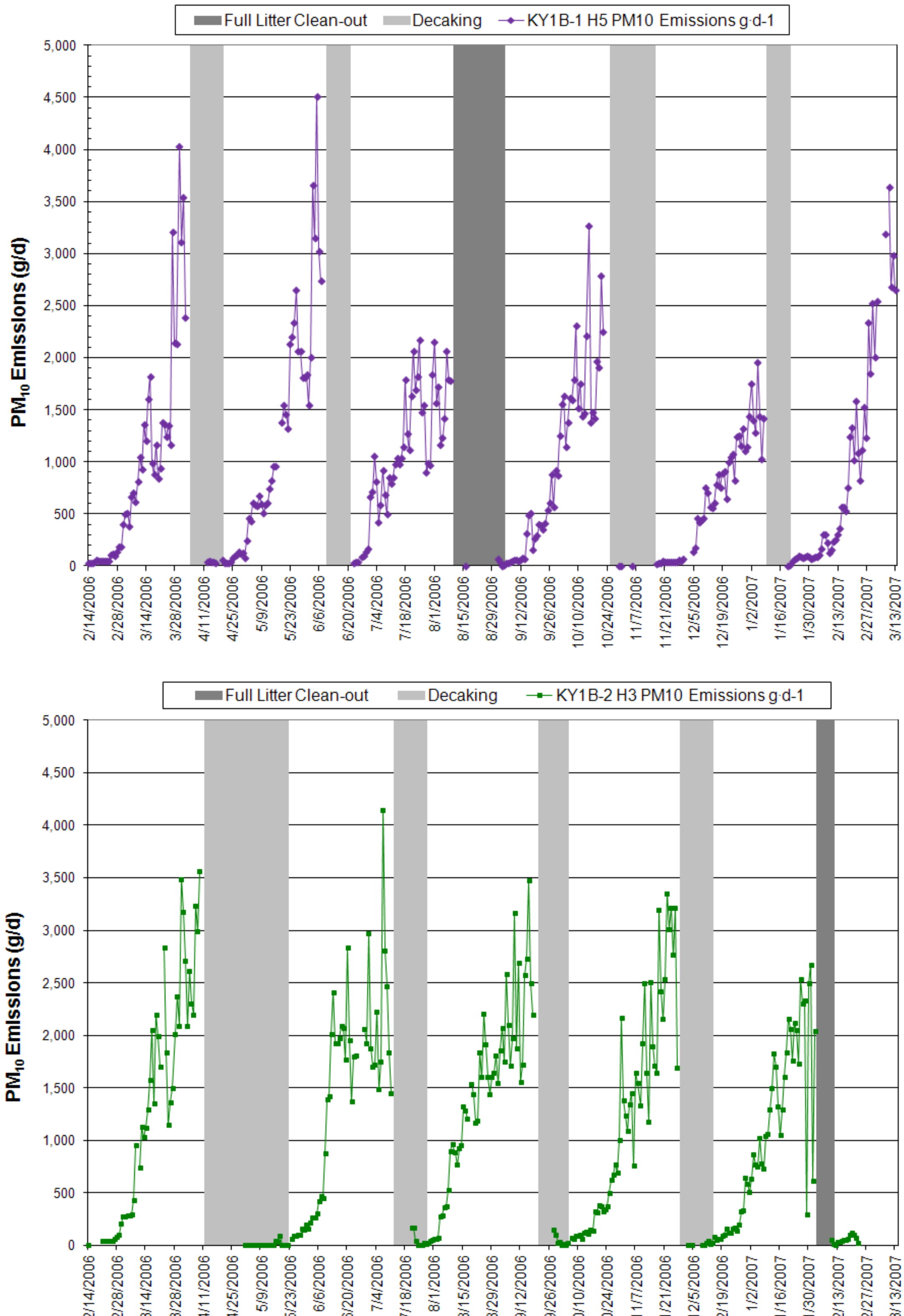


Figure 6-16. PM_{10} Emissions from the Kentucky Broiler Houses

6.4.2 Seasonal Trends

Figure 6-17 presents the daily PM_{10} emissions for the grow-out, decaking and full litter clean-out periods for all flocks monitored under the NAEMS, color coded by season. Figure 6-18, Figure 6-19, Figure 6-20 and Figure 6-21 present the same data shown in Figure 6-17, grouped by season. The black line on the figures represents the average emissions for all flocks.

These plots show that the PM_{10} emissions at the beginning of the grow-out period for several flocks were higher than the other flocks and were elevated for several days before returning to levels comparable with the other flocks. For site CA1B, the four flocks that stand out from the mean are flocks 6 and 7 from both Houses 10 and 12 for days 11 through 20 of the grow-out period. In addition, PM_{10} emissions were elevated from days 21 to 30 of the grow-out period for flock 2 at KY1B-2 H3. The grow-out periods for these five flocks occurred during the summer (see Figure 6-18) or during the transition period from summer to fall (see Figure 6-19). The confinement houses during these periods had above-average ambient temperatures and increased ventilation air flow rates, which could explain the increased PM_{10} emissions rates.

Emissions of PM_{10} also show seasonality with flocks. The PM_{10} emissions are higher than average from most flocks raised during the summer and below average from wintertime flocks. Emissions of PM_{10} for spring and fall flocks generally fall close to the average daily flock value.

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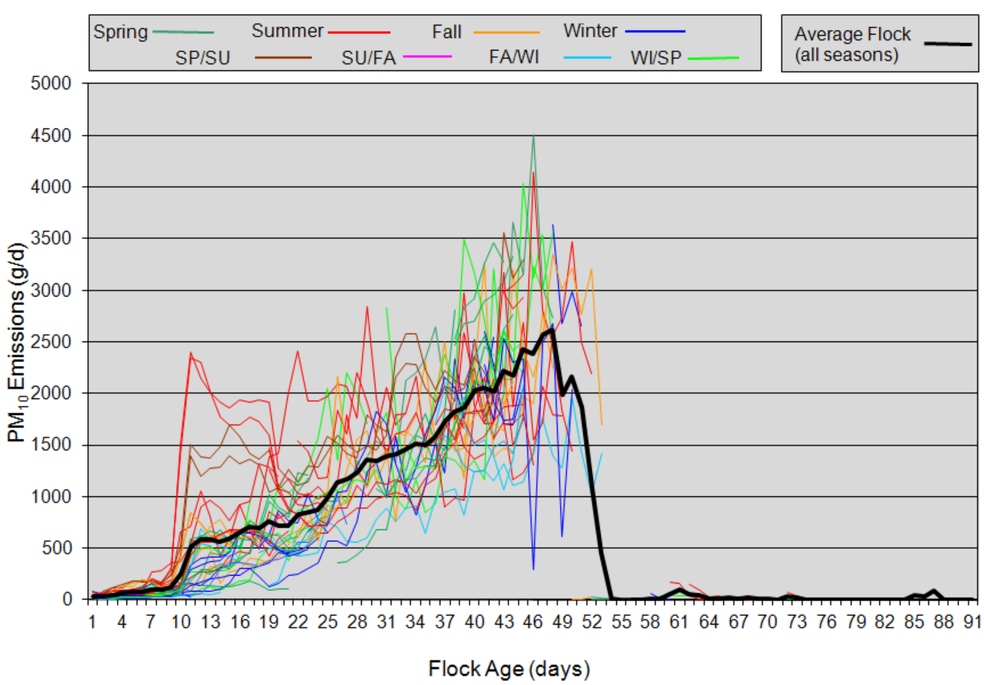

Figure 6-17. PM_{10} Emissions by Flock, Color Coded by Season

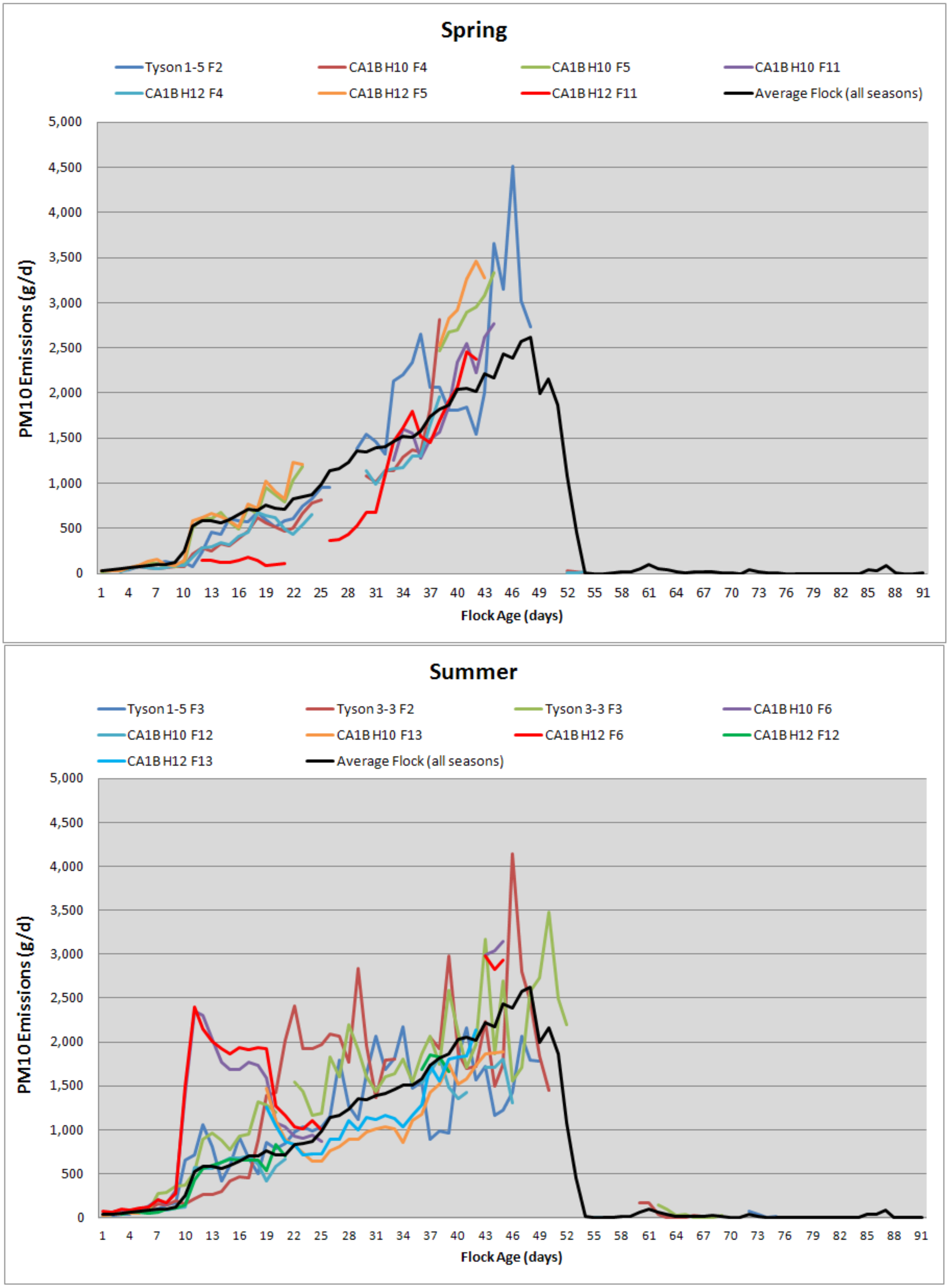

Figure 6-18. PM_{10} Emissions from the Broiler Sites for Spring and Summer

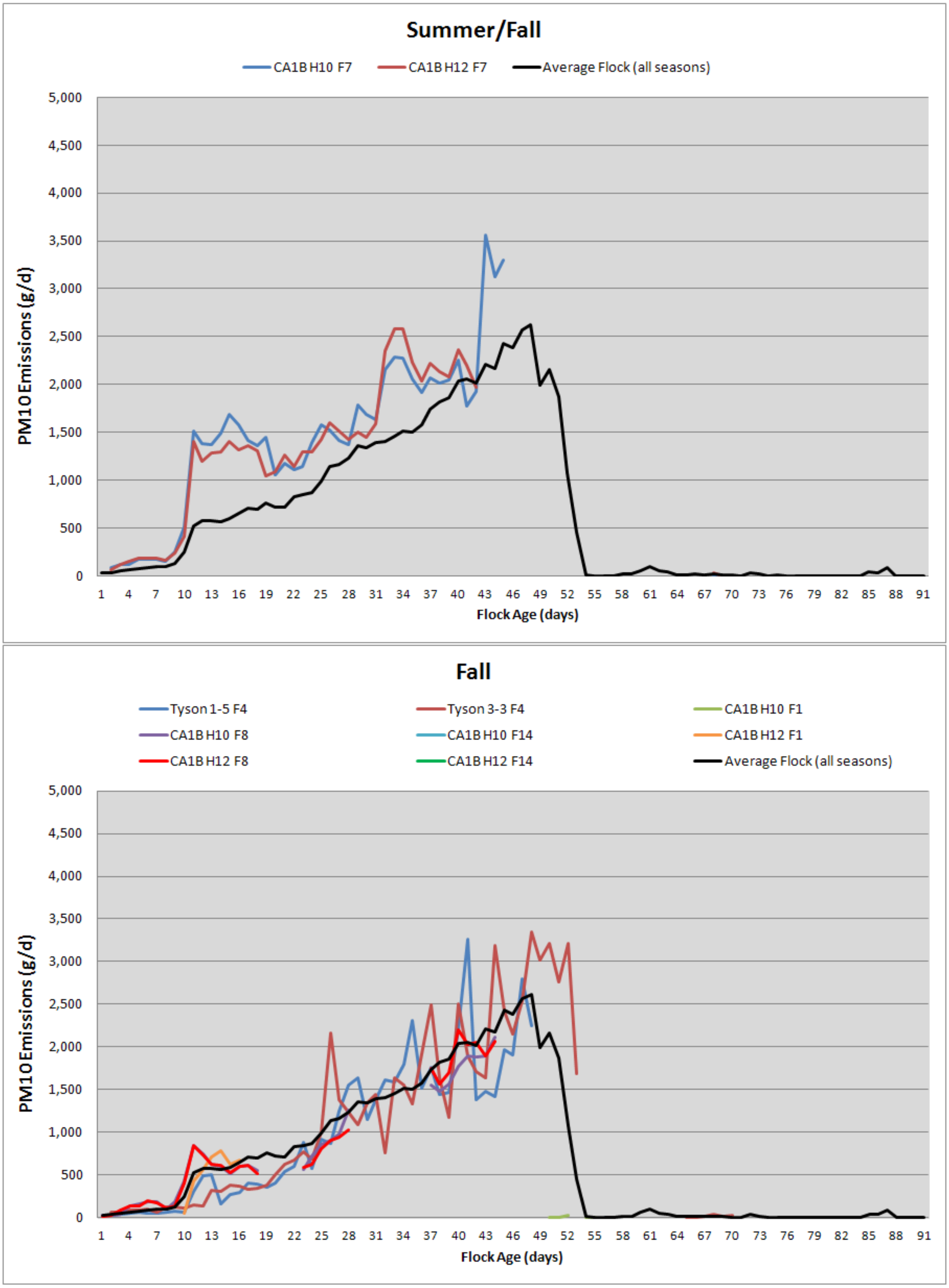

Figure 6-19. PM_{10} Emissions from the Broiler Sites for Fall and Fall/Winter

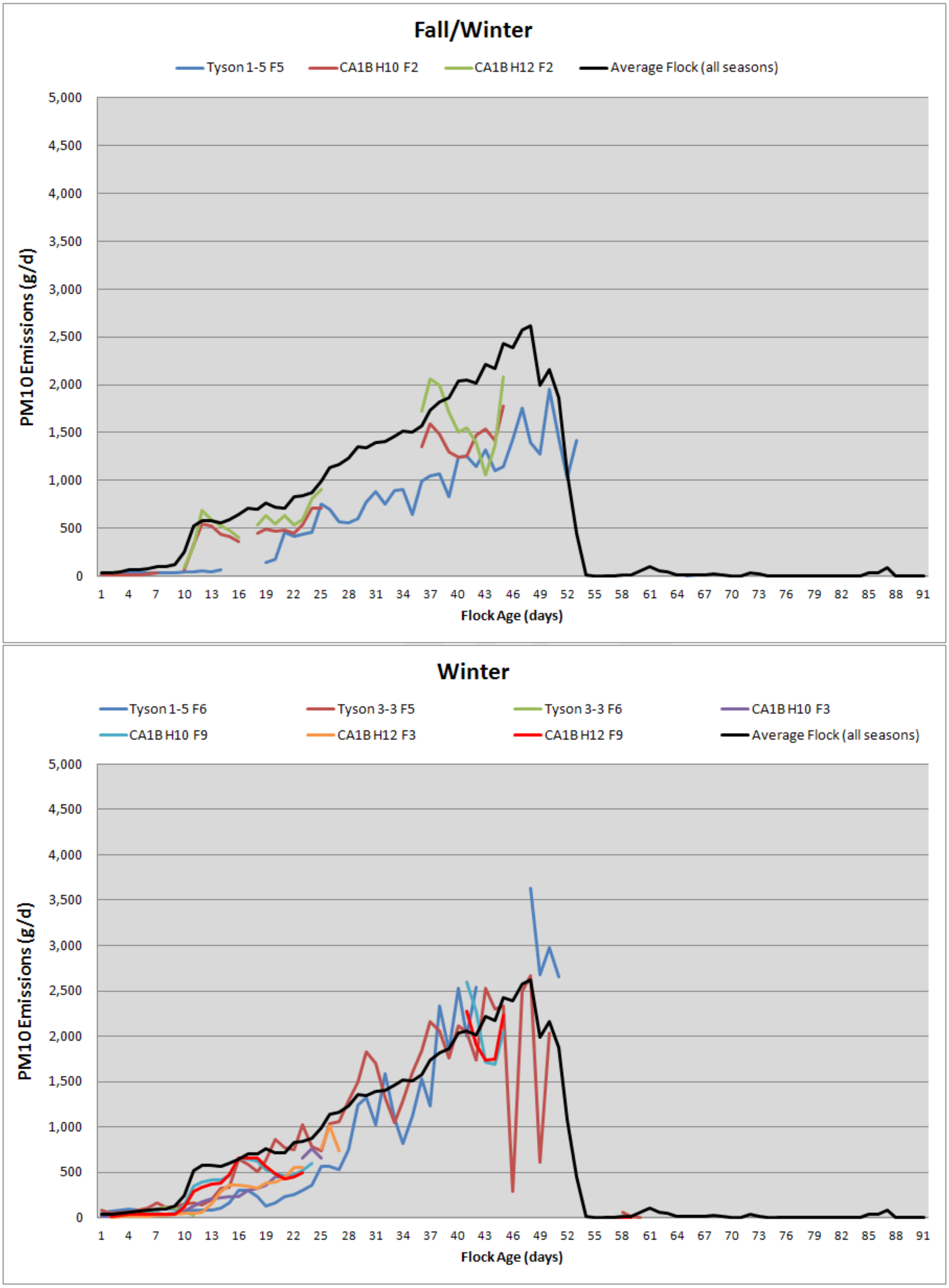

Figure 6-20. PM_{10} Emissions from the Broiler Sites for Fall/Winter and Winter

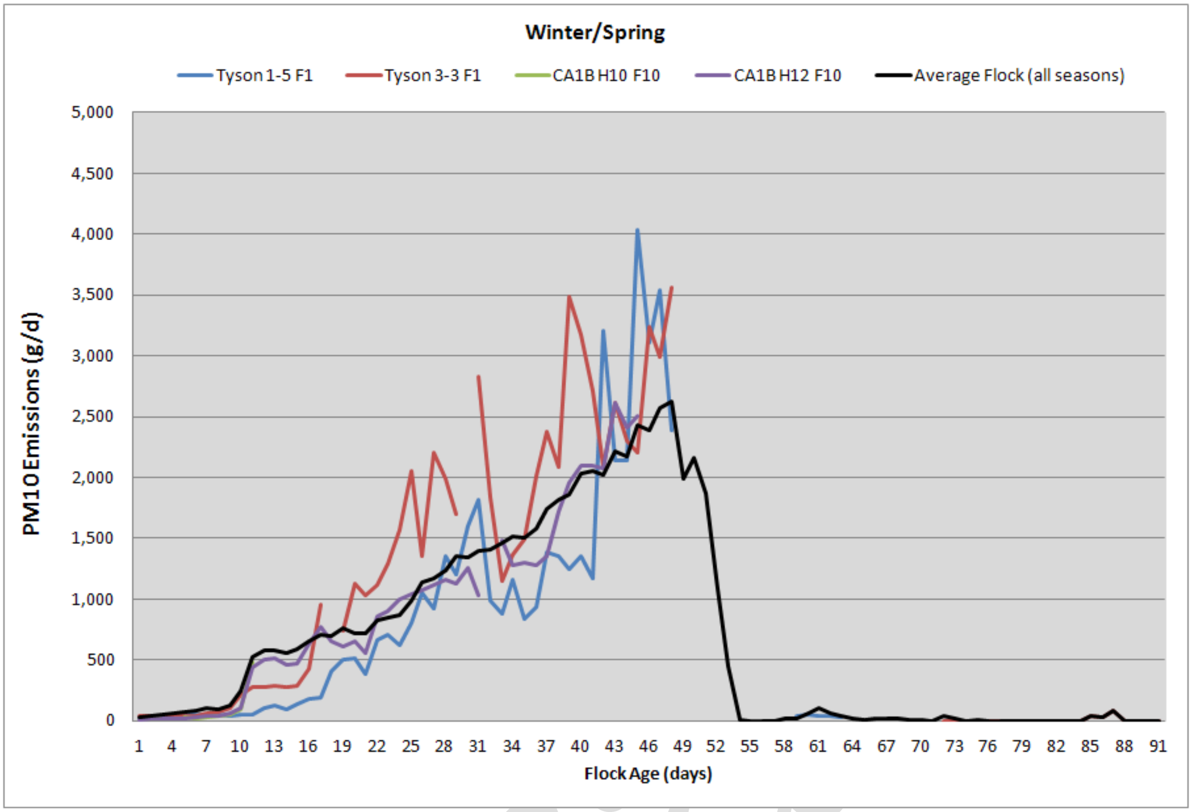

Figure 6-21. PM_{10} Emissions from the Broiler Sites for Winter/Spring

6.5 $PM_{2.5}$ Emissions

6.5.1 General Trends

The $PM_{2.5}$ emissions were monitored continuously over the study period for the two Kentucky sites. At site CA1B, $PM_{2.5}$ emissions were monitored in accordance with the monitoring protocol and data were collected for two weeks each during the summer and the winter to capture any differences in emissions between warm and cold seasons.

Table 6-4 shows the number of daily $PM_{2.5}$ emission values that are available for each day of the broiler grow-out, decaking and full litter clean-out periods, and illustrates the gaps in data from the CA1B houses. Section 5.1.3 presents the sampling schedule for $PM_{2.5}$ monitoring activities at CA1B.

Figure 6-22 and Figure 6-23 present the daily $PM_{2.5}$ emissions rates calculated over the study period for the CA1B and Kentucky sites, respectively. As with the other monitored pollutants, the figures show that the $PM_{2.5}$ emissions steadily increase over the grow-out period.

Table 6-4. Available $PM_{2.5}$ Emissions Days by Site

Cycle Day	Number of Available Daily $PM_{2.5}$ Emissions Values				Cycle Day	Number of Daily $PM_{2.5}$ Emissions Values			
	CA1B H10	CA1B H12	KY1B-1 H5	KY1B-2 H3		CA1B H10	CA1B H12	KY1B-1 H5	KY1B-1 H3
1	0	0	6	6	47	0	0	6	5
2	1	0	6	6	48	0	0	6	5
3	1	0	6	6	49	0	0	6	5
4	1	0	6	6	50	0	0	6	5
5	1	0	6	6	51	0	0	6	5
6	1	0	6	6	52	0	0	6	5
7	1	0	6	6	53	0	0	5	5
8	1	0	6	6	54	0	0	5	5
9	1	0	6	6	55	0	0	5	5
10	1	0	6	6	56	0	0	5	5
11	1	0	6	6	57	0	0	5	5
12	0	0	6	6	58	0	0	5	5
13	0	0	6	6	59	0	0	5	5
14	0	0	6	6	60	0	0	5	5
15	0	0	6	6	61	0	0	5	4
16	0	0	6	6	62	0	0	5	4
17	0	0	6	6	63	0	0	4	4
18	0	0	6	6	64	0	0	4	4
19	0	0	6	6	65	0	0	4	4
20	0	0	6	6	66	0	0	4	4
21	0	0	6	6	67	0	0	2	4
22	0	0	6	6	68	0	0	2	3
23	0	0	6	5	69	0	0	2	3
24	0	0	6	5	70	0	0	2	2
25	0	0	6	5	71	0	0	2	1
26	1	1	6	5	72	0	0	2	1
27	2	2	6	5	73	0	0	2	1
28	2	2	6	5	74	0	0	1	1
29	2	2	6	5	75	0	0	1	1
30	3	2	6	5	76	0	0	0	1
31	3	2	6	5	77	0	0	0	1
32	3	3	6	5	78	0	0	0	1
33	3	3	6	5	79	0	0	0	1
34	3	3	6	5	80	0	0	0	1
35	3	3	6	5	81	0	0	0	1
36	3	3	6	5	82	0	0	0	1
37	3	3	6	5	83	0	0	0	1
38	3	3	6	5	84	0	0	0	1
39	3	3	6	5	85	0	0	0	1
40	2	2	6	5	86	0	0	0	1
41	2	2	6	5	87	0	0	0	1
42	1	1	6	5	88	0	0	0	1
43	1	1	6	5	89	0	0	0	1
44	0	1	6	5	90	0	0	0	1
45	0	1	6	5	91	0	0	0	1
46	0	0	6	5	**Total**	**53**	**43**	**276**	**252**

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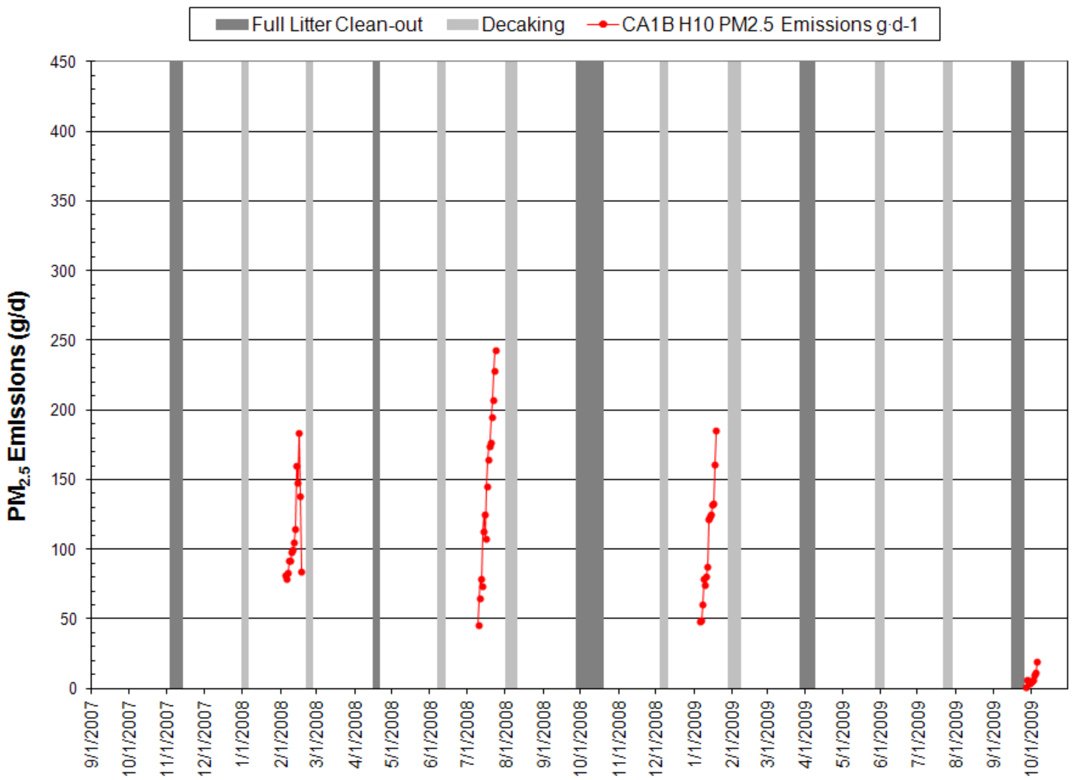

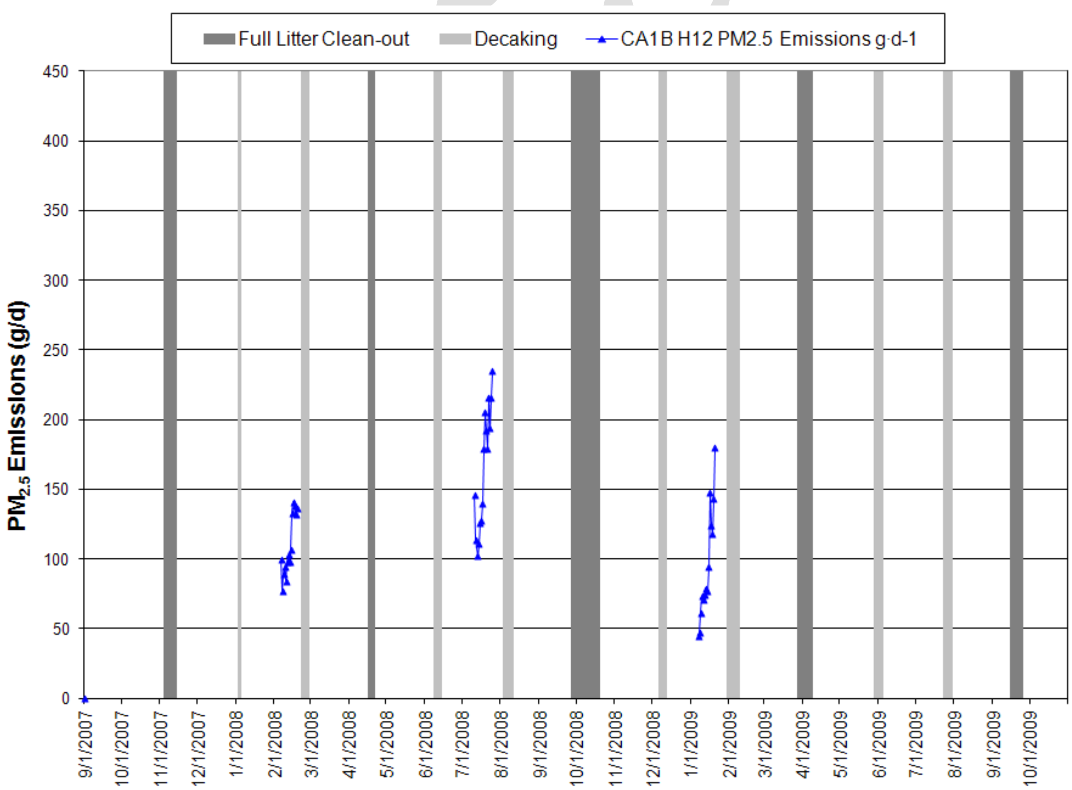

Figure 6-22. $PM_{2.5}$ Emissions from the CA1B Broiler Houses

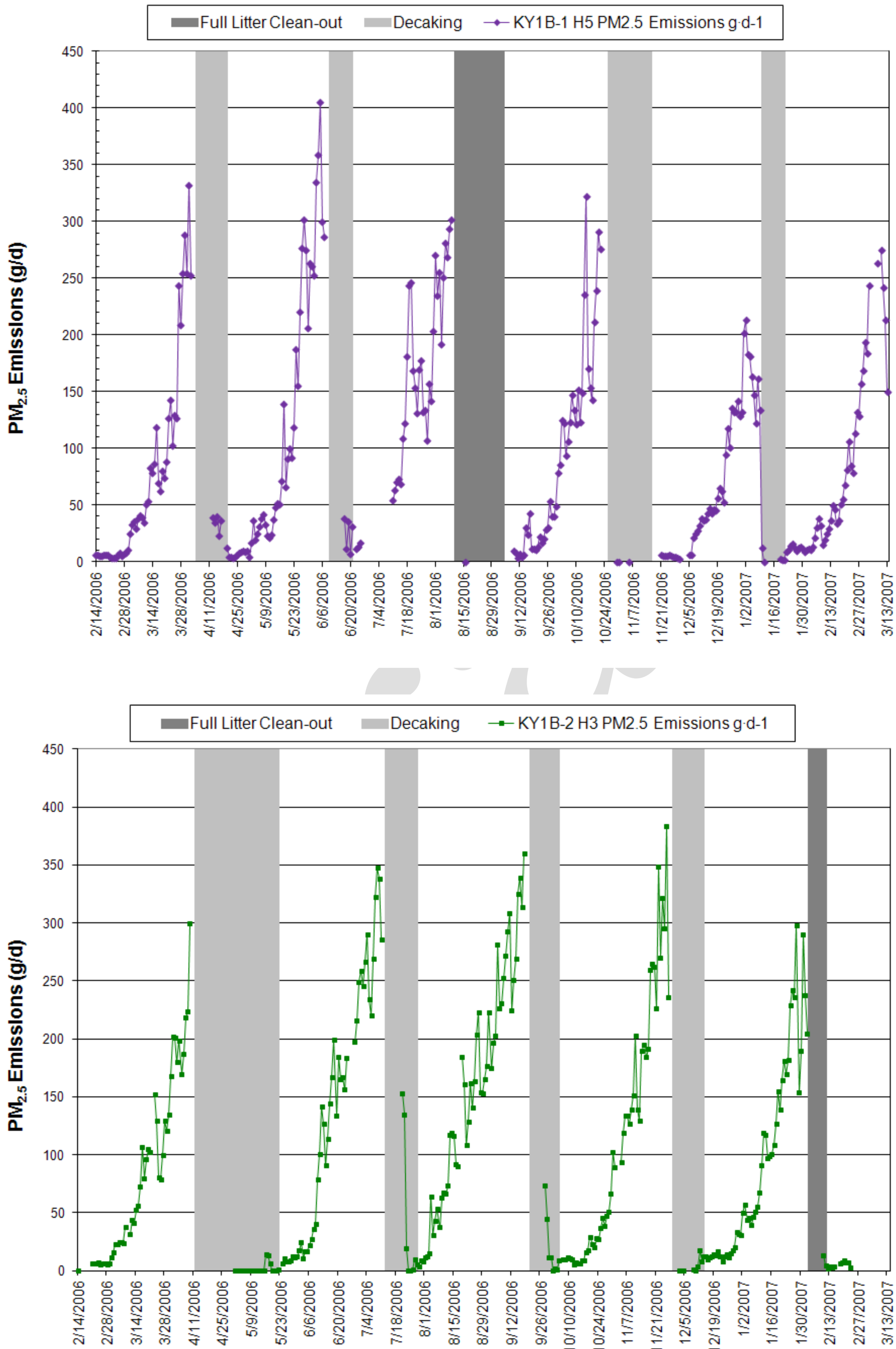

Figure 6-23. PM$_{2.5}$ Emissions from the Kentucky Broiler Houses

Data for $PM_{2.5}$ emissions were not collected at site CA1B during the decaking and full litter clean-out periods. At the Kentucky sites, the PM monitor was removed during the litter removal periods; monitoring resumed in 9 days, on average. As with PM_{10} emissions, the $PM_{2.5}$ emissions values recorded during litter removal periods presented in Figure 6-23 correspond to the time when the house was sitting idle waiting for the next flock to be placed (i.e., $PM_{2.5}$ emissions data were not collected while decaking and full litter clean-out activities were being conducted).

6.5.2 Seasonal Trends

Figure 6-24 presents daily $PM_{2.5}$ emissions for the grow-out, decaking and full litter clean-out periods for all flocks monitored under the NAEMS, color coded by season. Figure 6- 25, Figure 6-26 and Figure 6-27 present the same data as Figure 6-24, grouped by season. The black line on the figures represents the average emissions for all flocks.

Because of the small number of $PM_{2.5}$ emissions values available for site CA1B (see Table 6-4), the comparison of the seasonal trends among the different sites is limited. The average $PM_{2.5}$ emissions values for the fall from CA1B House 10, flock 14, are for the first 10 days of the grow-out period and do not represent the emissions over the entire period. The data for the winter flocks are from measurements taken late in the grow-out period, when emission rates are peaking (emissions data for days early in the grow-out period or during decaking and full litter clean-out periods are not available). Based on the available data, emissions for summer are typically above average, with winter falling just below average. Fall and spring emissions are close to the overall average, except spring deviates late in the grow-out period.

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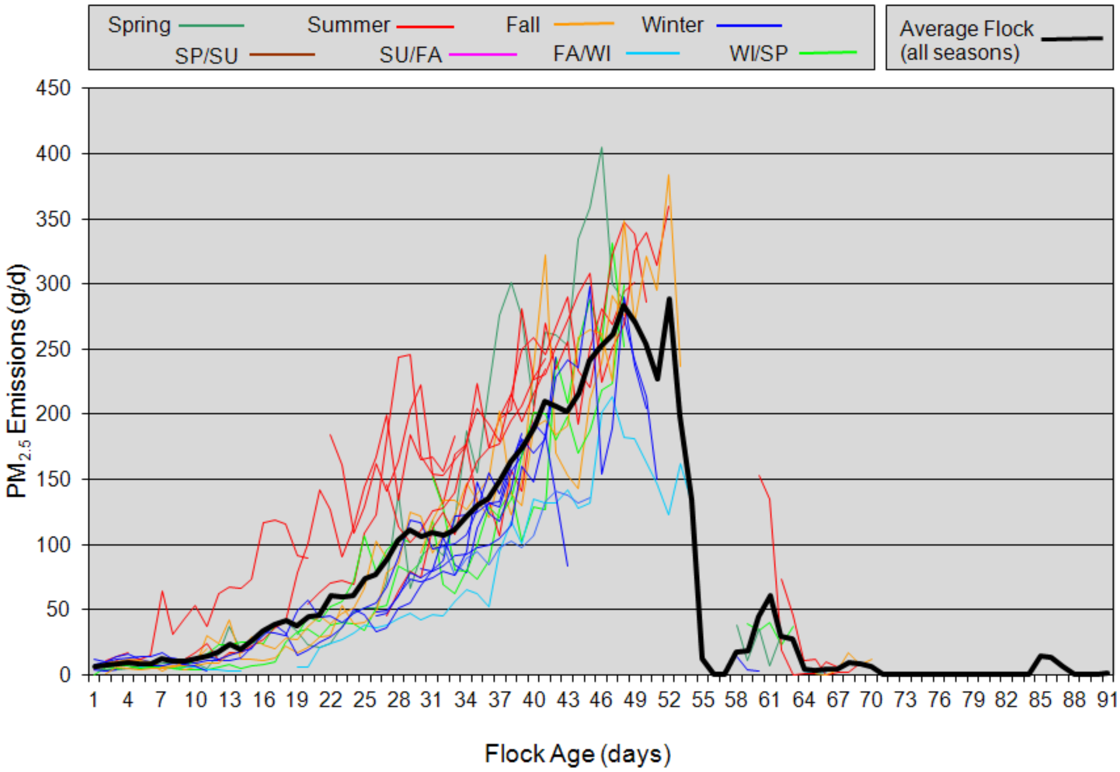

Figure 6-24. $PM_{2.5}$ Emissions by Flock, Color Coded by Season

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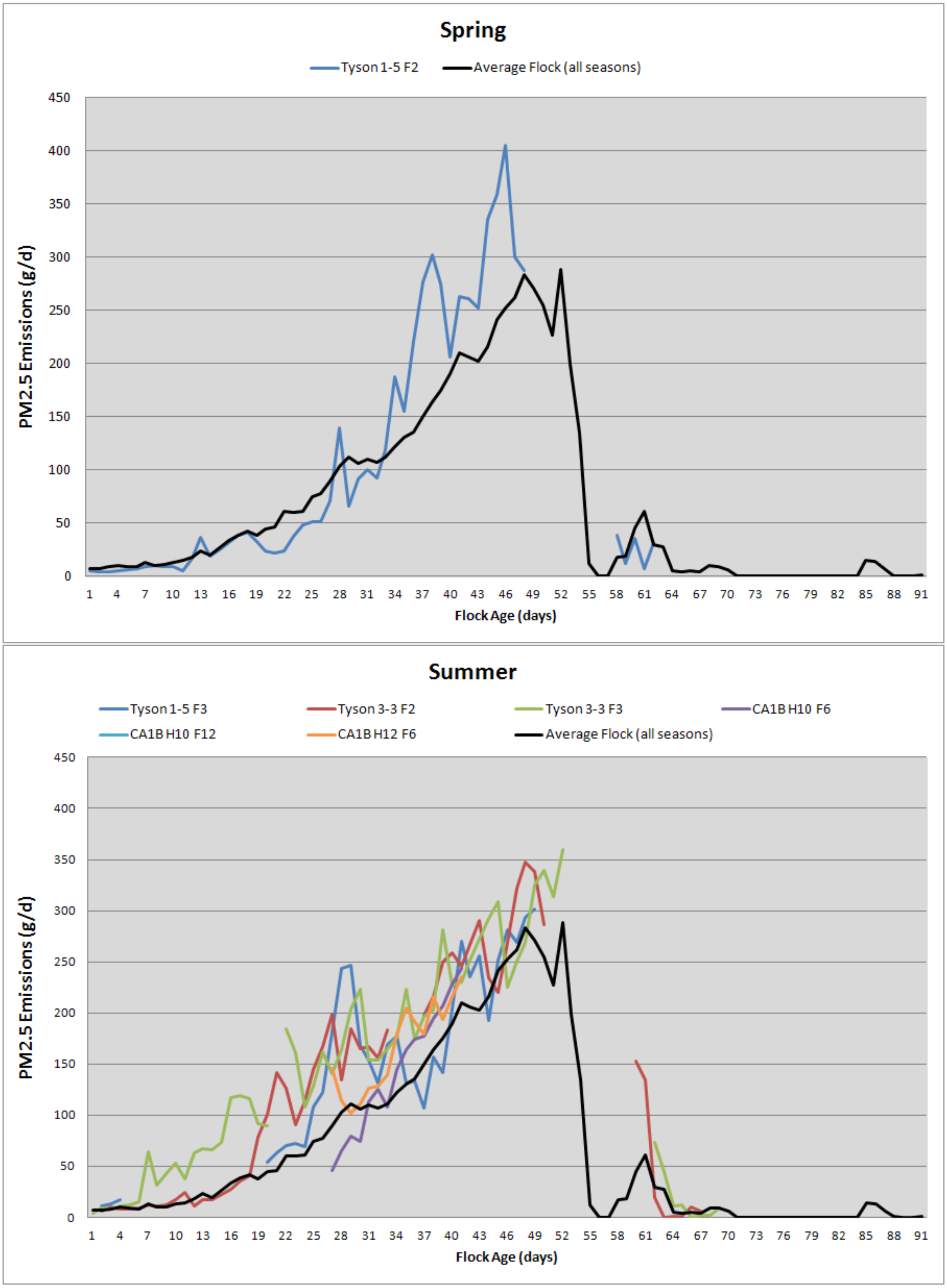


Figure 6-25. $PM_{2.5}$ Emissions from the Broiler Sites for Spring and Summer

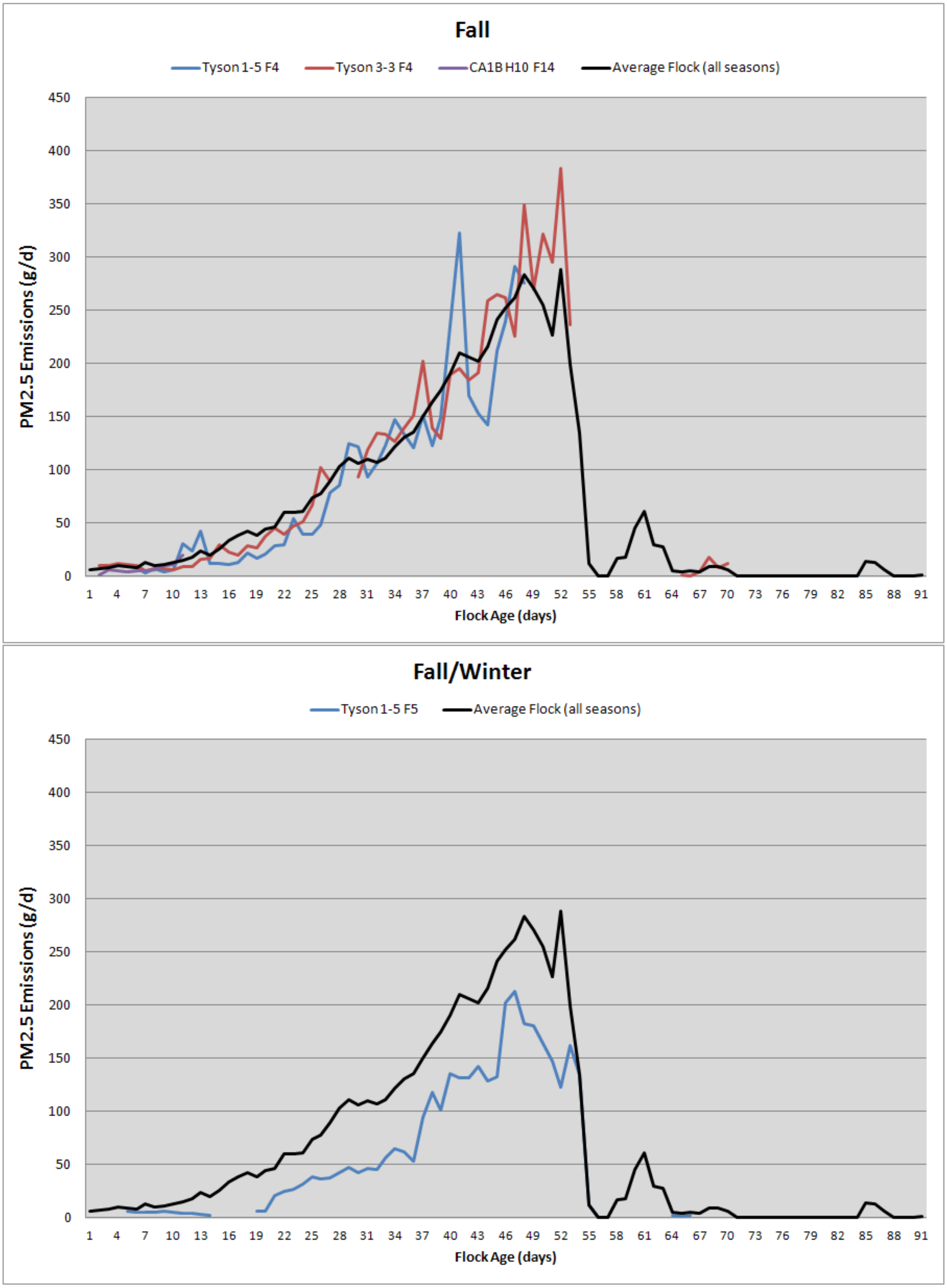
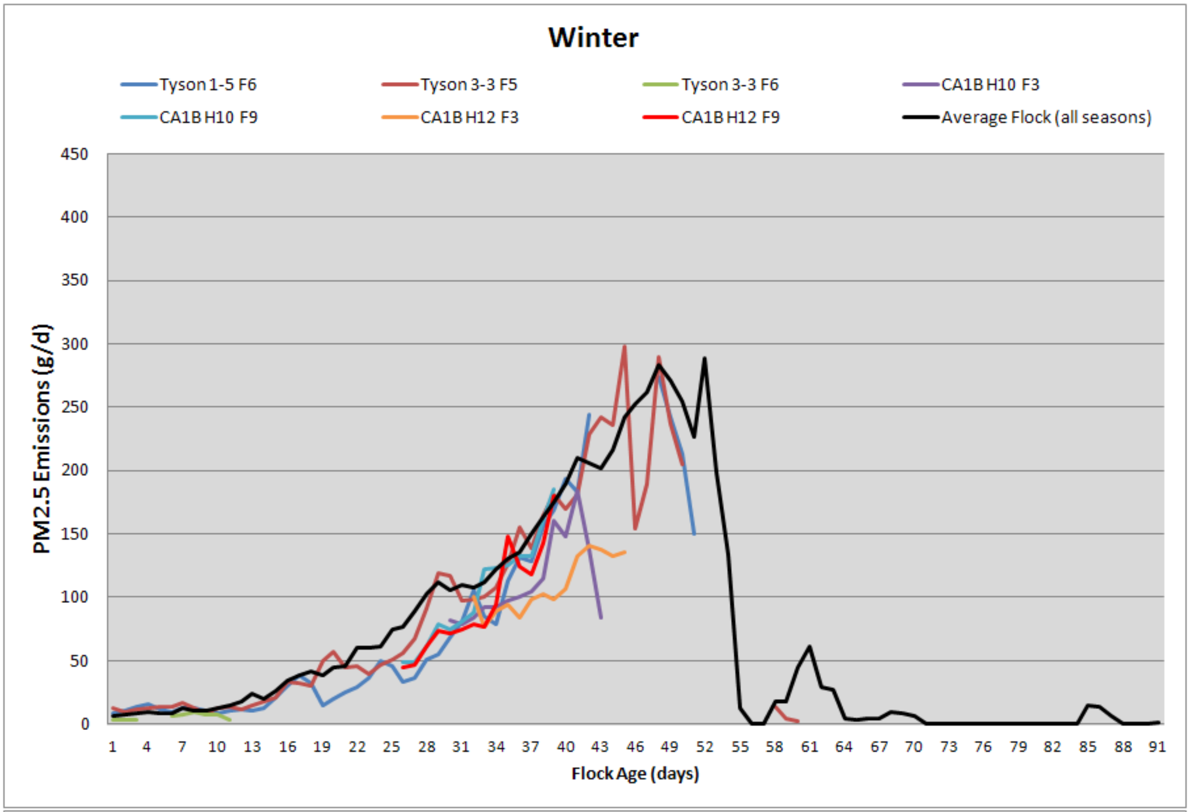


Figure 6-26. $PM_{2.5}$ Emissions from the Broiler Sites for Fall and Fall/Winter



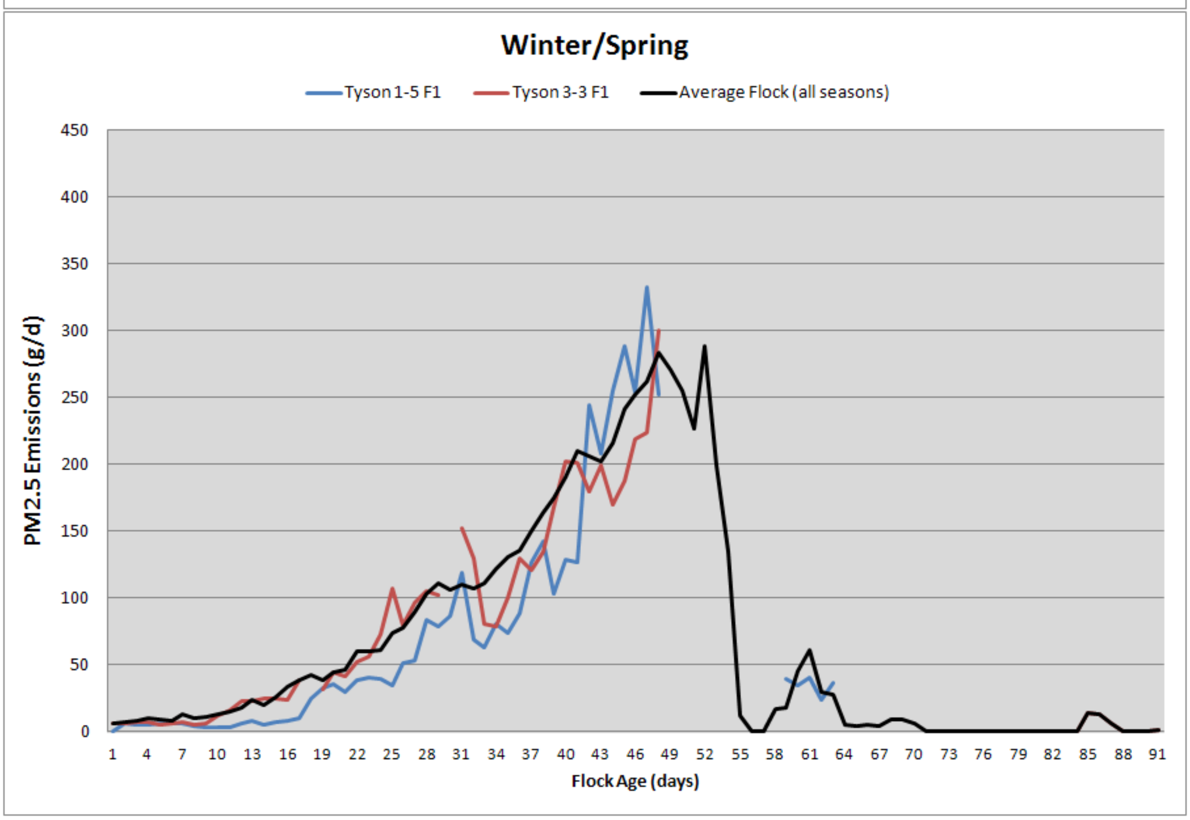


Figure 6-27. $PM_{2.5}$ Emissions from the Broiler Sites for Winter and Winter/Spring

6.6 TSP Emissions

6.6.1 General Trends

Figure 6-28 and Figure 6-29 present the annual emission plots for TSP for the CA1B and Kentucky sites, respectively. The plots of annual emissions from the CA1B site reflect the abbreviated sampling schedule for those houses. The CA1B study monitored one week out of every 8 weeks; in practice, this yielded 7 weeks of data collection. Table 6-5 shows the number of daily TSP emission values that are available for each day of the broiler grow-out, decaking and full litter clean-out periods, and illustrates the gaps in data from the CA1B houses. Section 5.1.3 presents the sampling schedule for TSP monitoring activities at CA1B. The Kentucky sites monitored TSP emissions continuously over their study period.

In general, the TSP emissions trend was similar to the other particulate sizes in that TSP emissions steadily increase over the grow-out period and decrease over the decaking and full litter clean-out periods. Data for TSP emissions were not collected from either house at the CA1B site during decaking or full litter clean-out periods. At the Kentucky sites, the PM monitor was removed during litter removal activities and reestablished in 7 to 10 days. As with PM_{10} and $PM_{2.5}$ emissions, the TSP emissions values for either type of litter removal period reflect emissions from the time when the house was sitting idle waiting for the next flock to be placed. The timing of the monitor removal makes it appear as though there is an abrupt decline in emissions when transitioning from the grow-out period to litter removal period, as opposed to a data gap.

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Table 6-5. Available Daily TSP Emission Values by Site

Cycle Day	Number of Daily TSP Emissions Values			
	CA1B H10	CA1B H12	KY1B-1 H5	KY1B-2 H3
1	0	0	6	6
2	0	1	6	6
3	0	1	6	6
4	0	1	6	6
5	0	1	6	6
6	0	1	6	6
7	0	1	6	6
8	0	1	6	6
9	0	1	6	6
10	0	1	6	6
11	0	0	6	6
12	0	0	6	6
13	1	0	6	6
14	1	0	6	6
15	1	0	6	6
16	1	0	6	6
17	1	0	6	6
18	1	0	6	6
19	0	0	6	6
20	0	0	6	6
21	0	0	6	6
22	1	0	6	6
23	1	1	6	5
24	1	1	6	5
25	1	1	6	5
26	1	1	6	5
27	1	1	6	5
28	2	2	6	5
29	3	3	6	5
30	3	3	6	5
31	3	4	6	5
32	4	4	6	5
33	4	4	6	5
34	3	4	6	5
35	2	1	6	5
36	1	0	6	5
37	0	0	6	5
38	0	0	6	5
39	0	0	6	5
40	0	0	6	5
41	0	0	6	5
42	0	0	6	5
43	0	0	6	5
44	0	0	6	5
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46	0	0	6	5
47	0	0	6	5
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76	0	0	0	1
77	0	0	0	1
78	0	0	0	1
79	0	0	0	1
80	0	0	0	1
81	0	0	0	1
82	0	0	0	1
83	0	0	0	1
84	0	0	0	1
85	0	0	0	1
86	0	0	0	1
87	0	0	0	1
88	0	0	0	1
89	0	0	0	1
90	0	0	0	1
91	0	0	0	1
Total	**37**	**39**	**276**	**252**

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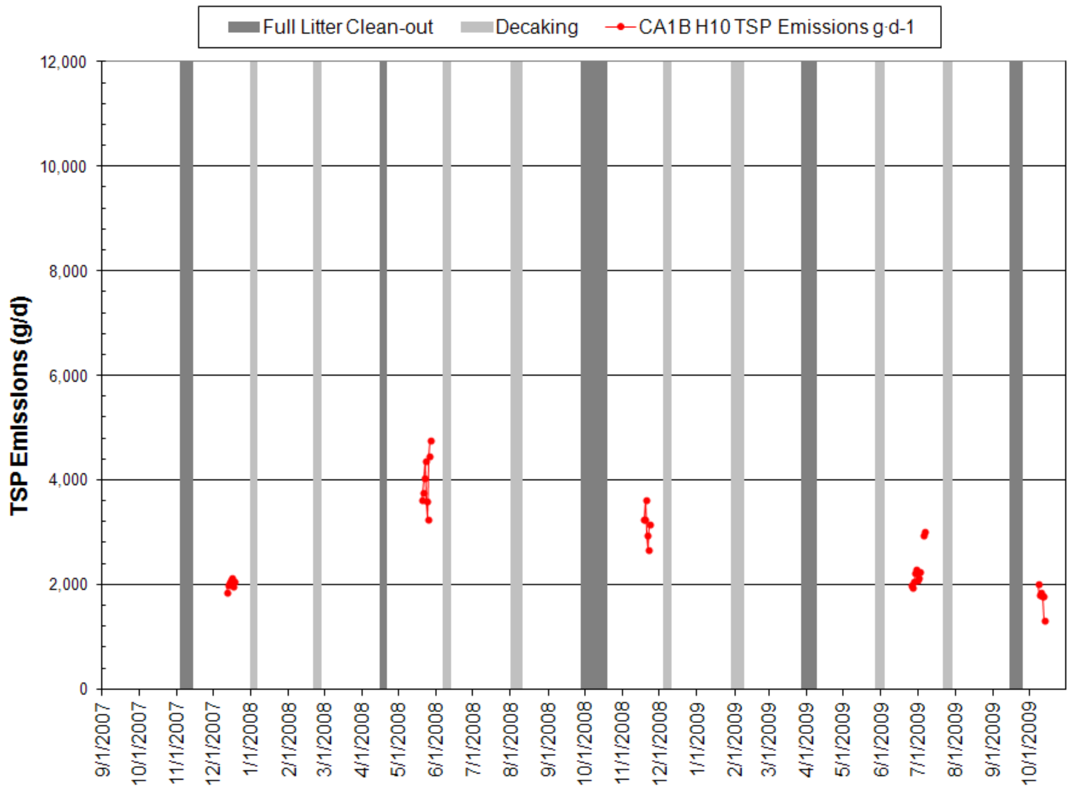


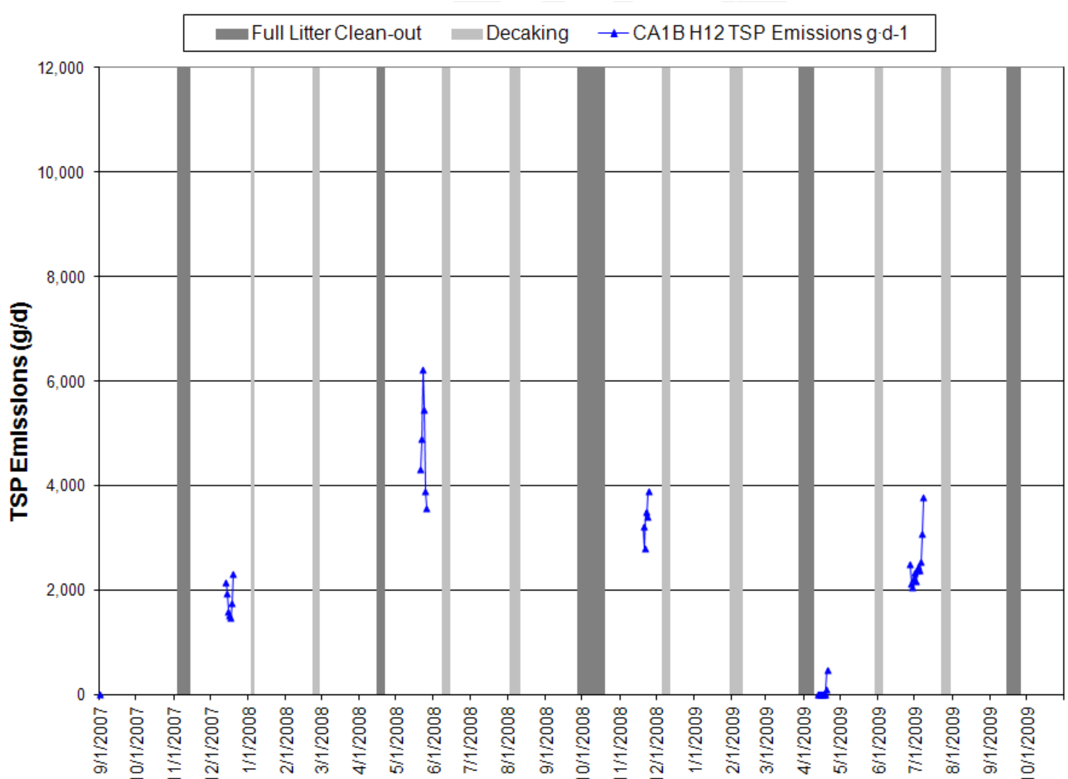


Figure 6-28. TSP Emissions from the CA1B Broiler Houses

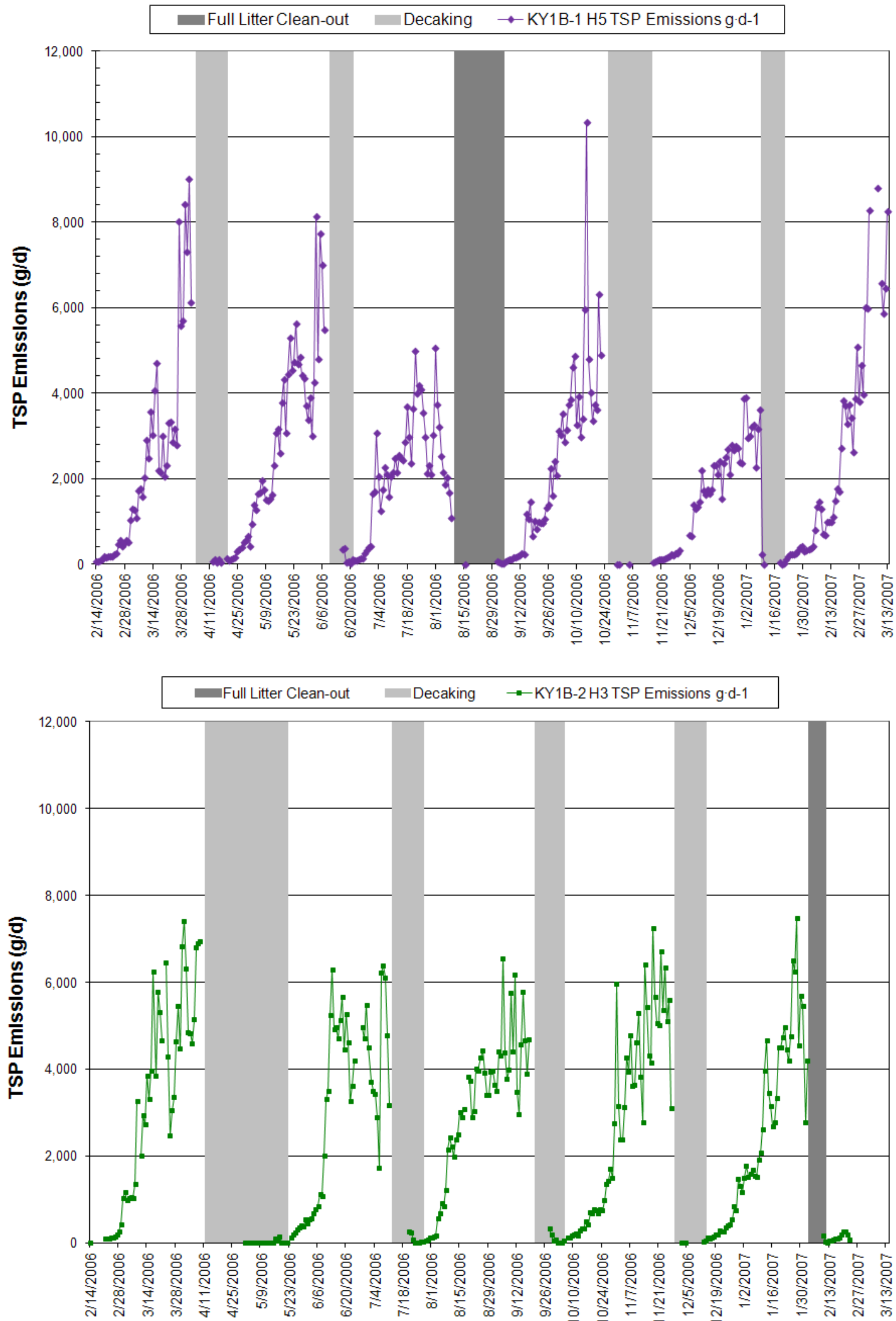


Figure 6-29. TSP Emissions from the Kentucky Broiler Houses

6.6.2 Seasonal Trends

Figure 6-30 presents daily TSP emissions for the grow-out, decaking and full litter clean-out periods for all flocks monitored under the NAEMS, color coded by season. The data spans both the grow-out and litter removal periods. The black line represents the average emissions for all flocks.

Comparisons between the TSP emissions for the different houses were limited due to the intermittent sampling periods for the CA1B houses. Available TSP emissions values from the CA1B houses are comparable to the emissions from the Kentucky houses, indicating that the emissions are representative of the housing type. The TSP emissions displayed a seasonal trend with emissions from summertime flocks typically above average and wintertime flocks below average. Figure 6-31, Figure 6-32 and Figure 6-33 present separate plots for each seasonal classification.

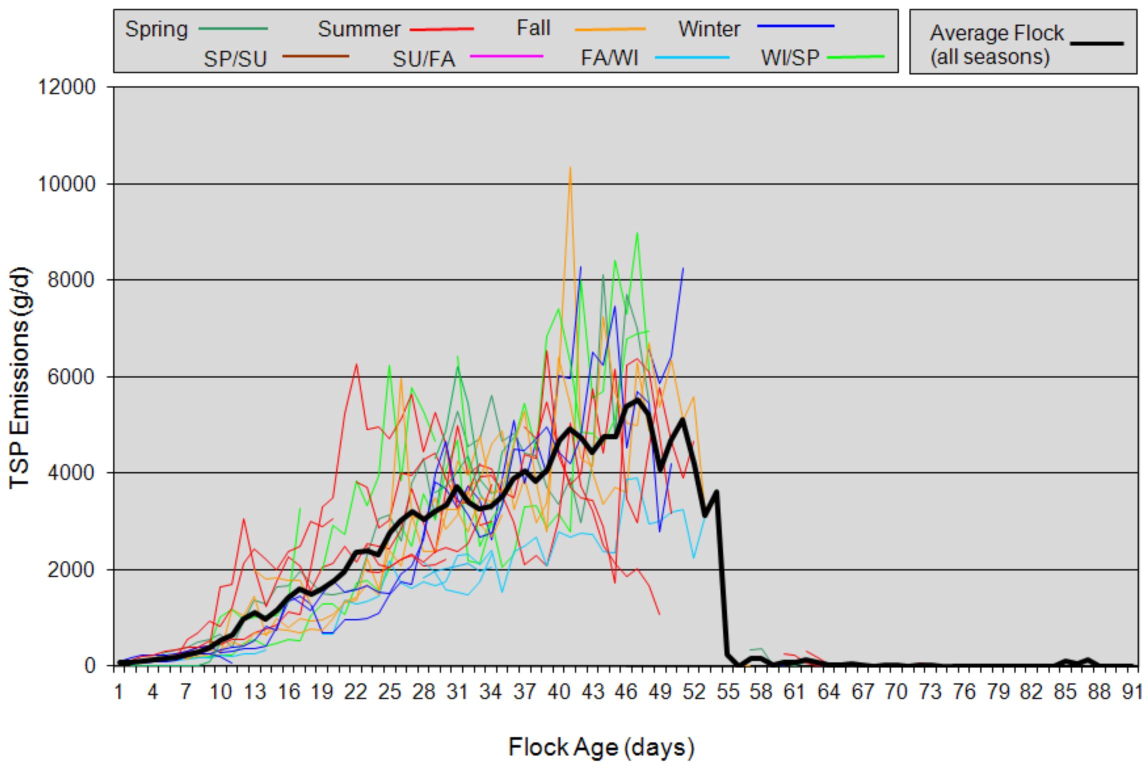


Figure 6-30. TSP Emissions by Flock, Color Coded by Season

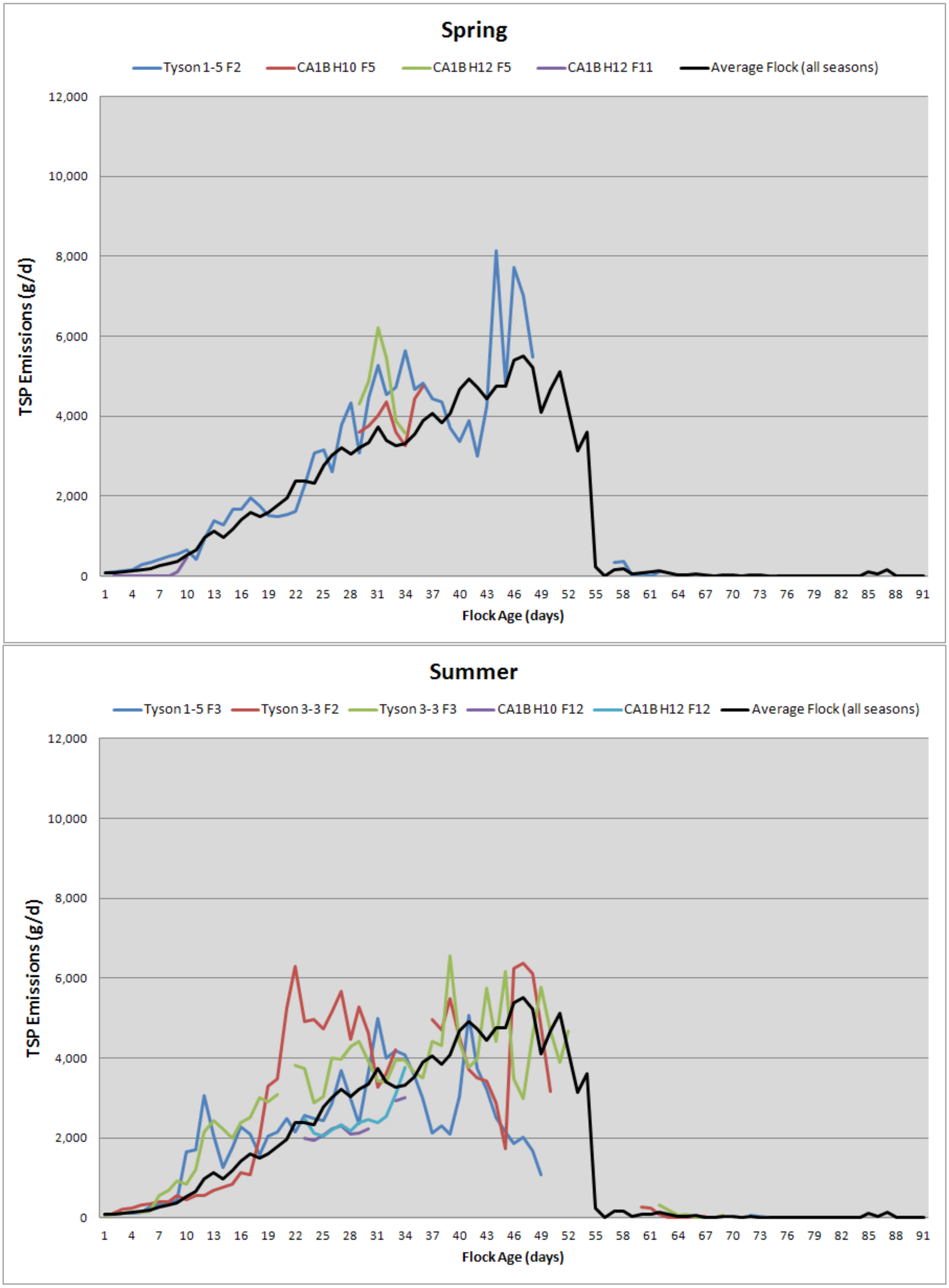
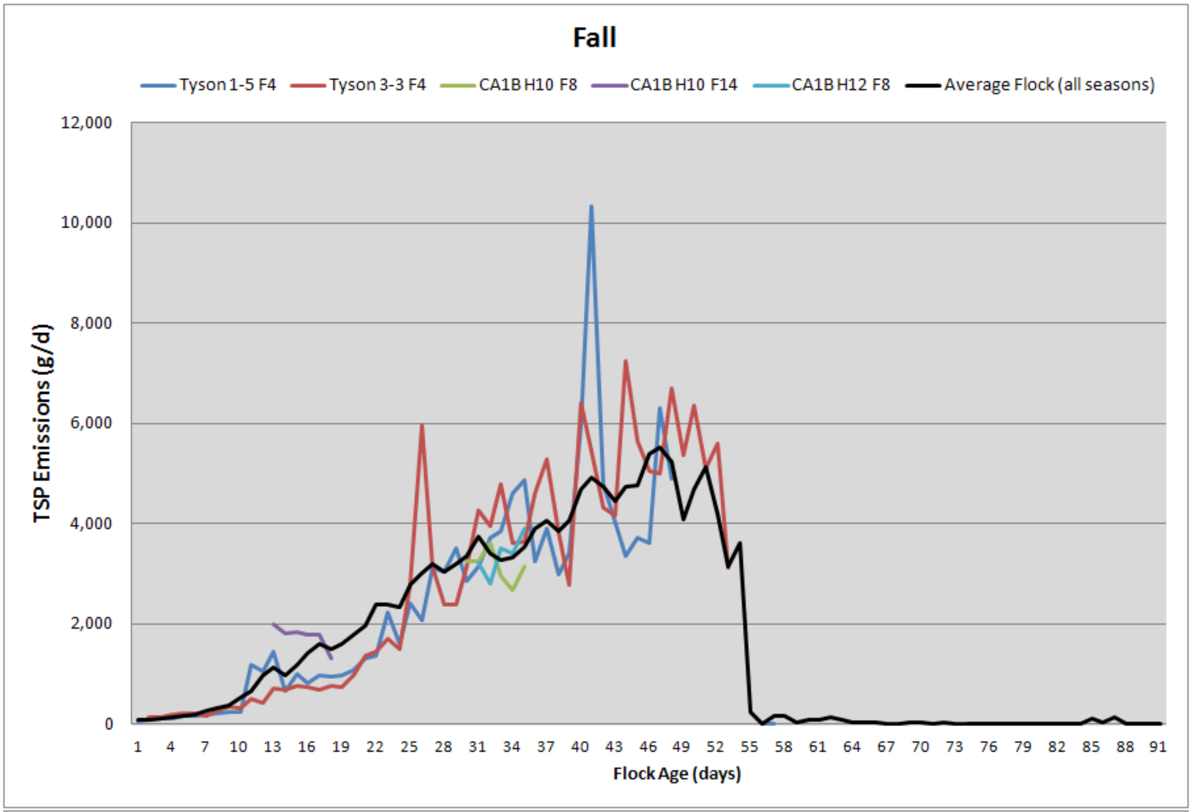


Figure 6-31. TSP Emissions from the Broiler Sites for Spring and Summer



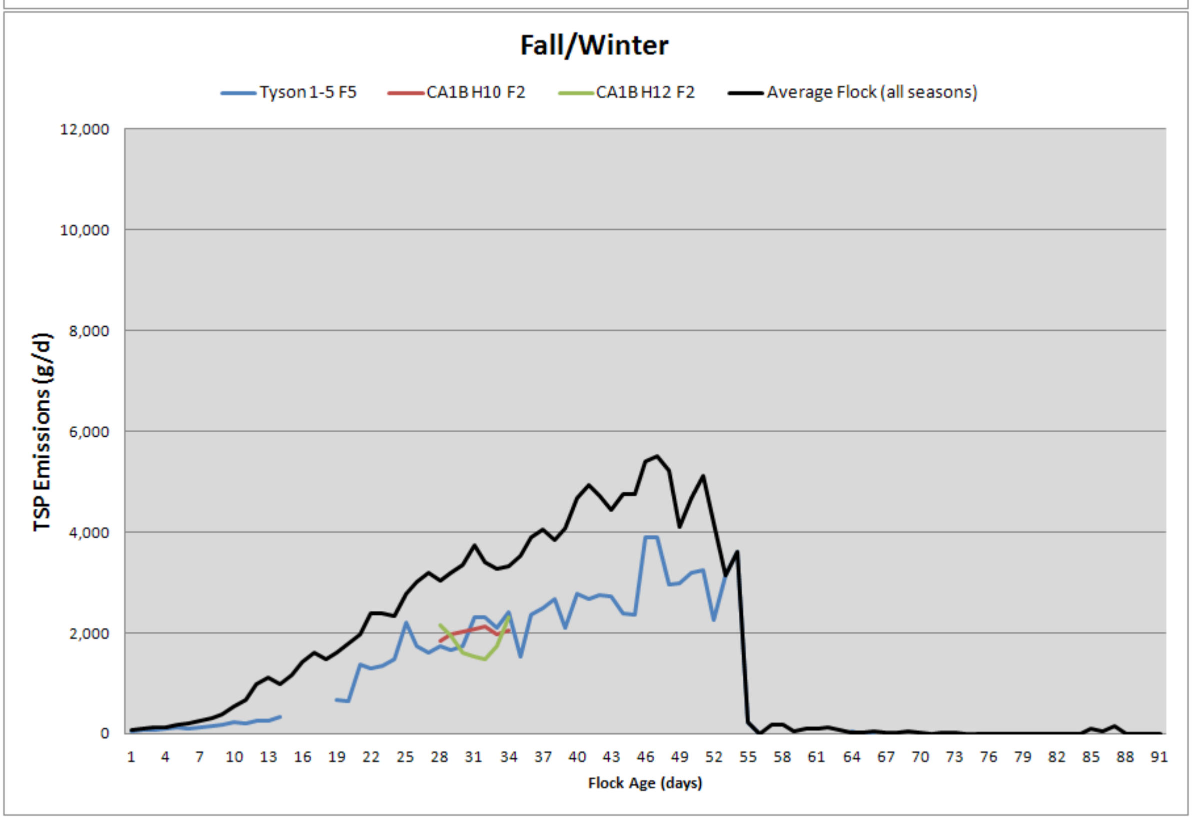
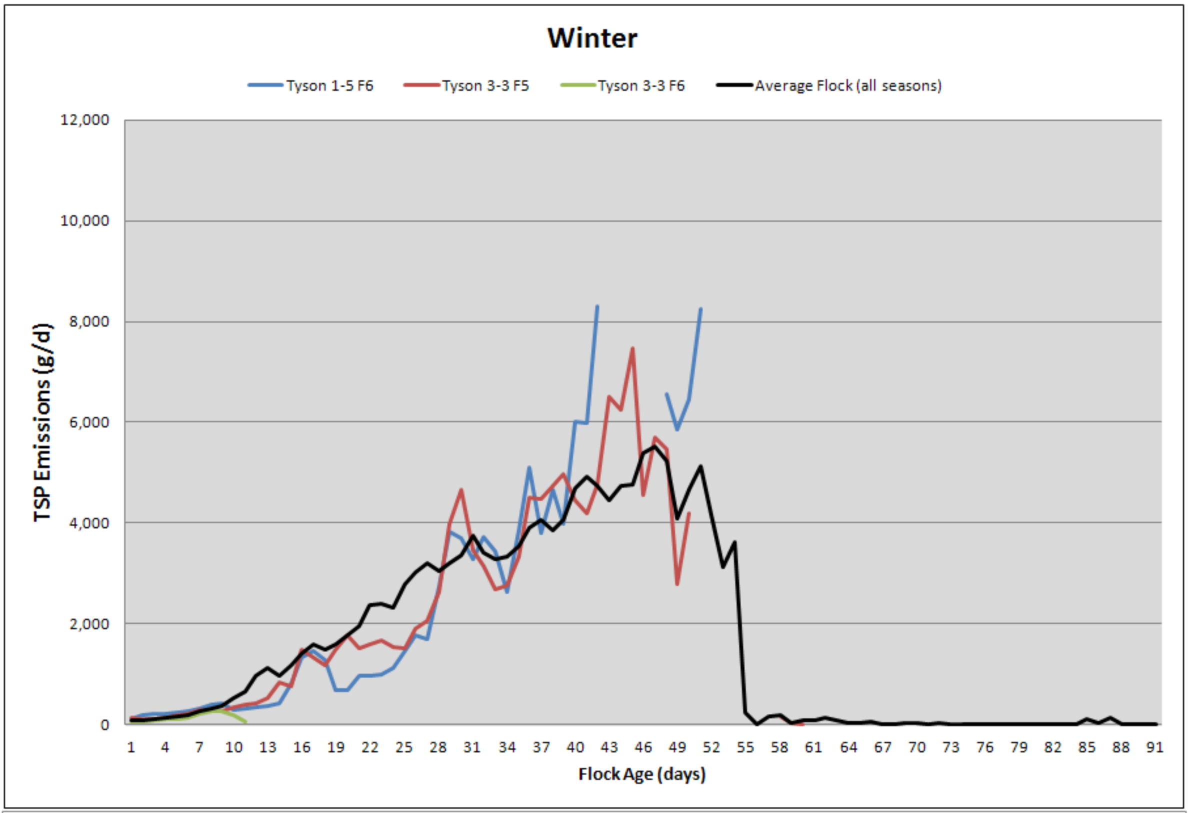


Figure 6-32. TSP Emissions from the Broiler Sites for Fall and Fall/Winter



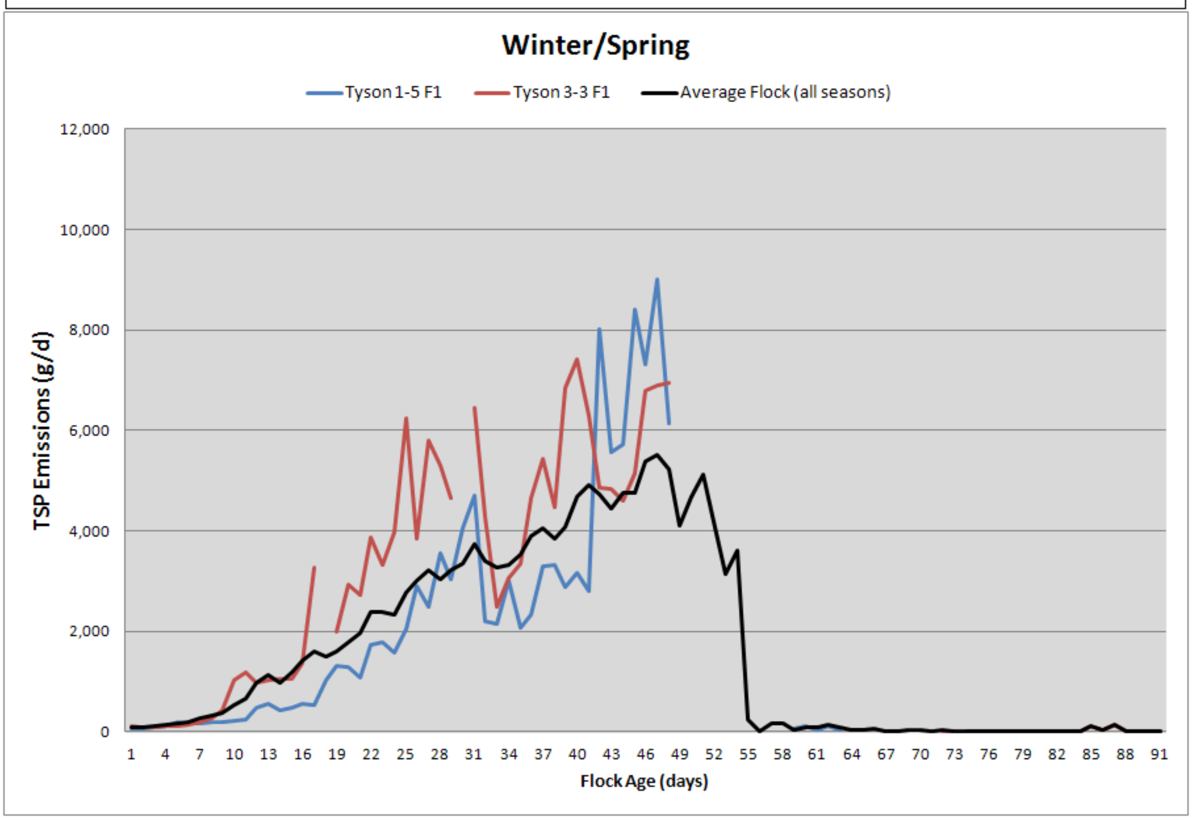


Figure 6-33. TSP Emissions from the Broiler Sites for Winter and Winter/Spring

6.7 VOC Emissions

6.7.1 General Trends

Figure 6-34 presents the annual emission plots for VOCs at the Kentucky broiler houses. The VOC data were collected continuously in the form of NMHC readings at the Kentucky sites. In general, emissions increase with bird age and weight, though the pattern is not as distinct as with the other gaseous species. Emissions of VOC are comparable between the two Kentucky houses.

At site CA1B, grab samples were collected periodically during the course of the study. Seven (7) grab samples were collected at House 10 and six (6) grab samples were collected at House 12. The samples were collected on nonconsecutive days from July 14, 2010 to October 7, 2010. Graphs of the grab sample data were not prepared because the limited number of data values and the short-term sampling period are not sufficient to indicate an emissions trends.

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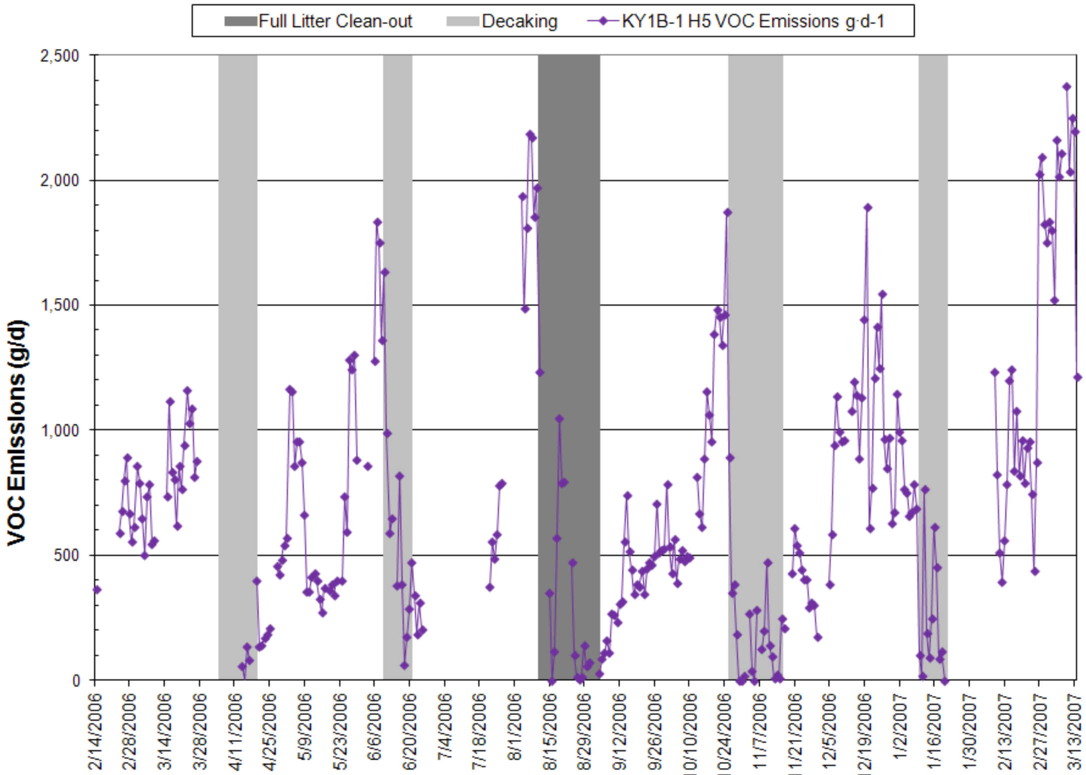


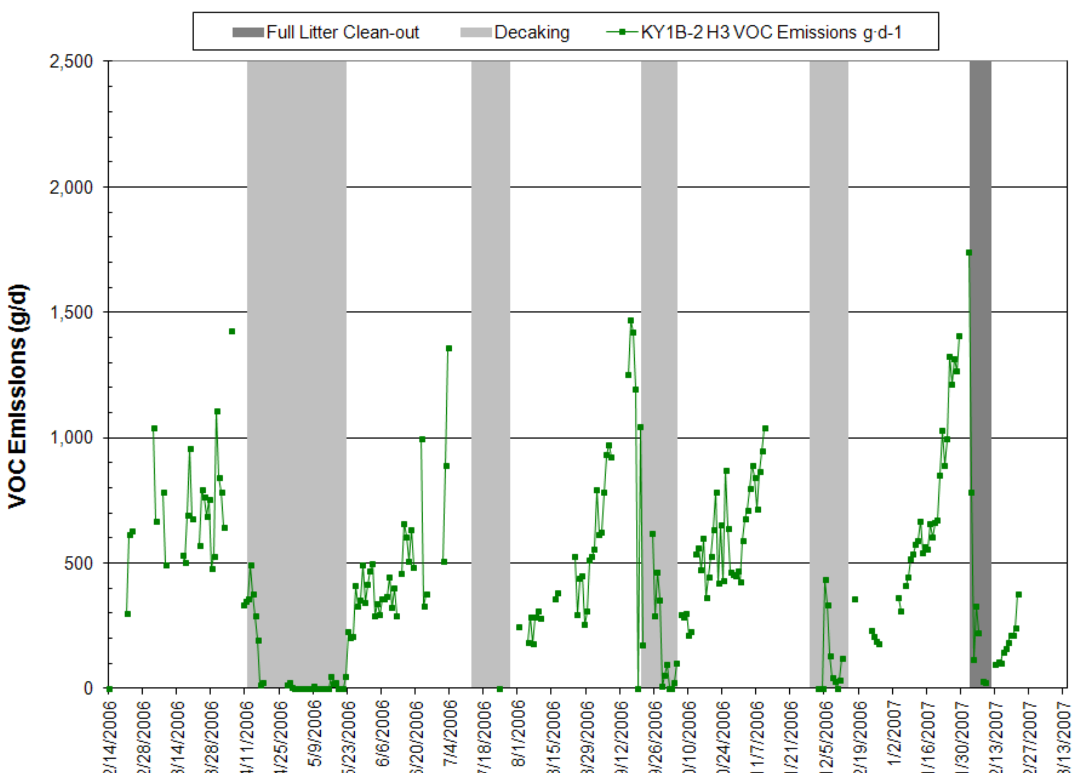


Figure 6-34. VOC Emissions from the Kentucky Broiler Houses

6.7.2 Seasonal Trends

Figure 6-35 presents flock VOC emissions for the Kentucky broiler houses, color coded by season. The data spans both the grow-out and litter removal periods. The black line represents average emissions for all flocks.

Based on the limited data (the two Kentucky houses were monitored for only one year each), VOC emissions do not appear to display any seasonality. Flock emissions for the various seasons tend to fluctuate across the average line (see Figure 6-36, Figure 6-37 and Figure 6-38). Emissions of VOC at site KY1B-1 H5 appear slightly higher than KY1B-2 H3 especially during the middle portion of the cycle, approximately days 35 to 50. Both house seem comparable, with KY1B-1 H5 running slightly higher than KY1B-2 H3, especially during the middle portion of the cycle (approximately day 35 to 50).

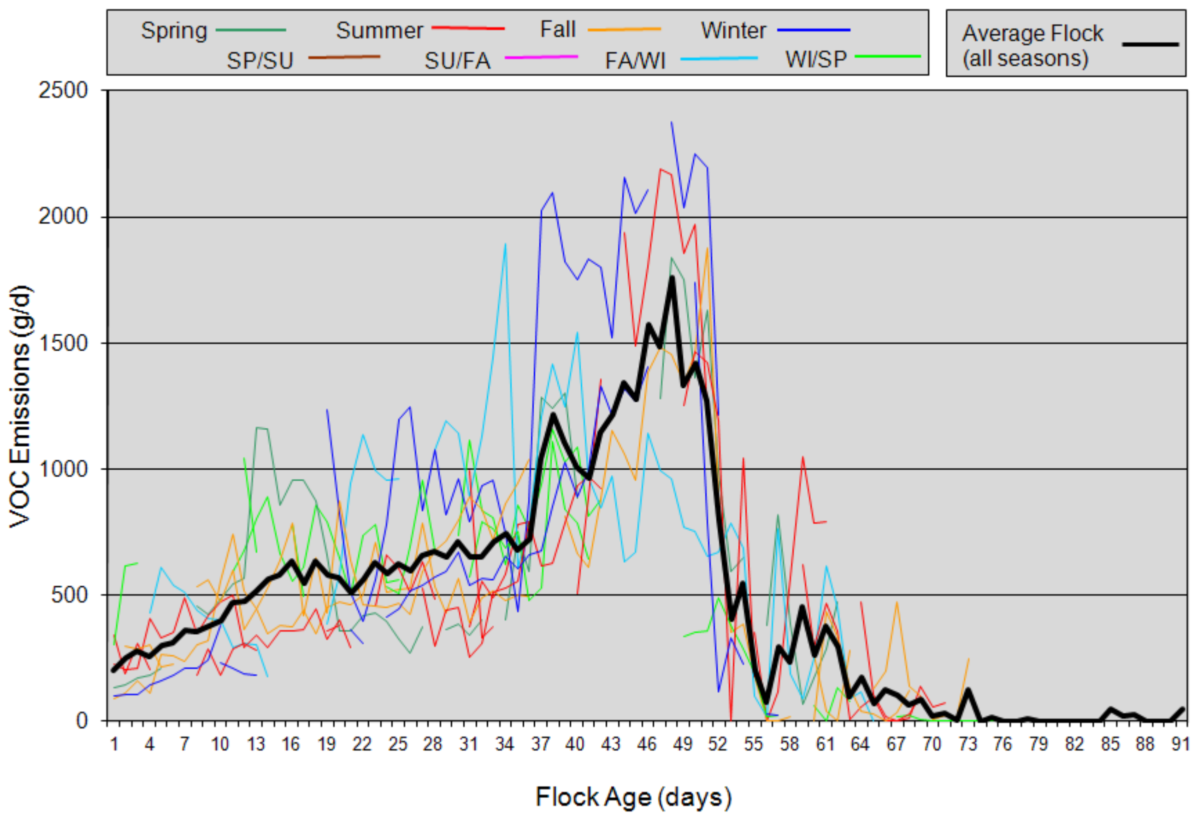


Figure 6-35. VOC Emissions by Flock, Color Coded by Season

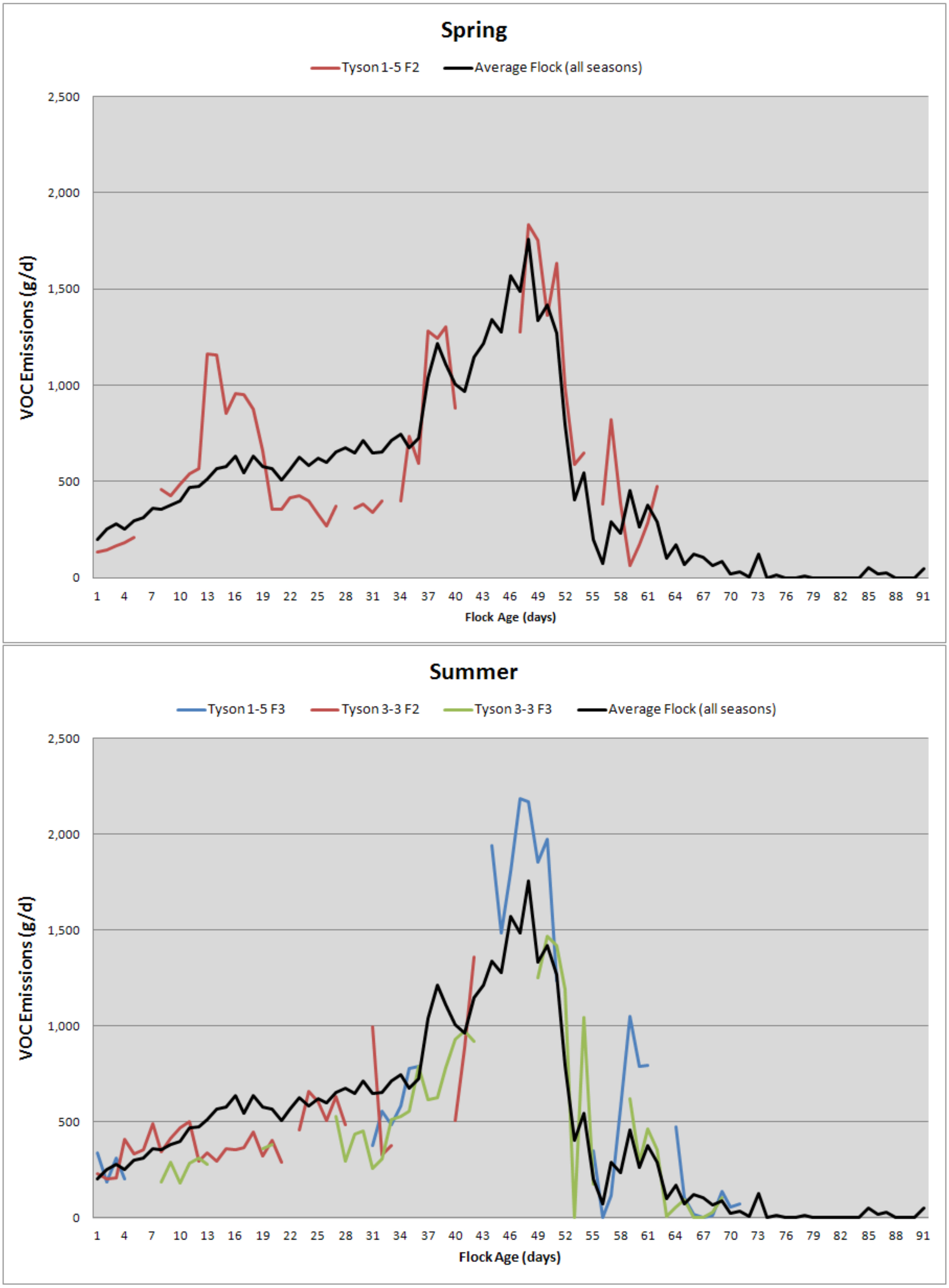
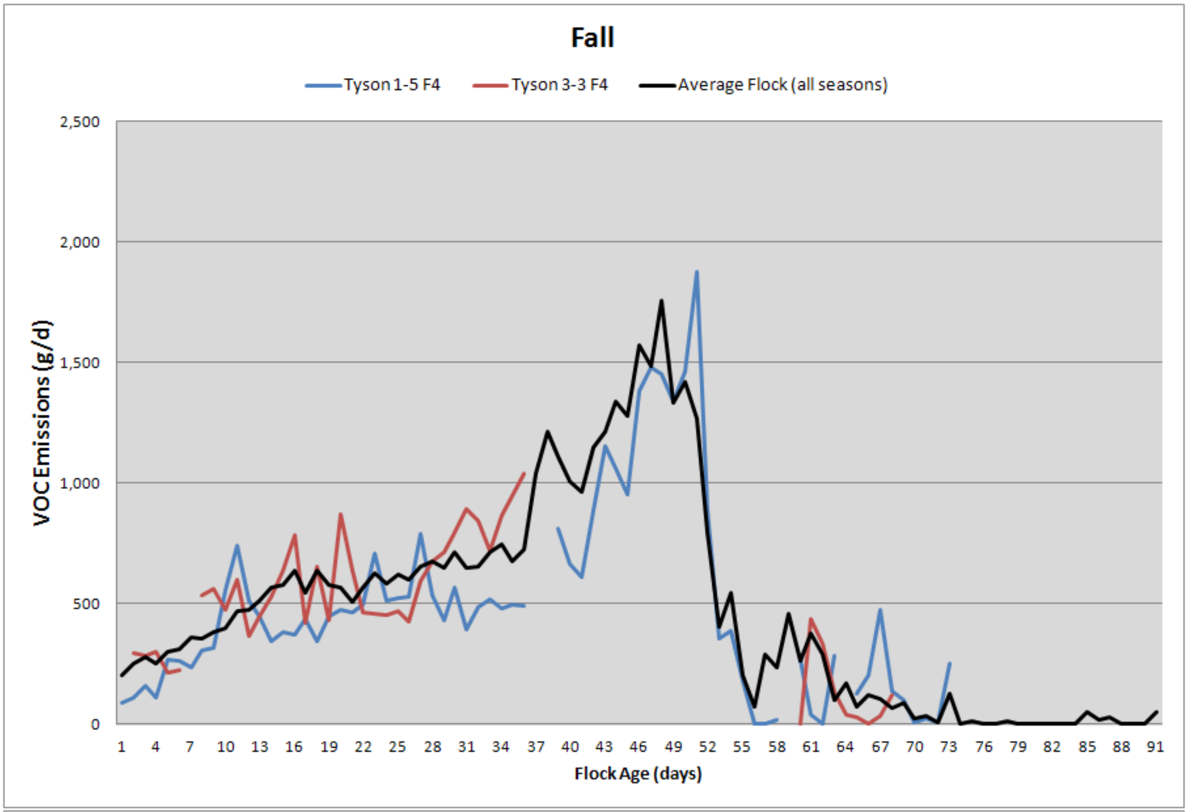


Figure 6-36. VOC Emissions from the Broiler Sites for Spring and Summer



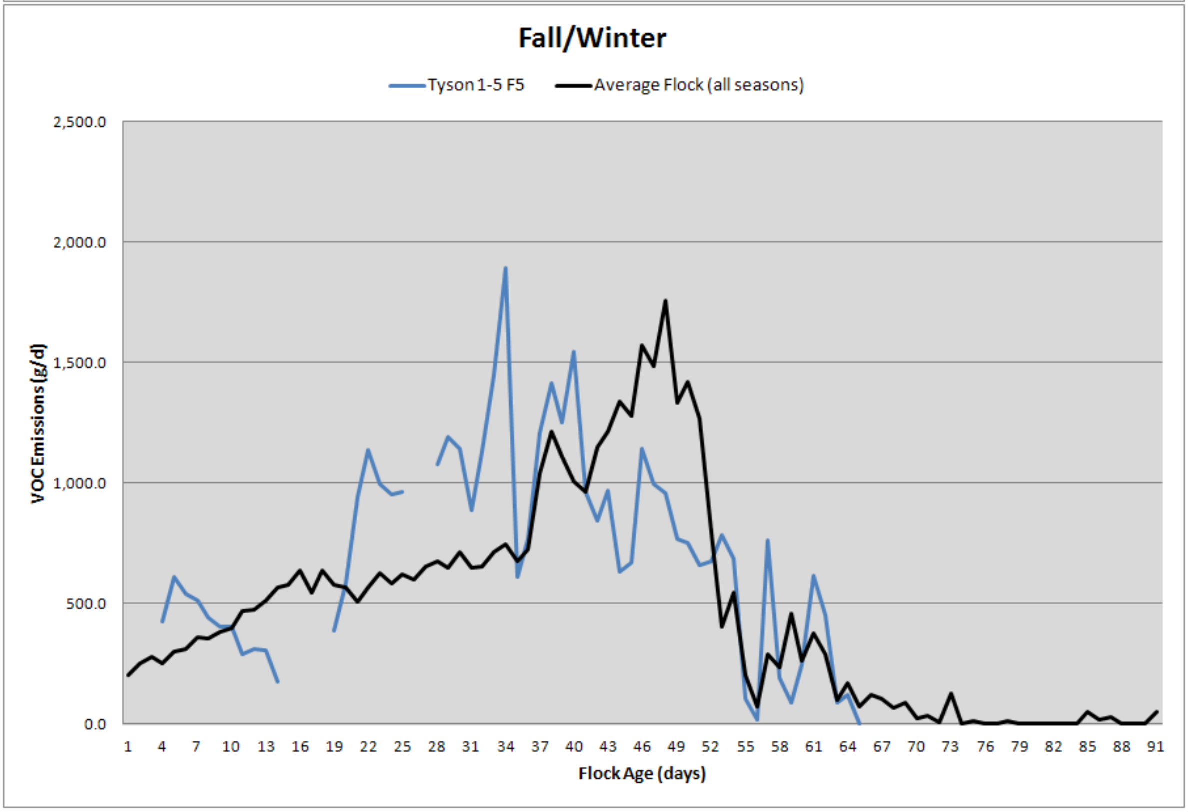
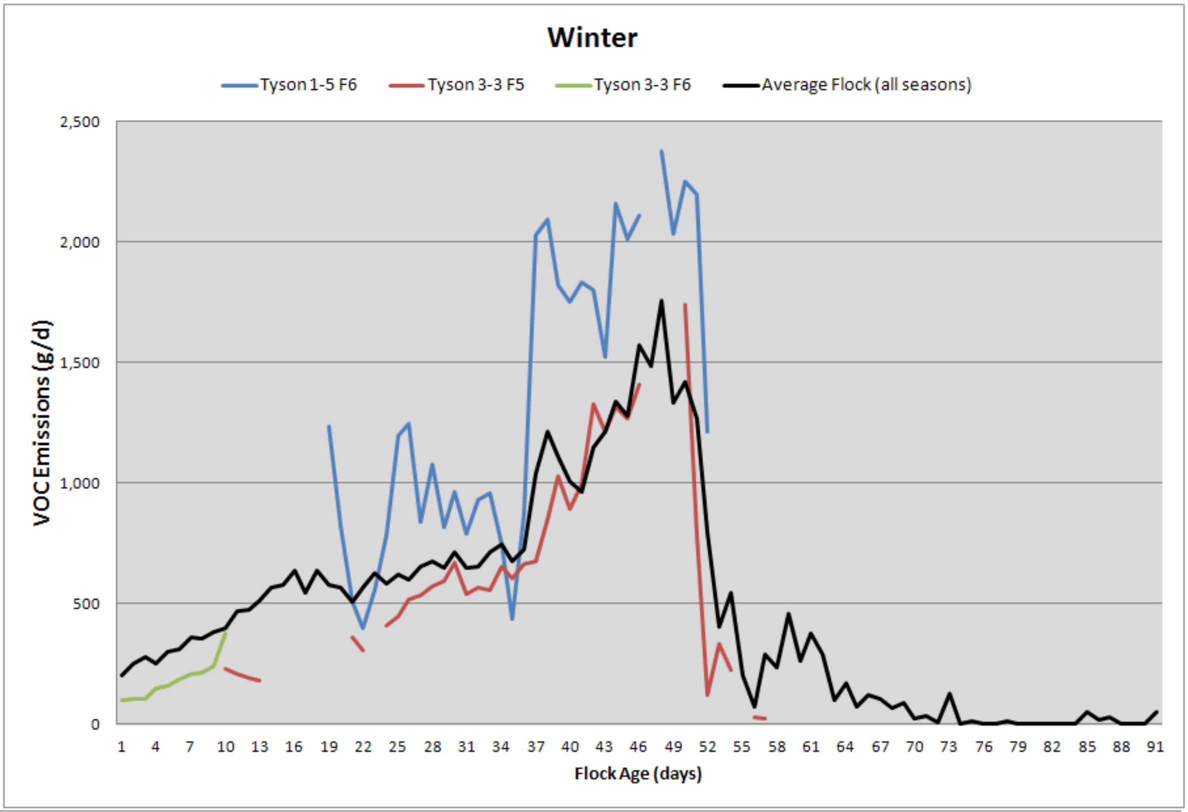


Figure 6-37. VOC Emissions from the Broiler Sites for Fall and Fall/Winter



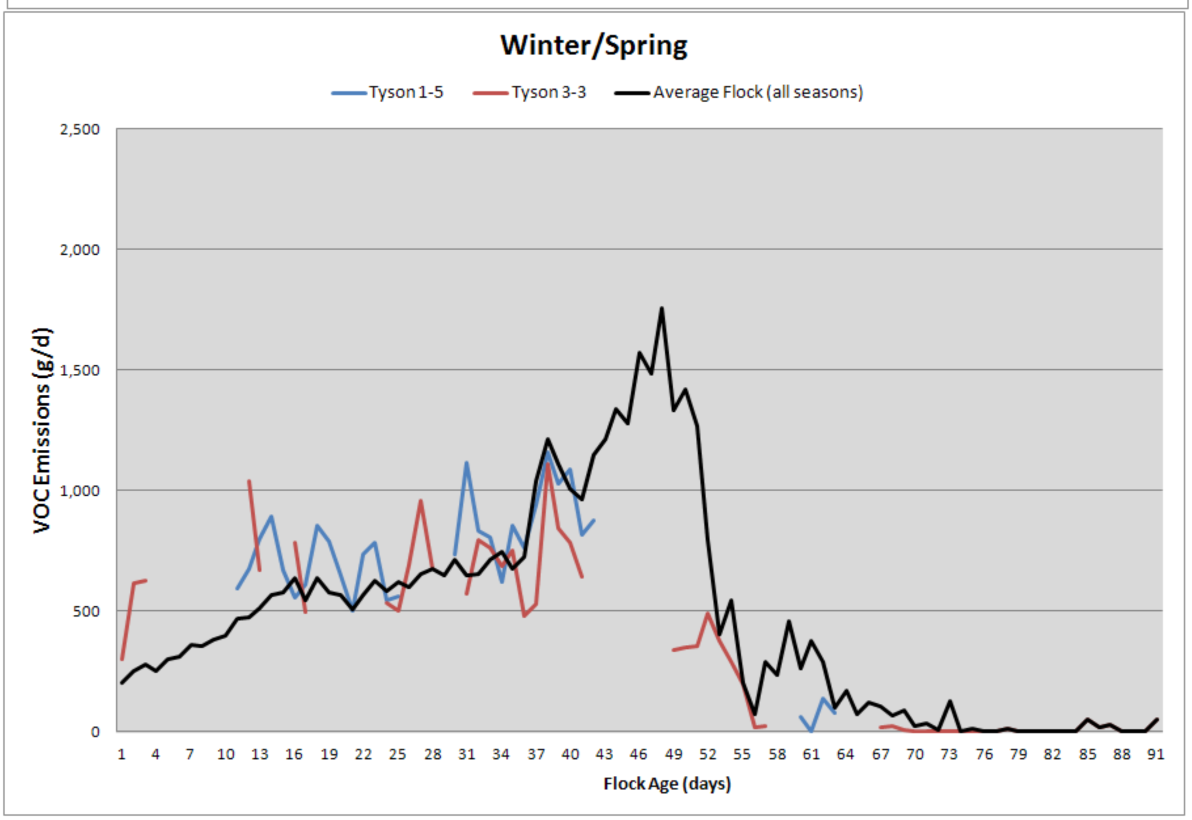


Figure 6-38. VOC Emissions from the Broiler Sites for Winter and Winter/Spring

7.0 DEVELOPMENT OF EEMS FOR GROW-OUT PERIODS

This section presents the statistical approach the EPA used to develop the EEMs for the grow-out periods associated with broiler operations using the NAEMS data. This section uses NH_3 as the example pollutant to demonstrate the statistical method. The remaining pollutants (H_2S, PM_{10}, $PM_{2.5}$, TSP and VOCs) followed this statistical approach and the resulting EEMs are presented in Section 8.

For each pollutant, the EPA developed an EEM for each of three sets of predictor variables: variables based on animal inventory alone (I), inventory variables supplemented with ambient meteorology (IA), and the combination of these variables with variables describing confinement conditions (IAC). For example, the I EEMs provide emissions estimates based on input data that characterize the bird population in the house (e.g., total bird inventory in the house and their average weight). These data are recorded routinely by growers and would not require additional data collection systems. For the IA EEMs, the input data include the bird inventory, average bird weight and ambient meteorological conditions (e.g., ambient temperature and relative humidity). Under the NAEMS, the ambient data were collected by a monitoring system installed at the participating farm. To apply the EEMs, ambient data gathered by other sources (e.g., National Weather Service stations) that are representative of the applicable site can be used if site-specific data are not available. For the IAC EEMs, the input data include the data used for the I and IA EEMs and data for confinement conditions (e.g., house temperature and relative humidity) that were collected for the NAEMS by a monitoring system installed in each house.

In previous sections, the terms "parameter" and "estimate" were used to describe the data and data collection methods used in the NAEMS. In this section, these terms are used in their formal statistical context. The term "parameter" refers to unknown constants (regression coefficients, the variance, and the auto-correlation coefficient, described below) whose values give the EEMs their shape. The EEM equations given in this section use Greek letters to represent parameters. The term "estimate" refers to the best approximation of a parameter value determined by fitting the EEM to the NAEMS data. The term "predict" refers to obtaining a value of emissions using the EEM, including the use of predictor variables and estimated parameters.

Each EEM produces a point prediction and a 95 percent prediction interval for pollutant emissions. A point prediction is a single value of emissions produced by the mean trend function (described below) for a given set of values of the predictor variables. A 95 percent prediction interval consists of two numbers, a lower and upper bound, on each side of the point prediction that quantify uncertainty about the point prediction due to natural variability in emissions and due to having estimated parameter values using data based on four broiler houses, which were selected under the NAEMS to represent all broiler houses in the United States.

Development of the EEMs followed the protocol outlined in Figure 7-1, in which the six phases parallel the structure of Sections 7.1 through 7.6. Phase 1 is the selection of the datasets to be used in EEM development. Part of this selection is based on the predictor variables that were monitored in the NAEMS as well as other important factors that affect emissions such as litter condition. The second part of dataset selection was based on additional analyses of data completeness.

Phases 2 through 6 involve the development and validation of the mathematical form of the EEM. Each EEM has three components: the probability distribution, the mean trend function, and the covariance function. Equation 7-1 provides the general form of each EEM, an explanation of which is given in the following paragraphs. Table 7-1 summarizes the symbols and terms used in the equation.

$$Y_{ht} = \beta_0 + \beta_1 x_{1ht} + \cdots + \beta_p x_{pht} + \cdots + \beta_P x_{Pht} + e_{ht}\,,\ h = 1, \ldots, 4,\ t \text{ varies}$$

$$\boldsymbol{e_{ht}} \sim \boldsymbol{N}\{\mathbf{0}, \boldsymbol{\sigma}^2\}, \boldsymbol{Cov}\left(\boldsymbol{e_{ht}}, \boldsymbol{e_{h't'}}\right) = \begin{cases} \mathbf{0} & \boldsymbol{h \neq h'} \\ \boldsymbol{\sigma^2 \rho^{|t-t'|}} & \boldsymbol{h = h'} \end{cases};\ \sigma > \mathbf{0}, \mathbf{0} < \boldsymbol{\rho} < 1 \qquad \text{Equation 7-1}$$

Table 7-1. Summary of Symbols and Terms Used in Equation 7-1

Description	Symbol
Index for houses	h
Index for dates	t
Mass of pollutant emitted from house h on date t	Y_{ht}
Index for regression coefficients, mean trend variables, and mean trend terms	p
Number of mean trend variables, number of regression coefficients, number of mean terms minus one (the intercept is also a mean term)	P
Value of mean trend variable p for house h on date t	x_{pht}
Regression coefficients	$\beta_p,\ p = 1, \ldots, P'$
Intercept	β_0
Mean trend terms	β_0 and $\beta_p x_{pht}$, $p = 1, \ldots, P$
Mean trend function	$\beta_0 + \beta_1 x_{1ht} + \cdots + \beta_p x_{pht} + \cdots + \beta_P x_{Pht}$
Deviation of emissions from house h on date t from the value given by the mean trend function	e_{ht}
Notation indicating that the random variables e_{ht} are normally distributed with mean 0 and variance σ^2	$e_{ht} \sim N(0, \sigma^2)$

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Table 7-1. Summary of Symbols and Terms Used in Equation 7-1

Description	Symbol
Notation indicating the serial correlation between emissions observed day-to-day	$Cov(e_{ht}, e_{h't'})$
Variance of the random deviations e_{ht} (a measure of both natural variability and uncertainty)	σ^2
The correlation between two deviations from the same house, separated by one day	ρ

In the first line of Equation 7-1, Y_{ht} represents pollutant emissions from house *h* on date *t*, where the index *h* takes values 1 through 4, corresponding to monitored houses CA1B H10, CA1B H12, KY1B-1 H5 and KY1B-2 H3, respectively. Values of *t* are nested within values of *h*, so that dates for different houses can be the same or different. The values that *t* takes for each house over the grow-out periods are given in Section 5.3.1. Due to missing data, the dates were not always consecutive.

The expression $\beta_0 + \beta_1 x_{1ht} + \cdots + \beta_p x_{pht} + \cdots + \beta_P x_{Pht}$ is the "mean trend function," and it describes the relationship between the predictor variables and the expected value of pollutant emissions. In the mean trend function, x_{pht} represents the value of the p^{th} mean trend variable for house *h* on date *t*, the symbol β_p denotes the regression coefficient for that variable and the symbol β_0 represents the intercept. The mean trend variables differ from the predictor variables in that they represent the functional form through which the predictor variables enter the mean trend function. This distinction will be discussed in detail in Section 7.3. Lower-case *p* is an index for regression coefficients β_p, mean trend variables x_{pht}, and their products, the non-intercept mean trend terms $\beta_p x_{pht}$. The index *p* takes values $1,\cdots, P$, so that upper-case *P* is the number of non-intercept mean trend terms.

In the second line of Equation 7-1, the symbol e_{ht} represents the deviation of emissions from house *h* on date *t* from the value given by the mean trend function. Because the e_{ht} are random variables, full EEM specification requires selecting a probability distribution and an appropriate covariance function for them. The notation $e_{ht} \sim N(0,\sigma^2)$ translated, says that the random variables e_{ht} are normally distributed with mean 0 and variance σ^2. The expression for the covariance, $Cov(e_{ht}, e_{h't'})$, describes the serial correlation between emissions observed day-to-day. Because the e_{ht} are random variables, and because the Y_{ht} are functions of them, the Y_{ht} are also random variables. Although the values of the mean trend variables x_{pht} differ for different values of *h* and *t*, for one specific combination of values of *h* and *t*, they are fixed (not random), known quantities. All of the parameters in the EEM (the intercept, β_0; the regression coefficients, β_p; the variance, σ^2; and the auto-correlation coefficient, ρ) were estimated based on the NAEMS data. The estimates of the parameters are written with "hats" on top of them (e.g., $\widehat{\beta_0}$).

The choice of probability distribution, the variables included in the mean trend function, and the form of the covariance function were all based on analyses of a subset of the NAEMS data called the “base” dataset, validated using another subset of the NAEMS data called the “cross-validation” dataset, and then modified and re-validated when necessary. After the final mathematical forms were chosen, the EPA re-estimated the parameters using the “full” dataset (i.e., the combined base and cross-validation datasets).

The following sections describe this process in detail. Section 7.1 describes selection of the full, base, and cross-validation datasets based on data completeness. Section 7.2 shows why the normal distribution was selected as the probability distribution. Section 7.3 details development of candidate mean trend variables from the predictor variables. Section 7.4 lists components considered for the covariance function and tells why some were included and others not. Section 7.5 describes the process through which final mean trend variables were chosen from the candidates. Section 7.6 describes how the EEMs are used to generate point and interval predictions for a single day and for the sum of days. The EEM development and results for H_2S, PM_{10}, $PM_{2.5}$, TSP and VOCs are explained in Section 8.

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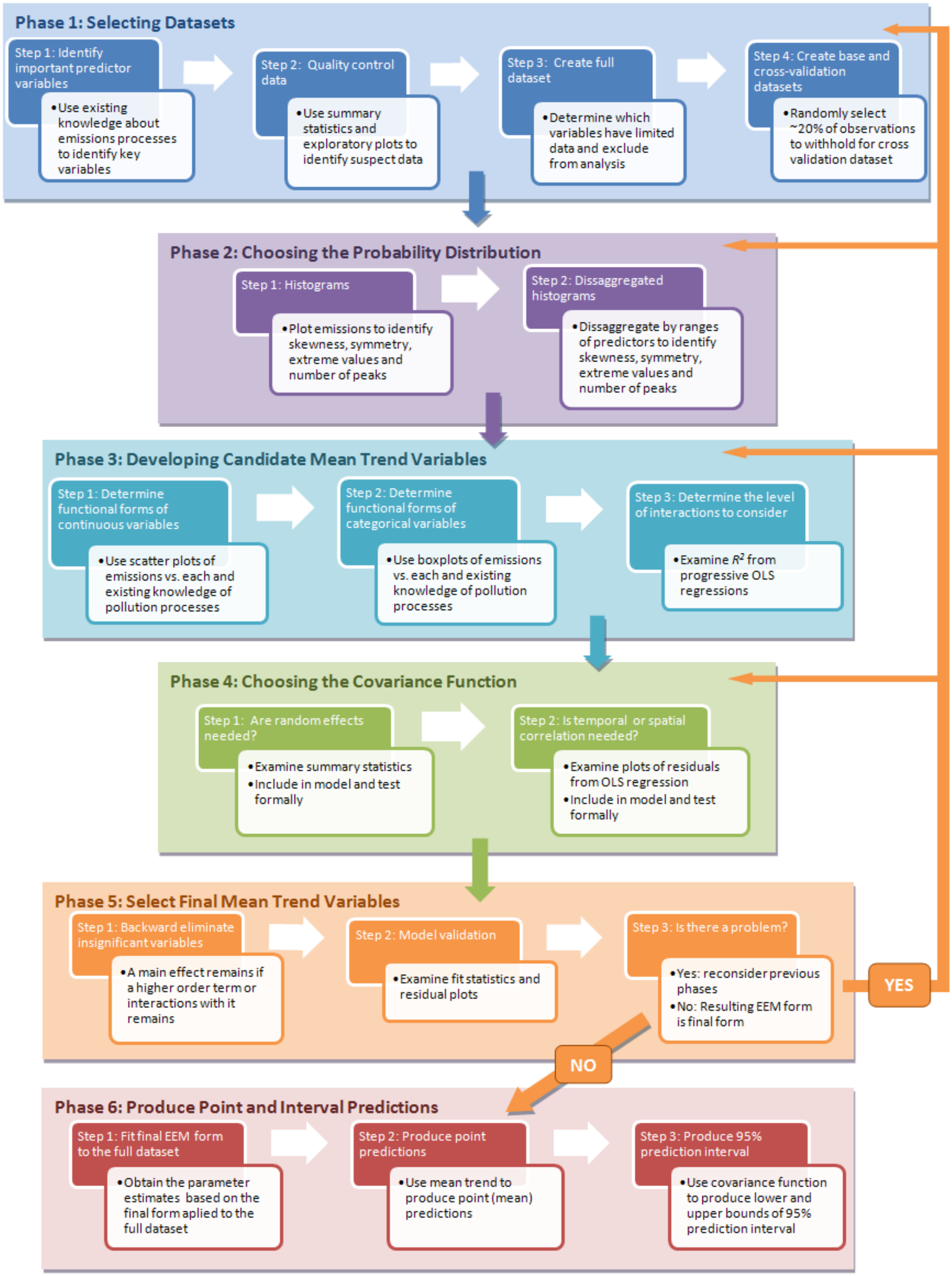

Figure 7-1. General Approach for EEM Development

7.1 Selecting Datasets

The data used to develop the EEMs for NH_3 were collected under the NAEMS from four houses at three sites: CA1B H10; CA1B H12; KY1B-1 H5; and KY1B-2 H3. Table 7-2 lists, for each of the three categories [animal inventory (I), ambient meteorology (A) and confinement conditions (C)], available predictor variables, the definitions and units of measure for each. Although ventilation flow rate and differential static pressure were monitored at each of the houses, they were not considered for use as confinement predictor variables for a variety of reasons. Because pollutant emissions are calculated using flow rate, and flow rate is calculated using differential pressure, the validity of using these as predictor variables is questionable. Additionally, the EPA did not consider ventilation flow rate and differential static pressure as predictor variables because these values are not expected to be readily available. For the NAEMS, differential static pressure ports were installed in the monitored houses and the ventilation flow rate values were calculated using continuous measurements of fan operational status (on/off), differential static pressure and fan-specific performance curves. In some cases, the flow rates of selected fans were directly measured using anemometers. The EPA does not expect that these types of monitoring systems and data will be available at typical broiler operations.

As explained in Section 5, the EPA did not use negative emissions to develop EEMs. Additionally, the EPA identified cases late in the grow-out period where bird inventory values remained constant for several consecutive dates. Figure 7-2 shows the number of birds for each date for the first flock monitored at KY1B-1 H5. The red box on the figure highlights the constant inventory values that were removed from the full dataset. This phenomenon occurred for every flock at sites KY1B-1 and KY1B-2, for 5 out of 14 flocks at CA1B H10, and for two flocks at CA1B H12. The EPA contacted the researchers for the California and Kentucky sites and industry representatives to determine whether the constant bird inventory values were valid. These contacts confirmed that the flat inventory values likely did not reflect the number of birds in the house on those dates. According to these contacts, to avoid stressing the birds in the last days of the grow-out period before harvesting, farm personnel did not enter the houses to count mortalities. In these instances, the personnel entered the same number of birds for several consecutive dates.

Table 7-2. Predictor Variables

Category	Predictor Variable[a]	Definition	Units
I: Inventory	*birds**	Number of birds	Thousands of birds
	*avem**	Average live bird mass	Kilograms (kg)
	*buildup**	Number of flocks since last full litter clean-out in house	Number of flocks
A: Ambient meteorology	*ta**	Temperature outside house	^{o}C
	*ha**	Relative humidity outside house	%
	*pa**	Barometric pressure outside house	kilopascals (kPa)
C: Confinement conditions	*tc**	Temperature inside house	^{o}C
	*hc**	Relative humidity inside house	%

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1).

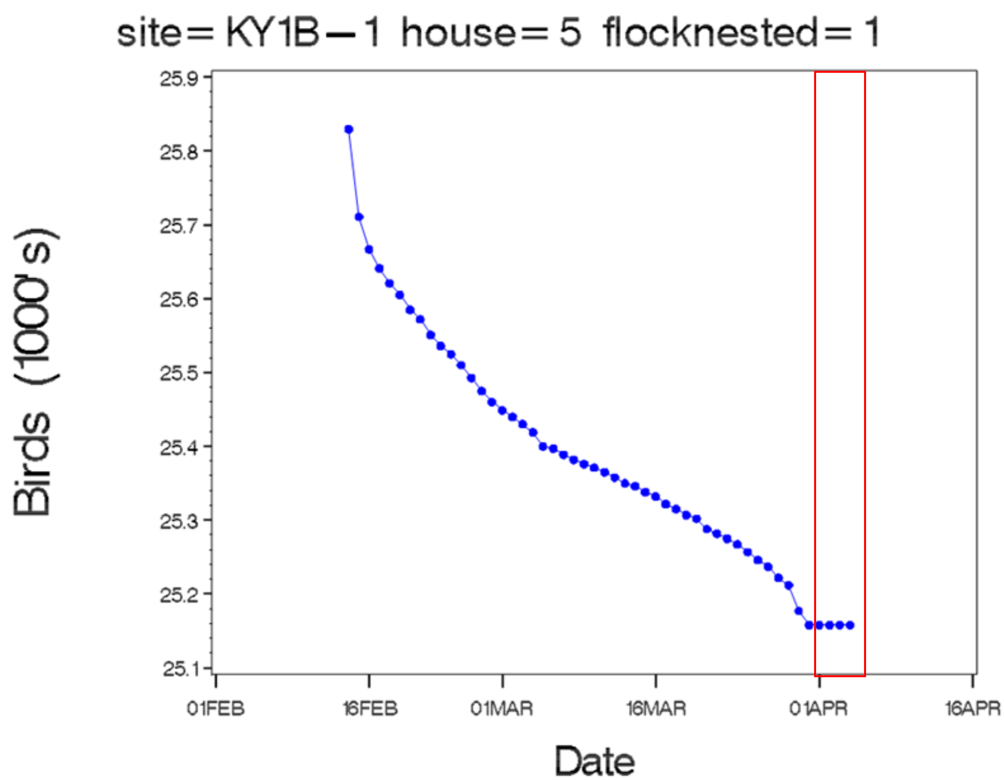

Figure 7-2. Example of Constant Late-Period Bird Inventory

Because it was unclear whether these constant inventory values represented the number of birds in the house on that date, the EPA excluded from the full dataset observations that satisfied the following criteria. If the number of birds in the house on date *t+1* was equal to the number of birds on date *t*, and these dates occurred at the end of the grow-out period, the observation for date *t+1* was excluded. Using this approach, the EPA excluded 44 observations for the grow-out period data for all sites, houses and flocks.

Table 7-3 shows the observations available for each monitoring site after exclusion of negative NH_3 emissions and constant late-period inventory values. For example, the total number of grow-out period observations for site CA1B H10 is 642, the number of days for which the NH_3 emissions value was available is 382, and the percent available is 60 percent. Although sites KY1B-1 and KY1B-2 conducted monitoring for approximately one year while site CA1B monitored for two years, the greater level of data completeness for KY1B-1 and KY1B-2 caused the number of available observations to be on the order of only 100 days fewer for the houses at each of the Kentucky sites than for the two houses at CA1B.

Table 7-3. Data Completeness for NH_3

Season	Description	CA1B		KY1B-1	KY1B-2	All Houses
		House 10	House 12	House 5	House 3	
All	No. of grow-out dates	642	647	288	267	1,844
	No. of NH_3 days available	382	385	280	232	1,279
	Percent complete	60%	60%	97%	87%	69%
Winter	No. of grow-out dates	150	153	87	74	464
	No. of NH_3 dates available	100	105	80	50	335
	Percent complete	66%	69%	92%	68%	72%
Spring	No. of grow-out dates	157	158	83	55	453
	No. of NH_3 dates available	133	134	82	49	398
	Percent complete	85%	85%	99%	89%	88%
Summer	No. of grow-out days	156	157	55	74	442
	No. of NH_3 dates available	109	108	55	70	342
	Percent complete	70%	69%	100%	95%	77%
Fall	No. of grow-out dates	179	179	63	64	485
	No. of NH_3 days available	40	38	63	63	204
	Percent complete	22%	21%	100%	98%	42%

7.1.1 Full dataset

To ensure that the data selected for EEM development were representative of more than one of the monitored sites, the EPA limited the dataset for use in EEM development to those records for which data values were available for all of the inventory, ambient, and confinement predictor variables. To identify this refined dataset, the EPA first evaluated the data records available for the I EEM.

The variables EPA considered for the I EEM were *birds** and *avem**. All of the 1,279 days with NH_3 observations include values for *birds**; however, 32 values for *avem** were missing. Examination of the sites, houses and dates for which *avem** values are missing shows that their absence appeared to be random (i.e., not all missing observations occur when NH_3 emissions are high or low). To confirm that the missing data would not bias the development of EEMs, the EPA compared the distribution of emission on the days with the missing values to the distribution of emissions in the full dataset across the quartiles (i.e., minimum, Q1, Q2, Q3, Q4, and maximum). This five-number summary for NH_3 emissions for the 32 dates missing *avem** is 0.08, 3.2, 9.3, 20 and 36, while the five-number summary over all 1,279 dates is 0.06, 3.3, 9.4, 19 and 36. Because the numbers for each component of the five-number summary are similar in magnitude, the EPA concluded that the distribution of the missing values was random. Excluding the 32 records for which *avem** values are not available results in a total of 1,247 observations for use in developing the I EEM for NH_3.

The ambient variables considered by EPA for the IA EEM were *ta**, *ha** and *pa**. Of the 1,247 observations in the NH_3 dataset, the number of missing values for each of the ambient variables is, respectively, 23, 23 and 9. Not all of the missing data occurred on the same days, thus there was a total of 36 missing observations. Excluding these values leaves 1,211 observations for the NH_3 dataset. Although wind speed, wind direction, and solar radiation were recorded at site CA1B, these data were not recorded at sites KY1B-1 and KY1B-2. Consequently, the EPA excluded these data from consideration. Confinement variables considered were *tc** and *hc**. Of the 1,247 observations for which none of the NH_3 emissions or the inventory variables are missing, the number of missing values for *tc** and *hc** are 0 and 5, respectively. The five observations missing for *hc** correspond to missing observations of other variables. Therefore, the EPA chose the data subset containing the 1,211observations for which none of the variables *ta**, *ha**, *pa**, *tc** or *hc** are missing. Hereafter, the EPA refers to this dataset as the “full” dataset.

7.1.2 Base and Cross-Validation Datasets

As one means of evaluating EEM performance, the EPA randomly selected 217 (approximately 20 percent) of the 1,211 observations in the full dataset to withhold as the “cross-validation" dataset. The remaining 994 observations are referred to as the "base" dataset. The EPA made decisions regarding the probability distribution, candidate mean trend variables and the covariance function using the base dataset for exploratory analyses, initial parameter estimation and tests of the significance of covariance parameters.

To select the final mean trend variables, the EPA primarily used p-values calculated on the base dataset to determine whether to keep or eliminate terms in a backward-elimination process. At each step in the backward-elimination process, however, the EPA also compared emissions predicted by the EEM to measured emissions contained in the cross-validation dataset. This practice, described in more detail in Section 7.5.1, ensured that the statistical significance of the estimated regression coefficients captured trends that applied generally, rather than over-fitting the data.

Analysis of cross-validation fit statistics and plots of cross-validation residuals also helped to validate the overall mathematical form of the EEM. The EPA performed multiple iterations of making EEM decisions in Phases 1 through 5, validating the resulting EEMs, modifying decisions, and re-validating. One of the decisions the EPA modified was the means of choosing the cross-validation dataset.

Initially, the EPA constructed the cross-validation dataset by withholding data for entire flocks. Of the 40 flocks in the NAEMS data, the EPA withheld data for six flocks that were chosen so that both the base and cross-validation datasets contained flocks from each season-site combination. A validation analysis later showed that the initial selection of cross-validation dataset resulted in disproportionate representation of different values of *buildup* in the two datasets. *Buildup* was not initially included as a predictor variable, and this same validation analysis led to an investigation of the data that revealed its importance.

The EPA attempted to modify selection of the cross-validation flocks to evenly represent site-season-*buildup* combinations in both the base and cross-validation datasets. However, due to the patterns of missing data, it was not possible to choose entire flocks in this manner without over-representing the Kentucky sites in the cross-validation dataset. On a flock-by-flock basis, the Kentucky flocks had fewer missing values than the flocks at site CA1B.

The EPA therefore chose to randomly select observations to withhold as the cross-validation dataset. To ensure that disproportionate representation of one or more sets of conditions in the cross-validation and base datasets chosen in this manner would not affect results, the EPA created two additional cross-validation datasets with corresponding base datasets and checked the results for the two additional cross-validation datasets for gross aberrations.

7.2 Choosing the Probability Distribution

Identifying the appropriate probability distribution ensures the validity of the p-values that are used to determine the statistical significance of regression coefficient estimates. The appropriate probability distribution is also needed to produce prediction intervals that quantify the uncertainty regarding the point predictions of NH_3 emissions. Many physical phenomena are normally distributed under a fixed set of conditions, and the point predictions and 95 percent prediction intervals generated from the normal distribution are easy for the EEM user to implement and interpret. Therefore, the normal distribution is commonly used unless there is substantial evidence that another distribution is more appropriate.

The EPA plotted the empirical distribution (i.e., histogram) of observed NH_3 emissions to determine whether use of the normal distribution could be justified. Figure 7-3 shows that there are many NH_3 observations at lower values, with a single peak around 2.5 kg, and the number of observations decreases as emissions increase. In statistical jargon, the empirical distribution is unimodal and skew right. This observation might at first seem to provide evidence against using the symmetric and bell-shaped normal distribution, but the second line of Equation 7-1 does not say that NH_3 emissions under all conditions have the same distribution. Instead, the equation says that the distribution of the deviations from the mean trend function, e_{ht}, are normally distributed. In other words, if the number of birds was 20,000 and the temperature was 20^o C, NH_3 emissions would have a symmetric and bell-shaped normal distribution centered at the value given by the mean trend function. For a different number of birds and temperature, the bell-shaped curve would be centered in a different location.

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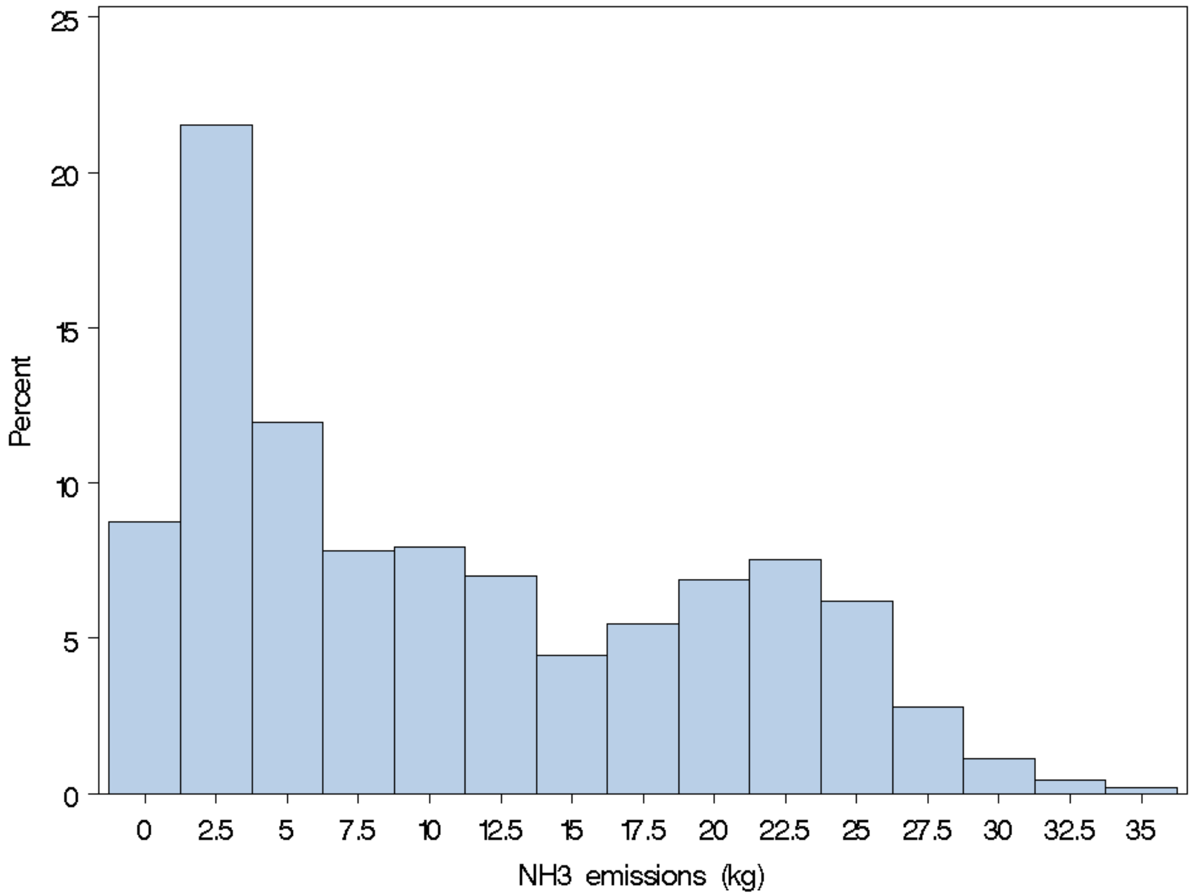

Figure 7-3. Histogram of NH_3 Emissions in the Base Dataset

Because aggregating all conditions into a single histogram masks differences in the distribution for different sets of conditions, the EPA separated the base dataset into bins according to values of average bird mass. Bin 1 contains the observations for which average bird mass takes values (in kg) 0.0 to 0.5; bin 2, 0.5 to 1.0; bin 3, 1.0 to 1.5; bin 4, 1.5 to 2.0; bin 5, 2.0 to 2.5; and bin 6, 2.5 to 3.0. The disaggregated histograms given in Figure 7-4 show that the NH_3 distribution for bins 1 and 2 are skew right, those for bins 3 and 5 are symmetric, and those for bins 4 and 6 are skew left. Further disaggregation according to the values of other variables shows a variety of empirical distributions for different sets of conditions, and the skew-right pattern is by no means ubiquitous. There are not enough observations under any specific set of conditions to use the empirical distribution to determine the true distribution. Therefore, in the absence of strong evidence against doing so, the EPA used the normal distribution.

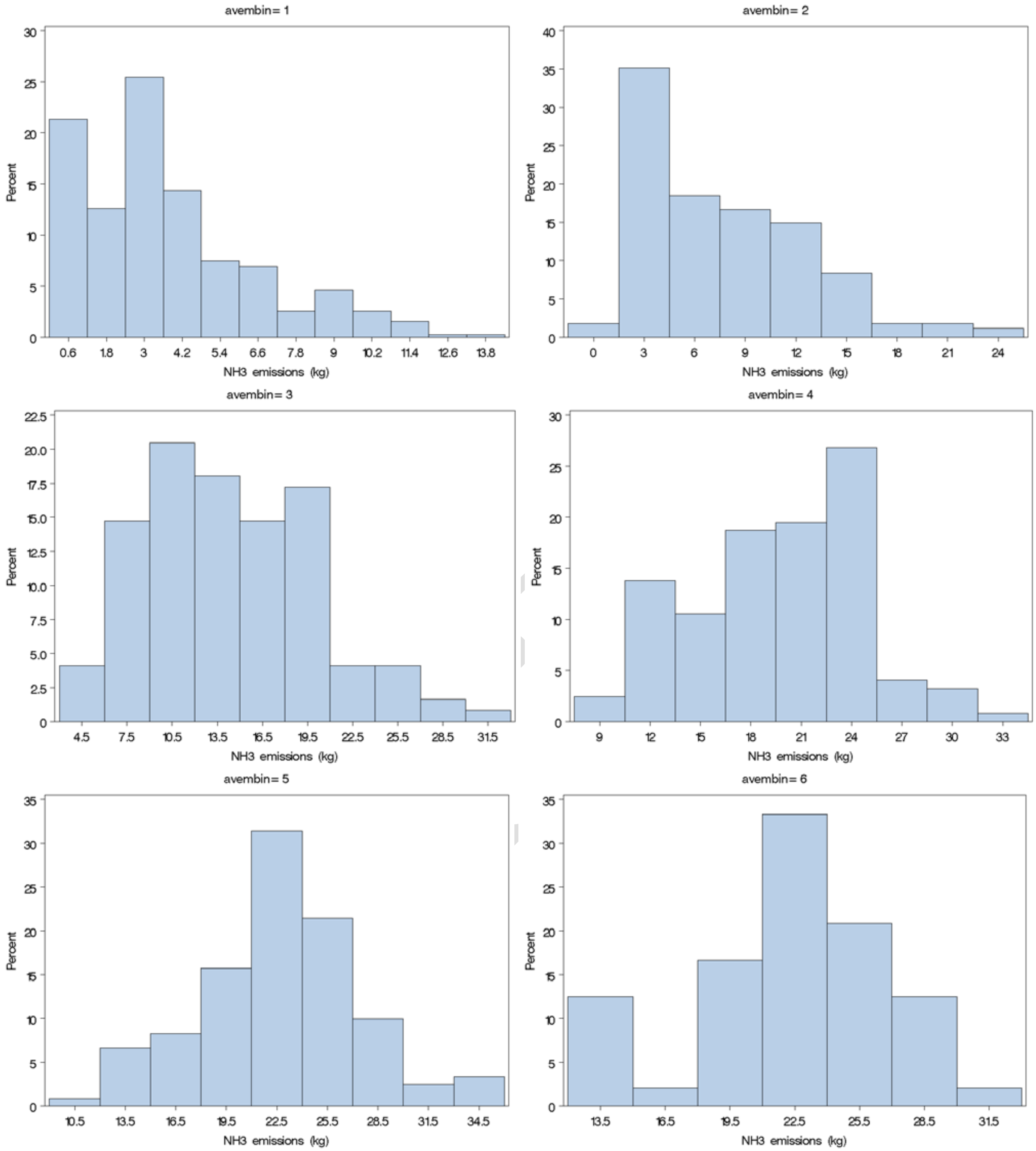

Figure 7-4. Histograms by *avem* Bins

7.3 Developing Candidate Mean Trend Variables

Development of candidate mean trend variables requires first choosing the appropriate functional form to describe the dependence of pollutant emissions on each predictor variable. Section 7.3.1 describes how one or more main effect mean trend variables were created as functions of the predictor variables. Section 7.3.2 explains the importance of including interactions between main effect mean trend variables, and shows how the EPA determined what level of interactions to include as candidate mean trend variables.

7.3.1 Choosing Predictor Variable Functional Forms

The EPA used a variety of exploratory plots, existing knowledge of the chemistry through which NH_3 emissions are formed in a broiler confinement house, and results from other studies to discover functional forms describing the relationship between NH_3 emissions and the predictor variables listed in Table 7-2. For continuous predictor variables, EPA prepared scatter plots of emissions versus the variable to determine if a relationship exists. If emissions increase (or decrease) as the predictor variable increases, and the rate of increase (or decrease) does not change, then a linear function of the predictor variable is appropriate. If emissions increase (or decrease) as the predictor variable increases, but the slope changes, a variety of functions could be considered, one of which is the exponential function. If emissions increase and then decrease (or decrease and then increase), this single change in direction of the relationship could be represented with a quadratic function. If there were two changes of direction (e.g., if emissions decrease, increase, then decrease or vice versa), a cubic polynomial would be appropriate. For discrete variables such as *buildup,* the decision is whether to allow each value of the variable (e.g., 0, 1, 2, 3, 4 and 5) to have a different effect on emissions, or whether to consolidate some of the values into a smaller number of categories.

Figure 7-5 displays a scatter plot of NH_3 emissions versus average live bird mass aggregated over all sites. The figure shows that, for values of $avem^*$ near 0, emissions range from 0 to approximately 15 kg, forming a "tail" on the leftmost side of the graph. The high variability in values decreases before average live bird mass reaches 0.125 kg. The plot slopes upward, with increasing steepness, until approximately 1.5 kg, when the steepness declines.

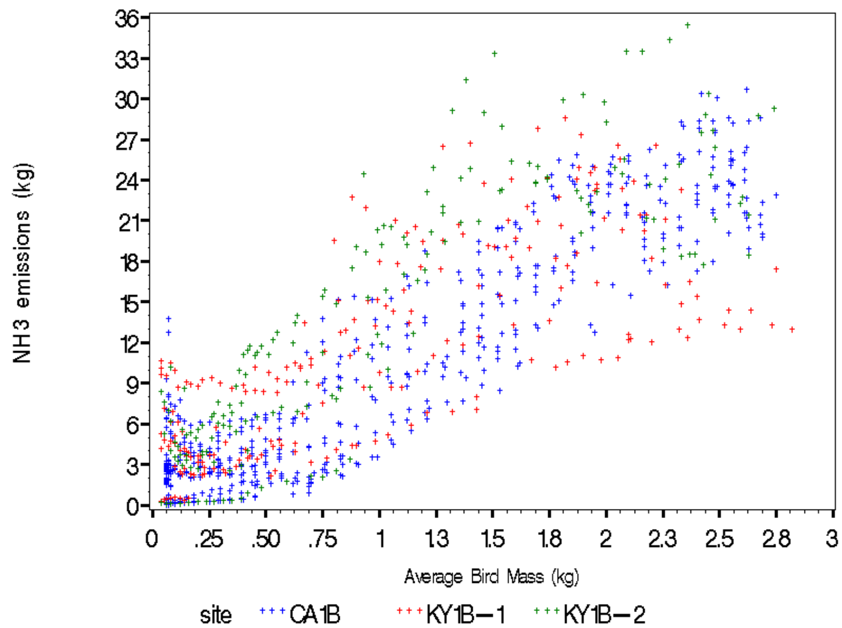

Figure 7-5. NH_3 Emissions vs. Average Live Bird Mass

To further investigate the relationship between NH_3 emissions and *avem**, the EPA created the variable *buildup* to represent the number of flocks introduced into a house since the last full litter clean-out. Although *buildup* takes values 0 through 5, values of 4 and 5 occurred only for site KY1B-2 H3. Site KY1B-1 H5 had a maximum *buildup* value of 3, and the CA1B houses had maximum *buildup* values of 2.

Figure 7-6 shows plots of NH_3 emissions disaggregated by house and with the value of *buildup* as the plot symbol. The curves with red zeros show that the flocks for which *buildup* = 0 have NH_3 emissions near 0 when *avem** is near 0. When the value of *buildup* is greater than zero, NH_3 values have greater variability, and the center of the distribution is greater than zero.

To determine how best to use the number of flocks since a full litter clean-out in the mean trend function, the EPA created two additional candidate mean trend variables: *build* and *bld*. The indicator variable *build* is defined as 0 when *buildup* is 0, and 1 otherwise. The categorical variable *bld,* takes the value 0 when *buildup* is zero, 1 when *buildup* is 1, 2 when *buildup* is 2, and 3 when *buildup* is greater than or equal to 3.

Table 7-4 summarizes the three variables that the EPA created to investigate the relationship between NH_3 emissions and the number of flocks since a full litter clean-out.

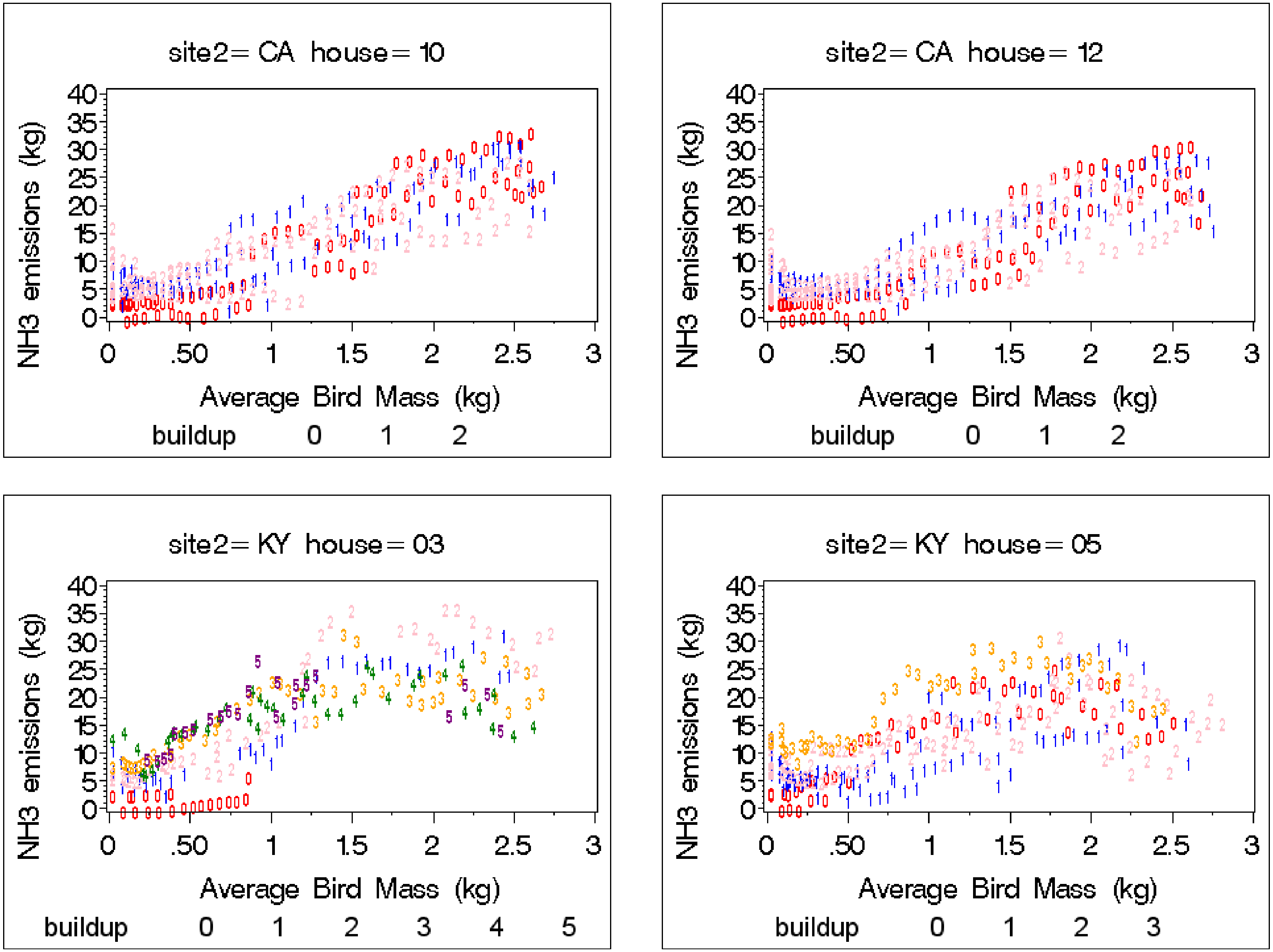

Figure 7-6. Overlay of *buildup* on NH_3 Emissions vs. Average Live Bird Mass

Table 7-4. Potential Mean Trend Variables to Account for Built-up Litter

Variable	Definition
buildup	No. of flocks introduced since last full litter clean-out: $0 \leq buildup \leq 5$
bld	0 if *buildup* = 0 1 if *buildup* = 1 2 if *buildup* = 2 3 if *buildup* $\geq$3
build	0 if *buildup* = 0 1 otherwise

Figure 7-7 shows three sets of box plots with NH_3 emissions on the vertical axis, and each of the three built-up litter variables on the horizontal axes. The edges of the boxes represent the first and third quartiles (25th and 75th percentiles) of the distribution of emissions for the value of the variable on the horizontal axis. The line in the middle of the box represents the median or 50th percentile. The “whiskers” extending above and below the box extend to the maximum or minimum value of NH_3 emissions, unless there are outliers, which are indicated with dots beyond the edges of the whiskers. An outlier is defined as a value that falls below (or above) the first (or third) quartile by more than 1.5 multiplied by the difference between the third and first quartile. Outliers were analyzed by the NAEMS Science Advisor and were determined to be valid emission values. As such, these values remained in the dataset for EEM development.

In the first set of box plots, when *buildup* = 0, the minimum and first quartile are indistinguishable, indicating that the first 25 percent of values of NH_3 emissions are near 0. Although the box covers all values of NH_3 emissions when *buildup* = 0, the values from the minimum to the first quartile are the values of interest. This range of NH_3 emissions occurs when $avem^*$ is near 0, when much of the NH_3 emissions signal might be attributable to built-up litter. In this same set of box plots, when *buildup* = 1 or 2, the minima and first quartiles are similar to each other and are both higher than the minimum and first quartile when *buildup* = 0. When *buildup* = 3, 4 or 5, the minima and first quartiles are higher again. These last three boxes, however, represent data from the Kentucky sites only, and the total number of observations represented by each box is 95, 42 and 24, respectively, while the number of observations represented by the first three boxes are 266, 383 and 402, respectively. The EPA decided against drawing conclusions regarding the effect of *buildup* from a small number of data points that do not represent all houses.

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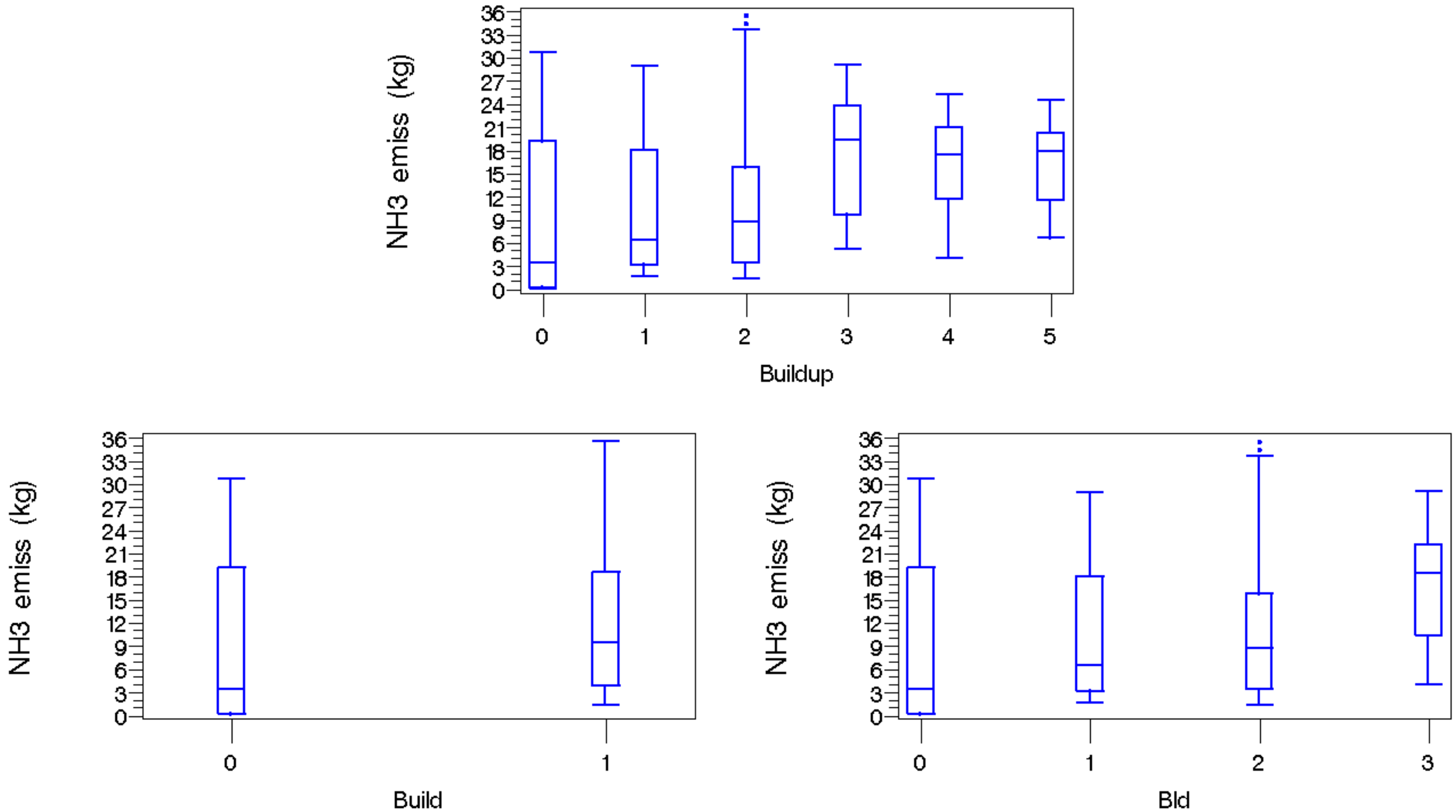

Figure 7-7. Box Plots of NH_3 Emissions vs. Candidate Categorical Variables

In the third set of plots, with *bld* on the horizontal axis, the first three boxes are the same as the first three boxes in the *buildup* plots, and the fourth box, where *bld* = 3, combines the data from the last three boxes in the *buildup* plots. Notice that the minimum and first quartile for *bld* = 3 are both higher than the minima and first quartiles for the other values of *bld*, but, again, all of the data in this box comes from the Kentucky sites. When *bld* = 1 or 2, there is very little difference in the minima or first quartiles, whether due to noise in the data or to an actual lack of signal, so that the EPA saw no use in distinguishing between these two values. The EPA therefore used the variable *build*, which simply indicates presence or absence of built-up litter, as the functional form through which the variable *buildup* enters the mean trend function. The second set of plots show the distinct difference in the minima and first quartiles for the boxes representing *build* = 0 and *build* = 1.

In determining the appropriate functional form through which *avem* enters the mean trend function, the EPA noticed that the slope in Figure 7-5 becomes steeper and then at some point becomes less steep. This change in slope was apparent as a more distinct leveling off or turning down for site KY1B-1 H5 (see Figure 7-6). The EPA further disaggregated the data into plots for individual flocks in Figure 7-8, Figure 7-9 and Figure 7-10. For site CA1B, flocks 1 and 2 were not included in the plots because there were 0 and 2 observations for House 10, and 0 and 3 observations for House 12. These figures show that for all houses, more often than not, NH_3 emissions as a function of *avem** slopes upward with increasing steepness, then the slope begins to decrease, and then the slope either becomes zero or negative. For a few flocks the curve continued to increase, and for a few flocks, missing data prohibited examination of a pattern.

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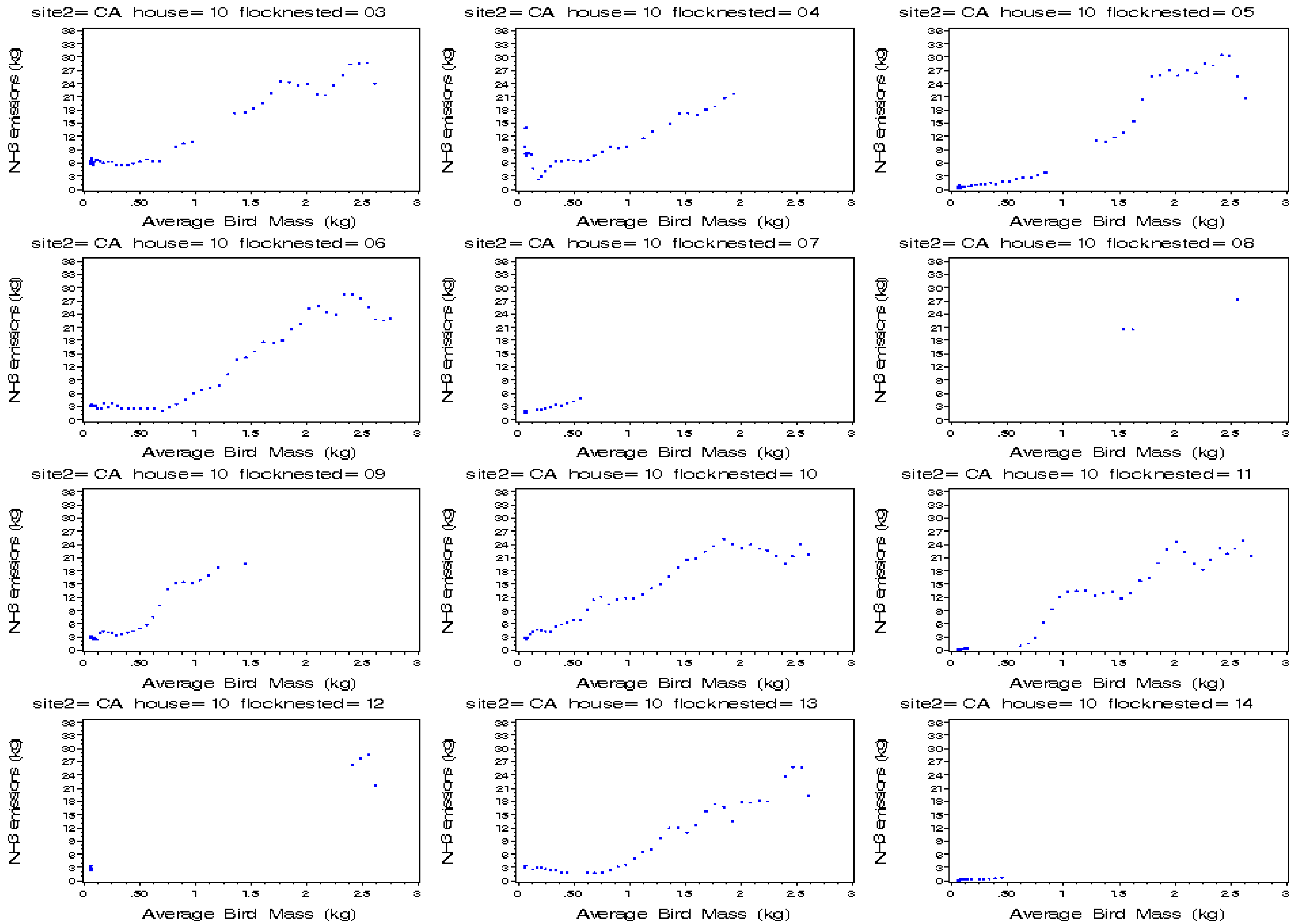


Figure 7-8. NH_3 Emissions vs. *avem* for Individual Flocks at CA1B H10

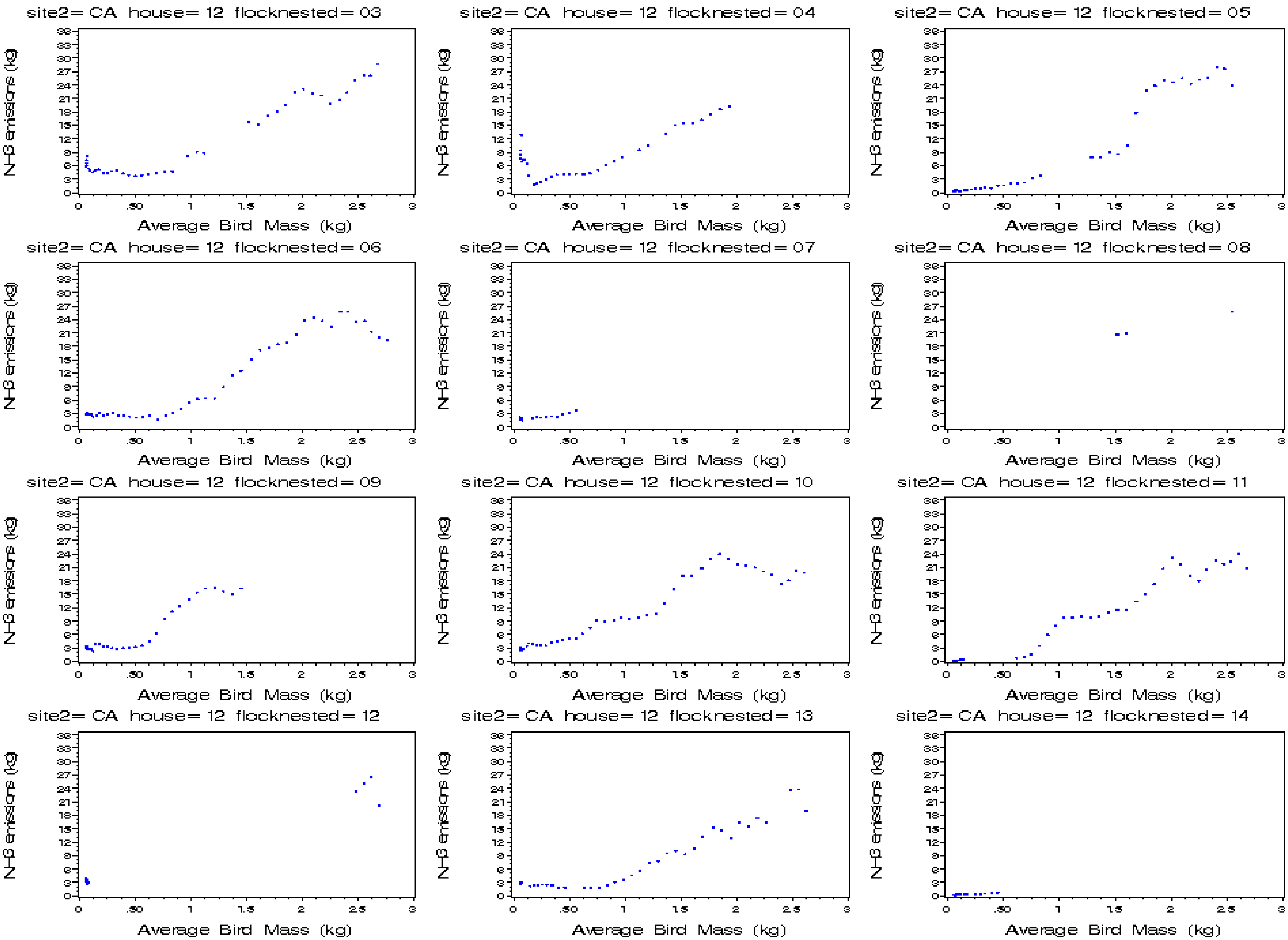


Figure 7-9. NH_3 Emissions vs. *avem* for Individual Flocks at CA1B H12

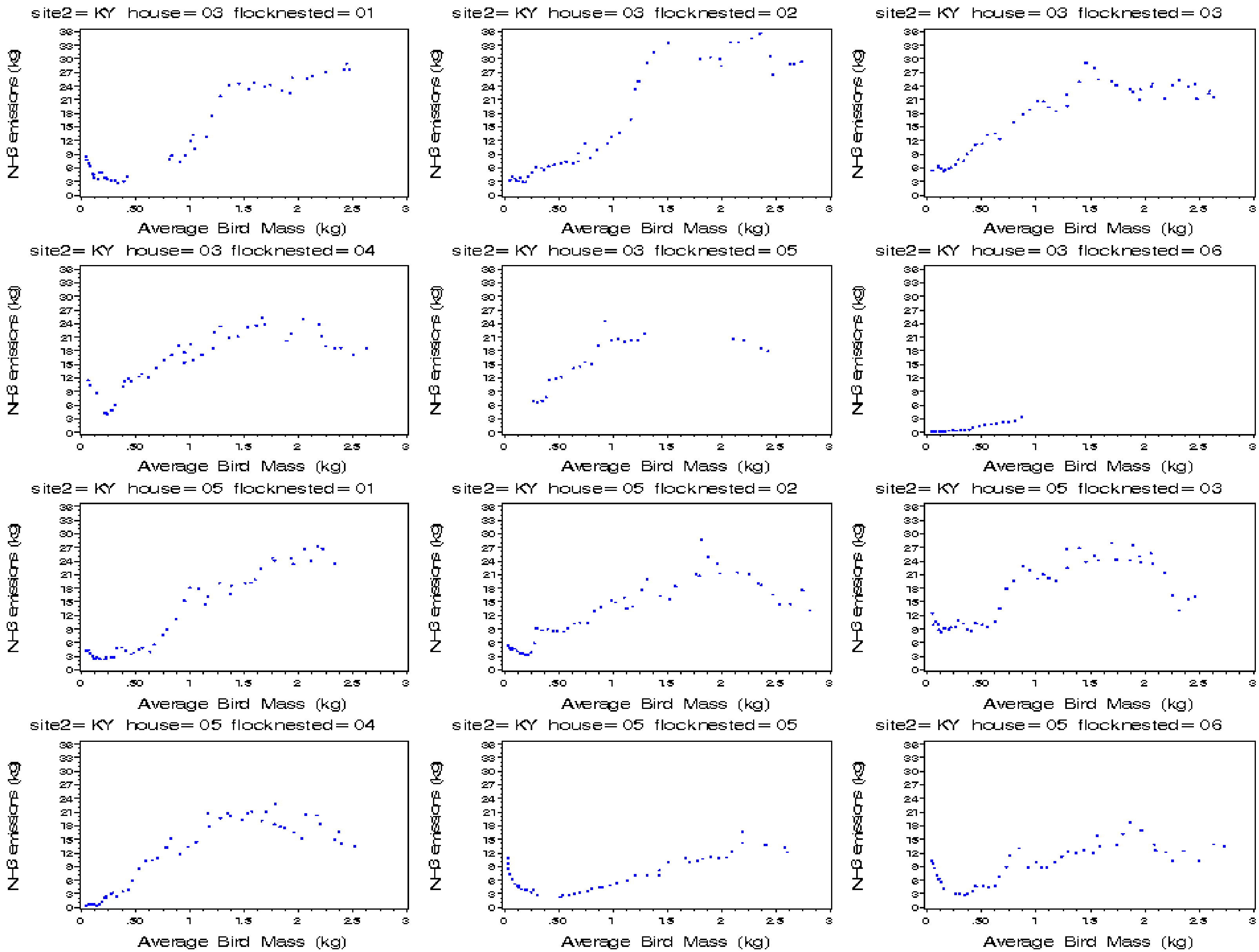
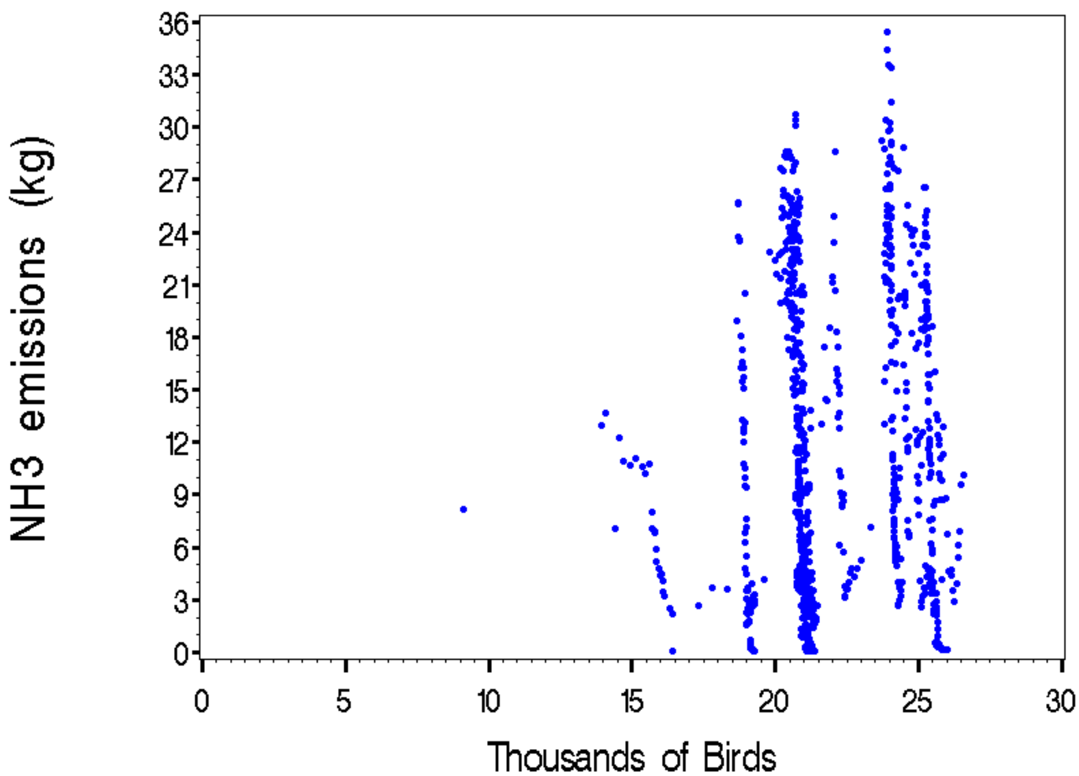


Figure 7-10. NH_3 Emissions vs. *avem* for Individual Flocks at the Kentucky Sites

The decreasing steepness and subsequent leveling-off and/or decrease in slope is apparent in the emissions plots contained in the final report for the Kentucky sites (see Appendix D). In conversations between the EPA, the researchers for the California and Kentucky sites and industry representatives, the hypotheses was raised that the slope may reflect changes in feed protein content that occur at multiple stages of the grow-out period. Protein excreted by the birds is the precursor to NH_3 emissions. As birds grow, metabolic changes lead to decreases in protein uptake. Therefore, it is a common practice in the broiler industry to progressively reduce the proportion of protein in the feed during the grow-out period. Reduced protein in the feed reduces protein excreted, thereby reducing the NH_3 precursor. To account for this curvature, the EPA chose a cubic polynomial to represent the main effect of average live bird mass on NH_3 emissions.

Figure 7-11, Figure 7-12 and Figure 7-13 display scatter plots of NH_3 emissions versus the remaining predictor variables. Intuition suggests that emissions of a pollutant will be greater when the number of birds is greater, if all other variables, especially average live bird mass, were held constant. The plot of NH_3 emissions versus *birds* corroborates this intuition. For example, consider a flock made up of 25,000 birds on the date of introduction into the house. On this date, the number of birds for this flock takes its maximum value, while the average live bird mass takes its minimum value. The total live bird mass, and thus the production of manure, is likely at or near its minimum value for this flock on this date. As each day passes, the bird inventory decreases due to mortality, but the average live bird mass increases, and the mortality rate is low enough that the total live bird mass, and thus the quantity of manure, increases as the grow-out period progresses. Thus, for a given flock, pollutant emissions increase as the number of birds decrease, as manifested by the collection of downward-sloping lines, some of which are indistinguishable from one another, in the scatter plot.

Now consider the difference between hypothetical flocks 1 and 2, with 25,000 and 21,000 birds, respectively, on the date of introduction to the house. Because the bird mortality rate is approximately the same for different flocks, if all other variables are held constant, flock 1 should produce more of the pollutant than flock 2. The tops of the downward sloping lines represent maximum NH_3 emissions for individual flocks, which occur when the number of birds for each flock is at its minimum. Notice that as the number of birds increases, the values of NH_3 emissions at the tops of those lines increase. After the effect of average live bird mass and the interaction between number of birds and average live bird mass were accounted for, the EPA expected the effect of *birds* to be positive. Figure 7-11 does not indicate that the EPA should use a functional form other than linear in the EEM. Thus, the mean trend variable, *birds*, represents the main effect of the predictor variable *birds**.



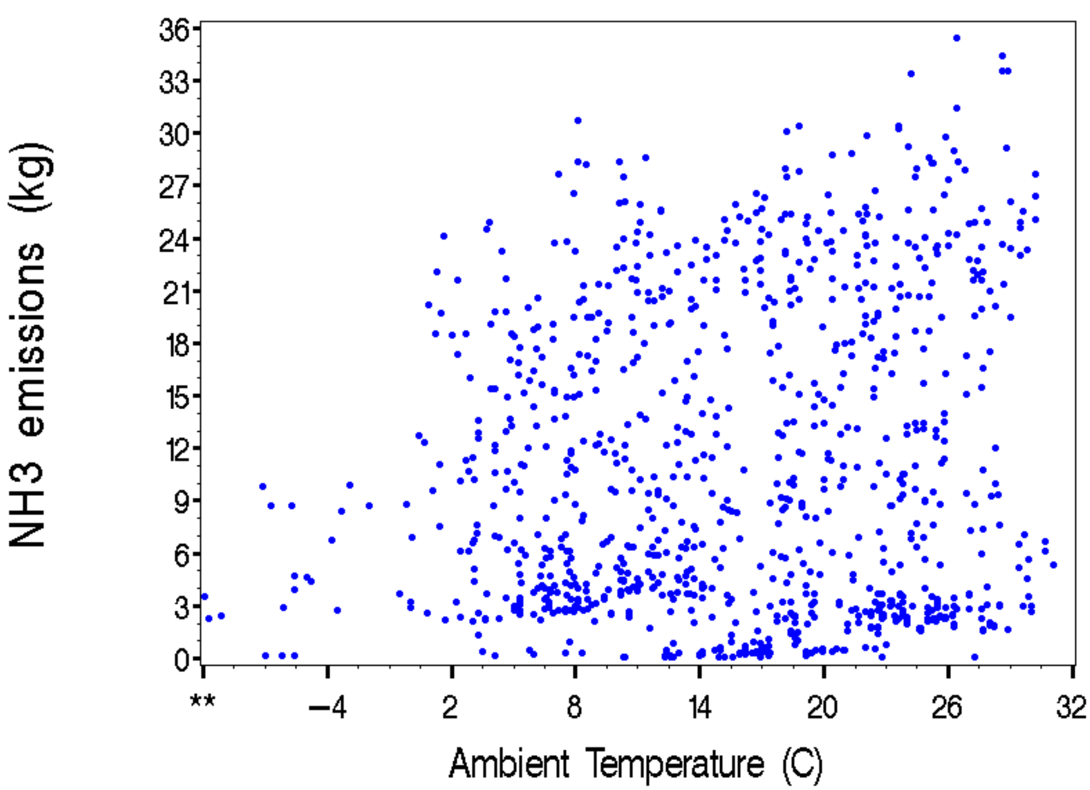


Figure 7-11. NH$_3$ Emissions vs. Predictor Variables *birds and *ta****

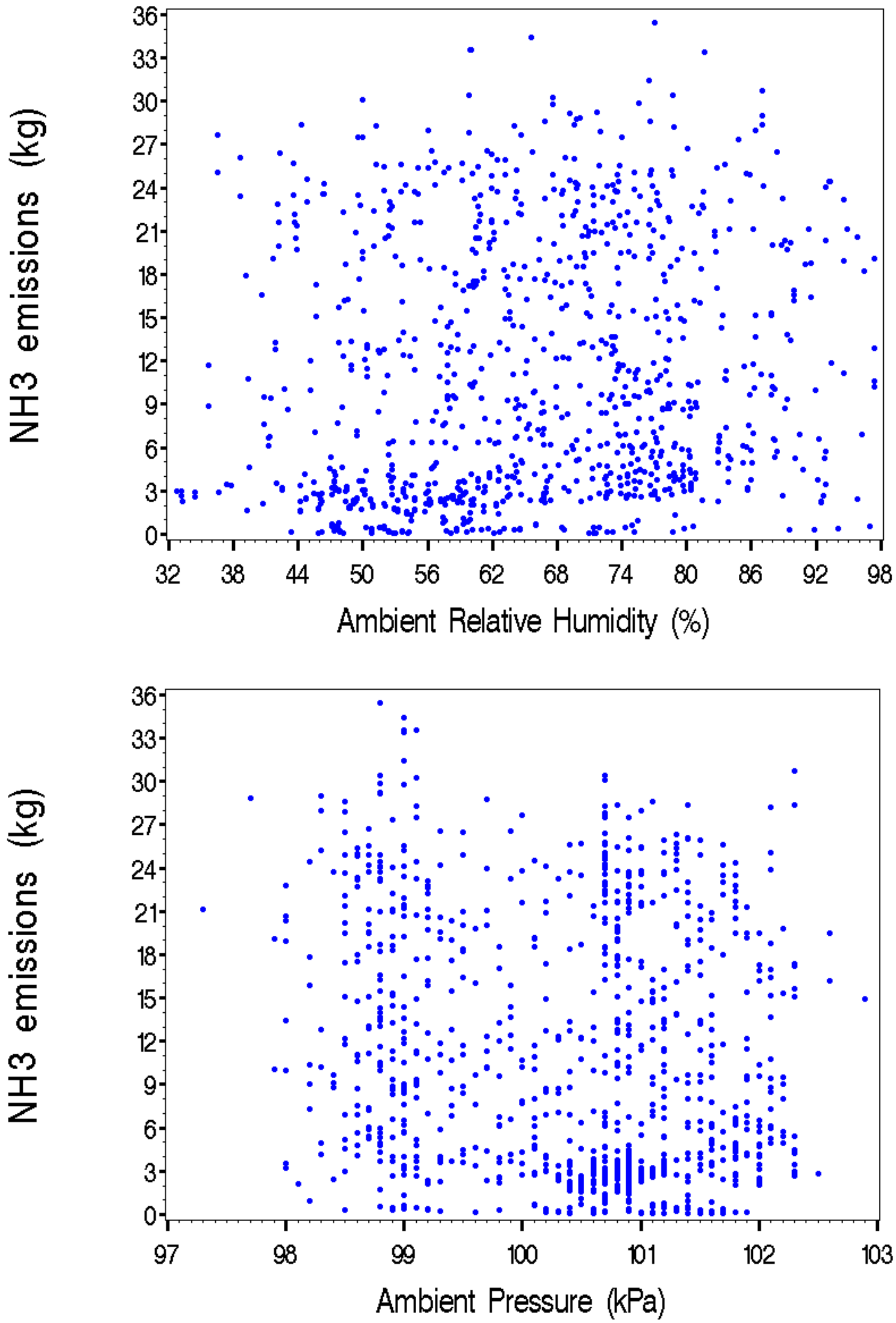


Figure 7-12. NH_3 Emissions vs. Predictor Variables *ha and *pa***

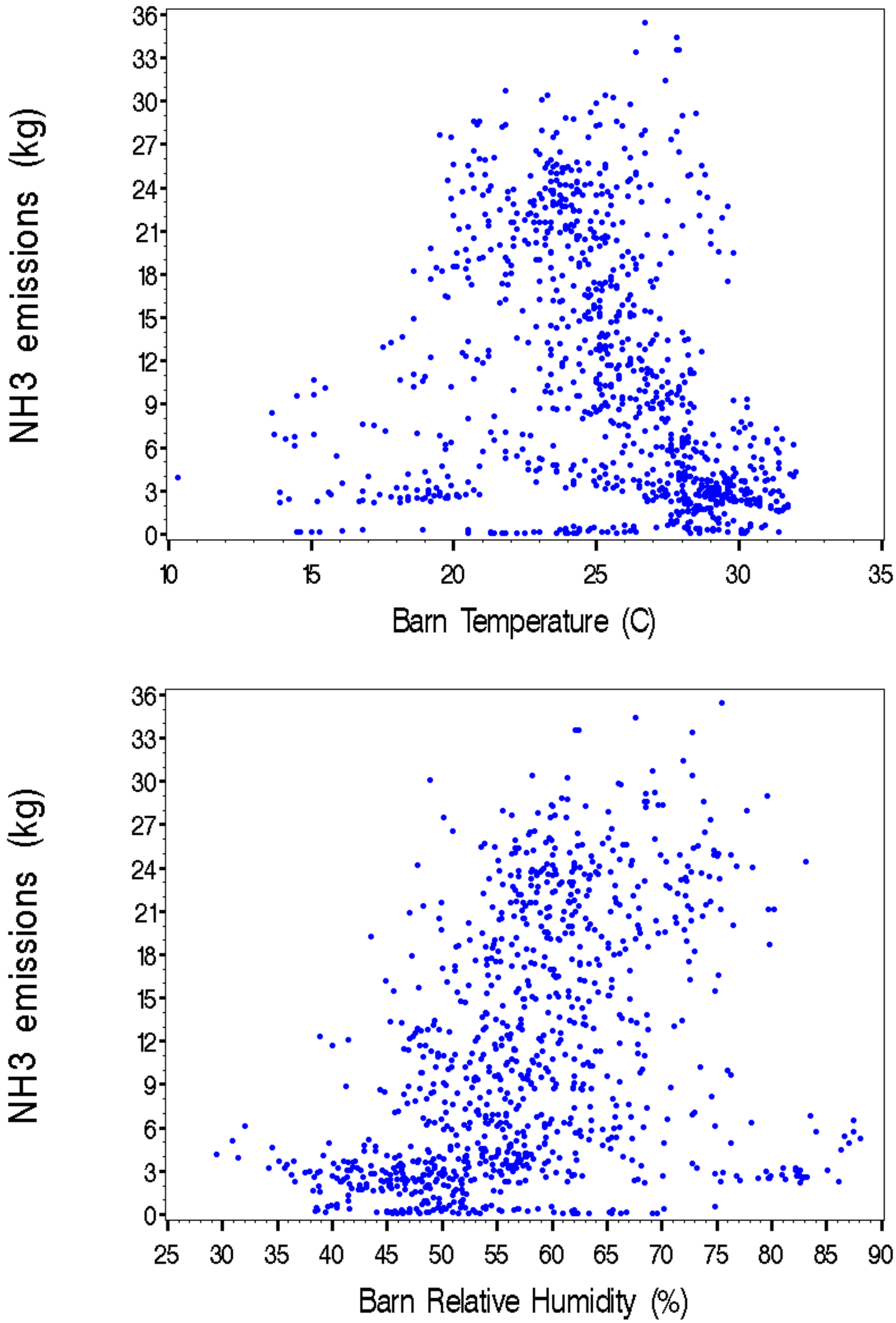


Figure 7-13. NH_3 Emissions vs. Predictor Variables *tc and *hc***

The relationships between NH_3 emissions and each of the ambient meteorological variables were not apparent in the plots of Figure 7-11 and Figure 7-12, nor were the relationships between NH_3 emissions and the confinement variables apparent in Figure 7-13. Such relationships are often hidden in plots aggregated over many different sets of conditions. Consequently, the EPA plotted NH_3 emissions versus each variable separately for the six $avem^*$ bins.

Figure 7-14 displays example plots of NH_3 emissions versus ha^*. Excluding bin 1, which has added variability due to differences in *buildup*, when enough data are available within a bin, the EPA detected a slight increasing trend. For each of these variables, the EPA chose a linear functional form, in the absence of a clear signal or a process-based reason to do otherwise.

Table 7-5 summarizes the functional form chosen by EPA to describe the dependence of NH_3 emissions on the original predictor variables. The first column gives the original predictor variable, and the second states the functional form chosen. The last column gives the mean trend variable or variables that represented the main effect of each predictor variable. For the discrete predictor variable *buildup*, the indicator variable *build* will be the mean trend variable.

Table 7-5. Summary of Main Effect Mean Trend Variables

Original Predictor Variable[a]	Functional Form Chosen	Centering Value	Scaling Value	Main Effect Mean Trend Variable(s)
*buildup**	Indicator variable	Not applicable	Not applicable	*build*
*birds**	Linear	22	2.5	*birds*
*avem**	Cubic polynomial	1.1	0.87	$avem$, $avem^2$, $avem^3$
*ta**	Linear	15	8.2	*ta*
*ha**	Linear	66	14	*ha*
*pa**	Linear	100	1.1	*pa*
*tc**	Linear	25	3.8	*tc*
*hc**	Linear	58	9.9	*hc*

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before centering and scaling (see Section 7.3.1).

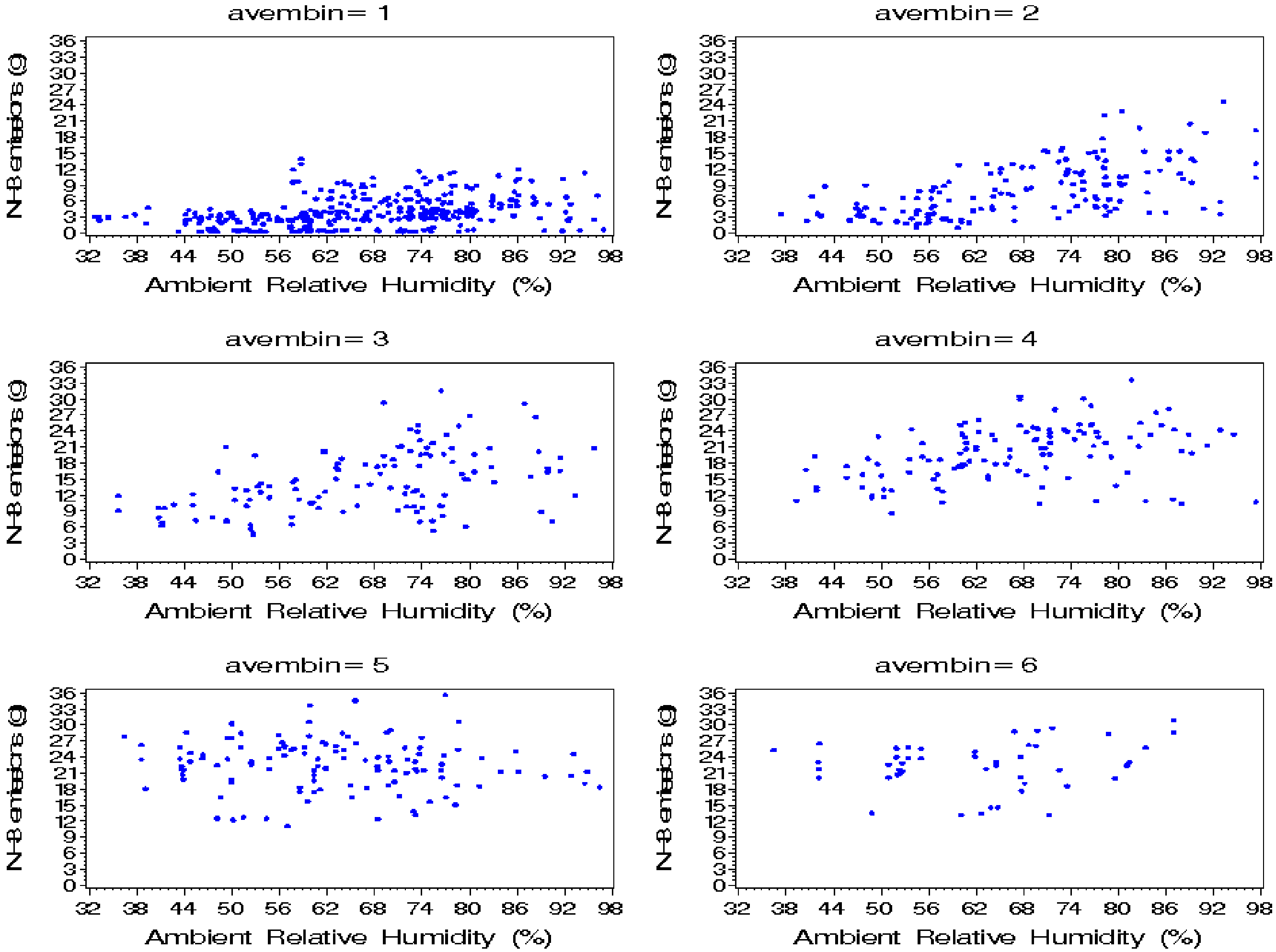


Figure 7-14. NH_3 Emissions vs. *ha for Six *avem* Bins**

All of the other predictor variables were continuous variables. Following standard statistical practice, the EPA transformed each predictor variable in Table 7-5 by subtracting the mean value of the original predictor variable and then dividing by the standard deviation. This practice is called centering and scaling the continuous predictor variables. For example, the mean value of *birds** in the base dataset, rounded to two significant digits, was 22, and the standard deviation was 2.5 (the unit of measure was thousands of birds.) The EPA created the new variable *birds* = (*birds** - 22)/2.5, and because the functional form chosen for birds is linear, the new variable *birds* is the mean trend variable that represents the main effect of birds. All of the variables except *avem** followed the same pattern as *birds*, with different centering and scaling values. For *avem**, the new variable *avem* was created by centering and scaling, and then the cubic polynomial functional form chosen for *avem* was represented by the terms *avem*, $avem^2$ and $avem^3$.

The reason for centering and scaling the continuous predictor variables prior to creating mean trend variables from them is to prevent collinearity problems. Collinearity occurs when one mean trend variable is equal to, or very nearly equal to, a linear combination of other mean trend variables. In lay terms, it can be thought of as the condition in which two or more mean trend variables in a multiple regression analysis are highly correlated. Collinearity problems can be produced when mean trend terms are created as the squared or cubed value of a predictor variable that takes primarily positive values. They can also be produced when one mean trend variable that takes primarily positive values is multiplied by another that takes primarily positive values to create an interaction between the two. The predictor variables *avem, ha, pa, tc* and *hc* have positive values for all 1,211 observations in the NAEMS data, but the centered and scaled versions *avem*, ha*, pa*, tc** and *hc** have positive values for half the observations, and negative values for the other half.

The potential negative effect of collinearity is that when it is present, small changes in the data could produce very different regression coefficient estimates, but these changes *do not* produce very different emissions predictions unless the collinearity is quite severe. Because the EPA prevented severe collinearity by centering and scaling the continuous predictor variables, and because the purpose of the EEMs is to produce predictions, collinearity is not a problem for the EEMs developed for broiler houses.

Table 7-5 shows the centering and scaling values used for each continuous predictor variable. The centering value for each variable is the mean value of that variable in the base dataset, and the scaling value is the standard deviation. When using the EEMs, new centering and scaling values are not calculated. The centering and scaling values in Table 7-5 must be used because the EEMs were created using these values.

7.3.2 Creating Mean Trend Variables from Main Effects and Interactions

After identifying functional forms through which each predictor should enter the mean trend function, the EPA created interaction terms and determined what level of interactions (e.g., two-way, three-way) to include in the set of candidate mean trend variables. An interaction between two mean trend variables occurs when the effect, or slope, of a main effect variable is different for different values of another variable.

A two-way interaction is the product of two main effect variables. For the I EEM, the two-way interaction between *build* and *birds* is the product *buildbirds.* The two-way interaction between build and avem consists of the collection of products *buildavem*, $buildavem^2$ and $buildavem^3$, and the 2-way interaction between *birds* and *avem* consists of the collection of products *birdsavem*, $birdsavem^2$ and $birdsavem^3$. A three-way interaction is the product of three main effect variables. The three way interactions for the I EEM included *buildbirdsavem*, $buildbirdsavem^2$ and $buildbirdsavem^3$. Higher order interactions for the I EEM were irrelevant.

Failure to consider interactions among main effect mean trend variables can result in exclusion of important variables from the EEM due to failure to notice their statistical significance. Some variables might affect NH_3 emissions only by way of an interaction with another variable. For example, the main effect of a variable such as *ta* might drop out of the EEM due to an insignificant regression coefficient. However, when its interaction with *avem* is considered, the regression coefficient for the interaction term might be statistically significant.

Furthermore, even if the main effects of both *ta* and *avem* were statistically significant, it might be the case that an interaction between them allows the EEM to explain even more of the variability in NH_3 emissions. Failure to consider such an interaction would result in decreased predictive performance in terms of both accuracy (establishing the optimal mean trend function) and precision (minimizing prediction error variance, manifested by the width of the prediction intervals). Including three-way interactions, or *n*-way interactions for $n > 3$, particularly when the set of predictor variables is large, might not improve the predictive ability of the EEM, and might lead to extreme collinearity. Therefore, the EPA adopted the following protocol, illustrated with the I EEM, for determining what level of interactions to use as candidate mean trend variables.

The EPA performed an ordinary least squares (OLS) regression of NH_3 emissions in the base dataset on main effect inventory variables, then repeated the regression adding two-way interactions, then three-way interactions. With each regression, the EPA examined the value of R^2 to determine what percent of variability in NH_3 emissions in the base dataset were explained by each set of variables. Using the maximum value of R^2 calculated from a regression on the base dataset is not appropriate to determine what mean trend variables should be included in the final EEM because adding variables to the EEM always increases R^2, even if some are spurious variables or if they explain anomalies in the base dataset as opposed to signals that apply generally. If adding variables increases R^2 only slightly, however, those additional variables are not important. Therefore, the EPA decided that only if increasing the level of interactions in the OLS regression from n-way to $n + 1$ way increased R^2 by 0.01 or more would the $n + 1$ way interactions be included as candidate mean trend variables.

Table 7-6 shows that including only main effects for the I EEM resulted in $R^2 = 0.8127$, and adding two-way interactions resulted in $R^2 = 0.8457$. Because the difference between the R^2 values was 0.033, the EPA included the two-way interactions. Because adding 3-way interactions produced $R^2 = 0.8493$, an increase of only 0.0036, the EPA did not include 3-way interactions in the set of candidate mean trend variables.

Table 7-6. Proportion of Base Dataset Variability Explained by EEMs by Interaction Level

EEM	Interaction Level	*P*	R^2
I	Main effects	5	0.8127
	Add 2-way	12	0.8457
	Add 3-way	15	0.8493
IA	Main effects	8	0.8365
	Add 2-way	33	0.9013
IAC	Main effects	10	0.8401
	Add 2-way	52	0.9149

Because they contain a superset of the predictor variables in the I EEM, the EPA did not consider interactions beyond two-way for the IA and IAC EEMs. However, the EPA conducted a test to determine whether adding two-way interactions to the main effect for these two EEMs was necessary. Because the OLS regression of NH_3 emissions on main effects for the IA EEM resulted in $R^2 = 0.8365$, and adding two-way interactions produced $R^2 = 0.9013$, the EPA considered two-way interactions for the IA EEM. Because the OLS regression of NH_3 emissions on main effects for the IAC EEM resulted in values of $R^2 = 0.8401$, and adding two-way interactions produced $R^2 = 0.9149$, the EPA also considered two-way interactions for the IAC EEM.

7.4 Choosing the Covariance Function

Use of OLS regression to determine what mean trend variables are statistically significant and to obtain prediction intervals requires that the random deviations e_{ht} are independent and identically distributed with mean 0 and variance σ^2. If they are not independent, the dependence, which is called correlation or covariance, can be accounted for in the EEM using random effects

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and/or a covariance function, via generalized least squares (GLS) regression. If they are not identically distributed, differences in the variance parameter σ^2 can be eliminated by transforming the original response variable (NH_3 emissions) or by allowing different values of σ^2 under different conditions.

Section 7.4.1 explains the meaning of and distinction between correlation and covariance. Sections 7.4.2 and 7.4.3, respectively, describe how the EPA assessed the need to account for serial correlation or correlation due to random effects. Section 7.4.4 explains the EPA's decision to use the single variance parameter σ^2 calculated from all four broiler houses and all three sites in the NAEMS.

7.4.1 Correlation Function as Subset of Covariance Function

The auto-correlation coefficient, ρ, which falls between -1.0 and 1.0, is a measure of the strength and direction of a linear relationship between two random variables. Values closer to 0 indicate little or no relationship, values close to -1.0 indicate a strong negative association, and values close to 1.0 indicate a strong positive association. In the EEM context, the random variables are both the random deviations, e_{ht}, from the mean trend function, and the NH_3 emissions, Y_{ht}, which are functions of the e_{ht}.

The covariance between two random variables is the correlation coefficient multiplied by the standard deviation of each: $\rho\sigma_1\sigma_2$. If the two have the same standard deviation (i.e., $\sigma_1 = \sigma_2 = \sigma$), then the covariance is simply the product $\rho\,\sigma^2$ of the correlation coefficient ρ and the variance σ^2. In short, the covariance is a measure of alikeness, for which the units are the squared units of the random variable (kg squared in the case of daily NH_3 emissions).

For the EEMs, EPA used the covariance matrix to calculate prediction error. The covariance matrix specifies the joint probability of all types of errors that are possible in the mean trend terms over all dates, houses and sites. For example, the EEM would specify a greater prediction error for mean trend values that are at the extreme values measured in the NAEMS monitoring study than for values that are closer to the central tendency of the measured emissions data.

Because the I EEM has fewer mean trend variables than the other EEMs, the covariance function has to account for more variability in NH_3 emissions than it will for the other EEMs. The EPA therefore used only inventory-based mean trend terms to make initial covariance function decisions. However, the EPA continually re-assessed the statistical significance of covariance parameters during the final EEM selection process in case addition of mean trend variables from the ambient and confinement categories explained so much more variability in NH_3 emissions that the covariance parameters were no longer needed.

7.4.2 Serial Correlation

Serial correlation in NH_3 emissions, Y_{ht}, occurs if the value of emissions at one point in time is related to the value at a nearby point in time. The deviations from the mean trend function, e_{ht}, can display serial correlation even when many of the reasons for the similarity between emissions for two consecutive days have been accounted for with the mean trend function. To assess the need to account for serial correlation in the deviations from the mean trend function, the EPA fit an OLS regression model, which does not account for serial correlation or random effects, to the base data and plotted pairs of residuals from the same house, $\hat{e}_{ht}$, (which are estimates of the deviations) at time t versus those at time t–1, (see Figure 7-15). Because of the strong relationship between the two terms, EPA accounted for serial correlation with the auto-regressive order 1 (AR(1)) covariance function. This function expresses the covariance $Cov(e_{ht}, e_{ht'})$ between two deviations from the mean trend function within the same house on different dates (t and t') as the product, $\sigma^2\rho^{|t-t'|}$, of the variance parameter, σ^2, and a power of the auto-correlation coefficient, ρ. Restricting ρ to take values between 0 and 1 ensures that when the distance, $|t-t'|$, between two dates increases, the correlation $\rho^{|t-t'|}$ between the two deviations decreases.

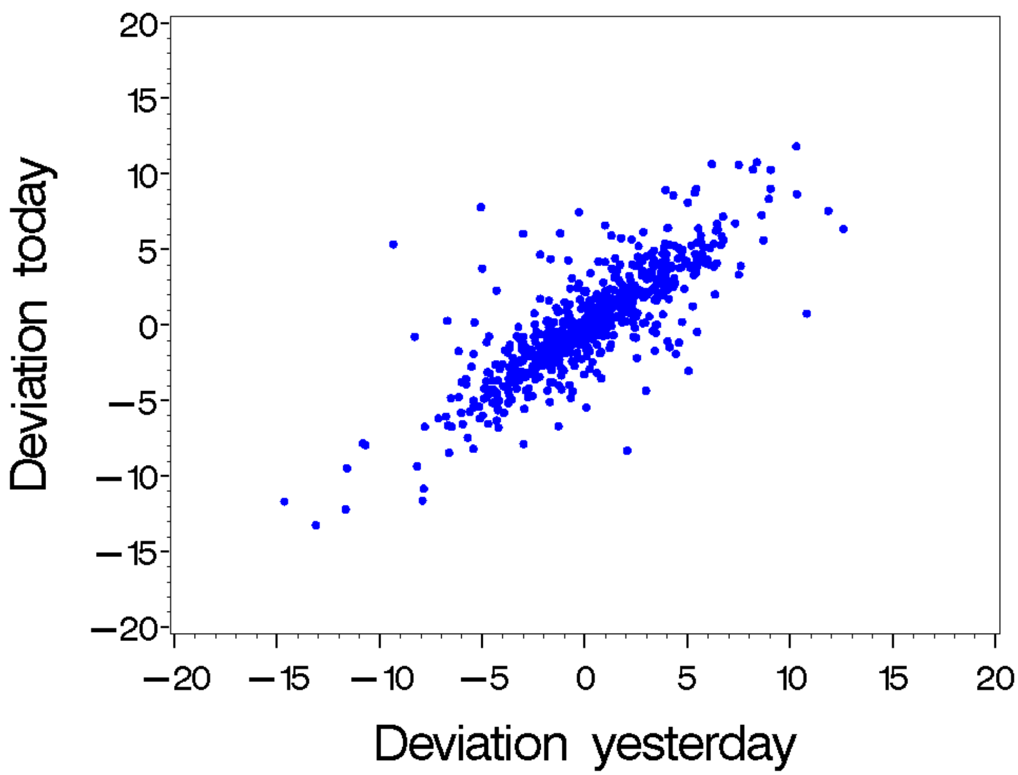

Figure 7-15. Deviations from the Mean Trend Function on Date *t* vs. Date *t*-1

7.4.3 Random Effects

Random effects must be accounted for if a variable that cannot be used as a predictor might nonetheless affect the value of NH_3 emissions. Variables that might affect pollutant emissions from broiler houses include information that was not provided by the NAEMS such as the nitrogen content of feed rations and the timing of changes in feed rations. Such variables might be the same for a given farm or company, but different for different farms or companies. The genetic make-up of the birds might also be the same for a given farm or company, but different for different farms or companies. Other variables that might affect the pollutant emissions measurements, which is different from affecting actual emissions, include the people conducting the measurement activities, the proximity of the house to another emissions source, and the distance separating the outdoor ambient monitor from the house. If, for hypothetical house 1, the distance between the outdoor monitor and the house were less than that of hypothetical house 2, the ambient emissions concentration from house 1 might be more contaminated by emissions from the house, and thus not represent background emissions alone. Then for house 1, the emissions measurement resulting from subtracting the outdoor "background" NH_3 concentration from the indoor concentration would not be as representative of true emissions as would the emissions measurement from house 2. To allow for differences in emissions due to such farm-to-farm, company-to-company, or house-to-house differences, known or unknown, the EPA considered random effects of site and house.

The EPA assessed the need to account for random effects first using summary statistics, and then by including each type of random effect in an EEM and testing the statistical significance of the effect. When values of other predictor variables such as *buildup*, $avem^*$ (*or avem*) and *birds** (*or birds*) are kept constant, a consistent pattern in mean emissions for the different houses or sites would support the need for a random effect. Table 7-7 shows mean NH_3 emissions within each house for different ranges of $avem^*$ for the subset of the base data for which *build* = 0. (Note that for the only flock for which KY1B-2 H3 had *build* = 0, the data beyond the first three weeks were missing.) For $avem^*$ bins 1 through 3, KY1B-1 H5 had a higher mean than CA1B H10 and CA1B H12, but the pattern did not continue over bins 4 through 6. Other breakdowns of the data showed a similar lack of consistent pattern. This observation implies that random effects of house or site are not needed.

Table 7-7. Mean NH_3 Emissions (kg) After Litter Clean-out

Site	House	Average Bird Mass											
		0-0.5 kg		0.5-1.0 kg		1.0-1.5 kg		1.5-2.0 kg		2.0-2.5 kg		2.5-3.0 kg	
		n	NH_3	n	NH_3	n	NH_3	n	NH_3	n	NH_3	n	NH_3
CA1B	10	41	0.42	12	3.97	9	12.4	14	19.1	14	24.7	8	25.2
	12	40	0.36	12	2.89	9	9.32	14	17.0	14	23.3	8	24.1
KY1B-1	5	17	1.78	8	11.6	7	18.9	9	19.4	7	17.0	1	13.3
KY1B-2	3	15	0.36	7	2.18	0	a	0	a	0	a	0	a

[a] Site KY1B-2 only had three weeks of data on new bedding.

To formally test the need for a random effect in the EEM, Equation 7-2 presents a modification of Equation 7-1 that includes a random effect of house, A_h. If there were a consistent pattern in mean NH_3 emissions for each house, then the random variables A_h, h = 1,…4, will have variance parameter, σ^2_H, significantly different from zero. Note that σ^2_H represents a single parameter, whereas the notation σ^2_h, h = 1,...,4, which will be used in Section 7.4.4, represents four different parameters.

$$Y_{ht} = \beta_0 + \beta_1 x_{1ht} + \cdots + \beta_p x_{pht} + \cdots + \beta_P x_{Pht} + A_h + e_{ht}, \; h = 1, \ldots, 4, \; t \text{ varies}, \; p = 1, \ldots, P$$

$$e_{ht} \sim N(0, \sigma^2); \quad A_h \sim N(0, \sigma_H^2);$$

$$Cov\left(e_{ht}, e_{h't'}\right) = \begin{cases} 0 & h \neq h' \\ \sigma^2 \rho^{|t-t'|} & h = h' \end{cases}; \quad 0 < \rho < 1 \qquad \text{Equation 7-2}$$

The first column of Table 7-8 lists all of the covariance parameters, and the second gives the estimate for each. The third column gives the p-value of a test of the null hypothesis that the covariance parameter equals zero. The p-value gives the probability (between 0 and 1) that the actual covariance parameter would be as far from zero as the estimate obtained if the null hypothesis were true. Because a small p-value indicates that the estimated value of the parameter is not significantly different from zero, the results provide strong evidence that the random effect of *house* is not needed in the EEM, but that the auto-correlation coefficient ρ and variance parameter σ^2 are needed. The EPA performed a similar test for the random effect of *site* instead of *house*, and in that case the estimated variance component for site $\hat{\sigma}_S^2$ was 0.27, and the p-value was 0.40. Consequently, the EPA did not include a random effect of either *house* or *site* in the EEMs.

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Table 7-8. Covariance Parameter Estimates

Covariance Parameter	Estimate	P-value
$\hat{\rho}$	0.9157	<0.0001
$\hat{\sigma}_h^2$	13.7004	<0.0001
$\hat{\sigma}_s^2$	0.2726	0.4028

7.4.4 Constant Variance

Another decision to be made regarding the covariance function was whether to use the same covariance parameters, σ^2 and ρ, for all houses and conditions. If the variance, σ^2, of the deviations, e_{ht}, from the mean trend function increase with the mean, or if they exhibit non-constant variance for some other reason, then a transformation of the response variable, NH_3 emissions, would be the most commonly used remedy. Such a transformation, however, would have made both the exploratory plots in Section 7.3, and the regression coefficient estimates, $\hat{\beta}_p$, more difficult to interpret.

The EPA did not find evidence supporting an increase in the variance of emissions with increasing values of mean emissions. Table 7-9 shows the mean and standard deviation for six different ranges of values of NH_3 emissions for which the first five ranges has enough data to discern patterns. As the mean increases from the first range to the third, the standard deviation does increase, but an increase of 0.1 kg is of no practical significance. Because these are standard deviations of NH_3 emissions, Y_{ht}, as opposed to the deviations from the mean trend function, e_{ht}, the EPA decided that it was not necessary to account for a variance that increases with mean emissions.

Table 7-9. Sample Size, Mean and Standard Deviation for NH_3 Bins

Range of NH_3 Emissions in kg	N	Mean (kg)	Std Dev (kg)
0-6	484	2.7	1.6
6-12	231	8.8	1.7
12-18	172	15	1.8
18-24	209	21	1.8
24-30	104	26	1.6
30-36	11	32	1.9

The plots in Section 7.3.1 showed that variability in NH_3 emissions was greater for the Kentucky houses than for the houses at site CA1B. If these differences were statistically significant, then an EEM with four variance parameters, σ_h^2, h = 1. …, 4, might fit the NAEMS data better than the EEM of Equation 7-1. These differences in the variability of emissions for the houses, which might require different variance parameters, σ_h^2, h = 1. …, 4, should not be confused with differences in mean emissions that would require a single random effect parameter, σ_H^2, as discussed in Section 7.4.3. It might also be the case that the auto-correlation coefficient, ρ, is different from house to house, so that an EEM with four auto-correlation coefficients, ρ_h^2, h = 1, …, 4, would fit the NAEMS data better than Equation 7-1.

An EEM with different variance parameters and auto-correlation coefficients for each house, however, could not be used to predict emissions for sites not included in the NAEMS. A variance and auto-correlation coefficients estimated for CA1B H10, for example, could only be used to predict emissions from CA1B H10. Because the NAEMS sites were selected to represent emissions for the industry as a whole, and the EEM will be used to quantify all such emissions, the EPA used a single pooled variance parameter, σ^2, and a single auto-correlation coefficient, ρ, the estimates of which were based on all four houses in the NAEMS.

7.5 Selecting Final Mean Trend Variables

Table 7-10 gives the candidate mean trend variables for the I, IA and IAC EEMs. To choose final mean trend variables from these candidates, the EPA used an approach that included simultaneous evaluation of fit statistics calculated on the base dataset with fit statistics calculated on the cross-validation dataset. Section 7.5.1 explains the process using the I EEM as an example, and Sections 7.5.2 and 7.5.3 follow with results for the IA and IAC EEMs.

Table 7-10. Candidate Mean Trend Variables for the I, IA and IAC EEMs

EEM	Main Effects	Two-Way Interactions
I	*build, birds,* *avem*, $avem^2$, $avem^3$	*buildbirds,* *buildavem*, $buildavem^2$, $buildavem^3$, *birdsavem*, $birdsavem^2$, $birdsavem^3$
IA	Same as I EEM plus: *ta, ha, pa*	Same as I EEM plus: *buildta, buildha, buildpa,* *birdsta, birdsha, birdspa,* *avemta*, $avem^2ta$, $avem^3ta$, *avemha*, $avem^2ha$, $avem^3ha$, *avempa*, $avem^2pa$, $avem^3pa$, *taha, tapa, ha, pa*

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Table 7-10. Candidate Mean Trend Variables for the I, IA and IAC EEMs

EEM	Main Effects	Two-Way Interactions
IAC	Same as IA EEM plus: *tc, hc*	Same as IA EEM plus: *buildtc, buildhc, birdstc, birdshc,* $avemtc$, $avem^2tc$, $avem^3tc$, $avemhc$, $avem^2hc$, $avem^3hc$, *tatc, tahc, hata, hahc, patc, pahc, tchc*

7.5.1 Inventory EEM

As discussed in Section 7.1.1, the fact that the EPA centered and scaled predictor variables prior to squaring, cubing or multiplying to create main effect and interaction variables necessitates that backward elimination of mean trend variables follows a particular protocol. Under this protocol, no lower-order term can be removed if a higher-order version of it or an interaction containing it remains in the EEM. Because the EPA treated the collection of terms $avem$, $avem^2$ and $avem^3$, as the main effect of *avem*, an interaction between *avem* and another mean trend variable, (e.g., *ta*) was considered to be the three new variables formed by multiplying each of the three *avem* terms by the other variable (e.g., $avemta$, $avem^2ta$, $avem^3ta$). This collection of terms could only be removed as a group if a test of the null hypothesis that all three regression coefficients equal zero could be rejected. If a mean trend variable has a regression coefficient equal to zero, then it is not needed in the EEM.

According to this protocol, the four null hypotheses to be tested in Run 0 of the I EEM were:

1. The term *buildbirds* has a regression coefficient equal to zero.

2. The three terms $avem^3$, $buildavem^3$ and $birdsavem^3$ have regression coefficients equal to zero.

3. The three terms $buildavem$, $buildavem^2$ and $buildavem^3$, representing the interaction between *build* and *avem*, have regression coefficients equal to zero.

4. The three terms $birdsavem$, $birdsavem^2$ and $birdsavem^3$, representing the interaction between *birds* and *avem*, have regression coefficients equal to zero.

The first column of Table 7-11 lists the mean trend variables involved in these four tests, and the second and third columns list the corresponding p-values for each test for the two runs in the backward-elimination process. The p-value is the probability that the estimated regression coefficients would have values as far from zero as the ones obtained merely by chance, even if the true values of the coefficients were zero. A small p-value is evidence that the regression coefficient is significantly different from zero, and therefore the corresponding mean trend term should remain in the EEM. To declare statistical significance, the EPA looked for p-values with an order of magnitude of $\alpha = 0.001$. This is a conservative value, much lower than the often-used $\alpha = 0.05$, to account for the fact that when many tests are performed, the actual significance level is much higher than the nominal significance level. Over the course of developing EEMs for all pollutants, many tests were performed.

Of the four tests, the EPA looked for the test that had the highest p-value. For the I EEM, Run 0, the test for *buildbirds* had a p-value 0.61, which indicates lack of significance. Therefore, the EPA eliminated that variable. Sometimes elimination of terms results in new mean trend variables being candidates for removal. For example, if all interactions with *birds* have been removed, then the main effect of *birds* becomes a candidate for removal. In the case of the I EEM, Run 1, following the first elimination, no additional terms became candidates for removal, so that tests 2 through 4 were the only relevant tests. Because the highest p-value of these, 0.0012, is of the order of magnitude of α = 0.001, no further terms were eliminated.

Table 7-11. Hypothesis Tests for the I EEM, Runs 0 and 1

Mean Trend Variables	Run 0[a]	Run 1
	p-value	p-value
buildbirds	0.6109	-
$avem^3$ $buildavem^3$ $birdsavem^3$	<0.0001	<0.0001
buildavem $buildavem^2$ $buildavem^3$	0.0014	0.0012
birdsavem $birdsavem^2$ $birdssavem^3$	0.0002	0.0002

[a] The EPA refers to the first run as Run 0 because none of the mean trend variables were eliminated at this step.

In addition to using p-values to determine what mean trend variables to keep in the EEM, with every EEM run (and thus with every elimination of a mean trend variable), the EPA examined the fit statistics listed in Table 7-12. The negative two log likelihood (-2LL) and the Bayesian information criterion (BIC), like the p-values, are calculated from the "likelihood function."

The likelihood function of an EEM quantifies the probabilities that different sets of values of the parameters will reproduce NH_3 emissions in the NAEMS data. "Fitting the EEM" refers to finding the parameter estimates that maximize the likelihood function, which simply means finding those values of the parameters that result in accounting for the most variability in the data. Minimizing the function that is equal to -2LL is mathematically equivalent to maximizing the likelihood, and the required computations take less time. When comparing the values of -2LL for two different EEMs, the one with the lower -2LL better fits the data.

The BIC statistic is a function of -2LL, with a penalty added for the number of parameters in the EEM for situations in which fewer parameters are desirable. Lower values of the BIC statistic are also better; however there are instances where eliminating a term increases the -2LL while decreasing the BIC. The second column of Table 7-12 shows that elimination of *buildbirds* from the I EEM resulted in the -2LL increasing from 3,810 for Run 0 to 3,811 for Run 1, but the BIC decreased from 3,819 to 3,815. If both the -2LL and the BIC decrease, there is strong evidence that the resulting EEM is superior, but sometimes when the statistics disagree, other fit statistics must be considered, or it may be the case that the difference between two EEMs has little practical significance.

The remaining fit statistics quantify how well an EEM fits the cross-validation dataset. The EPA fit an EEM of the form given in Equation 7-1 to the base dataset. Using that EEM and the values of the predictor variables corresponding to the 217 values of NH_3 emissions in the cross-validation dataset, the EPA then produced point predictions, denoted with $\hat{Y}_{ht}$, and the lower and upper bounds of the 95 percent prediction intervals for the actual emissions, Y_{ht}. The fit statistics are different ways of assessing how well the 217 point predictions, $\hat{Y}_{ht}$, compare to the 217 actual values of NH_3 emissions, Y_{ht}, as well as how well the prediction intervals quantify uncertainty in the point predictions.

The row labeled "% in PI" gives the percent of cross-validation emissions, Y_{ht}, that fall inside the 95 percent prediction intervals for them. Values close to 95 indicate that the quantification of uncertainty is on target. For both runs of the I EEM, this value was 94 percent. The width of each prediction interval, in kg of NH_3 emissions, quantifies the uncertainty of the point prediction. For a given confidence level, narrower intervals are desirable. A 95 percent prediction interval that says the NH_3 emissions for a single date under a given set of conditions will fall between 0 and 36 kg is less useful than a prediction interval that says the emissions will fall between 15 and 30 kg. The width of the interval is a function of the natural variability in the deviations from the mean trend function as well as uncertainty regarding the point estimate due to using sample data. Including more relevant predictor variables, if possible, is one way to obtain narrower intervals, a fact that emphasizes the importance of the collinearity mitigation strategies of Section 7.3.1. The best of a set of candidate EEMs would be one that minimizes these widths, while at the same time ensuring that the statistic “% in PI” is close to 95. In other words, the best EEM minimizes uncertainty while at the same time quantifying it accurately. The average width of the prediction intervals produced by the I EEM, Run 0 was 14 kg, and this width did not change upon elimination of the predictor *buildbirds*.

Table 7-12. Backward Elimination Fit Statistics for the I EEM

Fit Statistic	I EEM Runs	
	0	**1**
-2LL	3,810	**3,811**
BIC	3,819	**3,815**
% in PI	94	**-**
Width (kg)	14	**-**
RMSE (kg)	3.8	**-**
R^2	0.81	**-**
Y_0 (kg)	-0.13✓	**-0.14✓**
Y_1	0.99✓	**-**
Eliminated	***buildbirds***	

Note: A dash indicates no change in the fit statistic from the previous EEM. A check mark (✓) indicates that the 95 percent confidence interval (CI) for the intercept (slope) contains zero (one) and the estimate is not significantly different from zero (one). Highlighting emphasizes the EEMs for which a given statistic obtained its optimal value.

To obtain the next four fit statistics, RMSE, R^2, Υ_0, and Υ_1, the EPA performed an OLS regression of the cross-validation dataset of NH_3 emissions, Y_{ht}, on the predictions, $\hat{Y}_{ht}$, of the withheld cross-validation data. In other words, the EPA fit the OLS regression given by Equation 7-3, where the values of *h* and *t* correspond to those in the cross-validation dataset. In Equation 7-3, Υ_0 represents the intercept of the fit line and Υ_1 represents the slope.

$$Y_{ht} = \Upsilon_0 + \Upsilon_1 \hat{Y}_{ht} + e_{ht} \qquad \text{Equation 7-3}$$

The root mean squared error (RMSE), in kg NH_3, is defined in Equation 7-4. The RMSE can be thought of as a measure of the average distance between the point predictions and the actual emissions. Smaller values indicate a better fit. For both runs of I EEM, the RMSE was 3.8 kg.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{n}\left(Yht - \hat{Y}ht\right)^{(2)}} \qquad \text{Equation 7-4}$$

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The value of R^2 is interpreted as the proportion of variability in the cross-validation emissions, Y_{ht}, explained by the predictions of them, $\hat{Y}_{ht}$. As mentioned in Section 7.3.2, when R^2 is calculated from a regression of the base data emissions on mean trend variables, it is not a good indication of EEM fit because it is a mathematical certainty that R^2 will increase when mean trend variables are added. When R^2 is calculated based on a regression of the cross-validation dataset, Y_{ht}, on the predictions of the cross-validation dataset, $\hat{Y}_{ht}$, from a given EEM, it is not a mathematical certainty that adding mean trend variables to that EEM will increase R^2. Thus, values of R^2 closer to one indicate better fit of the EEM to the cross-validation data. The proportion of the variability in cross-validation emissions explained by both of the I EEMs is 0.81, or 81 percent.

If the EEM fit the cross-validation data perfectly, the intercept Υ_0 of the regression in Equation 7-3 would equal zero, and the slope Υ_1 would equal one. If the estimate of the intercept or slope, Υ_0 or Υ_1, is significantly different from 0 or 1, respectively, the EEM has systematic bias. A check ✓ beside either estimate indicates that the 95 percent confidence interval (CI) for it contains zero or one, and thus the estimate is not significantly different from zero or one. Both runs of I EEM were free from systematic bias.

Because elimination of *buildbirds* from the I EEM based on the regression coefficient p-value did not have a negative impact on the other fit statistics, the EPA chose the variables from Run 1 as the final mean trend variables for the I EEM.

7.5.2 Inventory and Ambient EEM

The hypotheses to be tested in Run 0 of IA EEM are listed in groups by type:

1. Any of the 7 individual variables that represent an interaction has a regression coefficient equal to zero. These variables are *buildbirds, buildta, buildha, buildpa*, *birdsta*, *birdsha* and *birdspa*.

2. All 5 variables containing $avem^3$ have regression coefficients equal to zero. These variables are *build* $avem^3$, *birds* $avem^3$, $avem^3$ *ta*, $avem^3$*ha* and $avem^3$*pa*.

3. All of the three regression coefficients corresponding to any of the five sets of triplets formed as the product of the terms *avem*, $avem^2$, $avem^3$ and another variable are equal to zero.

Table 7-13 gives the progression of fit statistics for each backward-elimination step, listing in the bottom row the variable eliminated.

Table 7-13. Backward Elimination Fit Statistics for the IA EEM

Fit Statistic	IA EEM Runs										
	0	1	2	3	4	5	6	7	8	9	**10**
-2LL	3,687	3,684	3,681	3,679	3,680	3,678	3,677	-	3,675	3,676	**-**
BIC	3,696	3,692	3,689	3,688	3,689	3,687	3,685	3,686	3,683	3,685	**3,684**
% in PI	97	-	-	-	96	-	-	-	97	-	**-**
Width (kg)	13	-	-	-	-	-	-	-	-	-	**-**
RMSE (kg)	3.2	-	-	-	-	-	3.3	-	-	-	**-**
R^2	0.86	-	-	-	-	-	-	-	-	-	**0.85**
γ_0 (kg)	-0.24✓	-0.25✓	-	-	-0.26✓	-0.27✓	-0.26✓	-0.24✓	-0.23✓	-0.24✓	**-0.23✓**
γ_1	0.99✓	-	-	-	-	-	-	-	-	-	**-**
Eliminated	-	*hapa*	*birdsha*	*buildha*	*buildbirds*	*birdspa*	*birdsta*	*buildta*	*taha*	*buildpa*	***tapa***

Note: A dash indicates no change in the fit statistic from the previous EEM. A check mark (✓) indicates that the 95 percent confidence interval (CI) for the intercept (slope) contains zero (one) and the estimate is not significantly different from zero (one). Highlighting emphasizes the EEMs for which a given statistic obtained its optimal value.

For all runs of the IA EEM, both -2LL and BIC, which evaluate fit to the base data, were considerably better than for either run of the I EEM. As each variable was eliminated, the values of -2LL and BIC decreased, indicating improved fit, up through Run 8. When the final two variables were eliminated, -2LL increased by one and then held that value, while BIC increased by two, then decreased by one. The optimal value for both of these statistics occurred at Run 8.

At 97 percent, the "% in PI" for the IA EEM Runs 0-3 and 8-10 was farther from the optimal value of 95 than for either run of the I EEM, but for Runs 4 through 7, it was equally close, so that these four runs achieved the optimal value of that statistic for the IA EEM. For all runs of the IA EEM, the PI width was 13 kg, one kg narrower (thus better) than for the I EEM.

The RMSE for the IA EEM Runs 0 through 5 was 3.2 kg, increasing to 3.3 kg for Runs 6 through 10. Considering that these value represent averages over 217 observations, both represent a considerable improvement over the 3.8 kg for the I EEM. Runs 0 through 9 of the IA EEM explained 86 percent of the variability in the cross-validation data, while the final Run 10 explained 85 percent. Both numbers represent a considerable improvement over the value of 81 percent for the I EEM.

For all runs of the IA EEM, the intercepts Υ_0 were approximately one tenth of a kg farther from 0 than were those for the I EEM, although no intercept for any run of either EEM was significantly different from 0. For all runs of both EEMs, the slope Υ_1 were 0.99, and for all, the slope was not significantly different from 1.

The EPA chose the variables from Run 10 as the final mean trend function for the IA EEM. The EPA chose to use the statistical significance of the regression coefficients, which was the basis of variable elimination at each step, as the primary criterion for variable selection, but used the other fit statistics as back-up in case any lingering collinearity caused variance inflation, and thus p-value inflation, masking the significance of some regression coefficients. Although the -2LL and BIC were slightly less optimal for Run 10 than for Run 8, an increase of 1 in the value of -2LL with a removal of a single parameter did not represent a statistically significant worsening of fit according to a likelihood ratio test based on the χ^2 (chi-squared) distribution with one degree of freedom.

The increase from 96 to 97 percent coverage of the prediction intervals was not sufficiently extreme to warrant over-riding the p-value-based decision, nor was the increase by 0.1 kg in RMSE. A decrease in the variability in the cross-validation data explained from 86 percent to 85 percent was not of concern because any set of cross-validation data, like the base data, might have its own anomalies, so that over-riding p-values calculated from

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994 observations in favor of statistics based on 217 would require a more dramatic difference. Finally, for the PI width, intercept Υ_0, and slope Υ_1, Run 10 had the optimal value.

7.5.3 Inventory, Ambient and Confinement EEM

Table 7-14 and Table 7-15 give the backward-elimination steps for the IAC EEM. The EPA chose variables from the p-value-based optimal Run 23 as the final mean trend function. Although Run 23 had the optimal value of only one fit statistic, the differences between the optimal values and those for Run 23 were not a concern. The EPA performed an additional formal hypothesis test to compare Run 23 with Run 16, which was the most recent run with the optimal value of -2LL. The difference of 18 between 3,504 and 3,522 is the value of a χ^2 (chi-squared) statistic for a likelihood ratio test. The null hypothesis is that the 7 eliminated variables had regression coefficients equal to zero, and thus were not needed in the model. The corresponding p-value was 0.01, which was not significant at the $\alpha = 0.001$ significance level; therefore, the EPA could not reject the hypothesis that those variables were not needed.

7.5.4 EEM Validation and Modification of Previous Versions

An important part of any statistical analysis is validation of results using a variety of techniques. Examination of the fit statistics described in Section 7.5.1 was not only used to validate backward-elimination decisions based on p-values, but also to assess other decisions. The EPA changed three major decisions as a result of validation analyses on previous versions of the EEMs. The first of these changes in decisions was the means of selecting the cross-validation dataset, described in Section 7.1.2. The other two are explained below.

In an earlier version of the EEM, the EPA did not include main effects of *birds** and *avem**, but instead used total live bird mass, calculated as *mass** = (*birds**)(*avem**). The underlying assumption was that the total live bird mass was the most important factor determining the amount of manure produced. Because a graph of NH_3 emissions versus *mass** showed curvature similar to that in Figure 7-5, the EPA used a cubic polynomial function of *mass* (i.e., the centered and scaled version of *mass**). When the statistics Υ_0 and Υ_1 were significantly different from 0 and 1, the EPA considered the variables *birds** and *avem** separately, producing the plots in Figure 7-5 and Figure 7-11. The EPA realized that cubing *mass* was equivalent to cubing both *birds* and *avem*, but it was only appropriate to cube *avem* because Figure 7-11 gave no indication that a cubic function of *birds** would be appropriate. The result was use of a linear function as the main effect of *birds**, a cubic polynomial as the main effect of *avem**, and the three terms *birdsavem*, $birdsavem^2$ and $birdsavem^3$ for the interaction.

Table 7-14. Backward Elimination Fit Statistics (Runs 0 – 11) for IAC EEM

Fit Statistic	IAC EEM Runs											
	0	1	2	3	4	5	6	7	8	9	10	11
-2LL	3,526	-	3,525	3,522	3,520	3,518	3,516	3,514	-	3,511	3,510	3,508
BIC	3,524	3,535	3,533	3,531	3,528	3,526	3,524	3,522	-	3,520	3,519	3,516
% in PI	96	-	-	-	-	-	-	-	-	-	-	-
Width (kg)	13	-	-	-	-	-	-	-	-	-	-	-
RMSE (kg)	3.4	-	-	-	-	-	-	-	-	-	-	-
R^2	0.85	-	-	-	-	-	-	-	-	-	0.84	-
Υ_0 (kg)	0.06✓	-	-	0.07✓	-	-	-	-	0.06✓	0.05✓	0.04✓	0.05✓
Υ_1	0.97✓	-	-	-	-	-	-	-	-	-	-	-
Eliminated	-	*buildta*	*tapa*	*taha*	*tatc*	*pahc*	*birdspa*	*taha*	*buildtc*	*hatc*	*paavem* $paavem^2$ $paavem^3$	*patc*

Note: A dash indicates no change in the fit statistic from the previous run. A check mark (✓) indicates that the 95 percent confidence interval (CI) for the intercept (slope) contains zero (one) and the estimate is not significantly different from zero (one). Highlighting emphasizes the EEM runs for which a given statistic obtained its optimal value.

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Table 7-15. Backward Elimination Fit Statistics (Runs 12 – 23) for IAC EEM

Fit Statistic	IAC EEM Runs											
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
-2LL	-	3,506	3,504	3,505	3,504	3,509	3,511	3,513	3,516	3,519	3,520	**3,522**
BIC	-	3,515	3,512	3,514	3,512	3,517	3,520	3,522	3,525	3,528	3,529	**3,531**
% in PI	-	-	-	-	-	97	-	-	-	-	-	**-**
Width (kg)	-	-	-	-	-	-	-	-	-	-	-	**-**
RMSE (kg)	-	-	-	-	-	3.5	-	-	-	-	-	**-**
R^2	-	0.85	-	-	0.84	-	-	-	-	0.83	0.84	**-**
Υ_0 (kg)	0.02✓	-0.004✓	-0.009✓	-0.02✓	-0.03✓	-0.11✓	-0.09✓	-	-0.07✓	-0.05✓	-0.03✓	**-0.04✓**
Υ_1	-	-	-	-	-	0.98✓	-	-	-	0.97✓	-	**-**
Eliminated	*buildpa*	*hapa*	*pa*	*buildha*	*buildhc*	*buildbirds*	*birdsha*	*birdstc*	*birdsta*	*birdshc*	*hahc*	***tchc***

Note: A dash indicates no change in the fit statistic from the previous run. A check mark (✓) indicates that the 95 percent confidence interval (CI) for the intercept (slope) contains zero (one) and the estimate is not significantly different from zero (one). Highlighting emphasizes the EEM runs for which a given statistic obtained its optimal value.

In another early version of the EEM considered as an alternative to the one in the previous paragraph, instead of using a cubic polynomial as the functional form through which *mass** would enter the model, the EPA used a function known as the Gompertz growth curve to capture the curvature in NH_3 emissions as a function of *mass**. The difference between the Gompertz curve and the cubic polynomial is that the Gompertz curve flattened out as a function of *mass**, while the cubic polynomial captured the decrease in NH_3 emissions as a function of *mass** at the end of the grow-out period. Curvature in plots of cross-validation residuals vs. *mass** from the Gompertz EEM led the EPA to further investigate the downturn in emissions at the end of the grow-out period. This investigation, and reaching the conclusions described in the previous paragraph, happened at the same time so that the EPA never considered a Gompertz growth curve as the functional form through which *avem** would enter the EEM. Investigation of the downturn in emissions at the end of the grow-out period led to producing the disaggregated plots in Figure 7-8, Figure 7-9 and Figure 7-10. This investigation resulted in use of the cubic polynomial as the functional form through which *avem** would enter the EEM.

7.5.5 Summary of Final Results for the I, IA and IAC EEMs

The fit statistics in Table 7-12, Table 7-13, Table 7-14 and Table 7-15 show that adding ambient meteorological predictor variables *ta*, *ha* and *pa* to inventory-based predictors *build*, *birds* and *avem* considerably improved the ability of the EEM to predict NH_3 emissions in both the base and cross-validation datasets. Adding confinement-based predictor variables *tc* and *hc* improved the ability to predict NH_3 emissions in the base dataset, and allowed all terms involving *pa*, some of which had been significant in the IA EEM, to be eliminated. The IAC EEM had less optimal values of cross-validation statistics RMSE and R^2 than did IA EEM, but only by 0.2 kg and 1 percent, respectively. Because the mean trend variables for the final IAC EEM were not a superset of those in the IA EEM, a likelihood ratio test comparing the differences in -2LL was not appropriate.

After selecting final I, IA and IAC EEMs, the EPA refitted each EEM to the full dataset to obtain the final regression coefficient estimates for use in estimating emissions. After selecting the final mean trend variables, the EPA refit the EEM using the full dataset. Re-fitting the final EEM to the full dataset allowed for more accurate estimation of the variance parameter, which quantifies both variability and uncertainty, manifested as prediction interval widths.

Table 7-16 lists the final mean trend variables and the estimated regression coefficients for each EEM, and Table 7-17 lists the final covariance parameter estimates for each EEM.

Table 7-16. Regression Coefficient Estimates for NH_3 EEMS

p	x_p	$\hat{\beta}_p$		
		I EEM	**IA EEM**	**IAC EEM**
0	Intercept	10.4845	10.3695	9.9947
1	*build*	2.3812	2.2340	2.5626
2	*birds*	3.0668	3.3263	3.0839
3	*avem*	14.9106	14.4635	16.5926
4	$avem^2$	1.4911	1.1737	2.6695
5	$avem^3$	-3.4083	-3.4425	-4.0508
6	*buildavem*	-4.7227	-4.4761	-5.0093
7	$buildavem^2$	-1.0359	-0.7518	-1.1414
8	$buildavem^3$	1.3166	1.3052	1.4978
9	*birdsavem*	-0.8076	-0.09837	-1.0318
10	$birdsavem^2$	-1.7600	-1.5965	-2.0927
11	$birdsavem^3$	0.8944	0.6744	0.7855
12	*ta*	-	1.6982	1.1261
13	*ha*	-	0.3647	0.3841
14	*pa*	-	0.06279	-
15	*avemta*	-	1.2416	-0.5759
16	$avem^2ta$	-	0.1117	-1.0748
17	$avem^3ta$	-	0.02461	0.06863
18	*avemha*	-	0.3230	-0.1160
19	$avem^2ha$	-	0.1217	-0.3436
20	$avem^3ha$	-	0.06174	-0.06470
21	*avempa*	-	0.5491	-
22	$avem^2pa$	-	0.4662	-
23	$avem^3pa$	-	-0.01466	-
24	*tc*	-	-	1.9043
25	*hc*	-	-	0.02233
26	*avemtc*	-	-	2.7732
27	$avem^2tc$	-	-	0.5435
28	$avem^3tc$	-	-	-0.4688
29	*avemhc*	-	-	0.7263

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Table 7-16. Regression Coefficient Estimates for NH_3 EEMS

p	x_p	$\hat{\beta}_p$ I EEM	IA EEM	IAC EEM
30	$avem^2hc$	-	-	0.5292
31	$avem^3hc$	-	-	0.06077

Note: Each main effect variable was centered and scaled prior to creating higher-order terms and interactions.

Table 7-17. Covariance Parameter Estimates for Final NH_3 EEMs

Covariance Parameter	Covariance Parameter Estimate		
	I EEM	IA EEM	IAC EEM
$\hat{\rho}$	0.9232	0.9306	0.9414
$\hat{\sigma}^2$	14.6086	13.5434	14.0816

7.6 Producing Point and Interval Predictions

This section uses an example based on the I EEM to show how point (i.e., mean) and interval predictions of NH_3 emissions are obtained for a single confinement house on two separate days, using the values of the predictor variables available for each day. These two example days are also used to show how to obtain a point and interval prediction for the sum of two days. For the point prediction of the sum of the two days, the point predictions for each day are simply added. The prediction interval for the sum of the two days is calculated using the variances of each day, as will be demonstrated below. The method used to obtain point and interval predictions of the sum of emissions for an entire year or for multiple houses on the same farm are simply expansions of that used to get the sum of two days.

As an example, suppose that on day 15 of a given flock, the house contains 24,147 birds with average bird mass 0.41 kg, and suppose that on day 46 of the same flock, the house contains 23,795 birds with average bird mass 2.4 kg. Suppose this is the third flock introduced into the house since the last full litter cleanout. Table 7-18 summarizes the values of the predictor variables resulting from this information.

Table 7-18. Values of Predictor Variables for the Example Calculation

Day	*buildup*	*birds**	*avem**
15	3	24.147	0.41
46	3	23.795	2.4

Note: The unit of measure for *birds** is thousands of birds and the unit of measure for *avem** is kg. The asterisk (*) denotes that these are the centered and scaled values of the original predictor variables.

The values of the mean trend variables can now be obtained from the values of the predictor variables as follows.

- *build*: The mean trend variable *build* was chosen to be the functional form that represents the discrete predictor variable *buildup*. Whenever there is any buildup of litter in the house, the value of *build* = 1. Otherwise, the value of *build* = 0. For both days 15 and 46, *build* = 1.

- *birds*: The house contained 24,147 birds on day 15 and 23,795 on day 46, but because the EPA used thousands of birds as the unit of measure, *birds** = 24.147 and 23.795, respectively. To get the value of *birds*, this value must be centered and scaled by subtracting from it the "centering value" for *birds* and dividing by the "scaling value" for *birds*, both of which are in presented in Table 7-5. The results are 0.859 and 0.718, for days 15 and 46, respectively.

- *avem*: The values of *avem** must also be centered and scaled using the values in Table 7-5. The centered and scaled values for days 15 and 46 are -0.793 and 1.49, respectively.

- $avem^2$: These centered and scaled values are the squares of the values of *avem* and are equal to 0.629 and 2.23, for days 15 and 46, respectively.

- $avem^3$, etc: The centered and scaled values are the cubic values of *avem* and are equal to -0.499 and 3.34, for days 15 and 46, respectively. The values above for *build*, *birds* and *avem* can be used to obtain the remaining mean trend variables, the values of which are listed in Table 7-19.

Table 7-19. Values of Mean Trend Variables for Example Days 15 and 46

p	Name of x_p	Value of x_p		$\hat{\beta}_p$
		Day 15	Day 46	

Table 7-19. Values of Mean Trend Variables for Example Days 15 and 46

p	Name of x_p	Value of x_p		$\hat{\beta}$
0	Intercept	Not applicable	Not applicable	10.4845
1	*build*	1	1	2.3812
2	*birds*	0.859	0.718	3.0668
3	*avem*	-0.793	1.49	14.9106
4	$avem^2$	0.629	2.23	1.4911
5	$avem^3$	-0.499	3.31	-3.4083
6	*buildavem*	-0.793	1.49	-4.7227
7	$buildavem^2$	0.629	2.23	-1.0359
8	$buildavem^3$	-0.499	3.34	1.3166
9	*birdsavem*	-0.681	1.07	-0.8076
10	$birdsavem^2$	0.540	1.60	-1.7600
11	$birdsavem^3$	-0.428	2.40	0.8944

To obtain the point estimate for each day, the values of the mean trend variables (x_p) and the estimated regression coefficients from Table 7-16 are inserted into Equation 7-5.

$$\hat{Y} = \widehat{\beta_0} + \widehat{\beta_1}x_1 + \cdots + \widehat{\beta_{11}}x_{11} + \hat{e}$$ Equation 7-5

For the point prediction (i.e., the mean), the value of $\hat{e}$ is zero. Thus, the point estimates for NH_3 emissions for days 15 and 46 are, respectively, 7.97 kg and 22.8 kg. The point estimate for the sum of the two days is simply the sum of the two point estimates (7.97 kg + 22.8 kg = 30.77 kg).

The uncertainty in the predicted emissions values, $\hat{Y}$, can be expressed as the 95 percent prediction interval, which is calculated as $\hat{Y} \pm 1.96\, \widehat{se}(\hat{Y})$. The symbol $\widehat{se}(\hat{Y})$ represents the "estimated prediction standard error," which is the square root of the "estimated prediction error variance," denoted as $\hat{V}ar\,(\hat{Y})$. The estimated prediction error variance has two components, as shown in Equation 7-6 and Figure 7-16.

$$\hat{V}ar\left(\hat{Y}\right) = \hat{\sigma}^2 + \boldsymbol{x}^T\,\hat{\Omega}\boldsymbol{x}$$ Equation 7-6

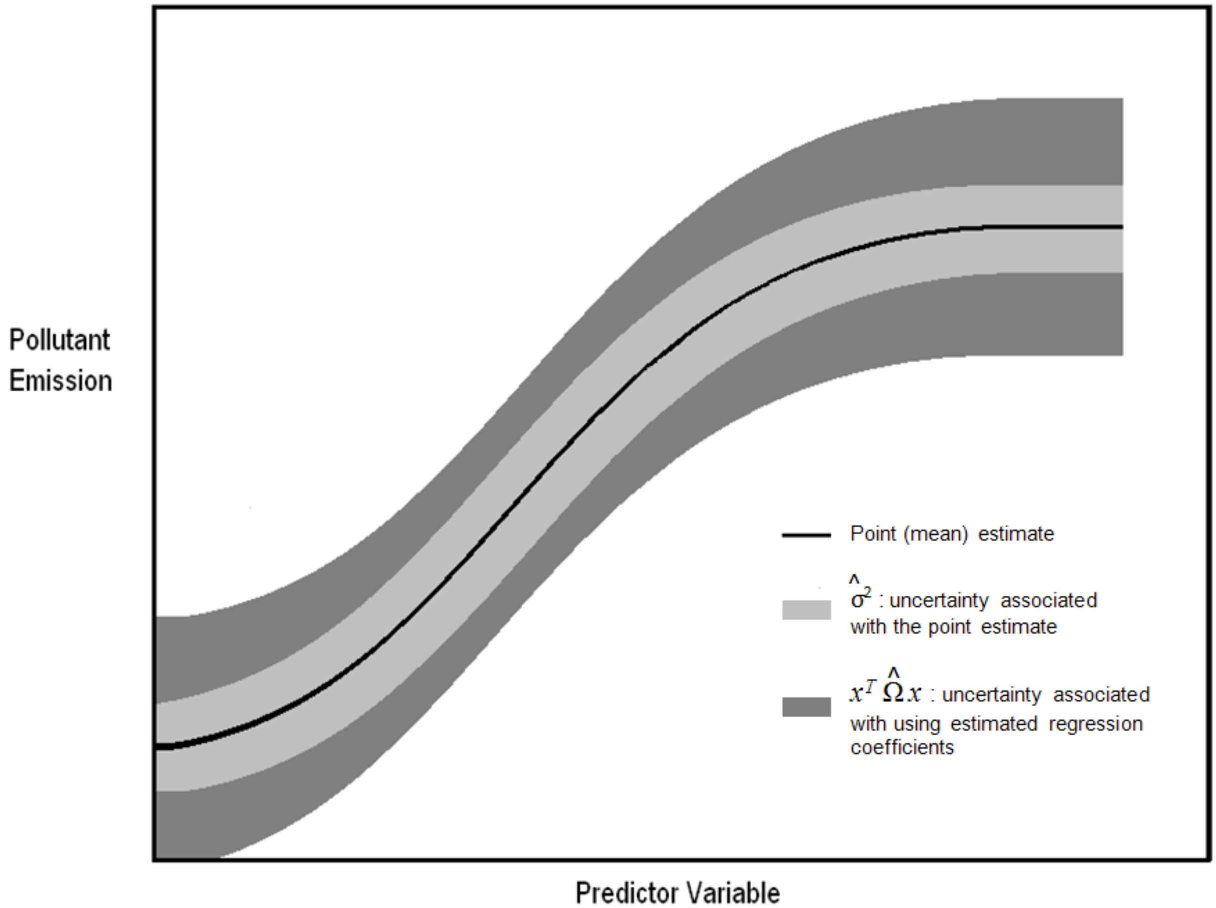


Figure 7-16. Illustration of the Relationship Between the Point Estimate and the Prediction Interval

The first component $\hat{\sigma}^2$, quantifies the uncertainty attributable to the deviation of emissions from the mean trend function. It is the estimated variance $\hat{\sigma}^2$, of the e_{ht}. The $\hat{\sigma}^2$ values for each EEM are presented in Table 7-17. For the I EEM, $\hat{\sigma}^2 = 14.6$.

The second component is the product of three terms, $\boldsymbol{x}^T\hat{\Omega}\boldsymbol{x}$. This component quantifies the uncertainty attributable to using estimated regression coefficients $\hat{\beta}_p$ in place of the true values β_p. The symbol $\boldsymbol{x}$ represents the 12×1 vector (column matrix) that contains the intercept (using 1 as a place holder) and the values of the 11 mean trend variables. The bold print indicates that $\boldsymbol{x}$ is a vector as opposed to a scalar (a single number). For the example of day 46, $\boldsymbol{x}^T$ = (1.0, 1.0, 0.72, 1.49, 2.23, 3.34, 1.07 1.60, 2.40). The symbol $\boldsymbol{x}^T$ represents the 1×12 transpose of this matrix. The matrix $\hat{\Omega}$ is the 12×12 covariance matrix for the intercept and regression coefficients, which are random variables. The covariance matrix accounts for the covariance of each mean trend term coefficient with the coefficient of every other mean trend term, and is standard output by software that produces regression coefficient estimates. Unlike the value of the first component, $\hat{\sigma}^2$ which is constant for a given EEM, the value of the second component varies for combinations of the predictor variables. The uncertainty is related to the number and range of data values available for developing the coefficient for a predictor variable. For example, if the number of NAEMS observations for a house with 20,000 birds is large and the range of emissions values was very narrow, the prediction interval at 20,000 birds will be relatively small. The prediction interval, therefore, will vary for different bird populations and for other mean trend terms (such as temperature if the IA EEM is used). Because the product $\boldsymbol{x}^T \hat{\Omega}\, \boldsymbol{x}$ includes values of the predictor variables, there also will be differing levels of certainty for different sets of inputs. For example, if the user enters as an input to the EEM an extreme value for *birds* relative to the mean value of *birds* in the NAEMS data that were used to develop the EEM, this component of the estimated prediction error variance would be relatively large. Using matrix multiplication, the product $\boldsymbol{x}^T \Omega \boldsymbol{x}$ for days 15 and 46 is respectively, 0.517 and 0.848.

The estimated prediction error variance for the two days can now be calculated as $\hat{\sigma}^2 + \boldsymbol{x}^T \hat{\Omega}\, \boldsymbol{x}$ = 14.6 + 0.517 = 15.1 kg^2 for day 15, and 14.6 + 0.848 = 15.4 kg^2 for day 46, where $\hat{\sigma}^2$ is from Table 7-16. The prediction standard errors are calculated as the square root of these values, such that $\widehat{se}(\hat{Y})$ = 3.89 kg and 3.93 kg, respectively. The 95 percent prediction interval for day 15 is calculated as 7.97 $\pm$ 1.96(3.89). Thus, the 95 percent confidence interval for NH_3 emissions for day 15 falls between 0.34 kg and 15.6 kg. Similarly, for day 46, the formula is 22.8 $\pm$ 1.96(3.93) and results in a 95 percent confidence interval of between 15.1 kg and 30.5 kg.

The point estimate for the sum of the emissions on days 15 and 46 is obtained by adding the two point estimates, which yields 30.77 kg. To obtain the lower (or upper) bound of the 95 percent prediction interval for the sum of daily emissions, however, it is not appropriate to add the two lower (or upper) bounds. Instead, the estimated prediction error variance of the sum of the two days is calculated as the sum of the prediction error variances for the two days, plus the estimated covariance between the two days. The covariance is calculated from the second line of Equation 7-1 using $\hat{\sigma}^2$ and $\hat{\rho}$: $Cov(\hat{Y}_{15}, \hat{Y}_{46}) = \hat{\sigma}^2\, \hat{\rho}^{46-15}$ =14.6(0.9232)^{31} = 1.23.

Therefore, for the example, the estimated prediction error variance for the sum of day 15 and day 46 is 15.1 + 15.4 + 1.23 = 31.73 kg^2. The square root of this value (5.63 kg) is the prediction standard error for the sum of days 15 and 46. The 95 percent prediction interval is calculated as 30.77 $\pm$ 1.96(5.63). Thus, the 95 percent confidence interval for the sum of NH_3 emissions on days 15 and 46 has a lower bound of 19.7 kg and an upper bound of 41.8 kg.

8.0 RESULTS OF GROW-OUT PERIOD EEM DEVELOPMENT

This section describes the development of the grow-out period EEMs for H_2S, PM_{10}, $PM_{2.5}$, TSP and VOCs. The EEMs for each pollutant were developed using the methodology discussed in Section 7. Sections 8.1 through 8.5 present the development of the EEMs for H_2S, PM_{10}, $PM_{2.5}$, TSP and VOCs, respectively. These sections summarize the decisions regarding the functional forms of the predictor variables, interaction terms included as candidate mean trend variables, selection of final mean trend variables, and the final form of the EEMs. For those components of the EEMs not discussed in detail in this section (e.g., the covariance function), the decision-making process and final decisions regarding the functional form were the same as those presented in Section 7.

8.1 EEMs for H_2S

8.1.1 Selecting Datasets

Table 8-1 shows the H_2S emissions observations available for each monitoring site after exclusion of the negative emissions and the records where the bird inventory remained constant over consecutive days late in the grow-out period (see Section 7.1). For example, the total number of grow-out period days for site CA1B H10 is 642 and the number of days for which an H_2S emissions value is available is 499. Therefore, the H_2S data availability is approximately 78 percent.

Of the 1,463 H_2S emissions values available, 68 lacked at least one of the inventory, ambient or confinement predictor variables needed for EEM development. After these missing data records were removed, the full dataset available for developing the H_2S EEMs consisted of 1,395 observations.

As one means of evaluating EEM performance, the EPA used fit statistics based on a cross-validation dataset (see Section 7.1.2). The EPA ultimately randomly withheld 266 (approximately 19 percent) of the 1,395 observations in the full dataset to serve as the cross-validation dataset.

Table 8-1. Data Completeness for H_2S EEMs

Season	Description	CA1B		KY1B-1	KY1B-2	All Houses
		House 10	House 12	House 5	House 3	
All seasons	Number of grow-out days	642	647	288	267	1,844
	Days H_2S data available	499	501	260	203	1,463
	Percent complete	78%	77%	90%	76%	79%
Winter	Number of grow-out days	150	153	87	74	464
	Days H_2S data available	141	146	80	72	439
	Percent complete	94%	95%	92%	97%	95%
Spring	Number of grow-out days	157	158	83	55	453
	Days H_2S data available	134	134	82	19	369
	Percent complete	85%	85%	99%	35%	81%
Summer	Number of grow-out days	156	157	55	74	442
	Days H_2S data available	148	146	35	53	382
	Percent complete	95%	93%	64%	72%	86%
Fall	Number of grow-out days	179	179	63	64	485
	Days H_2S data available	76	75	63	59	273
	Percent complete	42%	42%	100%	92%	56%

8.1.2 Choosing the Probability Distribution

The EPA first evaluated the empirical distribution (i.e., histogram) of the observed H_2S daily emissions to determine whether using the normal distribution was appropriate (see Section 7.2). The histogram in Figure 8-1 shows that many of the H_2S observations correspond to lower emissions values, with a single peak at emissions values less than 15 g. Also, the figure shows that the number of observations decreases as emissions increase. Based on this histogram, the EPA determined that the empirical distribution was unimodal (single-peaked) and skew right.

The EPA separated the base dataset into bins according to values of average bird mass. Figure 8-2, for example, shows histograms of H_2S emissions within the following six evenly distributed bins of average bird mass (*avem**) values (in kg): 0.0 to 0.5, 0.5 to 1.0, 1.0 to 1.5, 1.5 to 2.0, 2.0 to 2.5 and 2.5 to 3.0. The figure shows that the histograms for bins 1, 2 and 3 are skew right while those for bins 4, 5 and 6 are symmetric. Further disaggregation according to the values of other variables shows a variety of empirical distributions for different sets of conditions, and the skew-right pattern was by no means a consistent pattern. There are not enough observations under any specific set of conditions (e.g., bird mass and range of humidity) to use the empirical distribution to determine the true distribution. Therefore, in the absence of strong evidence against doing so, the EPA used the normal distribution.

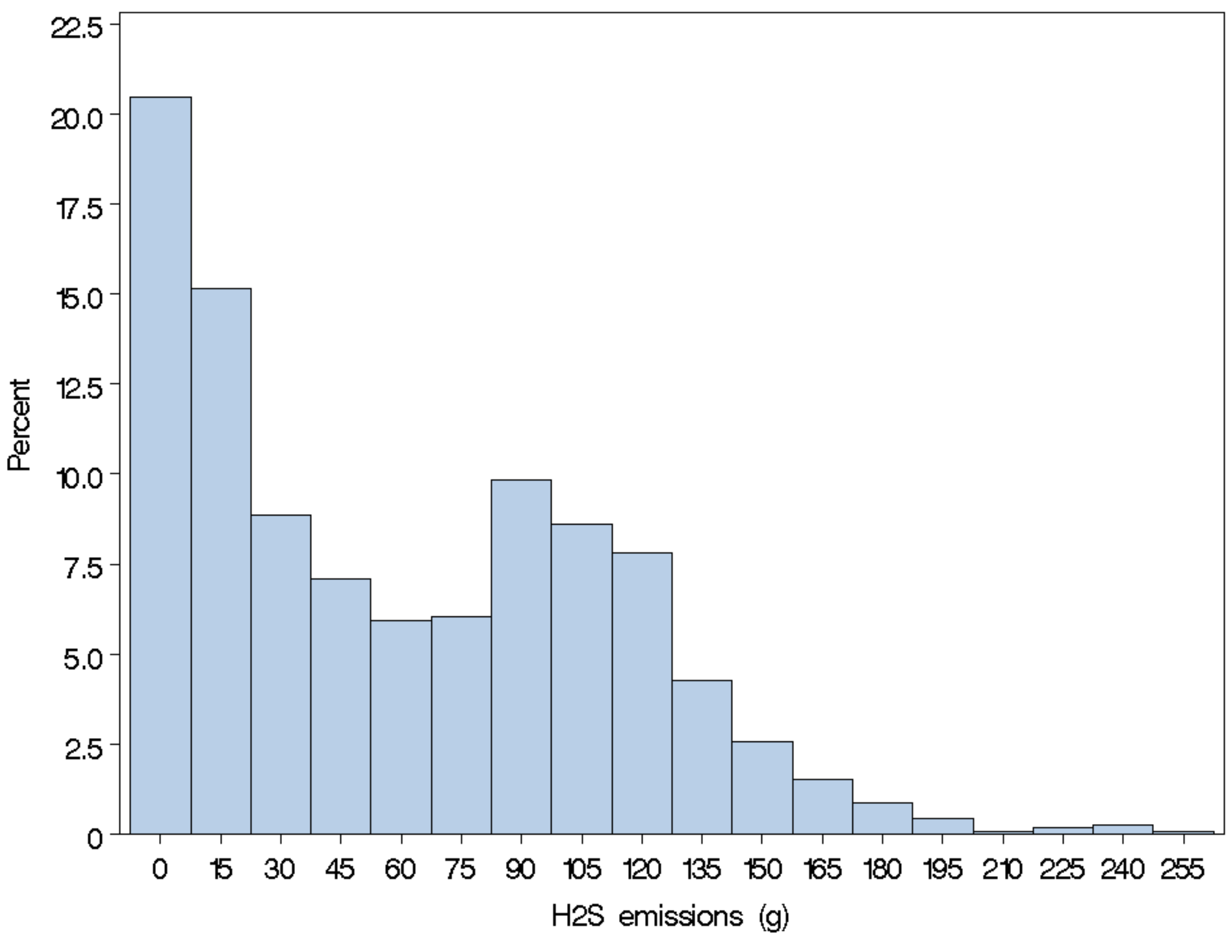


Figure 8-1. Histogram of H_2S Emissions in the Base Dataset

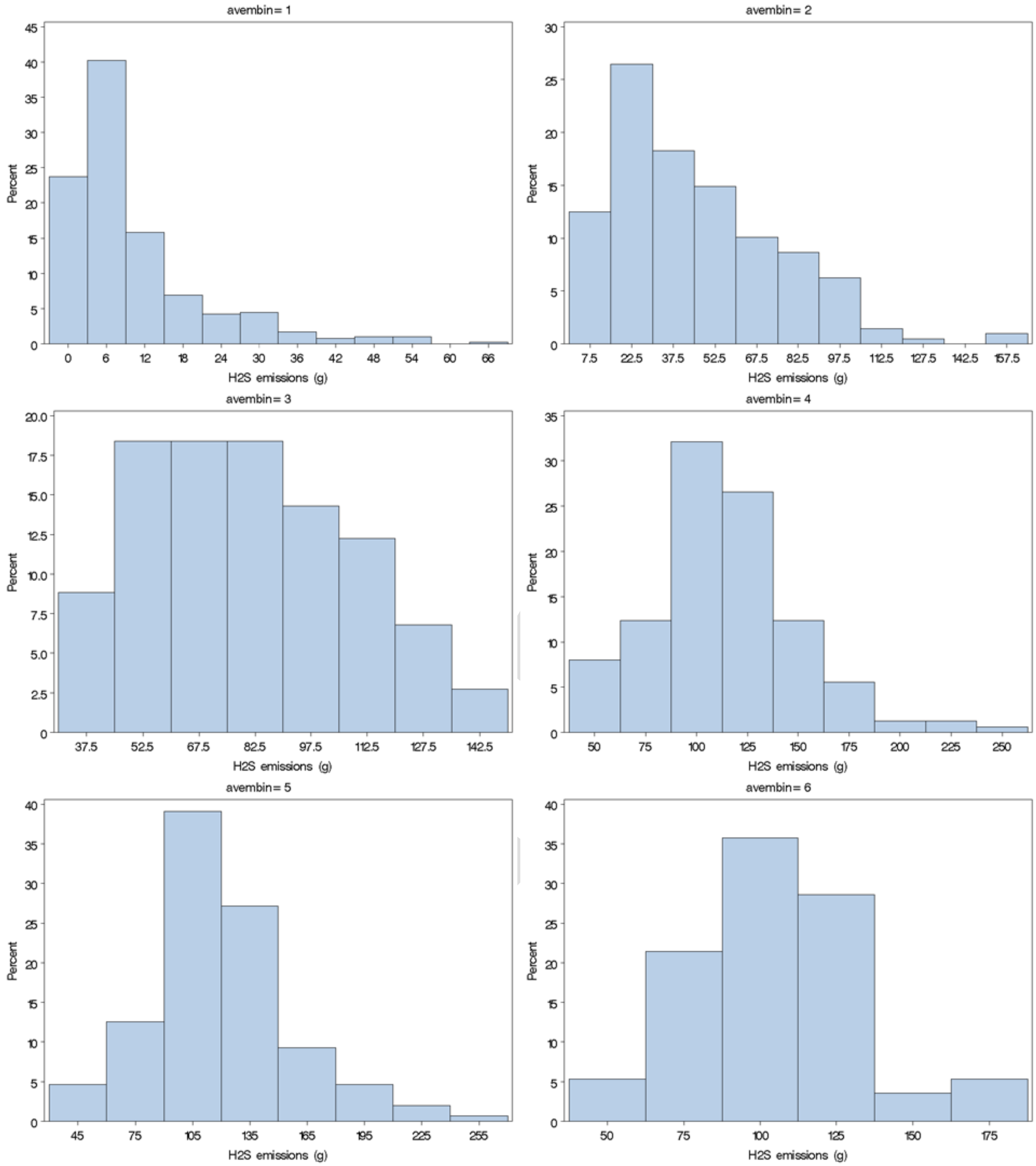


Figure 8-2. Histograms of H_2S Emissions by *avem Bins**

8.1.3 Developing Candidate Mean Trend Variables for H_2S

8.1.3.1 *Choosing Predictor Variable Functional Forms*

The plot of H_2S emissions for all houses display a flattened "S" shape over the grow-out period. The plot of H_2S emissions versus average mass for all flocks is shown in Figure 8-3. To provide a reference for determining the functional form, the figure also depicts overlays of the linear, quadratic, and cubic regressions. The "S" trend is not as obvious in the aggregated plot due to high variability, especially for higher average bird mass values. However, when the plots are disaggregated by house (Figure 8-4), the trend becomes more apparent, especially in the CA1B houses. It appears that the increased variance in KY1B-1 H5 seen in Figure 8-4 masks the curvature when all house and flocks are plotted together. The trend is further evident in all houses when the H_2S emissions are plotted versus average mass by flock (see Appendix F). Due to this curvature, the EPA determined that a cubic form of average mass was appropriate to characterize H_2S emissions.

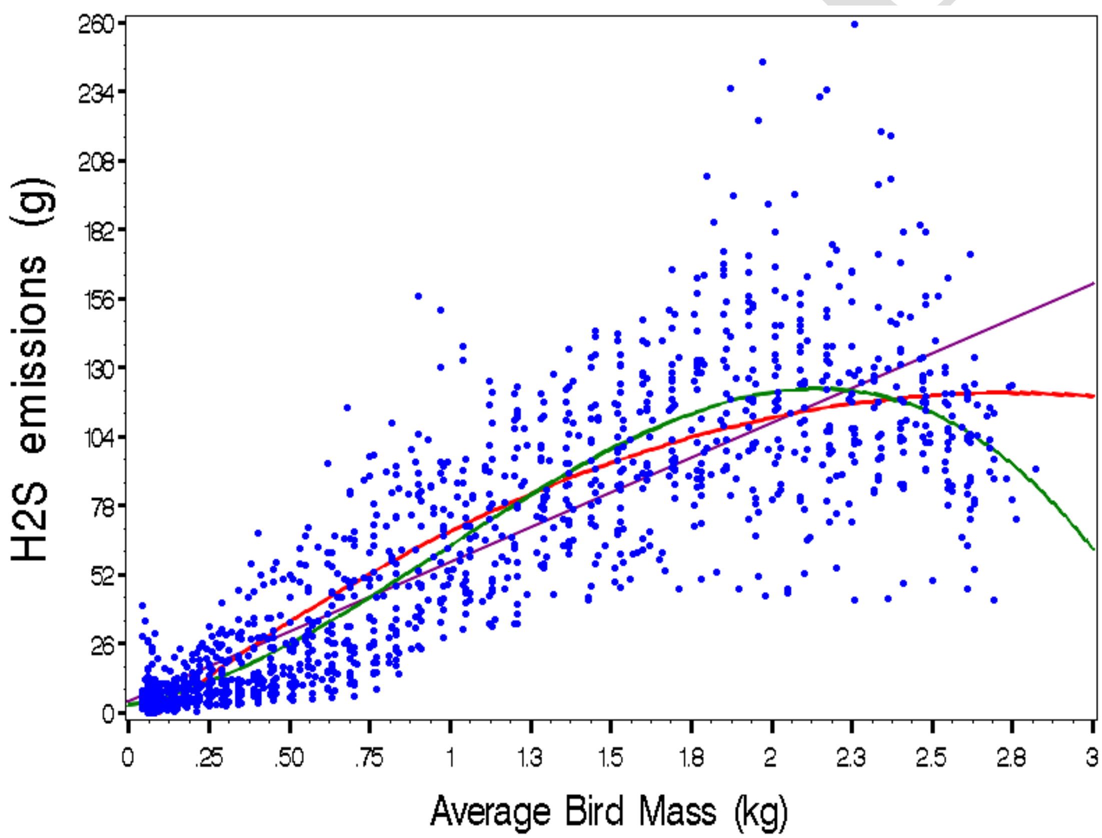


Figure 8-3. H_2S Emissions vs. Average Bird Mass (Regression Overlays: purple = linear, red = quadratic, green = cubic)

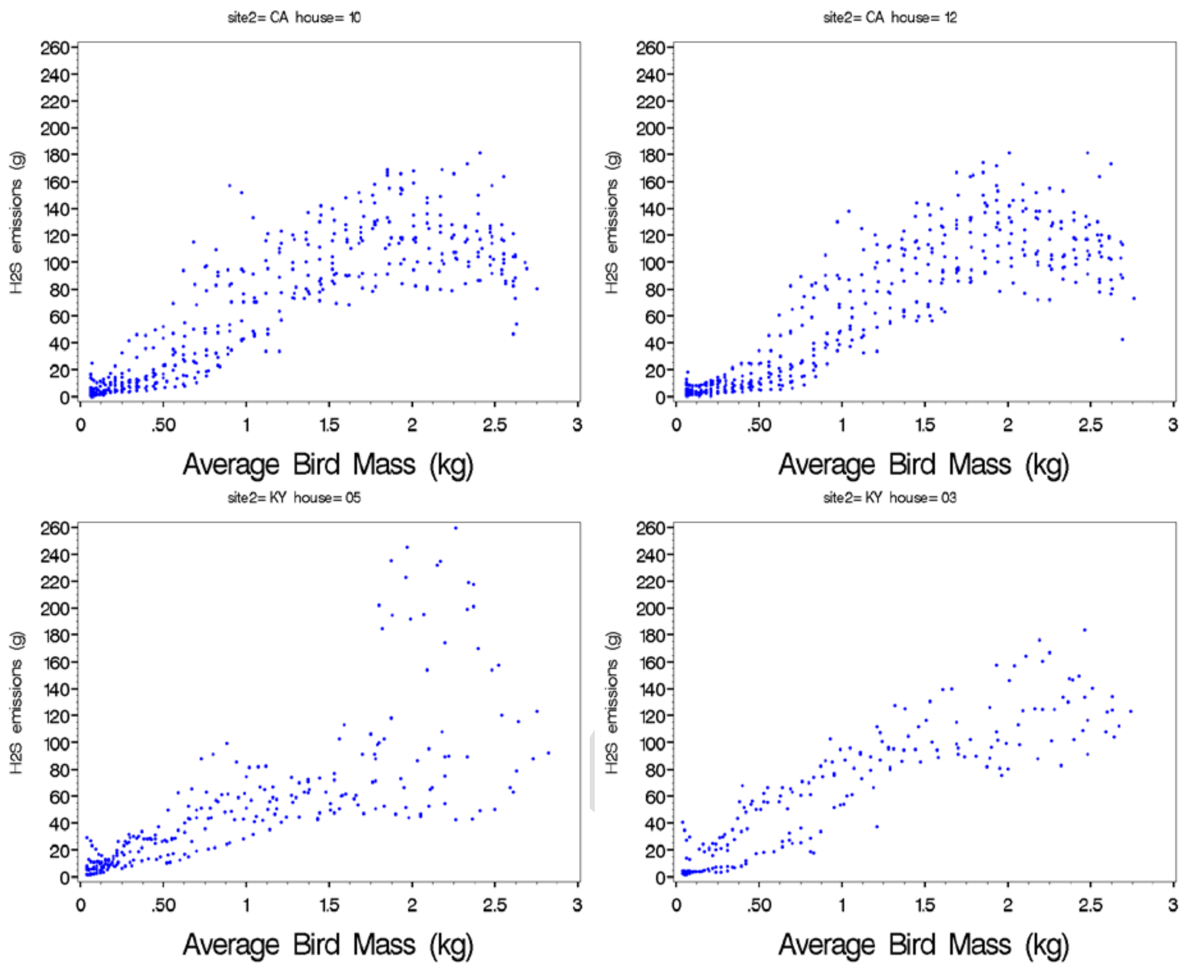


Figure 8-4. H_2S Emissions vs. Average Bird Mass, by House

With regard to the effect of accumulated litter (*buildup*) on H_2S emissions (see Section 7.3.1), the EPA did not discern a relationship between H_2S emissions and the degree of litter accumulation, based on a visual review of the data. The scatter plot of H_2S emissions versus average mass in Figure 8-5 shows very low variability in emissions during periods of low bird mass. The plot also shows that there is very little difference between the levels of litter condition, as the flocks of each *buildup* level are evenly distributed through the scatter plot. The EPA also created box plots (Figure 8-6) of the *buildup* variable to determine if the effect of accumulated litter should be included in the candidate mean trend variables for EEM development. The box plots, which depict the emissions for new bedding (*build* = 0) and any degree of accumulated litter (*build* = 1), show little difference in H_2S emissions when flocks were raised on new bedding or on built-up litter.

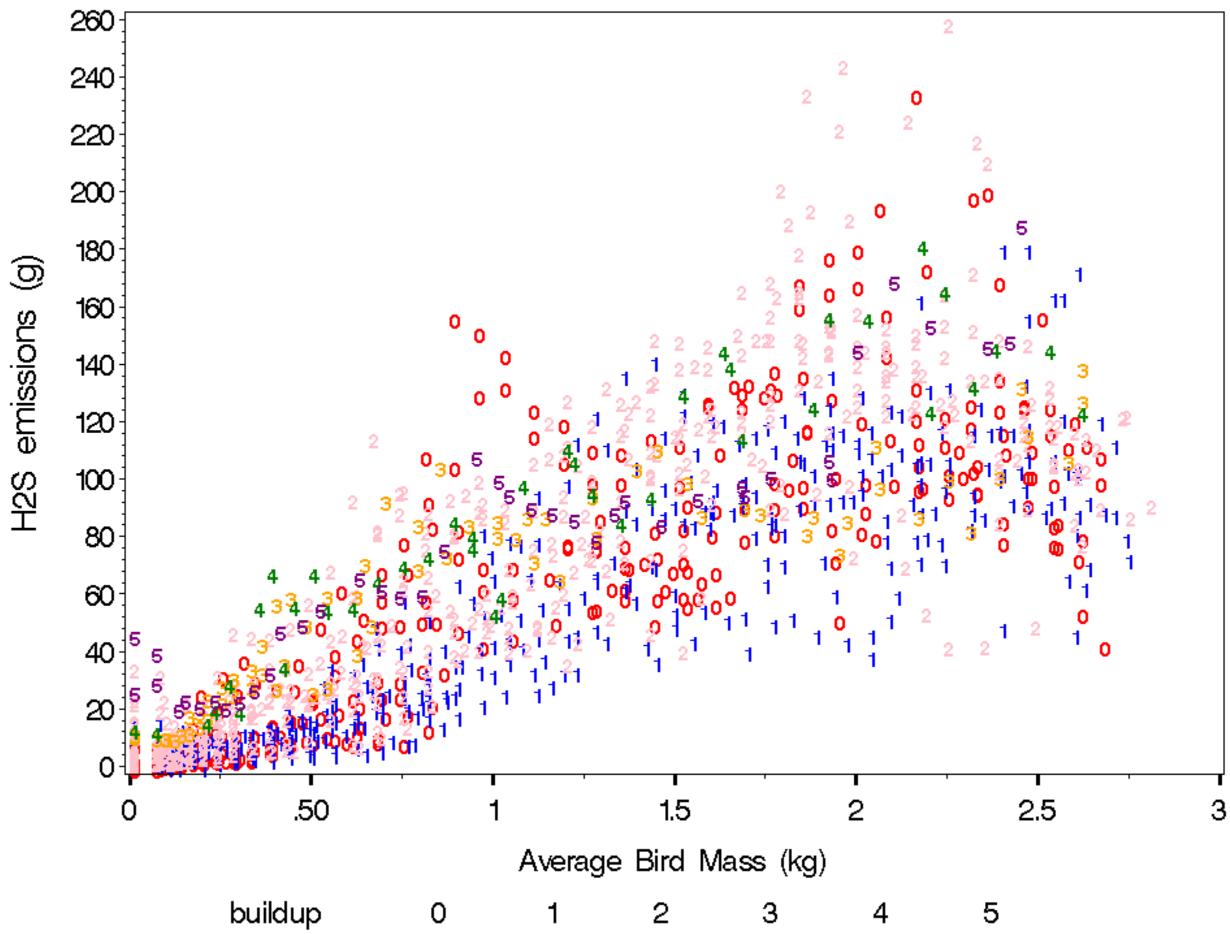


Figure 8-5. Overlay of *buildup* on H_2S Emissions vs. Average Live Bird Mass

Although the visual analysis of the data indicated that litter condition should not be included in the candidate mean trend, the EPA examined the effect of litter condition further by plotting emissions based on two additional build-up indicators: *build* and *bld*. As described in Section 7.3.1, these two indicators note how many flocks were raised on the litter since the previous full litter clean-out was conducted. Examining these box plots (Figure 8-6) shows that there is an increase in average H_2S emissions for flocks raised on litter that had been decaked and replenished for two or more grow-out periods. Therefore, the EPA used the variable *build*, which indicates the presence or absence of built-up litter, as the functional form through which the variable *buildup* entered the mean trend function.

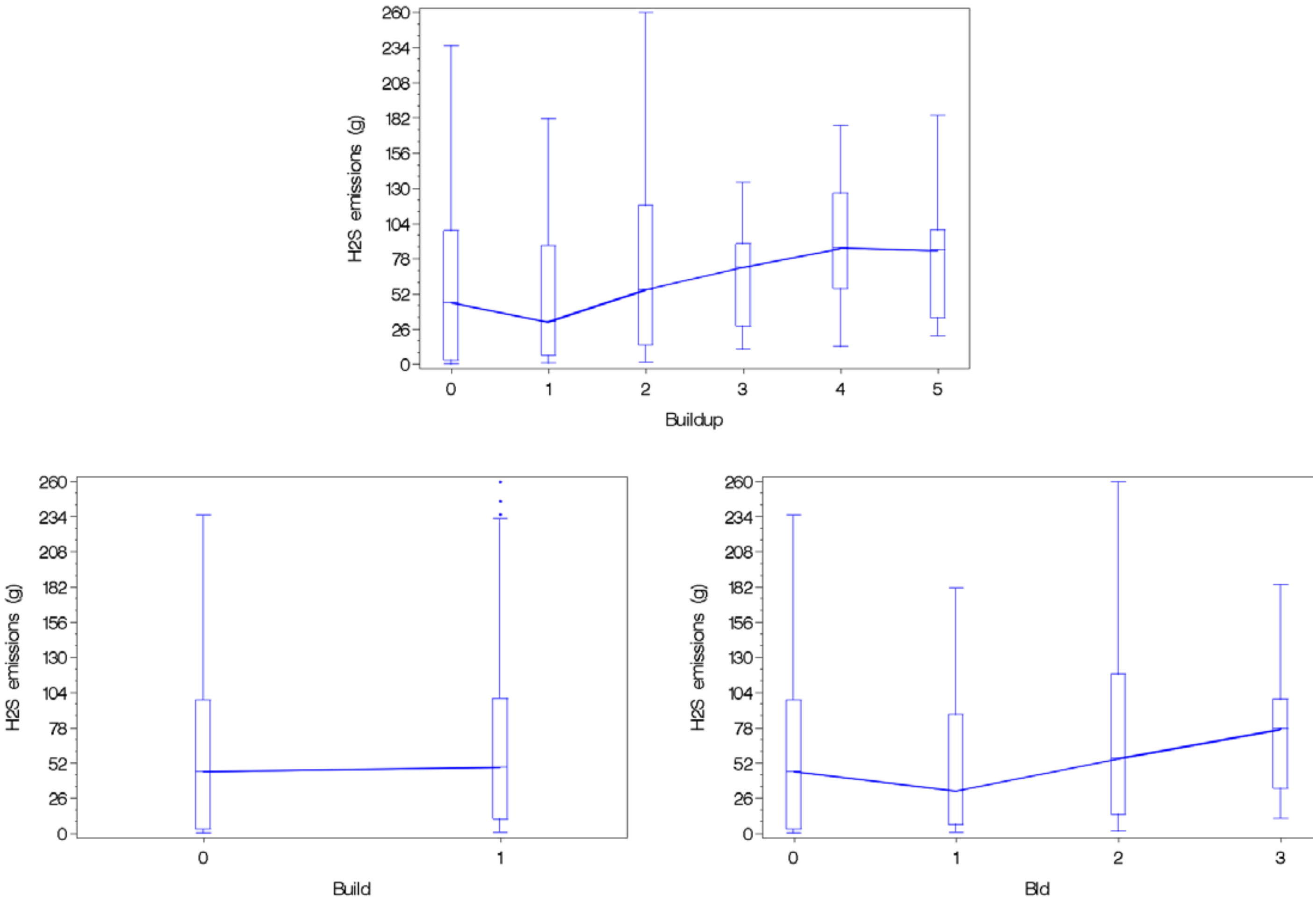
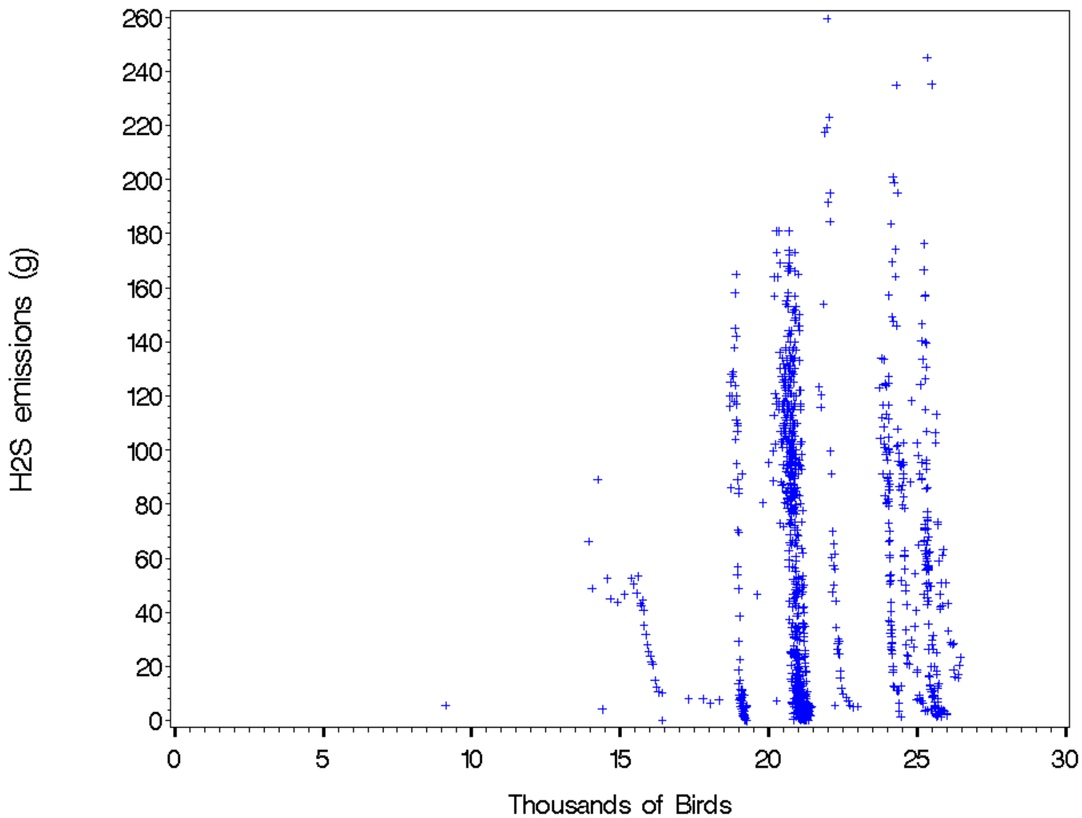


Figure 8-6. Box Plots of H_2S Emissions vs. Categorical Variables for *buildup*

Figure 8-7, Figure 8-8 and Figure 8-9 show the scatter plots of H_2S emissions by the remaining predictor variables (i.e., number of birds, ambient temperature, ambient relative humidity, ambient pressure, house temperature and house relative humidity). Appendix F contains scatter plots of the predictor variables by average animal mass bin. The plots do not indicate that the EPA should use a functional form other than linear. Based on this visual analysis, the EPA chose a linear functional form for all variables except average bird mass in developing the H_2S EEMs.



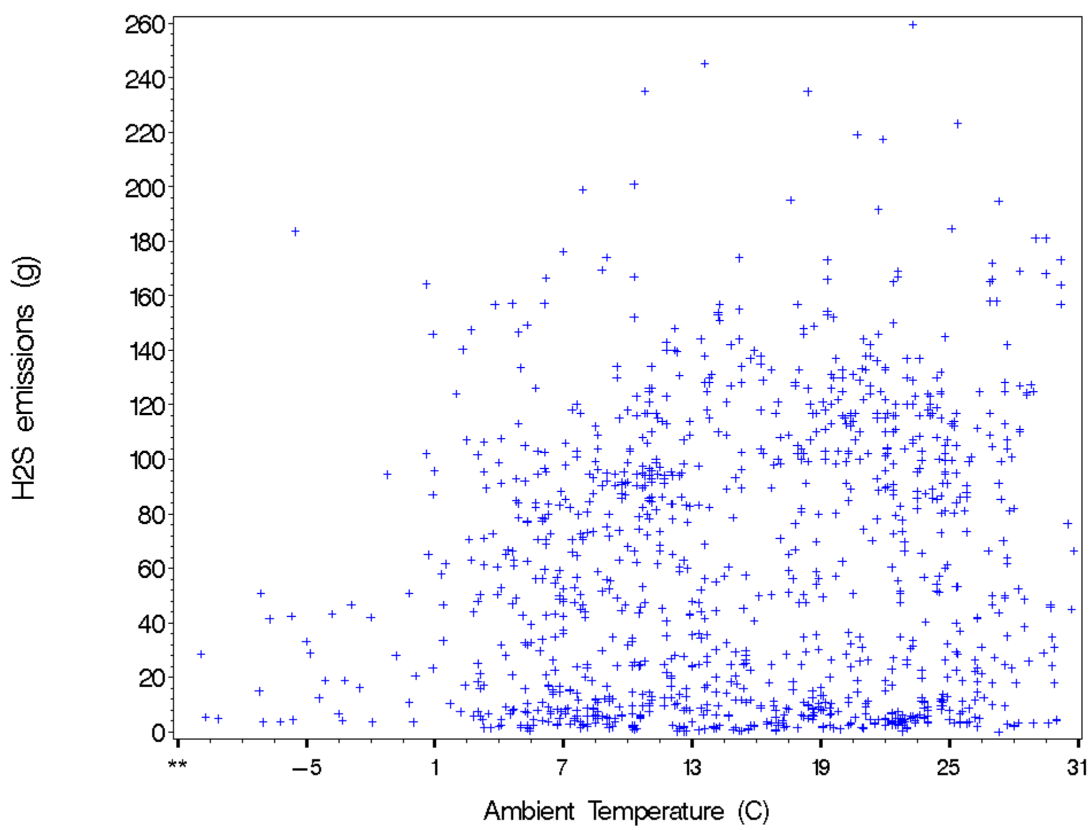
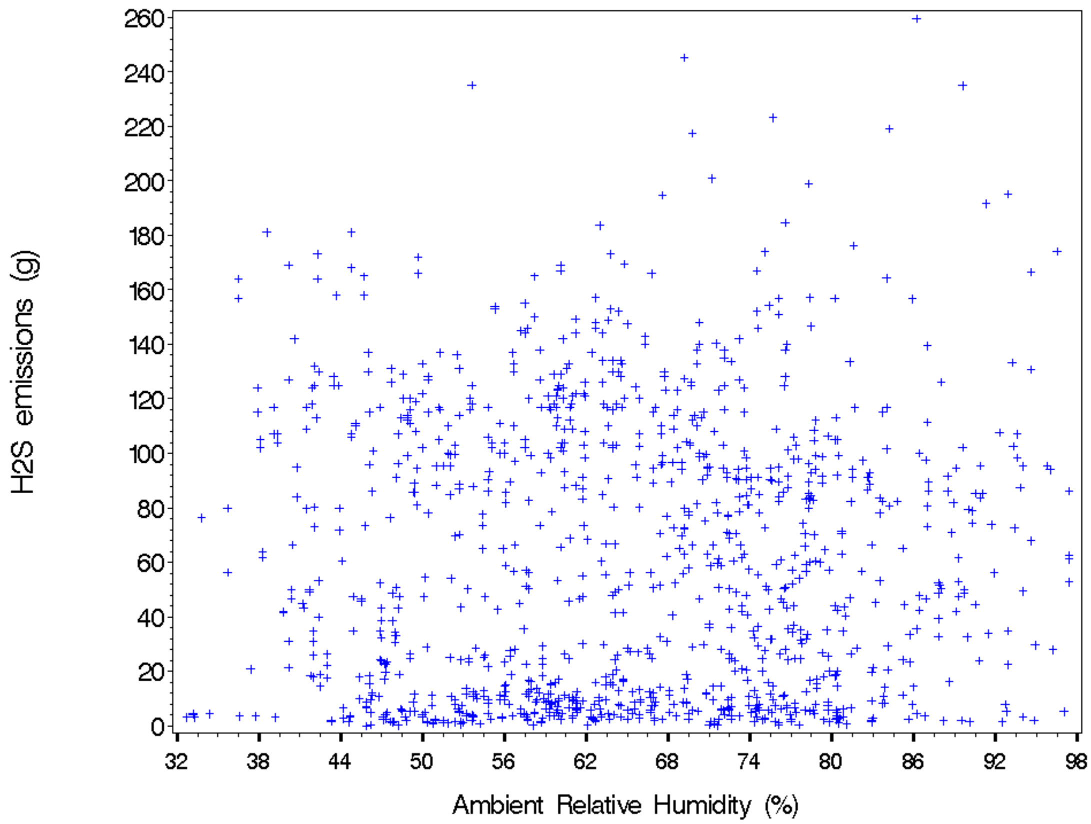


Figure 8-7. H_2S Emissions vs. Predictor Variables *birds and *ta***



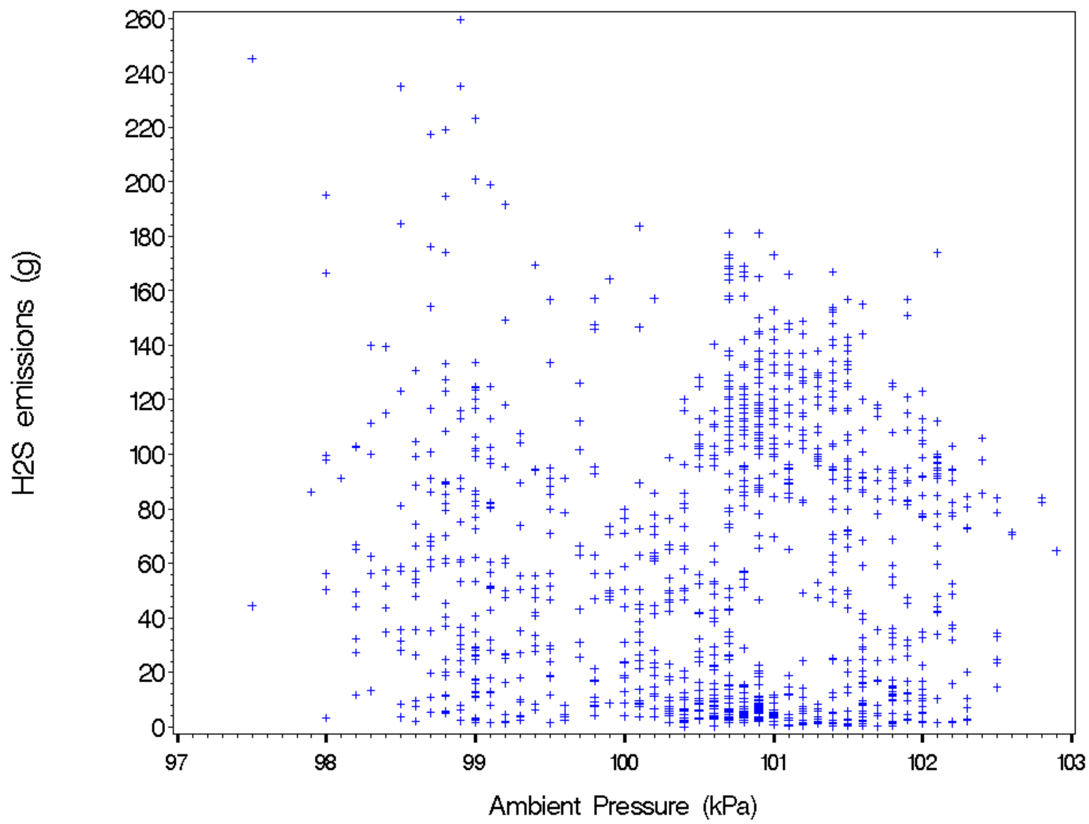


Figure 8-8. H_2S Emissions vs. Predictor Variables *ha and *pa***

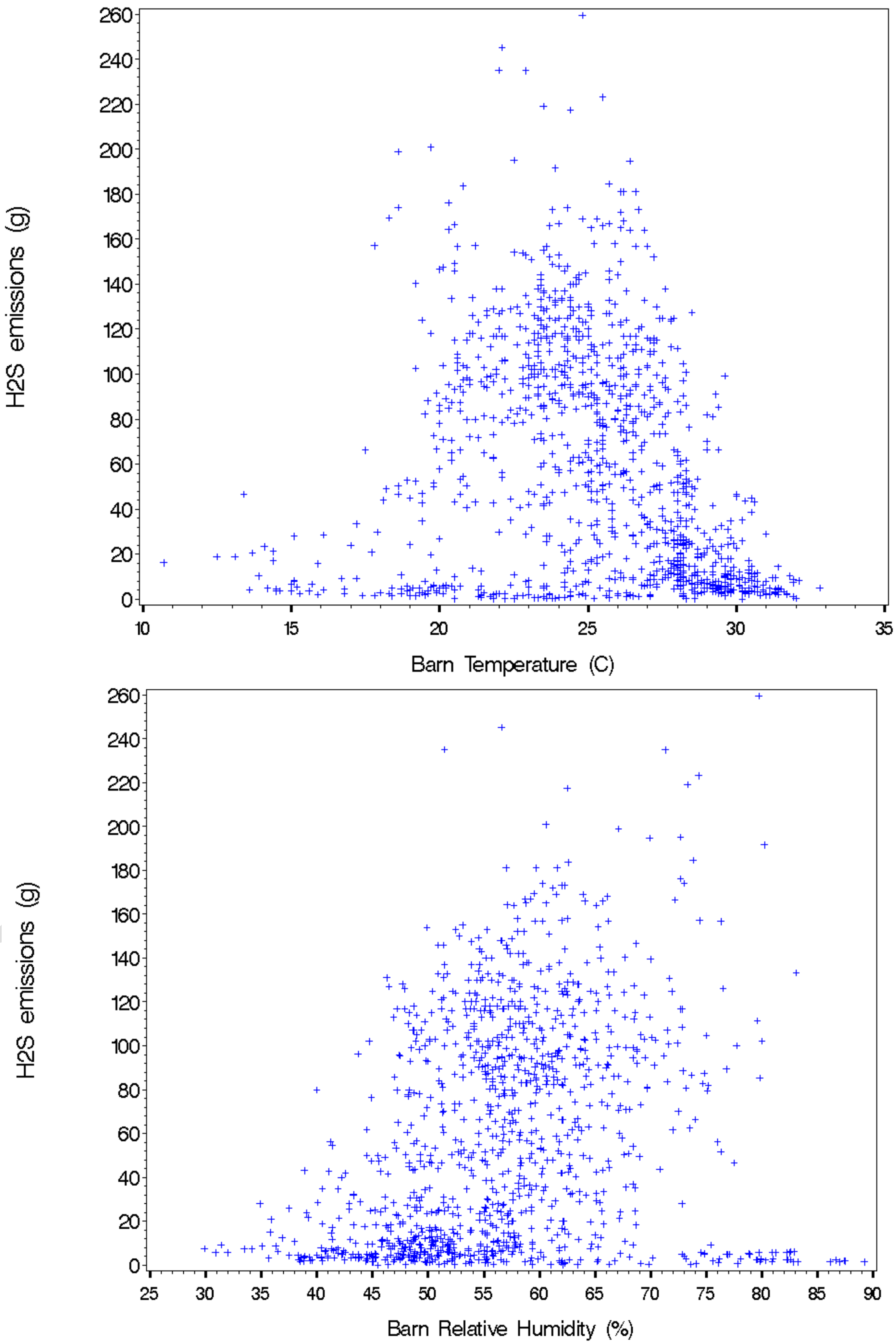


Figure 8-9. H_2S Emissions vs. Predictor Variables *tc and *hc***

Table 8-2 summarizes the mean trend variables that describe the dependence of H_2S emissions on the original predictor variables. The variables in column two were taken to be the main effect of the original predictors in column one of the table. For all predictors except *buildup* and *avem**, the mean trend variable was the same as the original variable. For *buildup*, the main effect was the indicator variable *build*. For *avem**, the linear, quadratic and cubic terms were collectively considered the main effect.

Table 8-2. Summary of Main Effect Mean Trend Variables for H_2S

Original Predictor Variable[a]	Main Effect Mean Trend Variable(s)
buildup	*build*
*birds**	*birds*
*avem**	$avem$, $avem^2$, $avem^3$
*ta**	*ta*
*ha**	*ha*
*pa**	*pa*
*tc**	*tc*
*hc**	*hc*

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1).

8.1.3.2 *Creating Mean Trend Variables from Main Effects and Interactions*

The EPA created interaction terms and determined what level of interactions (e.g., two-way, three-way) to include in the set of candidate mean trend variables of Table 8-2. Initial testing of the R^2 of two-way and three-way terms suggested that consideration of two-way interactions was appropriate for development of H_2S EEMs. The main effects and interaction terms for the three EEMs tested are presented in Table 8-3.

Table 8-3. Candidate Mean Trend Variables for the I, IA and IAC H_2S EEMs

EEM (Form)	Main Effects	Two-Way Interaction Terms
I, Cubic (I EEM_C)	*birds, build, avem,* $avem^2$, $avem^3$	*buildbirds, buildavem,* $buildavem^2$, $buildavem^3$, *birdsavem,* $birdsavem^2$, $birdsavem^3$
IA, Cubic (IA EEM_C)	Same as I EEM_C plus: *ta, ha, pa*	Same as I EEM_C plus: *buildta, buildha, buildpa, birdsta, birdsha, birdspa, avemta,* $avem^2ta$, $avem^3ta$, *avemha,* $avem^2ha$, $avem^3ha$, *avempa,* $avem^2pa$, $avem^3pa$, *taha, tapa, hapa*
IAC, Cubic (IAC EEM_C)	Same as IA EEM_C plus: *tc, hc*	Same as IA EEM_C plus: *buildtc, buildhc, birdstc, birdshc, avemtc,* $avem^2tc$, $avem^3tc$, *avemhc,* $avem^2hc$, $avem^3hc$, *tatc, tahc, hatc, hahc, patc, pahc, tchc*

8.1.3.3 *Centering and Scaling Predictors*

The EPA centered and scaled each continuous predictor variable prior to creating higher order terms and interaction terms by subtracting the mean of all observations in the base dataset from each value, then dividing by the standard deviation of the base dataset. The centering and scaling factors for the predictor variables for the H_2S final EEMs are presented in Table 8-4.

Table 8-4. Centering and Scaling Reference Values for Continuous H_2S Predictor Variables

Predictor Variable[a]	Centering Value	Scaling Value
*birds**	22	2.2
*avem**	1.0	0.83
*ta**	15	8
*ha**	65	14
*pa**	101	1.1
*tc**	25	3.7
*hc**	57	9.5

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1). Predictor variables are centered and scaled prior to the creation of higher-order terms (e.g., *eavem* or $avem^2$) and the creation of interaction terms (e.g., *avemta*).

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8.1.4 Selecting Final Mean Trend Variables for H_2S

Table 8-5 contains the final mean trend variables for the selected form of each EEM after backward elimination of mean trend variables (see Section 7.5). Table 8-6 shows the fit statistics for each EEM. A check mark (✓) in the column for γ_0 indicates that the estimate is not significantly different from zero at the α = 0.05 significance level, while an "x" indicates that it is significantly different from zero. Similarly, a check mark or an "x" in the column for γ_1 indicates whether the estimate is significantly different from one.

Table 8-5. Final I, IA and IAC EEM Mean Trend Variables for H_2S EEMs

EEM	Main Effects	Two-Way Interaction Terms
I	*build, birds, avem,* $avem^2$, $avem^3$	*buildbirds, buildavem,* $buildavem^2$, $buildavem^3$, *birdsavem,* $birdsavem^2$, $birdsavem^3$
IA	*build, birds, avem,* $avem^2$, $avem^3$, *ta, ha, pa*	*buildavem,* $buildavem^2$, $buildavem^3$, *buildpa, birdsta, birdsha, birdspa, avemta,* $avem^2ta$, $avem^3ta$, *avemha,* $avem^2ha$, $avem^3ha$, *avempa,* $avem^2pa$, $avem^3pa$, *taha, tapa, hapa*
IAC	*build, birds, avem,* $avem^2$, $avem^3$, *ta, ha, pa, tc, hc*	*buildavem,* $buildavem^2$, $buildavem^3$, *buildta, buildha, buildpa, buildtc, buildhc, birdspa, birdshc, avemta,* $avem^2ta$, $avem^3ta$, *avemtc,* $avem^2tc$, $avem^3tc$, *avemhc,* $avem^2hc$, $avem^3hc$, *hapa, tatc, tahc, hatc, tchc*

For all EEMs, the intercept, γ_0, was significantly different from 0 at the α = 0.05 significance level. For the IA EEM, the slope, γ_1, was significantly different from 1. These differences in γ_0 and γ_1 from 0 and 1 may indicate systematic bias, but the phrase "significantly different" refers to statistical significance, which is not the same as practical significance. The estimates of γ_0 and γ_1 mean that the relationship between the value of H_2S emissions, Y_{ht}, in the cross-validation data to the point prediction produced by the EEM, $\hat{Y}_{ht}$, is given by $Y_{ht} = \gamma_0 + \gamma_1 \hat{Y}_{ht}$. Using the IA EEM as an example, this relationship is $Y_{ht} = 6.4 + 0.94\hat{Y}_{ht}$. That means that instead of the H_2S emissions being equal to the point prediction, on average, they are equal to 6.4 grams plus 0.94 times the prediction of them. The practical significance of adding 6.4 grams is small, and it is offset by the fact that the multiplier 0.94 is less than 1, which reduces the predicted value of emissions.

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Table 8-6. Final I, IA and IAC EEM Fit Statistics for H_2S

EEM	Fit Statistics							
	-2LL	BIC	% in PI	Width (g)	RMSE (g)	R^2	γ_0 (g)	γ_1
I	9,143	9,152	98	91	23	0.80	4.7 x	1.0 ✓
IA	8,945	8,954	97	89	23	0.80	6.4 x	0.94 x
IAC	8,759	8,767	95	85	23	0.80	6.3 x	0.95 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the $\alpha = 0.05$ significance level.

8.1.5 Summary of Final Results for the I, IA and IAC EEMs for H_2S

The covariance parameters for the final EEMs are listed in Table 8-7. The coefficients for the EEM mean trend variables are listed in Table 8-8. The value of each main effect variable (x_p) must be centered and scaled when using these terms in Equation 7-1. The centering and scaling constants for the predictor variables of the H_2S EEMs are presented in Table 8-4.

Table 8-7. Covariance Parameters for Final H_2S EEMs

Covariance Parameter	Estimate		
	I	IA	IAC
$\hat{\rho}$	0.8628	0.8683	0.8876
$\hat{\sigma}^2$	577.84	534.28	522.84

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Table 8-8. Regression Coefficients for Final H_2S EEMs

p	x_p	$\hat{\beta}_p$			p	x_p	$\hat{\beta}_p$		
		I	IA	IAC			I	IA	IAC
0	*Intercept*	56.75	55.23	51.53	24	*avemta*	a	14.54	1.15
1	*birds*	2.85	1.31	1.04	25	$avem^2ta$	a	2.97	-0.35
2	*build*	4.36	5.43	5.43	26	$avem^3ta$	a	-5.18	-2.95
3	*avem*	64.99	69.23	73.93	27	*avemha*	a	4.83	a
4	$avem^2$	0.71	1.89	9.44	28	$avem^2ha$	a	-0.34	a
5	$avem^3$	-11.95	-14.43	-14.80	29	$avem^3ha$	a	-0.57	a
6	*ta*	a	8.03	-2.25	30	*avempa*	a	8.46	a
7	*ha*	a	5.61	-2.36	31	$avem^2pa$	a	0.28	a
8	*pa*	a	0.24	-3.84	32	$avem^3pa$	a	-4.14	a
9	*tc*	a	a	15.09	33	*taha*	a	1.52	a
10	*hc*	a	a	10.58	34	*tapa*	a	-0.91	a
11	*buildbirds*	-0.32	a	a	35	*hapa*	a	0.16	-0.16
12	*buildavem*	-0.45	-1.35	-3.72	36	*avemtc*	a	a	18.41
13	$buildavem^2$	1.86	0.95	0.99	37	$avem^2tc$	a	a	3.13
14	$buildavem^3$	0.65	0.82	2.15	38	$avem^3tc$	a	a	-1.99
15	*buildta*	a	a	2.87	39	*avemhc*	a	a	9.12
16	*buildha*	a	a	2.28	40	$avem^2hc$	a	a	0.06
17	*buildpa*	a	3.70	4.70	41	$avem^3hc$	a	a	-1.41
18	*birdsavem*	-4.04	a	a	42	*birdshc*	a	a	-0.32
19	$birdsavem^2$	-1.03	a	a	43	*buildhc*	a	a	-2.23
20	$birdsavem^3$	3.36	a	a	44	*buildtc*	a	a	-1.85
21	*birdsta*	a	-3.35	a	45	*tahc*	a	a	1.77
22	*birdsha*	a	0.07	a	46	*tatc*	a	a	0.82
23	*birdspa*	a	-1.25	-0.71	47	*hatc*	a	a	1.04
					48	*tchc*	a	a	-0.84

Note: Each main effect variable was centered and scaled prior to creating higher-order terms and interactions.
[a] This mean trend variable is not included in the EEM.

8.2 EEMs for PM_{10}

8.2.1 Selecting Datasets

Data was available for PM_{10} was 66 percent of the grow-out period days (Table 8-9). Particulate matter was monitored on a rotating schedule at the CA1B houses, which limited the number of PM_{10} observations collected at that site. Table 8-9 shows that PM_{10} emissions values were available for just over 50 percent of the time for the CA1B houses. The Kentucky sites had better completeness with seasonal completeness ranging from 84 to 98 percent. The available data are evenly distributed across the seasons.

Of the 1,219 PM_{10} emission readings, 45 did not have values for the inventory, ambient and confinement predictor variables necessary for the EEM development. After these data records were removed, the base dataset for PM_{10} EEM development consisted of 1,174 records. The EPA then randomly withheld 233 observations (approximately 20 percent of the 1,174 observations) to serve as the cross-validation dataset.

Table 8-9. Data Completeness for PM_{10} EEMs

Season	Description	CA1B		KY1B-1	KY1B-2	All Houses
		House 10	House 12	House 5	House 3	
All seasons	Number of grow-out days	642	647	288	267	1,844
	Days PM_{10} data available	333	365	274	247	1,219
	Percent complete	52%	56%	95%	93%	66%
Winter	Number of grow-out days	150	153	87	74	464
	Days PM_{10} data available	80	92	83	68	323
	Percent complete	53%	60%	95%	92%	70%
Spring	Number of grow-out days	157	158	83	55	453
	Days PM_{10} data available	72	109	77	46	304
	Percent complete	46%	69%	93%	84%	67%
Summer	Number of grow-out days	156	157	55	74	442
	Days PM_{10} data available	101	89	52	70	312
	Percent complete	65%	57%	95%	95%	71%
Fall	Number of grow-out days	179	179	63	64	485
	Days PM_{10} data available	80	75	62	63	280
	Percent complete	45%	42%	98%	98%	58%

8.2.2 Choosing the Probability Distribution for PM_{10}

The EPA first evaluated the empirical distribution (i.e., histogram) of the observed PM_{10} daily emissions to determine whether using the normal distribution could be justified. The histogram in Figure 8-10 shows that many of the PM_{10} observations correspond to lower values, with a single peak at emissions values less than 0.3 kg. Also, the figure shows that the number of observations decreases as emissions increase. Based on this histogram, the EPA determined that the empirical distribution was unimodal (single-peaked) and skew right.

The EPA separated the base dataset into bins according to values of average bird mass. Figure 8-11, for example, shows histograms of PM_{10} emissions within the following six evenly distributed bins of average bird mass (*avem**) values (in kg): 0.0 to 0.5, 0.5 to 1.0, 1.0 to 1.5, 1.5 to 2.0, 2.0 to 2.5 and 2.5 to 3.0. The figure shows that the histograms for bins 1, 2 and 5 are skew right while those for bins 3, 4 and 6 are symmetric. Further disaggregation according to the values of other variables shows a variety of empirical distributions for different sets of conditions, and the skew-right pattern is by no means ubiquitous. There are not enough observations under any specific set of conditions (e.g., bird mass and humidity) to use the empirical distribution to determine the true distribution. Therefore, in the absence of strong evidence against doing so, the EPA used the normal distribution.

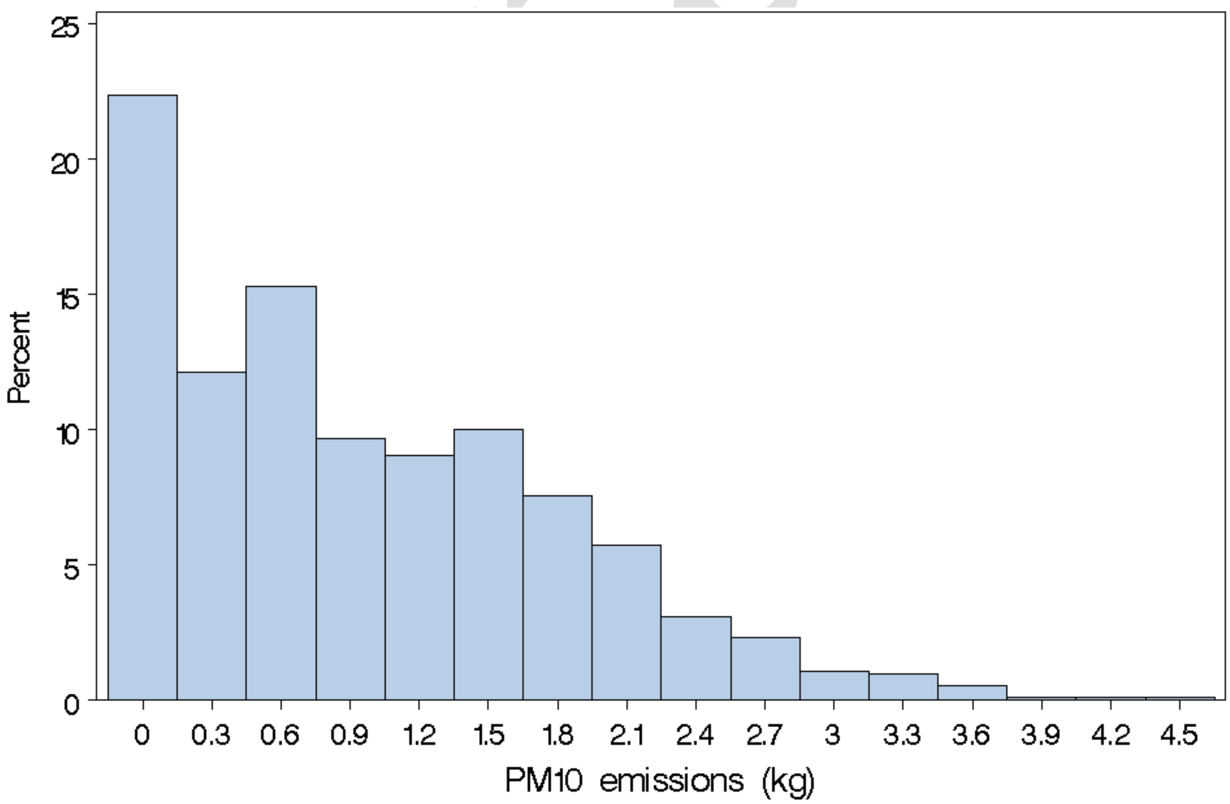


Figure 8-10. Histogram of PM_{10} Emissions in the Base Dataset

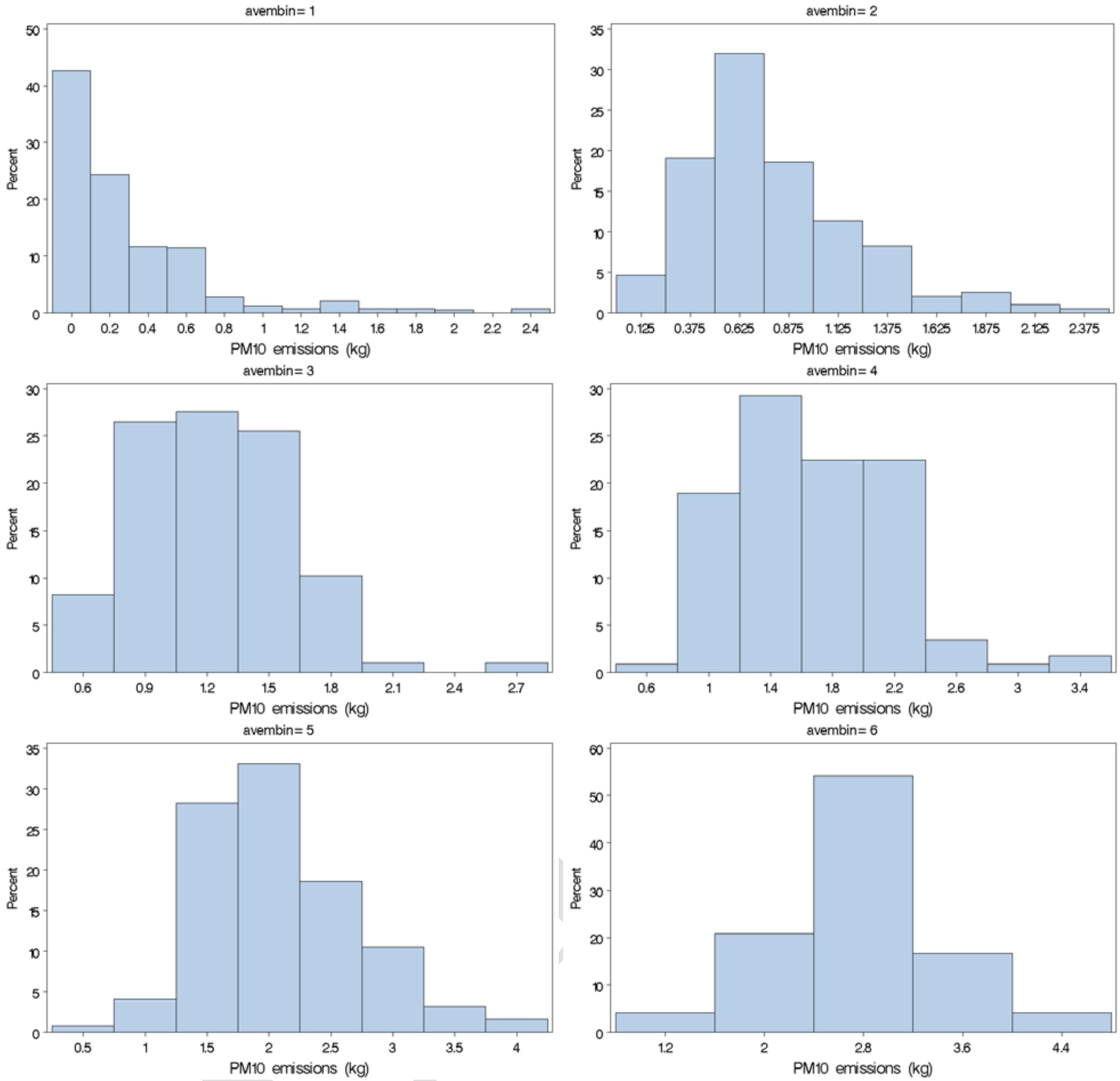


Figure 8-11. Histograms of PM_{10} Emissions by *avem Bins**

8.2.3 Developing Candidate Mean Trend Variables for PM_{10}

8.2.3.1 Choosing Predictor Variable Functional Forms for PM_{10}

Plots of PM_{10} emissions versus average bird mass, for all houses, suggested a positive relationship, with a slight upward curvature. Figure 8-12 shows a scatter plot of PM_{10} emissions versus average mass, with overlays of linear, quadratic and cubic regressions. The gradual increasing trend suggested either a quadratic or exponential relationship between PM_{10} emissions and average bird mass. Accordingly, the EPA tested two forms of the EEMs: an EEM based on a quadratic relationship with average mass (*avem and avem*^{2}), and an EEM based on an exponential relationship (*eavem*).

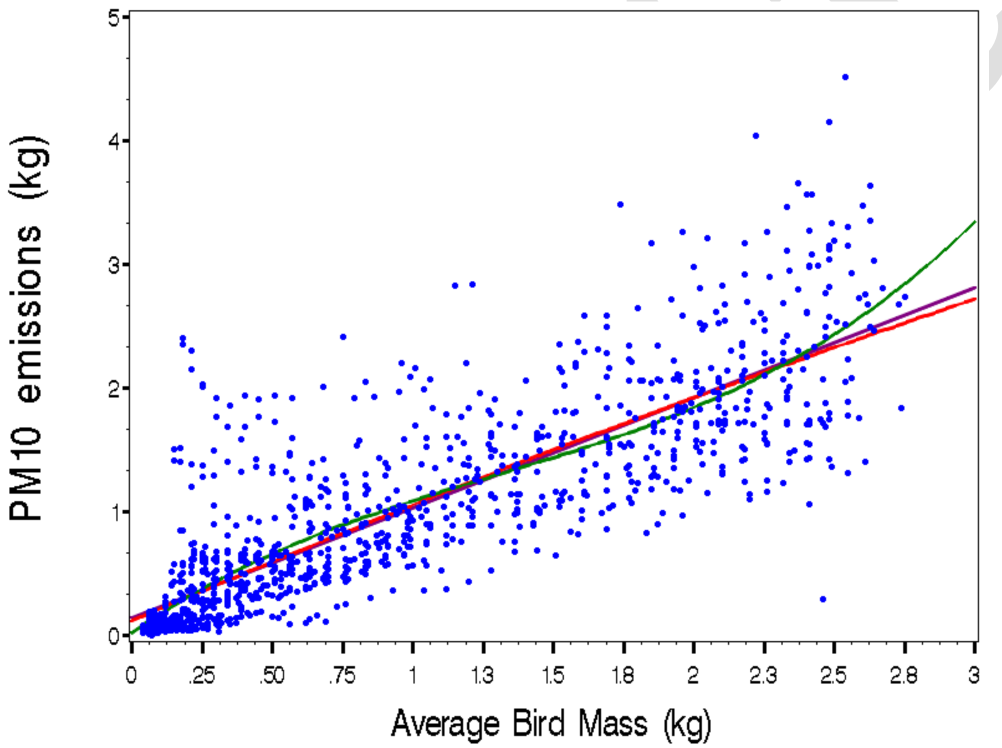


Figure 8-12. PM_{10} Emissions vs. Average Bird Mass (Regression Overlays: purple = linear, red = quadratic, green = cubic)

With regard to the effect of accumulated litter (*buildup*) on PM_{10} emissions (see Section 7.3.1), the EPA discerned a relationship between PM_{10} emissions and the degree of litter accumulation, based on the variance in PM_{10} emissions values for lower bird weights (see Figure 8-13). When PM_{10} emissions are plotted by average mass and color-coded to indicate the level of *buildup*, there is some indication that higher emissions correspond to built-up litter at lower animal mass. Further investigations showed that the increased variance was due to two flocks at each of the CA1B houses (Figure 8-14). Both of these flocks (6 and 7) were raised in the summer on built-up litter.

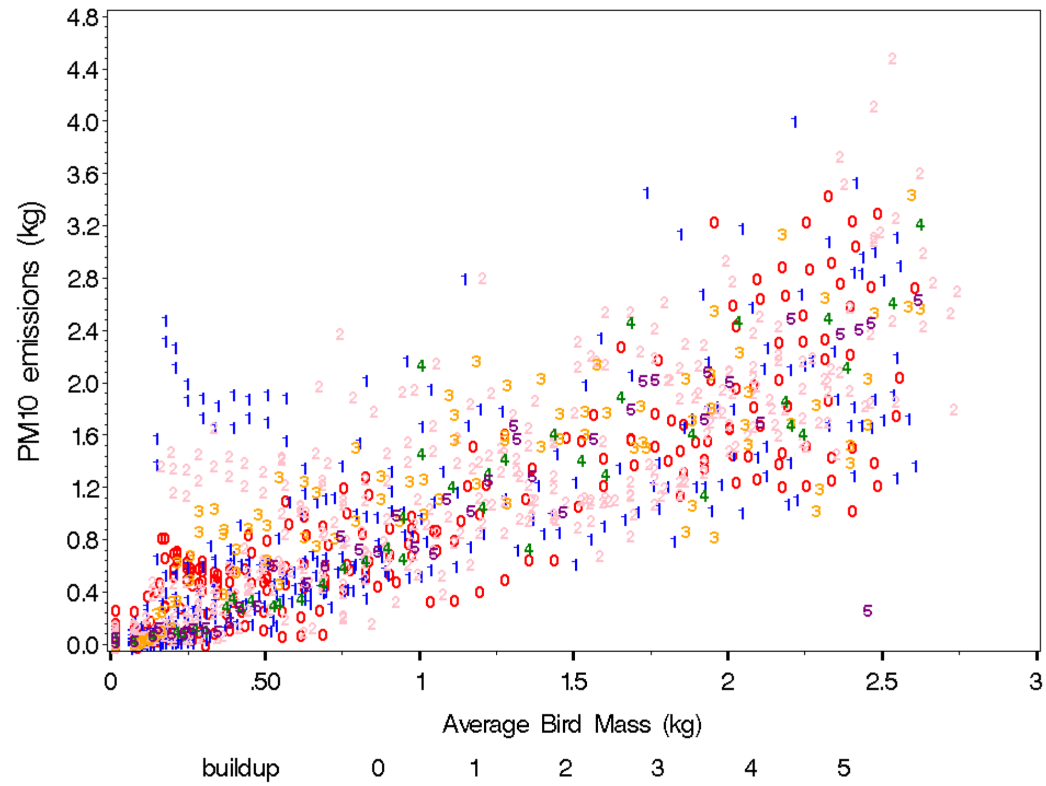


Figure 8-13. Overlay of *buildup* on PM_{10} Emissions vs. Average Live Bird Mass

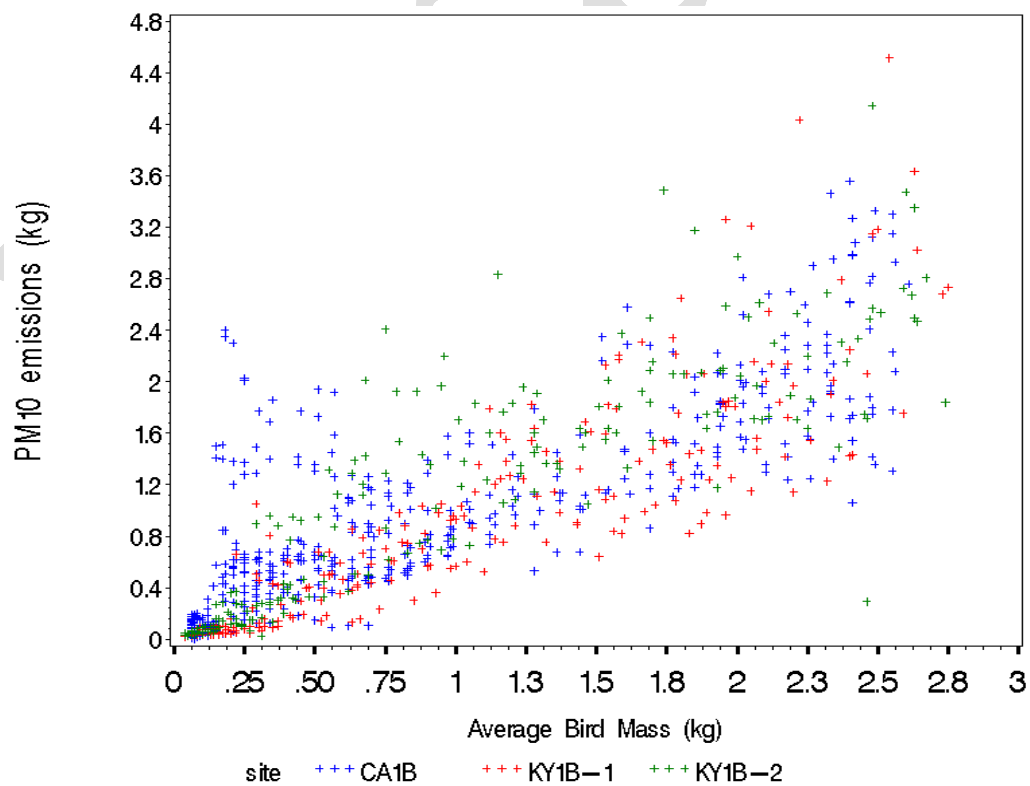


Figure 8-14. PM_{10} Emissions vs. Average Bird Mass, Color-coded by Site

Plots of the build-up indicator parameters (i.e., *buildup*, *build*, *bld*) suggested average PM_{10} emissions do not increase for flocks raised on built-up litter, because there is little difference in the minimum emissions levels between the litter conditions (Figure 8-15), and only a slight difference in average values. The EPA decided to include *build* as the functional form through which the variable *buildup* enters the mean trend function and test its significance using the p-value analysis to determine the final mean trend variables.

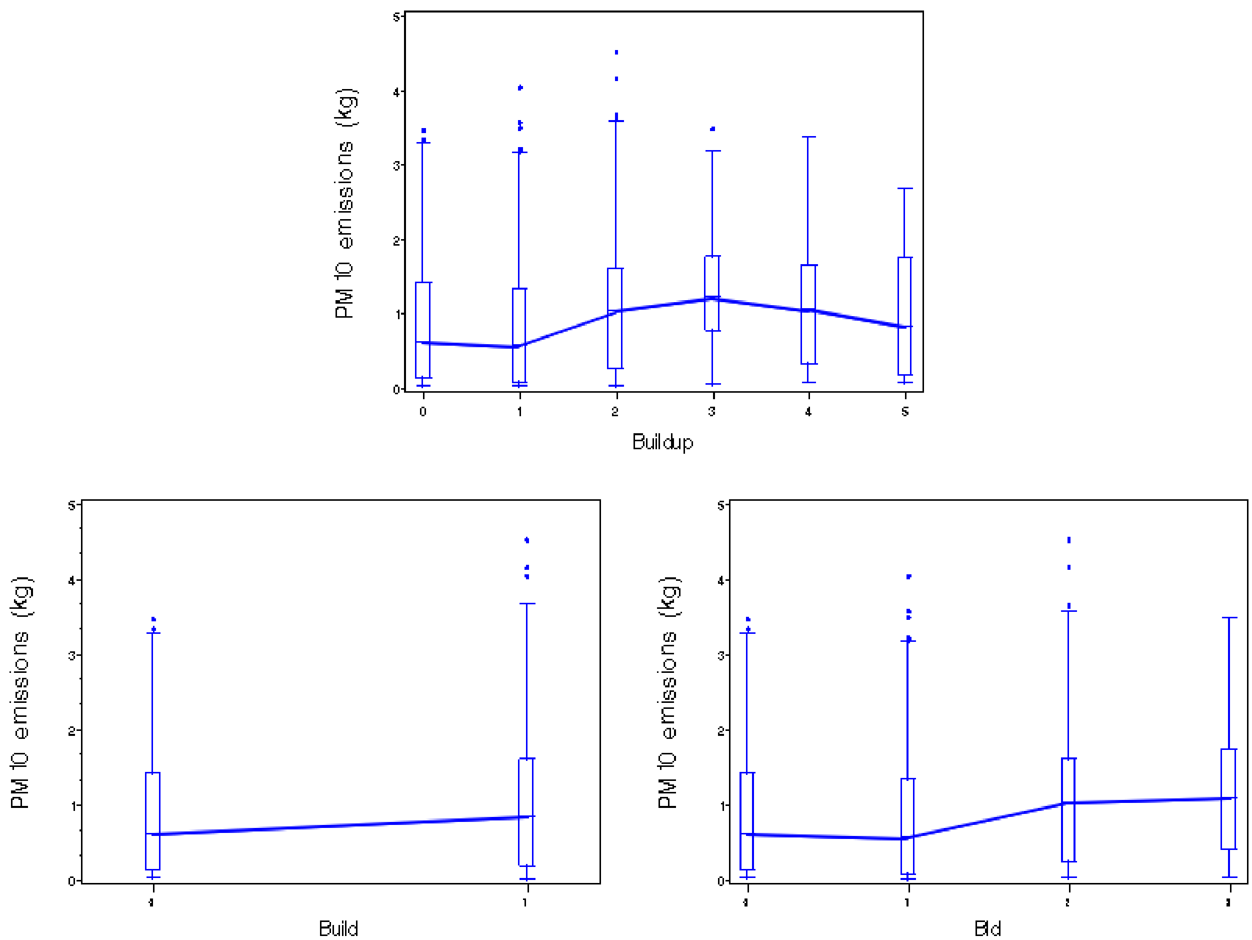


Figure 8-15. Box Plots of PM_{10} Emissions vs. Categorical Variables for *buildup*

Figure 8-16, Figure 8-17, and Figure 8-18 show the scatter plots of PM_{10} emissions versus the remaining predictors (i.e., number of birds, ambient temperature, ambient relative humidity, ambient pressure, house temperature and house relative humidity). Appendix F contains scatter plots of the predictor variables by average animal mass bin. The plots do not indicate that the EPA should use a functional form other than linear for all variables other than *avem*. Based on this visual analysis, and the absence of a process-based reason to do otherwise, the EPA chose a linear functional form for all variables except average bird mass in developing the PM_{10} EEMs.

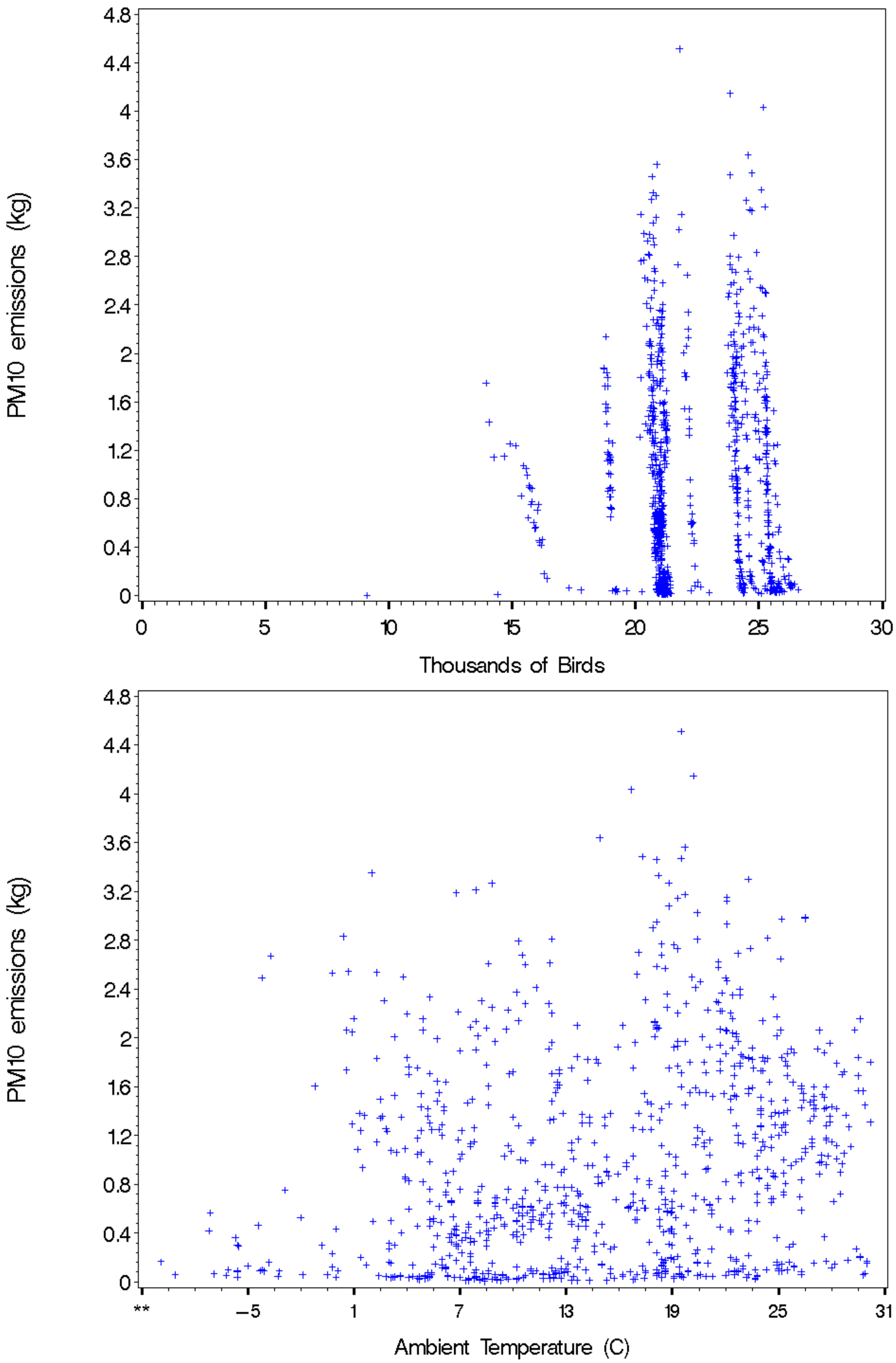
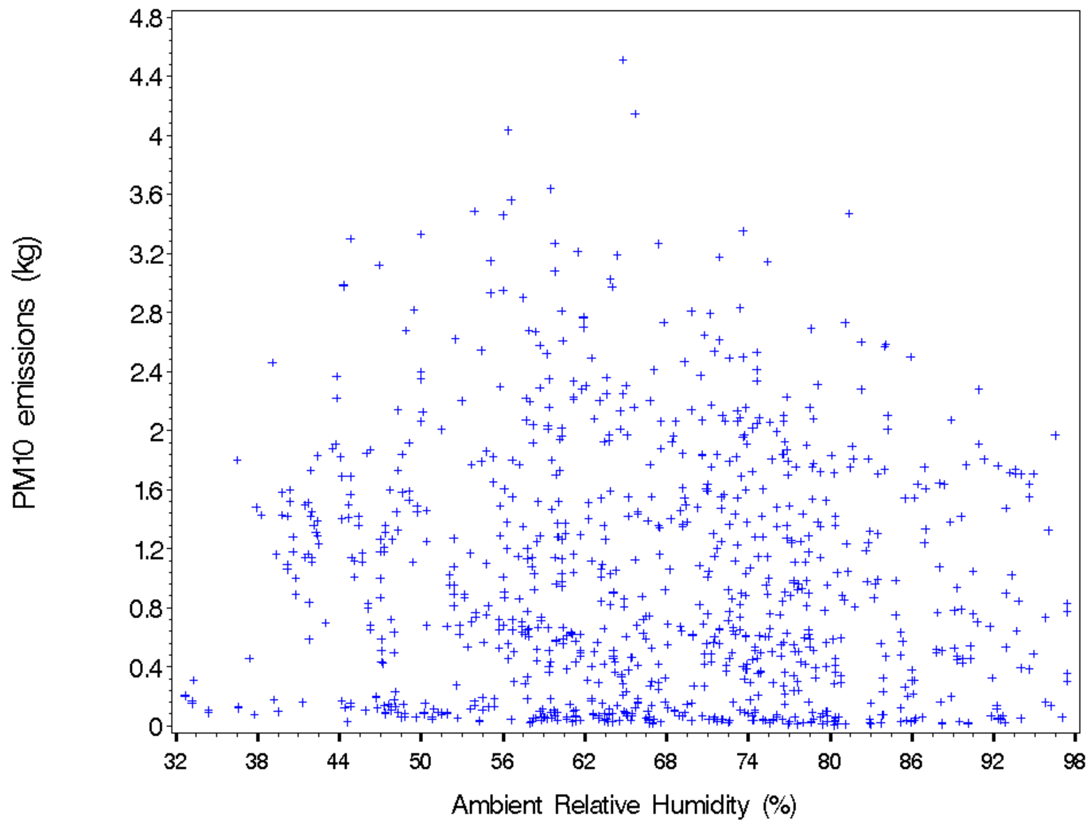


Figure 8-16. PM_{10} Emissions vs. Predictor Variables *birds and *ta****



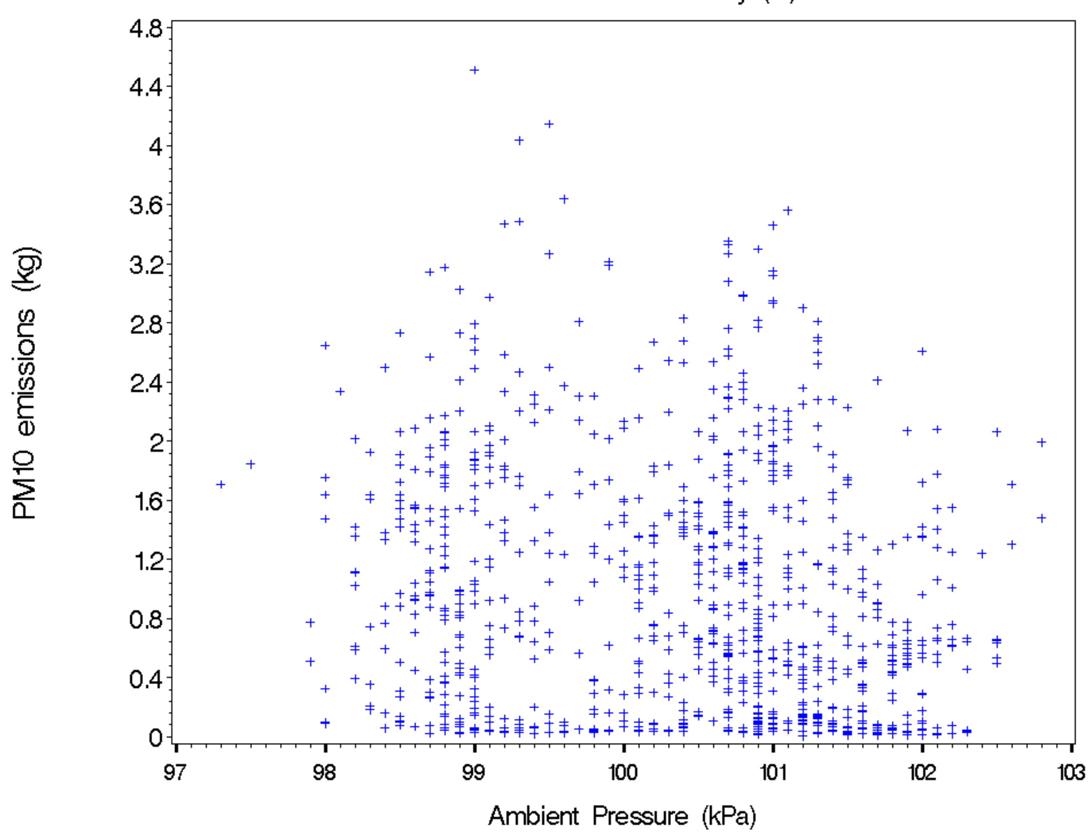


Figure 8-17. PM_{10} Emissions vs. Predictor Variables *ha and *pa***

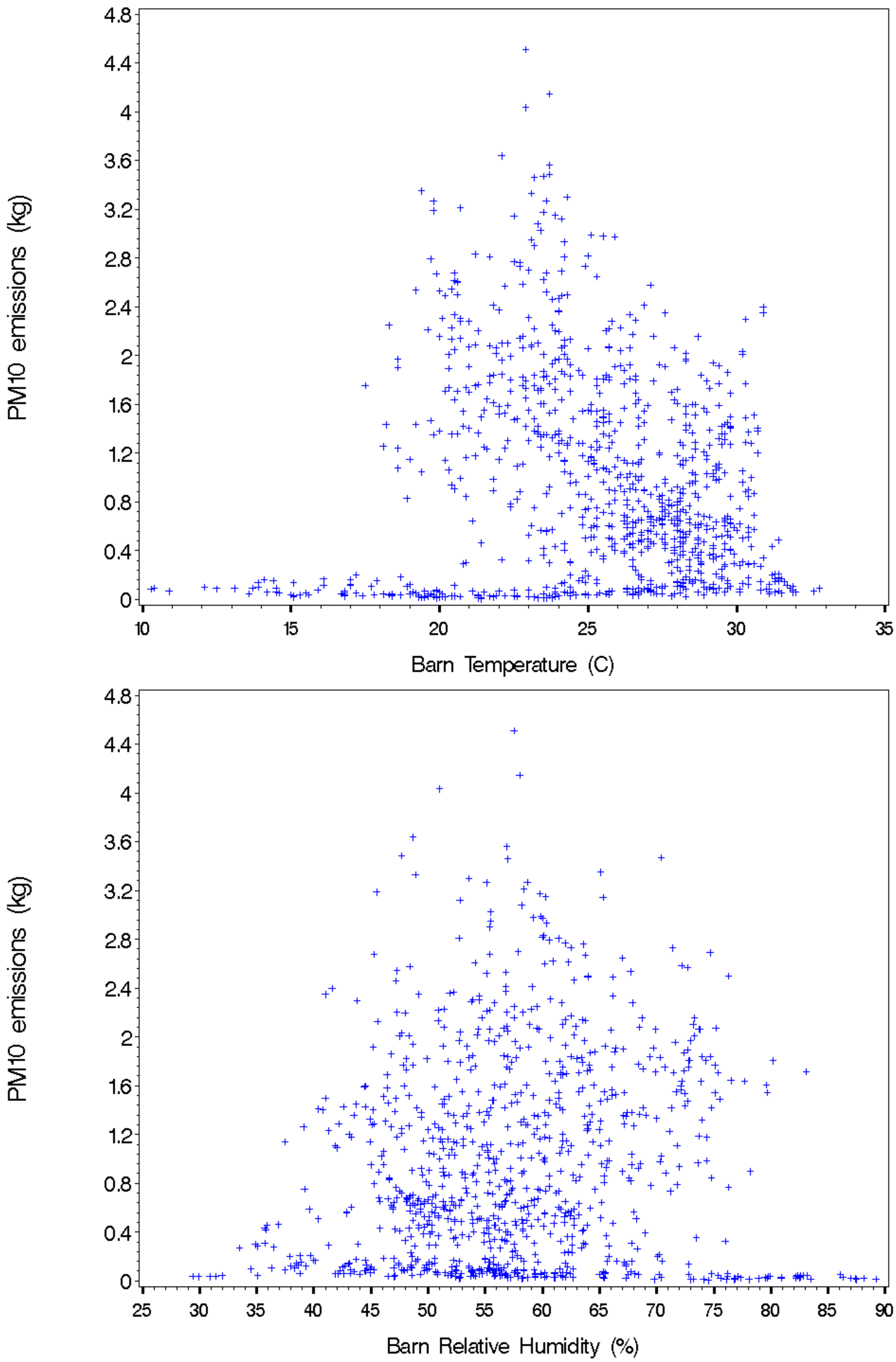


Figure 8-18. PM_{10} Emissions vs. Predictor Variables *tc and *hc***

Table 8-10 summarizes the mean trend variables that describe the dependence of PM_{10} emissions on the original predictor variables. The variables in column two were taken to be the main effect of the original predictors in column one of the table. For all predictors except *buildup* and *avem**, the mean trend variable was the same as the original variable. For *buildup*, the main effect was the indicator variable, *build*. For *avem**, the linear and quadratic terms were collectively considered the main effect for one version of the EEM tested, and the exponential of average bird mass (*eavem*) was considered in a second version of the EEM.

Table 8-10. Summary of Main Effect Mean Trend Variables for PM_{10}

Original Predictor Variable[a]	Main Effect Mean Trend Variable(s)
buildup	*build*
*birds**	*birds*
*avem**	*avem*, $avem^2$ *eavem*
*ta**	*ta*
*ha**	*ha*
*pa**	*pa*
*tc**	*tc*
*hc**	*hc*

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1).

8.2.3.2 *Creating Mean Trend Variables from Main Effects and Interactions*

The EPA created interaction terms and determined what level of interactions (e.g., two-way, three-way) to include in the set of candidate mean trend variables of Table 8-10. Initial testing of the R^2 of two-way and three-way terms conducted by the EPA suggested that consideration of two-way interactions was appropriate for development of PM_{10} EEMs. The main effects and interaction terms for the versions of the three EEMs tested are presented in Table 8-11.

Table 8-11. Candidate Mean Trend Variables for the I, IA and IAC PM_{10} EEMs

EEM	Main Effects	Two-Way Interaction Terms
I, Quadratic ($I\ EEM_Q$)	*build, birds, avem,* $avem^2$	*buildbirds, buildavem,* $buildavem^2$, *birdsavem,* $birdsavem^2$
I, Exponential ($I\ EEM_E$)	*build, birds, eavem*	*buildbirds, buildeavem, birdseavem*
IA, Quadratic ($IA\ EEM_Q$)	Same as $I\ EEM_Q$ plus: *ta, ha, pa*	Same as $I\ EEM_Q$ plus: *buildta, buildha, buildpa, birdsta, birdsha, birdspa, avemta,* $avem^2ta$, *avemha,* $avem^2ha$, *avempa,* $avem^2pa$, *taha, tapa, hapa*
IA, Exponential ($IA\ EEM_E$)	Same as $I\ EEM_E$ plus: *ta, ha, pa*	Same as $I\ EEM_E$ plus: *buildta, buildha, buildpa, birdsta, birdsha, birdspa, eavemta, eavemha, eavempa, taha, tapa, hapa*
IAC, Quadratic ($IAC\ EEM_Q$)	Same as $IA\ EEM_Q$ plus: *tc, hc*	Same as $IA\ EEM_Q$ plus: *buildtc, buildhc, birdstc, birdshc, avemtc,* $avem^2tc$, *avemhc,* $avem^2hc$, *tatc, tahc, hatc, hahc, patc, pahc, tchc*
IAC, Exponential ($IAC\ EEM_E$)	Same as $IA\ EEM_E$ plus: *tc, hc*	Same as $IA\ EEM_E$ plus: *buildtc, buildhc, birdstc, birdshc, eavemtc, eavemhc, tatc, tahc, hatc, hahc, patc, pahc, tchc*

8.2.3.3 *Centering and Scaling Predictors*

The EPA centered and scaled each continuous predictor variable prior to creating interaction terms by subtracting the mean of all observations in the base dataset from each value, then dividing by the standard deviation of the base dataset. The centering and scaling factors for the predictor variable for the PM_{10} final EEMs are presented in Table 8-12.

Table 8-12. Centering and Scaling Reference Values for Continuous PM_{10} Predictor Variables

Predictor Variable[a]	Centering Value	Scaling Value
*birds**	22	2.5
*avem**	1.1	0.87
*ta**	15	8.2
*ha**	66	14
*pa**	100	1.1
*tc**	25	3.8
*hc**	58	9.9

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1). Predictor variables are centered and scaled prior to the creation of higher-order terms (e.g., *eavem* or $avem^2$) and the creation of interaction terms (e.g., *avemta*).

8.2.4 Selecting Final Mean Trend Variables for PM_{10}

8.2.4.1 Inventory EEM

The EPA tested two forms of the I EEM; a quadratic and an exponential form (Table 8-13). Predictions based on the quadratic form of the EEM (I EEM_Q) always had systematic bias for the intercept, γ_0, regardless of the number of parameters eliminated. Predictions based on the exponential form of the EEM (I EEM_E) demonstrated systematic bias after initial backward elimination steps.

The selected form of the I EEM_Q contains all of the initial interaction terms. This EEM displayed the best fit-statistics against the cross-validation dataset (lowest RMSE and highest R^2); however, the EEM still exhibited systematic bias. The best form of the I EEM_E also included all the initial interaction terms. This version of the I EEM_E had the best fit-statistics against the cross-validation dataset, as well as the coverage percentage (% in PI) closest to 95 percent, without exhibiting systematic bias. The fit statistics for the selected I EEM_Q and I EEM_E are presented in Table 8-14. A check mark (✓) in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level, while an "x" indicates that it is significantly different from zero. Similarly, a check mark or an "x" in the column for γ_1 indicates whether or not the estimate is significantly different from one.

Because the I EEM_Q always exhibited systematic bias, the EPA retested the I EEM_Q using different versions of the base and cross-validation datasets to verify that the systematic bias was not due to random selection of an improper cross-validation dataset. Examples of an improper cross-validation dataset include a dataset where the values are skewed to one end of the distribution, or a dataset that contains too many extreme values. In these examples, the fit statistics would be biased for the extreme values of the dataset. Based on the results of the retest, the systematic bias for the I EEM_Q could not be attributed to improper selection of a cross-validation dataset. Therefore, the EPA selected the I EEM_E (highlighted in gray) because it did not display systematic bias.

Table 8-13. Final Candidate I EEM Mean Trend Variables for PM_{10}

EEM	Main Effects	Two-Way Interaction Terms
I EEM_Q	*build, birds, avem, avem*^{2}	*buildbirds, buildavem, buildavem*^{2}*, birdsavem, birdsavem*^{2}
I EEM_E	*build, birds, eavem*	*buildbirds, buildeavem, birdseavem*

Table 8-14. Final Candidate I EEM Fit Statistics for PM_{10}

Candidate EEM	Fit Statistics							
	-2LL	BIC	% in PI	Width (kg)	RMSE (kg)	R^2	γ_0 (kg)	γ_1
I EEM_Q	646	654	93	2.1	0.51	0.65	0.16 ×	0.92 ✓
I EEM_E	621	630	91	2.0	0.52	0.63	-0.12 ✓	1.1 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the $\alpha = 0.05$ significance level.

8.2.4.2 *Inventory and Ambient EEM*

The selected form of IA EEM_Q and IA EEM_E are presented in Table 8-15. Similar to the I EEM, the quadratic form of the EEM (IA EEM_Q) always demonstrated systematic bias for the slope, γ_0, regardless of the number of parameters eliminated. The initial eliminations produced minor systematic bias, with the range of estimates for γ_0 failing to cover zero by only 0.001. Predictions based on the exponential form of the EEM (IA EEM_E) demonstrated systematic bias after the third backward elimination steps. The selected version of the IA EEM_E occurs prior to the development of systematic bias and displays the best fit-statistics against the cross-validation dataset (lowest RMSE and highest R^2) and the smallest confidence interval width and best coverage percentage of the backward elimination steps.

Although both selected EEMs had similar fit statistics (Table 8-16), the IA EEM_Q had persistent systematic bias. This systematic bias could not be contributed to improper selection of a cross-validation data set. Therefore, the EPA selected the IA EEM_E (highlighted in gray), which retains the terms listed in Table 8-15.

Table 8-15. Final Candidate IA EEM Mean Trend Variables for PM_{10}

EEM	Main Effects	Two-Way Interaction Terms
IA EEM_Q	*build, birds, avem, avem^2*	*buildbirds, buildavem, buildavem^2, buildta, buildha, buildpa, birdsavem, birdsavem^2, birdsta, birdsha, birdspa, avemta, avem^{2}ta,avemha avem^{2}ha, avempa, avem^{2}pa*
IA EEM_E	*build, birds, eavem, ta, ha, pa*	*buildbirds, buildeavem, birdseavem, eavemha, eavempa,*

Table 8-16. Final Candidate IA EEM Fit Statistics for PM_{10}

EEM	Fit Statistics							
	-2LL	BIC	% in PI	Width (kg)	RMSE (kg)	R^2	γ_0 (kg)	γ_1
IA EEM_Q	614	622	94	1.9	0.46	0.71	0.10 x	0.95 ✓
IA EEM_E	579	587	91	1.9	0.50	0.67	-0.11 ✓	1.1 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the $\alpha = 0.05$ significance level.

8.2.4.3 *Inventory, Ambient and Confinement EEM*

With the addition of confinement variables, IAC EEM_Q no longer had systematic bias for predictions. The IAC EEM_E produced systematic bias prior to completing the backward elimination process. The selected version of the IAC EEM_E is the version of the model with the best fit statistics against the cross-validation dataset (highest R^2), the smallest confidence interval width and the best coverage percentage compared to the other elimination steps. This version also occurs prior to the development of systematic bias. The selected versions of the mean trend variables for the EEMs are presented in Table 8-17.

In general, the two final candidate EEMs had similar fit statistics (Table 8-18). The IAC EEM_E did a slightly better job at fitting the base dataset (smaller BIC and -2LL values), with the IAC EEM_Q providing a slightly better fit to the cross-validation dataset and a slightly better confidence interval width. Consequently, the EPA selected the IAC EEM_Q (highlighted in gray) as the final version of the EEM.

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Table 8-17. Final Candidate IAC EEM Mean Trend Variables for PM_{10}

EEM	Main Effects	Two-way Interaction Terms
IAC EEM_Q	*build, birds, avem, avem², ta, ha, pa, tc, hc*	*buildbirds, buildavem, buildavem², buildta, buildha, buildpa, buildtc, buildhc, birdsavem, birdsavem², birdsta, birdsha, birdspa, birdstc, birdshc, avemta, avem²ta, avemha, avem²ha, avempa, avem²pa, avemtc, avem²tc, avemhc, avem²hc, taha, tapa, hapa, tatc, tahc, tchc*
IAC EEM_E	*build, birds, eavem, ta, ha, pa, tc, hc*	*buildbirds, buildeavem, buildta, buildha, buildpa, buildtc, buildhc, birdseavem, eavemta, eavemha, eavempa, eavemtc, eavemhc, taha, tapa, hapa, tatc, tahc, hatc, hahc, patc, pahc, tchc*

Table 8-18. Final Candidate IAC EEM Fit Statistics for PM_{10}

Candidate EEM	Fit Statistics							
	-2LL	BIC	% in PI	Width (kg)	RMSE (kg)	R^2	γ_0 (kg)	γ_1
IAC EEM_Q	519	526	94	1.7	0.40	0.79	0.03 ✓	1.0 ✓
IAC EEM_E	507	515	93	1.8	0.45	0.73	-0.09 ✓	1.08 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the $\alpha = 0.05$ significance level.

8.2.5 Summary of Final Results for the I, IA and IAC EEMs for PM_{10}

A summary of the final mean trend variables for the three EEMs is provided in Table 8-19. The covariance parameters for the final forms of the EEMs are listed in Table 8-20. The coefficients for the EEM mean trend variables are listed in Table 8-21. The value of each main effect variable (x_p) must be centered and scaled when using these terms in Equation 7-1. The centering and scaling factors for the predictor variables used in the final PM_{10} EEMs are presented in Table 8-12.

Table 8-19. Final EEM Mean Trend Variables for PM_{10}

EEM	Main Effects	Two-Way Interaction Terms
I	*build, birds, eavem*	*buildbirds, buildeavem, birdseavem*
IA	*build, birds, eavem, ta, ha, pa*	*buildbirds, buildeavem, birdseavem, eavemha, eavempa,*
IAC	*build, birds, avem, avem², ta, ha, pa, tc, hc*	*buildbirds, buildavem, buildavem², buildta, buildha, buildpa, buildtc, buildhc, birdsavem, birdsavem², birdsta, birdsha, birdspa, birdstc, birdshc, avemta, avem²ta, avemha, avem²ha, avempa, avem²pa, avemtc, avem²tc, avemhc, avem²hc, taha, tapa, hapa, tatc, tahc, tchc*

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Table 8-20. Covariance Parameter for Final PM_{10} EEMs

Covariance Parameter	Estimate		
	I	IA	IAC
$\hat{\rho}$	0.7486	0.7513	0.6984
$\hat{\sigma}^2$	0.2131	0.1977	0.1404

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Table 8-21. Regression Coefficient for Final PM_{10} EEMs

p	x_p	$\hat{\beta}_p$				***p***	x_p	$\hat{\beta}_p$		
		I	**IA**	**IAC**				**I**	**IA**	**IAC**
0	*Intercept*	-0.9544	-0.9162	0.821		24	*eavemha*	a	-0.1407	a
1	*build*	0.2722	0.263	0.3658		25	*eavempa*	a	0.0229	a
2	*birds*	-0.174	-0.1874	0.1941		26	*avemta*	a	a	0.1749
3	*eavem*	1.1093	1.0842	a		27	$avem^2ta$	a	a	0.05689
4	*avem*	a	a	0.7447		28	*avemha*	a	a	0.03161
5	$avem^2$	a	a	0.08099		29	$avem^2ha$	a	a	-0.01245
6	*ta*	a	0.07748	0.3429		30	*avempa*	a	a	0.03111
7	*ha*	a	0.1404	0.1763		31	$avem^2pa$	a	a	0.01967
8	*pa*	a	-0.03434	0.1246		32	*taha*	a	a	0.0631
9	*tc*	a	a	-0.1338		33	*tapa*	a	a	-0.02629
10	*hc*	a	a	-0.3531		34	*hapa*	a	a	0.0337
11	*buildbirds*	0.05141	0.03733	0.03798		35	*avemhc*	a	a	-0.2287
12	*birdseavem*	0.1119	0.1503	a		36	$avem^2hc$	a	a	-0.02424
13	*birdsavem*	a	a	0.176		37	*avemtc*	a	a	-0.1866
14	$birdsavem^2$	a	a	-0.08347		38	$avem^2tc$	a	a	-0.109
15	*buildeavem*	-0.1199	-0.1149	a		39	*buildtc*	a	a	0.1014
16	*buildavem*	a	a	0.06747		40	*buildhc*	a	a	0.05585
17	$buildavem^2$	a	a	-0.1888		41	*birdstc*	a	a	-0.08495
18	*buildta*	a	a	-0.12		42	*birdshc*	a	a	-0.01929
19	*buildha*	a	a	-0.07546		43	*tahc*	a	a	-0.0308
20	*buildpa*	a	a	-0.1342		44	*tatc*	a	a	0.03133
21	*birdsta*	a	a	0.05334		45	*tchc*	a	a	-0.04071
22	*birdsha*	a	a	0.005728						
23	*birdspa*	a	a	0.04285						

Note: Each main effect variable was centered and scaled prior to creating higher-order terms, exponential terms and interactions.
[a] This variable is not included in the EEM.

8.3 EEMs for $PM_{2.5}$

8.3.1 Selecting Datasets

The majority of the data available for developing the $PM_{2.5}$ EEMs were from the Kentucky broiler sites. The CA1B site had an abbreviated collection schedule for $PM_{2.5}$. For $PM_{2.5}$ sampling at the California site, the goal of the NAEMS was to collect data for one week in the winter and summer to represent extreme temperature chemistry. As a result, the CA1B site has a higher percent of missing data (see Table 8-22) when compared to the total number of monitoring days for the grow-out periods.

Table 8-22 shows relatively good completeness for $PM_{2.5}$ emissions for the Kentucky sites, ranging from 69 to 95 percent over the seasons. Data completeness at KY1B-1 House 5 for summer is the lowest data completeness at 69 percent. However, when considered with the data from the CA1B houses, there are a substantial number of observations over all the seasons for EEM development.

Of the 593 $PM_{2.5}$ emissions values available, 14 lacked all of the inventory, ambient and confinement predictor variables needed for EEM development. After these missing data records were removed, the base dataset available for developing the $PM_{2.5}$ EEMs consisted of 579 observations. The EPA then randomly withheld 116 observations (approximately 20 percent of the 579 observations in the base dataset) for the cross-validation data set.

Table 8-22. Data Completeness for $PM_{2.5}$ EEMs

Season	Description	CA1B		KY1B-1	KY1B-2	All Houses
		House 10	House 12	House 5	House 3	
All seasons	Number of grow-out days	642	647	288	267	1,844
	Days $PM_{2.5}$ data available	53	43	254	243	593
	Percent complete	8%	7%	88%	91%	32%
Winter	Number of grow-out days	150	153	87	74	464
	Days $PM_{2.5}$ data available	28	28	83	66	205
	Percent complete	19%	18%	95%	89%	44%
Spring	Number of grow-out days	157	158	83	55	453
	Days $PM_{2.5}$ data available	0	0	79	46	125
	Percent complete	0%	0%	95%	84%	28%

Table 8-22. Data Completeness for $PM_{2.5}$ EEMs

Season	Description	CA1B		KY1B-1	KY1B-2	All Houses
		House 10	House 12	House 5	House 3	
Summer	Number of grow-out days	156	157	55	74	442
	Days $PM_{2.5}$ data available	15	15	38	70	138
	Percent complete	10%	10%	69%	95%	31%
Fall	Number of grow-out days	179	179	63	64	485
	Days $PM_{2.5}$ data available	10	0	54	61	125
	Percent complete	6%	0%	86%	95%	26%

8.3.2 Choosing the Probability Distribution for $PM_{2.5}$

The EPA first evaluated the empirical distribution (i.e., histogram) of the observed $PM_{2.5}$ daily emissions to determine whether using the normal distribution could be justified (see Section 7.2). The histogram in Figure 8-19 shows that many of the $PM_{2.5}$ observations correspond to lower emissions values, with a single peak at emission values less than 40 g. The figure also shows that the number of observations decreases as emissions increase. Based on this histogram, the EPA determined that the empirical distribution was unimodal (single-peaked) and skew right.

The EPA separated the base dataset into bins according to values of average bird mass. Figure 8-20 shows histograms of $PM_{2.5}$ emissions within the following six evenly distributed bins of average bird mass (*avem**) values (in kg): 0.0 to 0.5, 0.5 to 1.0, 1.0 to 1.5, 1.5 to 2.0, 2.0 to 2.5 and 2.5 to 3.0. The figure shows that the histograms for bins 1, 2, 3, and 4 are skew right, while bin 5 is symmetric and 6 is skew left, though it has fewer data points than the other bins. Further disaggregation according to the values of other variables shows a variety of empirical distributions for different sets of conditions, and the skew patterns were by no means a consistent pattern. There are not enough observations under any specific set of conditions (e.g., bird mass and humidity ranges) to use the empirical distribution to determine the true distribution. Therefore, in the absence of strong evidence against doing so, the EPA used the normal distribution.

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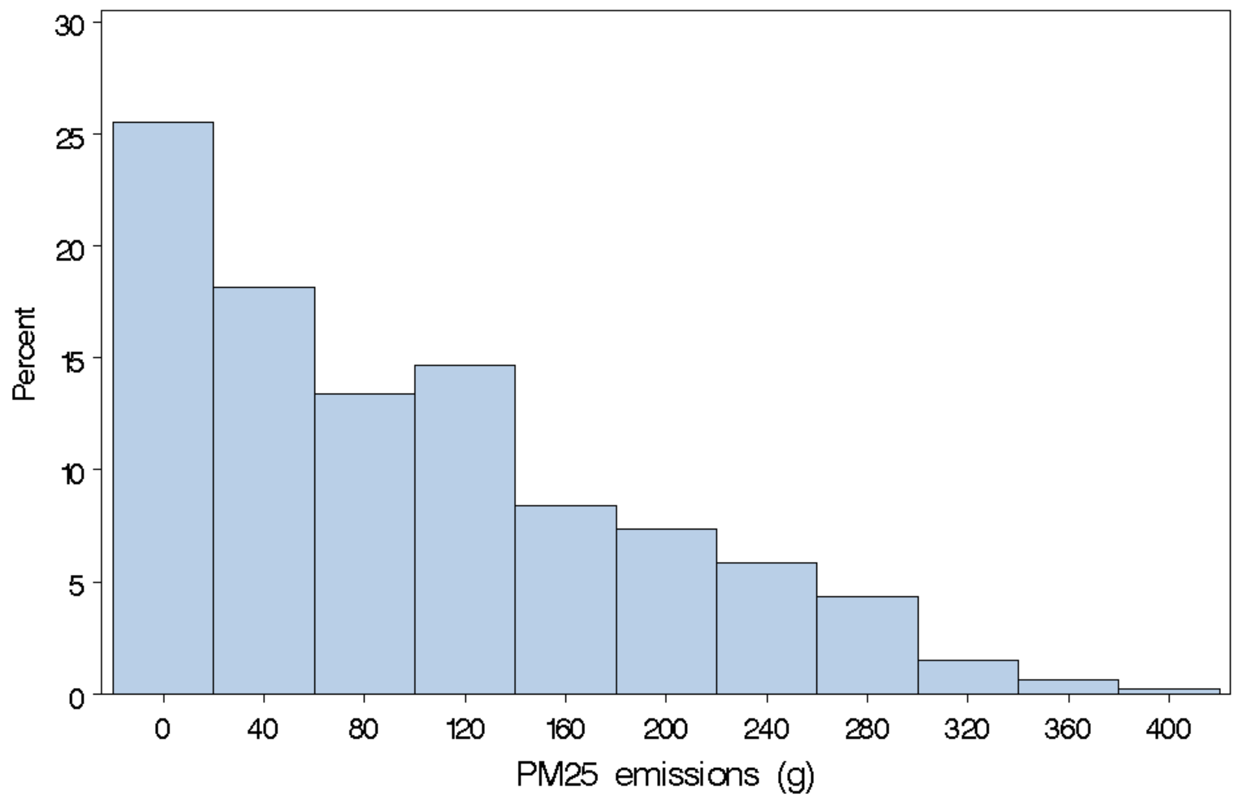

Figure 8-19. Histogram of $PM_{2.5}$ Emissions in the Base Dataset

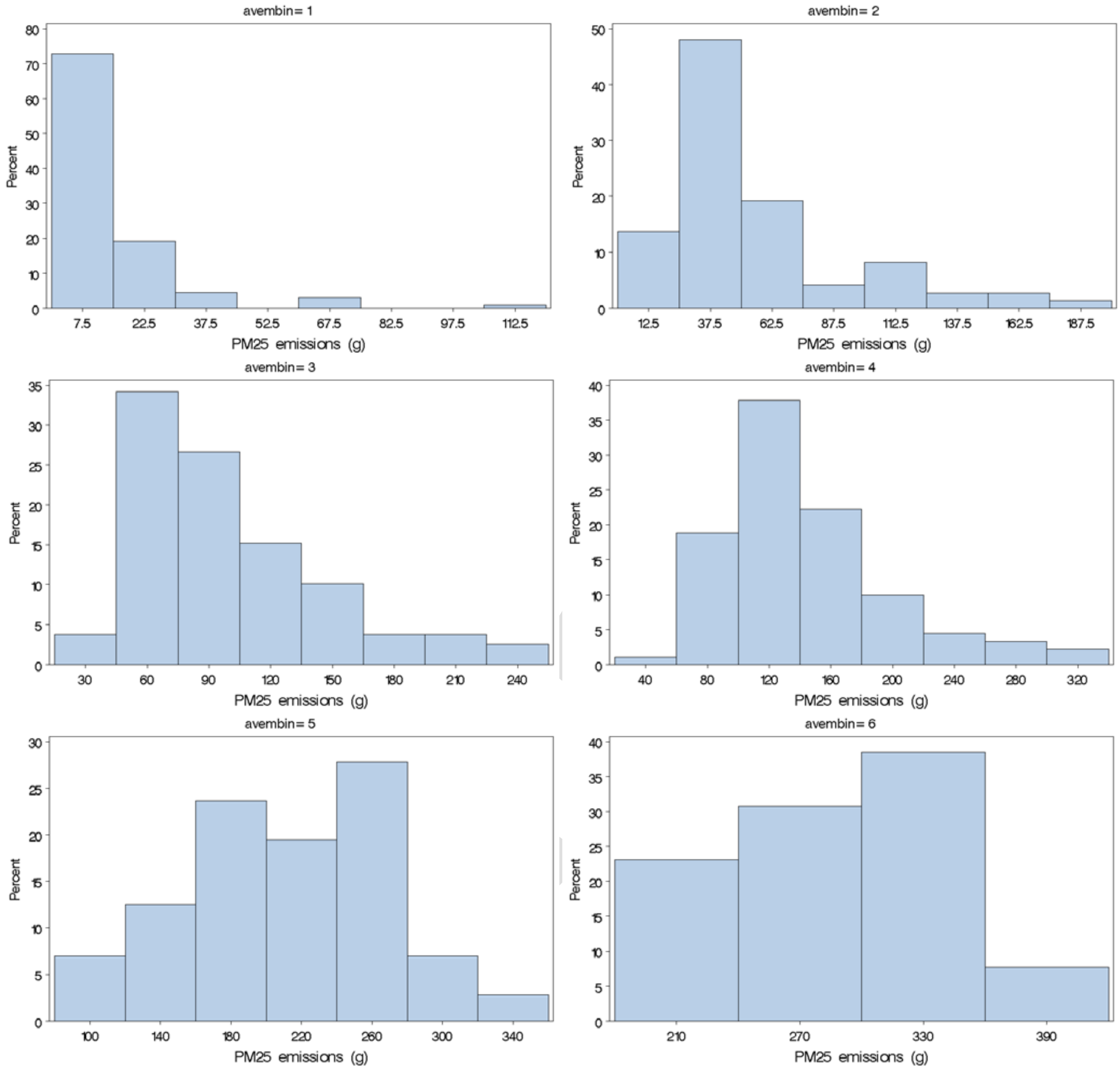

Figure 8-20. Histograms of $PM_{2.5}$ Emissions by *avem Bins**

8.3.3 Developing Candidate Mean Trend Variables for $PM_{2.5}$

8.3.3.1 Choosing Predictor Variable Functional Forms for $PM_{2.5}$

Similar to PM_{10}, plots of $PM_{2.5}$ emissions versus average bird mass, for all houses (Figure 8-21), suggested a positive relationship, with a slight upward curvature. The gradual increasing trend suggested either a quadratic or exponential relationship between $PM_{2.5}$ emissions and the average bird mass. For the $PM_{2.5}$ analysis, the EPA tested two functional forms of average mass: one form based on a quadratic relationship with average mass (*avem* and $avem^2$), and the second form based on an exponential relationship (*eavem*).

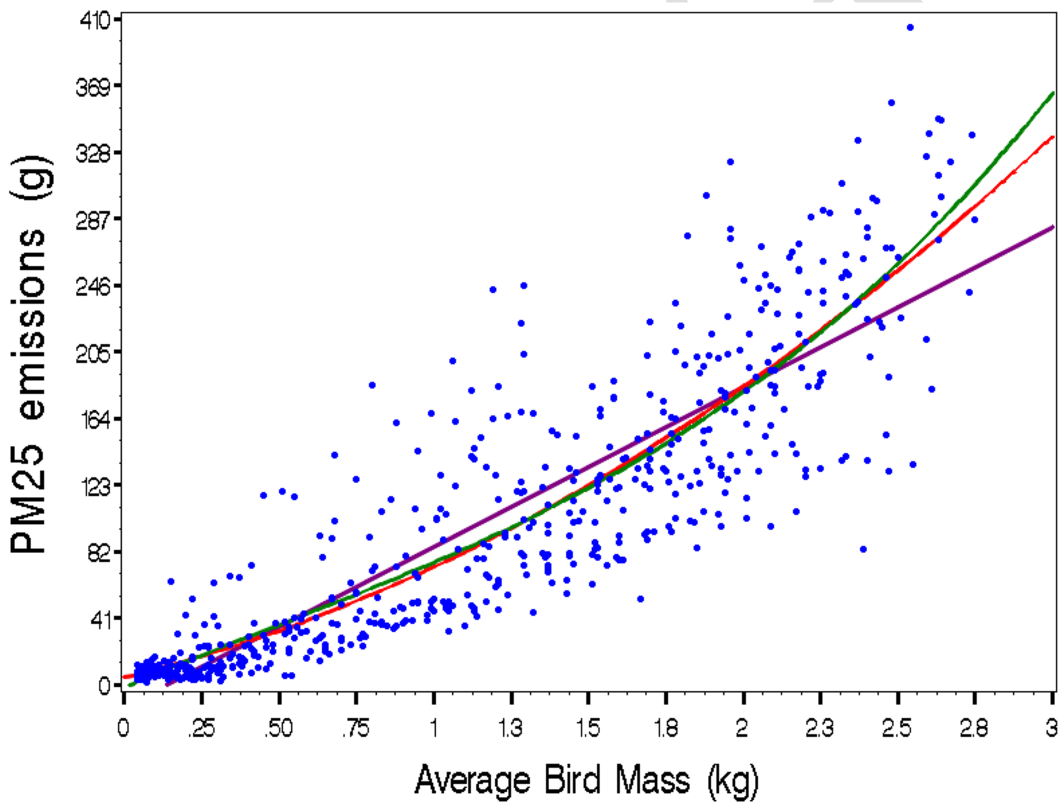

Figure 8-21. $PM_{2.5}$ Emissions vs. Average Bird Mass (Regression Overlays: purple = linear, red = quadratic, green = cubic)

With regard to the effect of accumulated litter (*buildup*) on $PM_{2.5}$ emissions (see Section 7.3.1), the EPA discerned a relationship between $PM_{2.5}$ emissions and the degree of litter accumulation, based on the variance in $PM_{2.5}$ emissions values for lower bird weights (see Figure 8-22). Plots of $PM_{2.5}$ emissions by average mass that are color-coded to indicate the level of *buildup* (Figure 8-22) suggested built-up litter correspond to higher emissions. However, the EPA was unable to draw a definitive conclusion from the scatter plot because only one full flock was raised on fresh bedding between the California and Kentucky sites due to the design of the study.

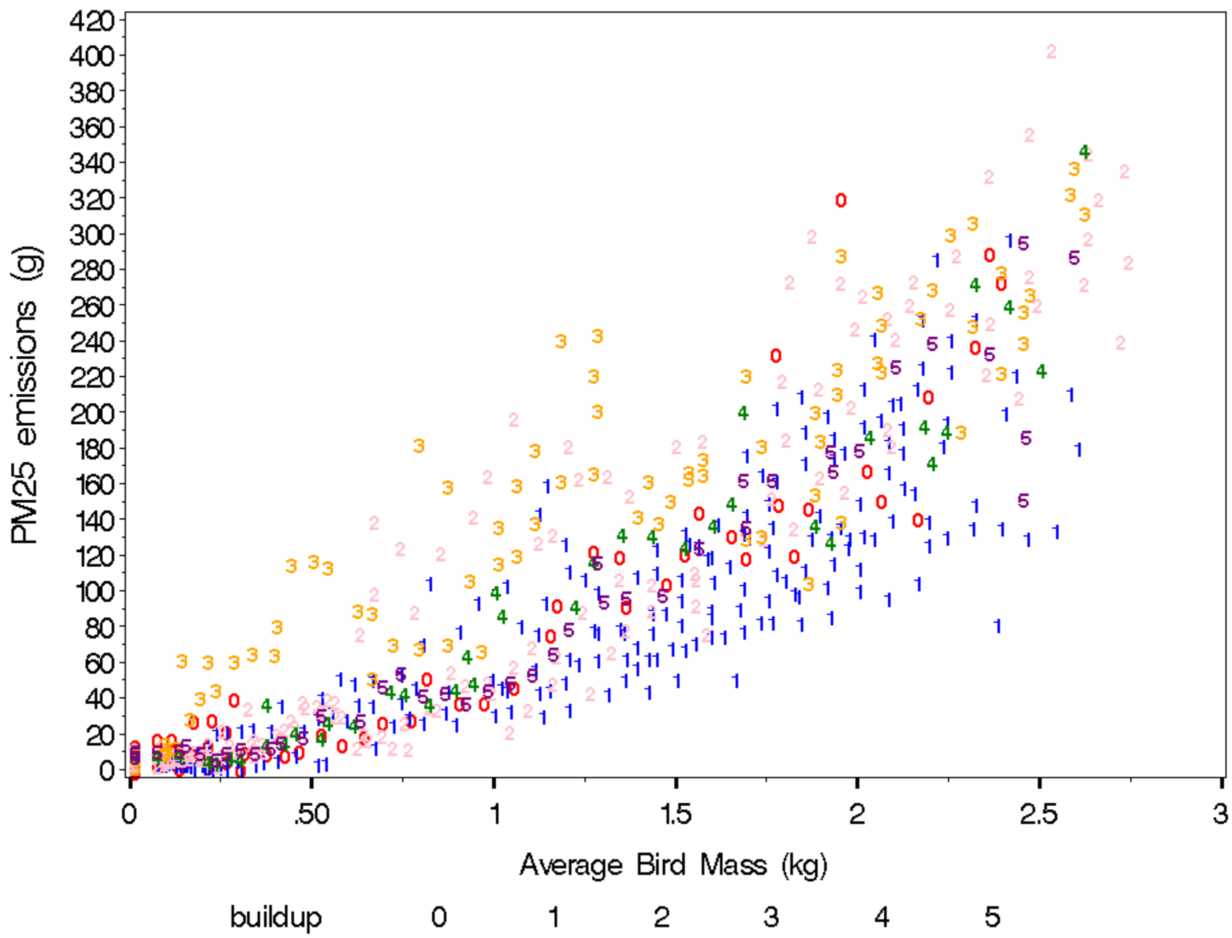

Figure 8-22. Overlay of *buildup* on $PM_{2.5}$ Emissions vs. Average Live Bird Mass

Plots of the build-up indicator parameters (i.e., *buildup*, *build* and *bld*) suggested that the average $PM_{2.5}$ emissions increase for flocks raised on built-up litter. The trend is not as strong as with other pollutants, as there is little difference between the minimum emissions levels between the litter conditions (Figure 8-23), although the average emissions for the litter conditions does vary greatly. Initial test runs without the inclusion of a representation of build-up displayed systematic bias. Because $PM_{2.5}$ is a subset of PM_{10}, the EPA conducted a revised development run was conducted that included *build*, the same representation used in the PM_{10} EEM, to determine if a build-up variable would correct the systematic bias. Initial tests including *build* showed improved results. Therefore, EEM development process for $PM_{2.5}$ proceeded with the inclusion of *build* as the functional form through which the variable *buildup* enters the mean trend function and test its significance using the p-value analysis to determine the final mean trend variables.

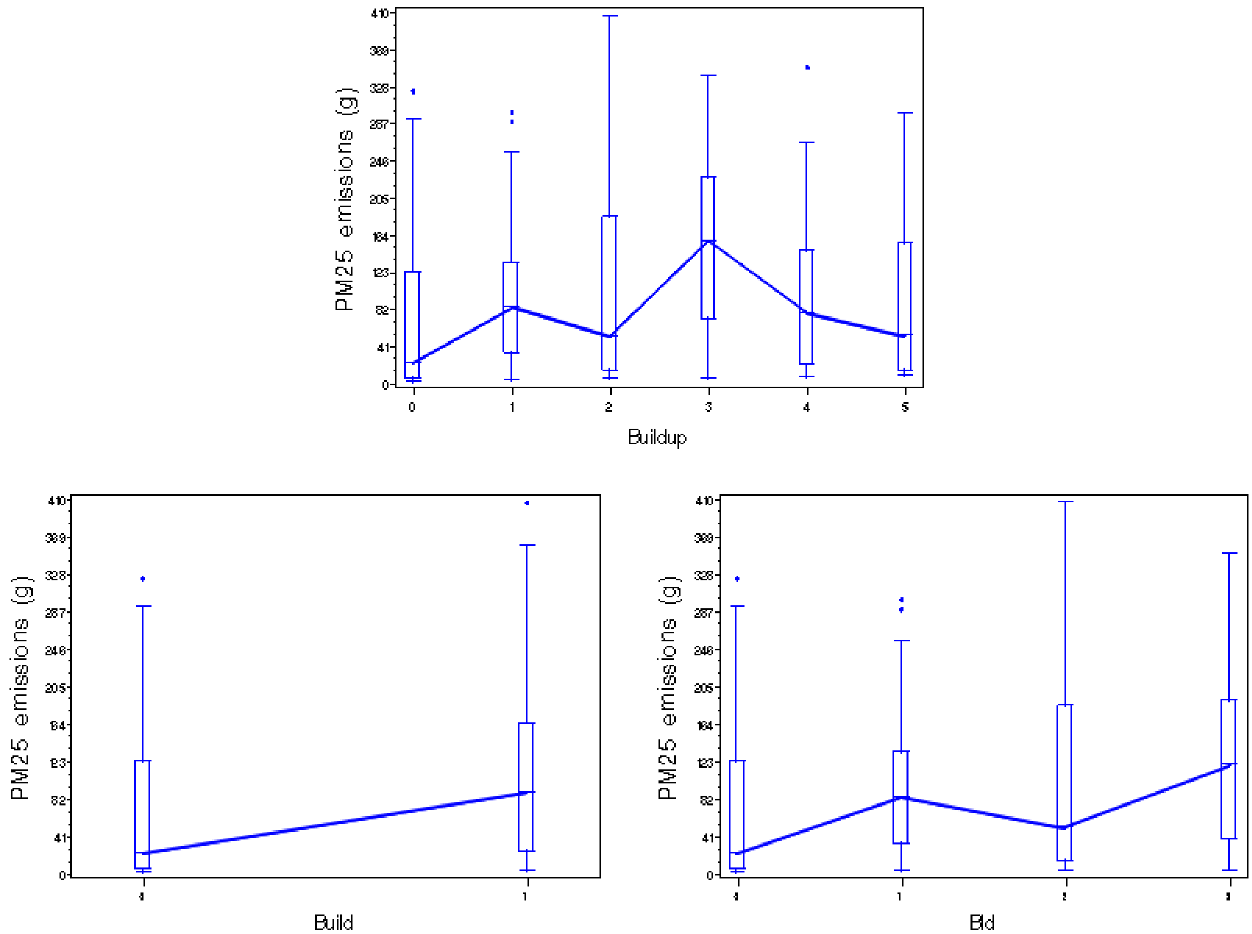

Figure 8-23. Box Plots of $PM_{2.5}$ Emissions vs. Categorical Variables for *buildup*

Figure 8-24, Figure 8-25 and Figure 8-26 show the scatter plots of $PM_{2.5}$ emissions by the remaining predictors (i.e., number of birds, ambient temperature, ambient relative humidity, ambient pressure, house temperature and house relative humidity). Appendix F contains scatter plots of the predictor variables by average animal mass bin. The plots do not indicate that the EPA should use a functional form other than linear. Based on this visual analysis, the EPA chose a linear functional form for all variables except average bird mass in developing the $PM_{2.5}$ EEMs.

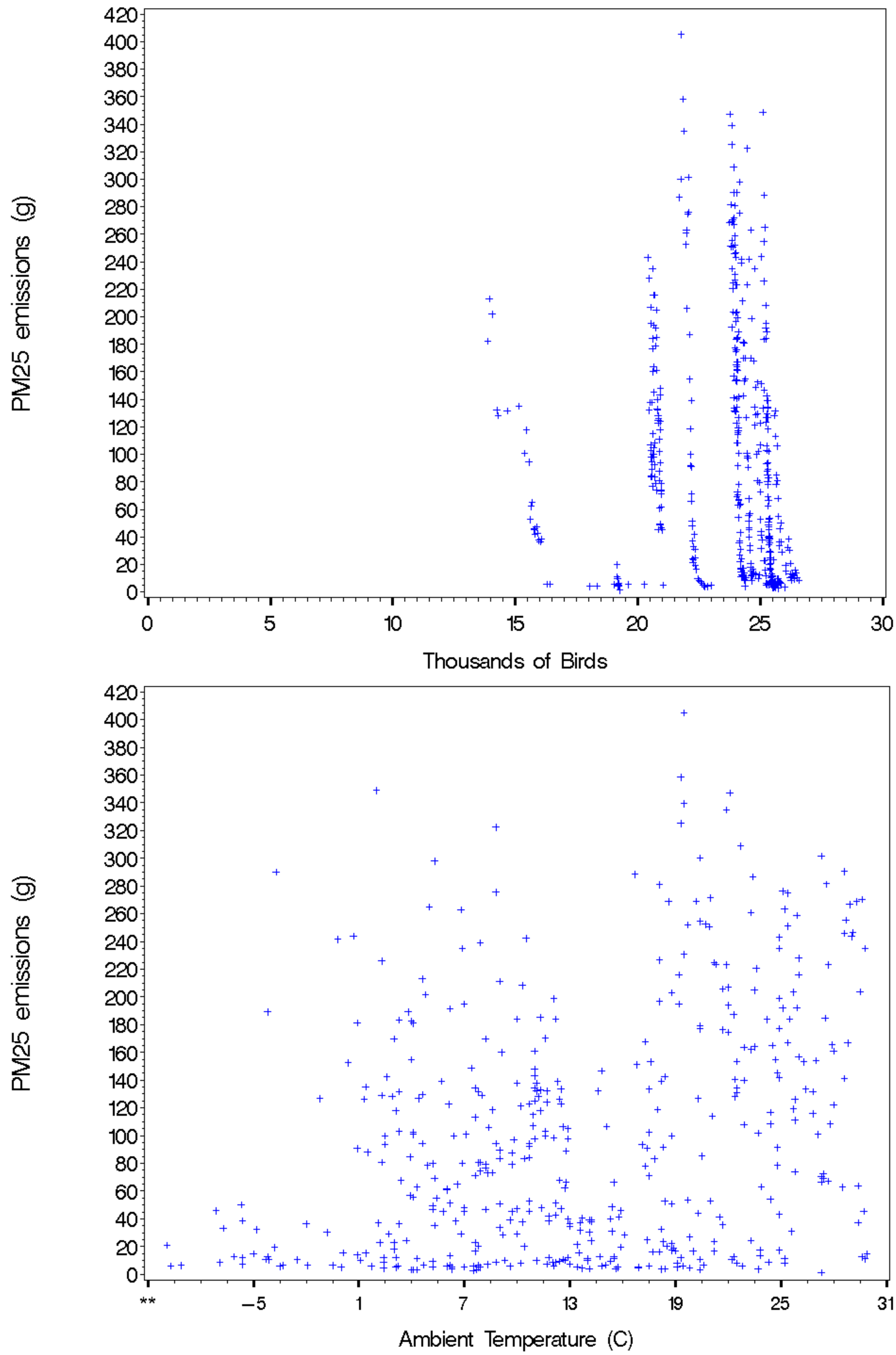

Figure 8-24. PM$_{2.5}$ Emissions vs. Predictor Variables *birds and *ta***

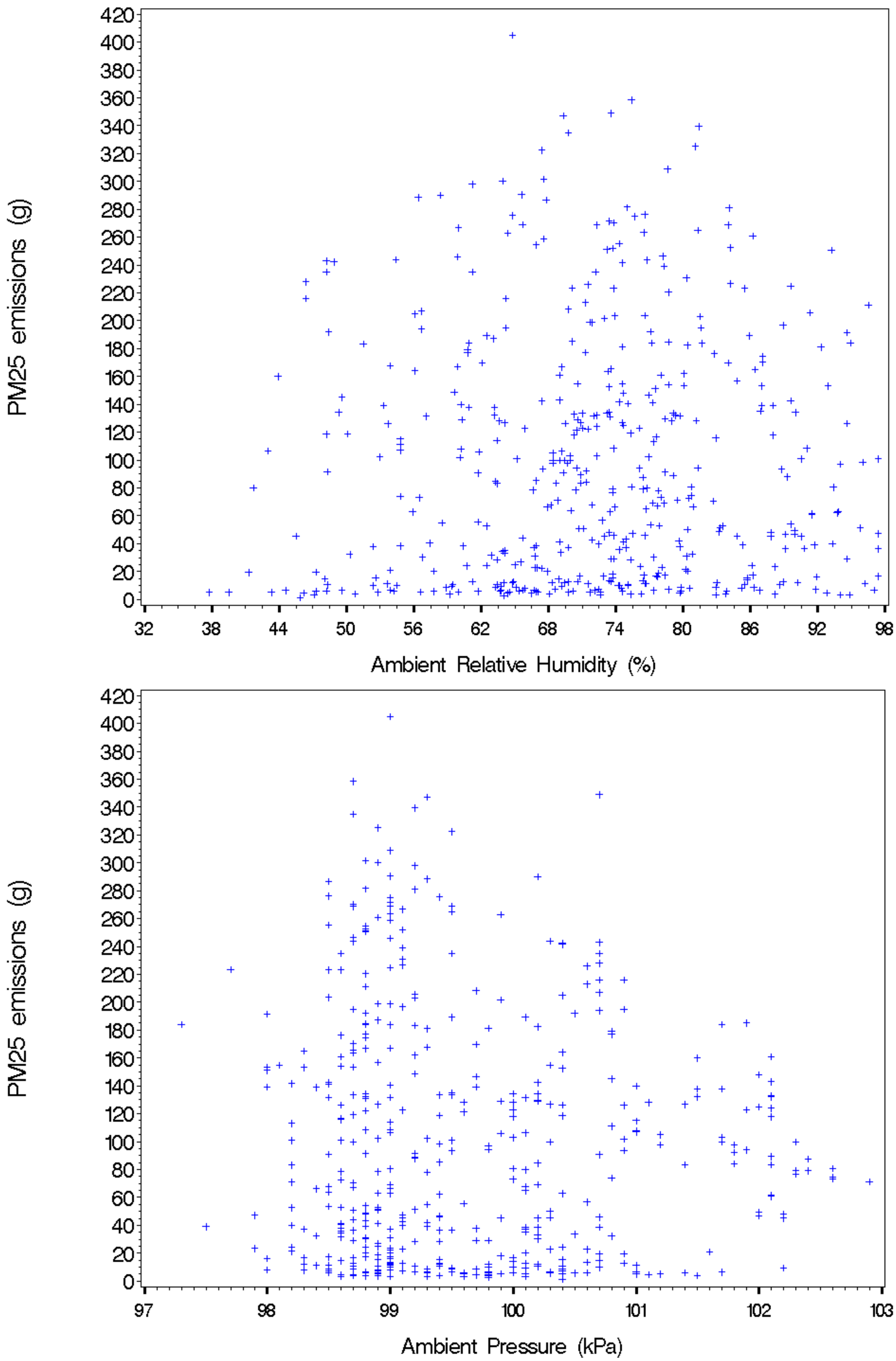

Figure 8-25. PM$_{2.5}$ Emissions vs. Predictor Variables *ha and *pa***

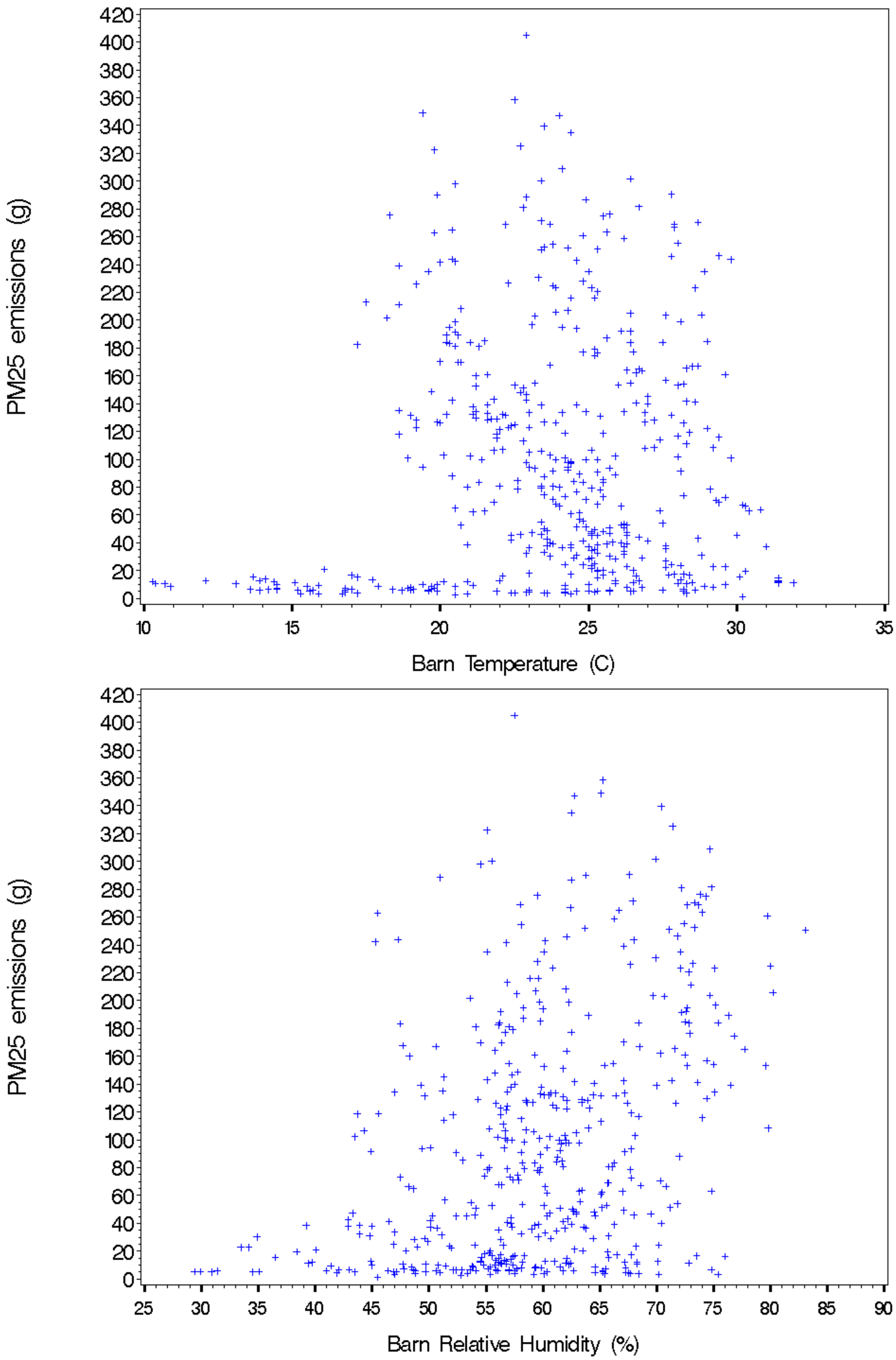

Figure 8-26. $PM_{2.5}$ Emissions vs. Predictor Variables *tc and *hc***

Table 8-23 summarizes the mean trend variables that describe the dependence of $PM_{2.5}$ emissions on the original predictor variables. The variables in column two were taken to be the main effect of the original predictors in column one of the table. For all predictors except *buildup* and *avem**, the mean trend variable was the same as the original variable. For *buildup*, the main effect was the indicator variable, *build*. For *avem**, the linear and quadratic terms were collectively considered the main effect for one version of the EEM tested, and the exponential of average bird mass (*eavem*) was considered in a second version of the EEM.

Table 8-23. Summary of Main Effect Mean Trend Variables for $PM_{2.5}$

Original Predictor Variable[a]	Main Effect Mean Trend Variable(s)
buildup	*build*
*birds**	*birds*
*avem**	$avem$, $avem^2$ *eavem*
*ta**	*ta*
*ha**	*ha*
*pa**	*pa*
*tc**	*tc*
*hc**	*hc*

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1).

8.3.3.2 *Creating Mean Trend Variables from Main Effects and Interactions for $PM_{2.5}$*

The EPA created interaction terms and determined what level of interactions (e.g., two-way, three-way) to include in the set of candidate mean trend variables of Table 8-23. Initial testing of the R^2 of two-way and three-way terms conducted by the EPA suggested that consideration of two-way interactions was appropriate for development of $PM_{2.5}$ EEMs. The main effects and interaction terms for the versions of the three EEMs tested are presented in Table 8-24.

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Table 8-24. Candidate Mean Trend Variables for the I, IA and IAC $PM_{2.5}$ EEMs

EEM	Main Effects	Two-Way Interaction Terms
I, Quadratic (I EEM_Q)	*build, birds, avem, avem^2*	*buildbirds, buildavem, buildavem^2, birdsavem, birdsavem^2*
I, Exponential (I EEM_E)	*build, birds, eavem*	*buildbirds, buildeavem, birdseavem*
IA, Quadratic (IA EEM_Q)	Same as I EEM_Q plus: *ta, ha, pa*	Same as I EEM_Q plus: *buildta, buildha, buildpa, birdsta, birdsha, birdspa, avemta, avem^{2}ta, avemha, avem^{2}ha, avempa, avem^{2}pa,taha, tapa, hapa*
IA, Exponential (IA EEM_E)	Same as I EEM_E plus: *ta, ha, pa*	Same as I EEM_E plus: *buildta, buildha, buildpa, birdsta, birdsha, birdspa, eavemta, eavemha, eavempa, taha, tapa, hapa*
IAC, Quadratic (IAC EEM_Q)	Same as IA EEM_Q plus: *tc, hc*	Same as IA EEM_Q plus: *buildtc, buildhc, birdstc, birdshc, avemtc, avem^{2}tc, avemhc, avem^{2}hc, tatc, tahc, hatc, hahc, patc, pahc, tchc*
IAC, Exponential (IAC EEM_E)	Same as IA EEM_E plus: *tc, hc*	Same as IA EEM_E plus: *buildtc, buildhc, birdstc, birdshc, eavemtc, eavemhc, tatc, tahc, hatc, hahc, patc, pahc, tchc*

8.3.3.3 *Centering and Scaling Predictors for $PM_{2.5}$*

The EPA centered and scaled each continuous predictor variable prior to creating interaction terms by subtracting the mean of all observations in the base dataset from each value, then dividing by the standard deviation of the base dataset. The centering and scaling factors for the predictor variable for the $PM_{2.5}$ final EEMs are presented in Table 8-25.

Table 8-25. Centering and Scaling Reference Values for Continuous $PM_{2.5}$ Predictor Variables

Predictor Variable[a]	Centering Value	Scaling Value
*birds**	24	2.8
*avem**	1.1	0.76
*ta**	13	8.8
*ha**	72	12
*pa**	99	0.73
*tc**	27	3.5
*hc**	58	9.7

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1). Predictor variables are centered and scaled prior to the creation of higher-order terms (e.g., *eavem or avem^2*) and the creation of interaction terms (e.g., *avemta*).

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8.3.4 Selecting Final Mean Trend Variables for $PM_{2.5}$

8.3.4.1 Inventory EEM for $PM_{2.5}$

Predictions based on the I EEM_Q developed systematic bias for the slope, γ_0, prior to completing the backwards elimination process. Predictions based on the I EEM_E completed the backward elimination process without developing any systematic bias.

The selected form of the I EEM_Q contained all the initial interaction terms (Table 8-26). This EEM displayed the best fit-statistics against the base dataset (lowest BIC and -2LL values) and the cross-validation dataset (lowest RMSE and highest R^2), without exhibiting systematic bias.

The selected form of the I EEM_E occurred after one backward elimination step, the removal of the interaction term *buildbirds*. The selected version of the I EEM_E had the best fit-statistics against the base dataset and good fit statistics versus the cross-validation dataset. The fit statistics for the final candidate I EEMs are presented in Table 8-27. A check mark (✓) in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level, while an "x" indicates that it is significantly different from zero. Similarly, a check mark or an "x" in the column for γ_1 indicates whether or not the estimate is significantly different from one.

Overall, the I EEM_Q has slightly better fit statistics against both the base and cross-validation dataset. Therefore, the EPA selected the quadratic version of the I EEM for $PM_{2.5}$ emissions.

Table 8-26. Final Candidate I EEM Mean Trend Variables for $PM_{2.5}$

EEM	Main Effects	Two-Way Interaction Terms
I EEM_Q	*build, birds, avem, avem*^{2}	*buildbirds, buildavem, buildavem*^{2}*, birdsavem, birdsavem*^{2}
I EEM_E	*build, birds, eavem*	*buildeavem, birdseavem*

Table 8-27. Final Candidate I EEM Fit Statistics for $PM_{2.5}$

Candidate EEM	Fit Statistics							
	-2LL	BIC	% in PI	Width (g)	RMSE (g)	R^2	γ_0 (g)	γ_1
I EEM_Q	4,320	4,327	97	168	36	0.84	9.6 ✓	0.95 ✓
I EEM_E	4,355	4,363	99	201	43	0.77	3.4 ✓	0.96 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the $\alpha = 0.05$ significance level.

8.3.4.2 *Inventory and Ambient EEM for $PM_{2.5}$*

The IA EEM_Q developed systematic bias for the slope, γ_0, prior to completing the backwards elimination process, and IA EEM_E completed the backward elimination process without any systematic bias.

The selected forms of the IA EEM_Q and IA EEM_E are presented in Table 8-28. The best version of the IA EEM_Q displayed the best fit-statistics against the cross-validation dataset (lowest RMSE and highest R^2) and the smallest confidence interval width and best coverage percentage, without exhibiting systematic bias. The mean trend variables for the selected version of the IA EEM_E included all the interaction terms. This version of the IA EEM_E had the best fit-statistics against the base dataset (lowest BIC and -2LL values, and smallest confidence interval width) and the cross-validation dataset (lowest RMSE and highest R^2). The fit statistics for the selected IA EEM_Q and IA EEM_E are presented in Table 8-29.

The IA EEM_Q generally had better fit statistic than the IA EEM_E version. The IA EEM_E version did have slightly better base dataset fit (smaller -2LL and BIC); however, the IA EEM_Q version was better with respect to all other fit statistics. Therefore, the EPA selected the quadratic version of the IA EEM for $PM_{2.5}$ emissions.

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Table 8-28. Final Candidate IA EEM Mean Trend Variables for $PM_{2.5}$

EEM	Main Effects	Two-way Interaction Terms
IA EEM_Q	*build, birds, avem, avem^2, ta, ha, pa*	*buildavem, buildavem^2, buildpa, birdsavem, birdsavem^2, birdsta, birdspa, avemta, avem^{2}ta, avemha, avem^{2}ha, avempa, avem^{2}pa, taha, tapa, hapa*
IA EEM_E	*build, birds, eavem, ta, ha, pa*	*buildbirds, buildeavem, buildta, buildha, buildpa, birdseavem, birdsta, birdsha, birdspa, eavemta, eavemha, eavempa, taha, tapa, hapa*

Table 8-29. Final Candidate IA EEM Fit Statistics for $PM_{2.5}$

Candidate EEM	Fit Statistics							
	-2LL	BIC	% in PI	Width (g)	RMSE (g)	R^2	γ_0(g)	γ_1
IA EEM_Q	4,208	4,216	97	144	28	0.90	7.6 ✓	0.96 ✓
IA EEM_E	4,210	4,217	99	196	39	0.80	1.4 ✓	0.98 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the $\alpha = 0.05$ significance level.

8.3.4.3 *Inventory, Ambient and Confinement EEM for $PM_{2.5}$*

The IAC EEM_Q regularly developed systematic bias for γ_0 prior to completing the backwards elimination process. The IAC EEM_Q also developed systematic bias for the intercept, γ_1, just prior to completing the backward elimination process. The IAC EEM_E completed the backward elimination process without any systematic bias.

The mean trend variables for the selected version of the IAC EEM_Q and IAC EEM_E are presented in Table 8-30. The IAC EEM_Q displayed the best fit-statistics against the cross-validation dataset (lowest RMSE and highest R^2) coupled with a small confidence interval width and approximately 95 percent inclusion in the confidence interval, without displaying systematic bias. The IAC EEM_E displayed the best fit-statistics against the cross-validation dataset (lowest RMSE and highest R^2) coupled with one of the smallest confidence interval widths and approximately 95 percent inclusion in the confidence interval. The fit statistics for both the selected IAC EEM_Q and IAC EEM_E are presented in Table 8-31. Overall, the IAC EEM_Q had slightly better fit statistics than the IAC EEM_E. Therefore, the EPA selected the quadratic version of the IAC EEM for $PM_{2.5}$ emissions.

Table 8-30. Final Candidate IAC EEM Mean Trend Variables for $PM_{2.5}$

EEM	Main Effects	Two-way Interaction Terms
IAC EEM_Q	*build, birds, avem, avem², ta, ha, pa, tc, hc*	*buildbirds, buildavem, buildavem², buildta, buildha, buildpa, buildtc, buildhc, birdsavem, birdsavem², birdsta, birdsha, birdspa, birdstc, birdshc, avemta, avem²ta, avemtc, avem²tc, avemhc, avem²hc, taha, tapa, hapa, tatc, tahc, hatc, hahc, patc, pahc, tchc*
IAC EEM_E	*build, birds, eavem, ta, ha, pa, tc, hc*	*buildeavem, buildtc, birdseavem, birdsta, birdspa, eavemta, eavempa, eavemtc, eavemhc, taha, hapa, tatc, tahc*

Table 8-31. Final Candidate IAC EEM Fit Statistics for $PM_{2.5}$

Candidate EEM	Fit Statistics							
	-2LL	BIC	% in PI	Width (g)	RMSE (g)	R^2	γ_0 (g)	γ_1
IAC EEM_Q	4,086	4,091	97	142	27	0.90	7.6 ✓	0.95 ✓
IAC EEM_E	4,169	4,176	98	165	32	0.87	-2.5 ✓	1.0 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the $\alpha = 0.05$ significance level.

8.3.5 Summary of Final Results for the I, IA and IAC EEMs for $PM_{2.5}$

A summary of the final mean trends terms for the $PM_{2.5}$ EEMs are provided in Table 8-32. The covariance parameters for the final forms of the EEMs are listed in Table 8-33.The coefficients for the EEM mean trend variables are listed in Table 8-34. The value of each main effect variable (x_p) must be centered and scaled when using the terms in Equation 7-1. The centering and scaling factors for the predictor variable for the final $PM_{2.5}$ EEMs are presented in Table 8-25.

Table 8-32. Final EEM Mean Trend Variables for $PM_{2.5}$

EEM	Main Effects	Two-Way Interaction Terms
I	*build, birds, avem, avem*^{2}	*buildbirds, buildavem, buildavem*^{2}*, birdsavem, birdsavem*^{2}
IA	*build, birds, avem, avem*^{2}*, ta, ha, pa*	*buildavem, buildavem*^{2}*, buildpa, birdsavem, birdsavem*^{2}*, birdsta, birdspa, avemta, avem*^{2}*ta, avemha, avem*^{2}*ha, avempa, avem*^{2}*pa, taha, tapa, hapa*
IAC	*build, birds, avem, avem*^{2}*, ta, ha, pa, tc, hc*	*buildbirds, buildavem, buildavem*^{2}*, buildta, buildha, buildpa, buildtc, buildhc, birdsavem, birdsavem*^{2}*, birdsta, birdsha, birdspa, birdstc, birdshc, avemta, avem*^{2}*ta, avemtc, avem*^{2}*tc, avemhc, avem*^{2}*hc, taha, tapa, hapa, tatc, tahc, hatc, hahc, patc, pahc, tchc*

Table 8-33. Covariance Parameter for Final $PM_{2.5}$ EEMs

Covariance Parameter	Estimate		
	I	IA	IAC
$\hat{\rho}$	0.7640	0.6833	0.6941
$\hat{\sigma}^2$	1,504.72	1031.15	981.22

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Table 8-34. Regression Coefficient for Final $PM_{2.5}$ EEMs

p	x_p	$\hat{\beta}_p$		
		I	IA	IAC
0	*Intercept*	73.69	57.76	78.21
1	*build*	15.64	28.45	9.22
2	*birds*	5.66	15.35	-14.10
3	*avem*	75.14	72.83	73.25
4	$avem^2$	17.2	28.31	-5.81
5	*ta*	a	27.22	29.64
6	*ha*	a	-5.20	12.39
7	*pa*	a	11.23	0.19
8	*tc*	a	a	-8.24
9	*hc*	a	a	-41.36
10	*buildbirds*	7.27	a	38.69
11	*buildavem*	-0.27	0.50	-3.01
12	$buildavem^2$	-6.31	-15.31	3.79
13	*buildta*	a	a	-2.80
14	*buildha*	a	a	-13.78
15	*buildpa*	a	-7.14	4.74
16	*buildtc*	a	a	9.99
17	*buildhc*	a	a	30.48
18	*birdsavem*	7.81	10.44	9.35
19	$birdsavem^2$	0.44	-2.30	2.03
20	*birdsta*	a	9.23	-2.40
21	*birdsha*	a	a	-0.56
22	*birdspa*	a	3.61	2.72
23	*birdstc*	a	a	6.35
24	*birdshc*	a	a	6.54
25	*avemta*	a	8.81	7.05
26	$avem^2ta$	a	-9.62	0.78
27	*avemha*	a	-3.40	a
28	$avem^2ha$	a	-0.06	a
29	*avempa*	a	1.48	a
30	$avem^2pa$	a	-2.82	a
31	*avemtc*	a	a	-6.23
32	$avem^2tc$	a	a	-10.27
33	*avemhc*	a	a	-8.14
34	$avem^2hc$	a	a	1.07
35	*taha*	a	-3.34	-4.27
36	*tapa*	a	-2.31	-2.01
37	*hapa*	a	1.06	1.35
38	*tatc*	a	a	3.28
39	*tahc*	a	a	13.00
40	*hatc*	a	a	0.46
41	*hahc*	a	a	-1.36
42	*patc*	a	a	2.35
43	*pahc*	a	a	2.89
44	*tchc*	a	a	-1.83

Note: Each main effect variable was centered and scaled prior to creating higher-order terms, exponential terms and interactions.
[a] This variable is not included in the EEM.

8.4 EEMs for TSP

8.4.1 Selecting Datasets

The majority of the data available for developing the TSP EEMs were from the Kentucky broiler sites. The CA1B site had an abbreviated collection schedule for TSP. For TSP sampling at the California site, the goal of the NAEMS was to collect data for one week every eight weeks.

As a result, the CA1B site has a higher percent of missing data (see Table 8-35) when compared to the total number of monitoring days for the grow-out periods.

Overall data completeness for TSP was 33 percent of the grow-out period days. Table 8-35 shows that TSP emissions values were available for just over 5 percent of the study period for the CA1B houses. The Kentucky sites had better completeness with seasonal completeness ranging from 84 to 98 percent. The available data are evenly distributed across the seasons.

Of the 601 TSP emission readings, 16 did not have values for the inventory, ambient and confinement predictor variables necessary for the EEM development. After these data records were removed, the base dataset for TSP EEM development consisted of 585 records. The EPA then randomly withheld 107 observations (approximately 18 percent of the 585 observations) to serve as the cross-validation data set.

Table 8-35. Data Completeness for TSP EEMs

Season	Description	CA1B		KY1B-1	KY1B-2	All Houses
		House 10	House 12	House 5	House 3	
All seasons	Number of grow-out days	642	647	288	267	1,844
	Days TSP data available	37	39	278	247	601
	Percent complete	6%	6%	97%	93%	33%
Winter	Number of grow-out days	150	153	87	74	464
	Days TSP data available	7	7	83	68	165
	Percent complete	5%	5%	95%	92%	36%
Spring	Number of grow-out days	157	158	83	55	453
	Days TSP data available	8	15	79	46	148
	Percent complete	5%	9%	95%	84%	33%
Summer	Number of grow-out days	156	157	55	74	442
	Days TSP data available	10	12	54	70	146
	Percent complete	6%	8%	98%	95%	33%
Fall	Number of grow-out days	179	179	63	64	485
	Days TSP data available	12	5	62	63	142
	Percent complete	7%	3%	98%	98%	29%

8.4.2 Choosing the Probability Distribution for TSP

The EPA first evaluated the empirical distribution (i.e., histogram) of the observed daily TSP emissions to determine whether using the normal distribution could be justified. The histogram in Figure 8-27 shows that many of the TSP observations correspond to lower values, with a single peak at emissions values less than 0.8 kg. Also, the figure shows that the number of

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observations decreases as emissions increase. Based on this histogram, the EPA determined that the empirical distribution was unimodal (single-peaked) and skew right.

The EPA separated the base dataset into bins according to values of average bird mass. Figure 8-28, for example, shows histograms of TSP emissions within the following six evenly distributed bins of average bird mass (*avem**) values (in kg): 0.0 to 0.5, 0.5 to 1.0, 1.0 to 1.5, 1.5 to 2.0, 2.0 to 2.5 and 2.5 to 3.0. The figure shows that the histograms for bins 1 and 2 are skew right while those for bins 3, 4, 5 and 6 are more symmetric. Further disaggregation according to the values of other variables shows a variety of empirical distributions for different sets of conditions, and the skew-right pattern is by no means ubiquitous. There are not enough observations under any specific set of conditions (e.g., bird mass and humidity) to use the empirical distribution to determine the true distribution. Therefore, in the absence of strong evidence against doing so, the EPA used the normal distribution.

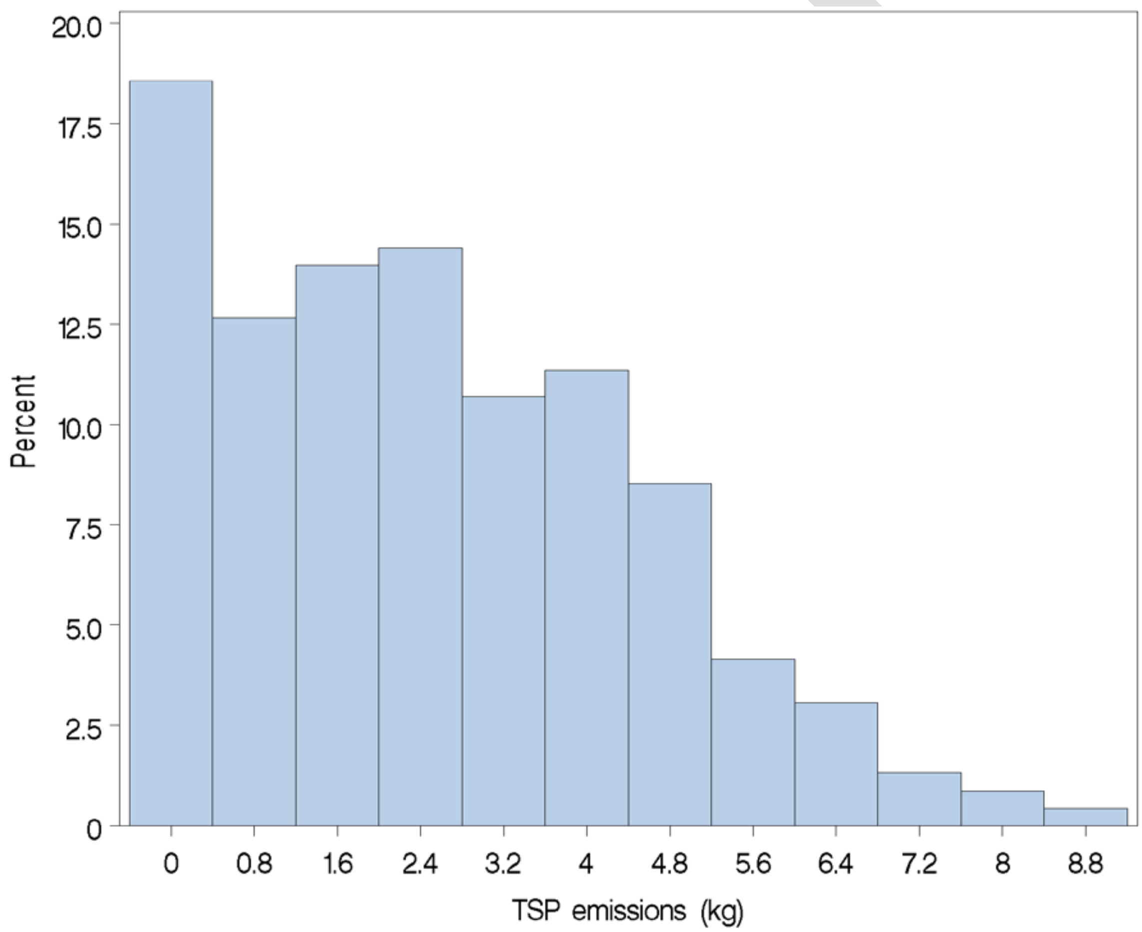


Figure 8-27. Histogram of TSP Emissions in the Base Dataset

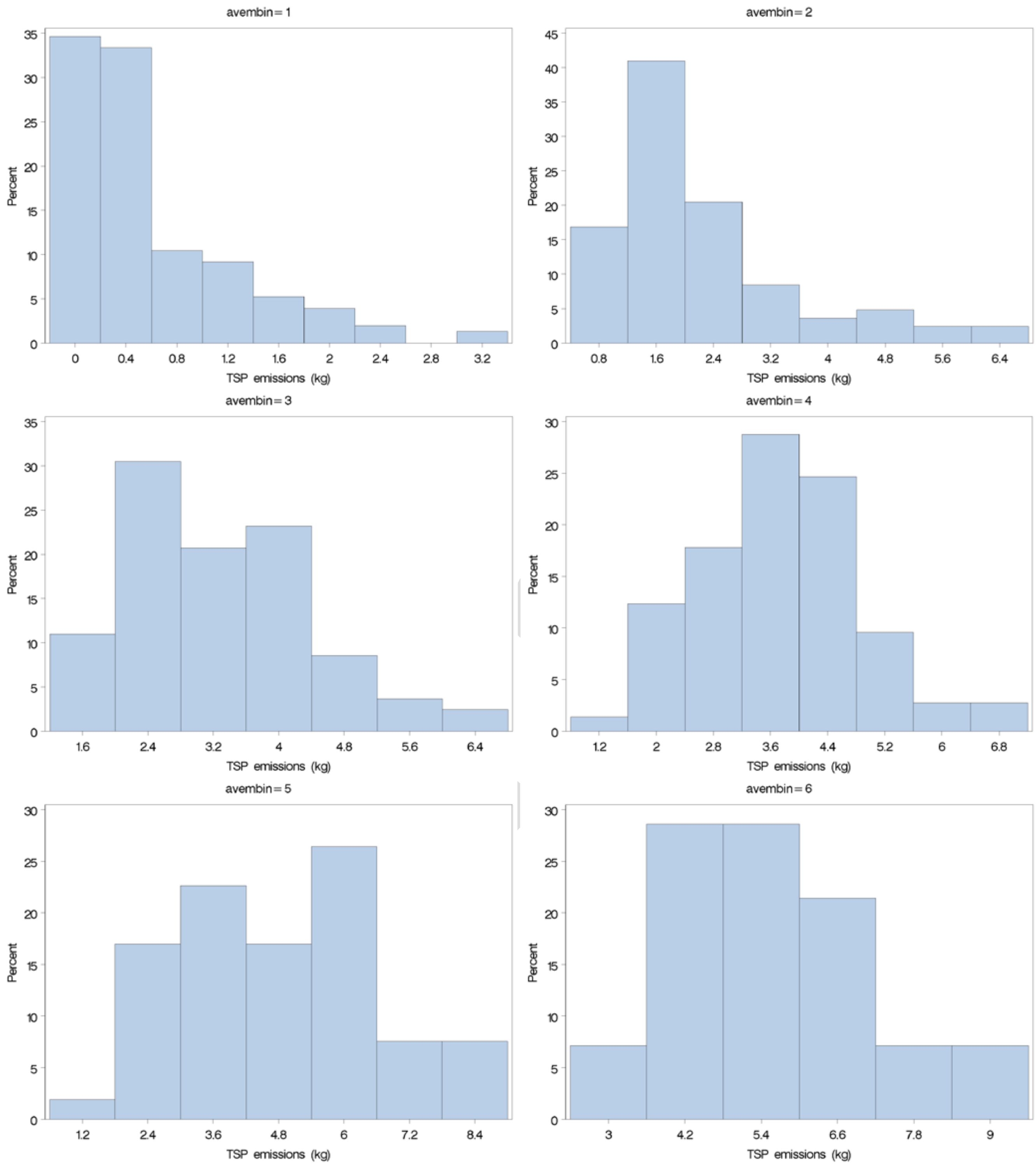


Figure 8-28. Histograms of TSP Emissions by *avem Bins**

8.4.3 Developing Candidate Mean Trend Variables for TSP

8.4.3.1 Choosing Predictor Variable Functional Forms for TSP

Plots of TSP emissions versus average bird mass, for all houses, suggested a positive relationship, with a slight curvature that levels off at higher average bird masses. Figure 8-29 shows a scatter plot of TSP emissions versus average mass, with overlays of linear, quadratic and cubic regressions. The gradual increasing trend suggested a quadratic relationship between TSP emissions and the average bird mass. Accordingly, the EPA tested one form of the EEM based on a quadratic relationship with average mass (*avem and avem*^{2}).

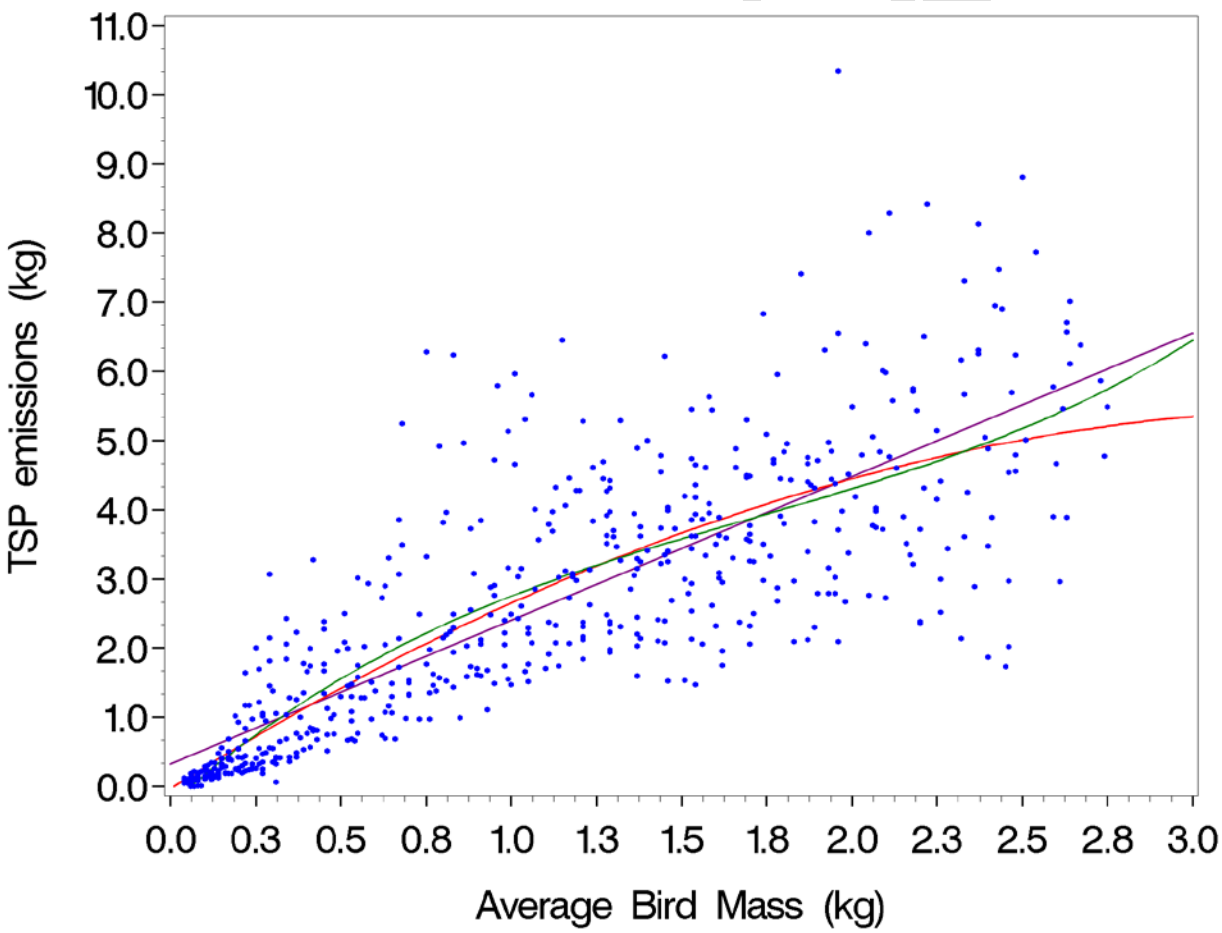


Figure 8-29. TSP Emissions vs. Average Bird Mass (Regression Overlays: purple = linear, red = quadratic, green = cubic)

With regard to the effect of accumulated litter (*buildup*) on TSP emissions (see Section 7.3.1), the EPA discerned a relationship between TSP emissions and the degree of litter accumulation, based on the variance in TSP emissions values for lower bird weights (see Figure 8-30). When TSP emissions are plotted by average mass and color-coded to indicate the level of buildup, there is some indication that higher emissions correspond to built-up litter at any animal mass; however, there is substantial variability in the data. Further investigations showed that the increased variance could not be attributed to differences in sites (Figure 8-31), as all three sites show the same variability across the grow-out period.

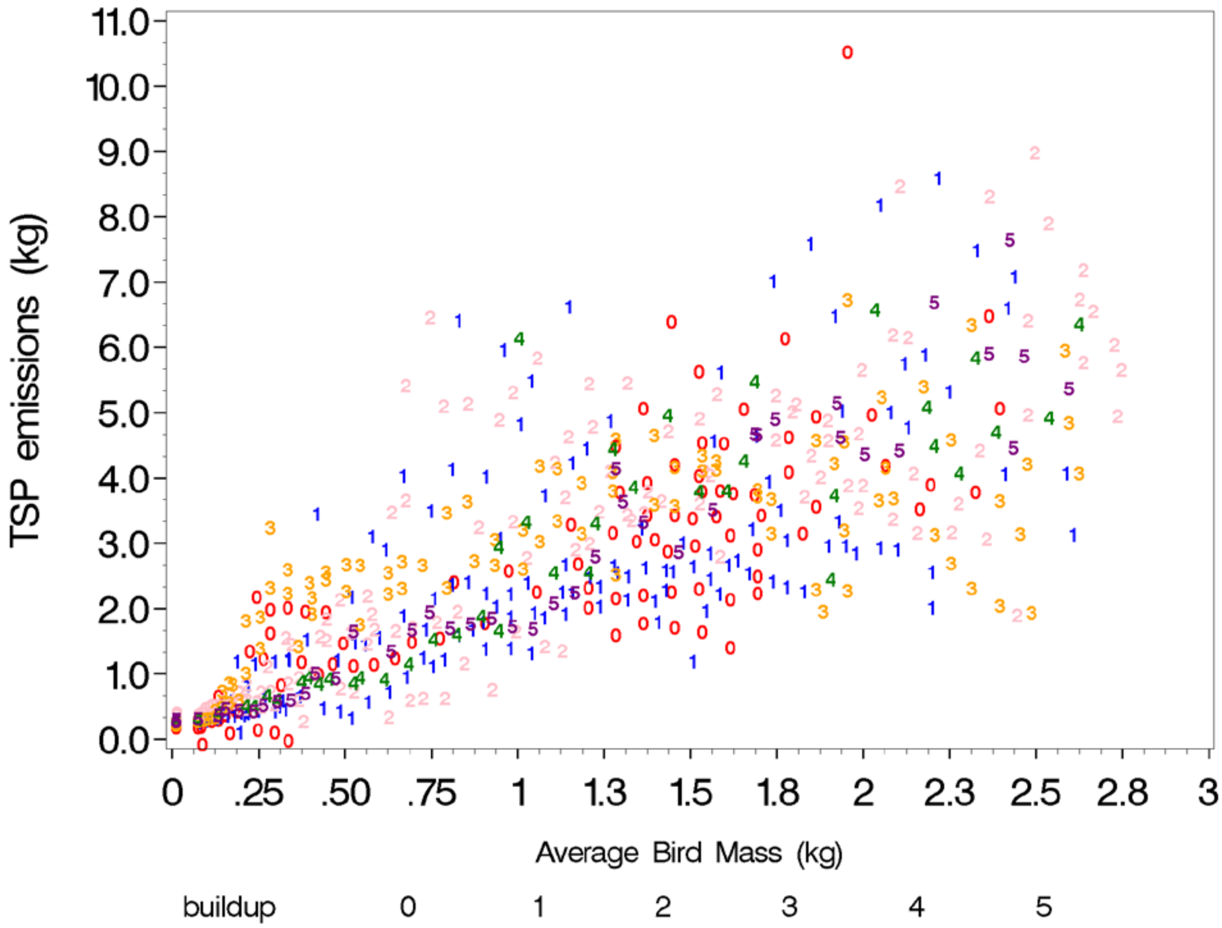


Figure 8-30. Overlay of *buildup* on TSP Emissions vs. Average Live Bird Mass

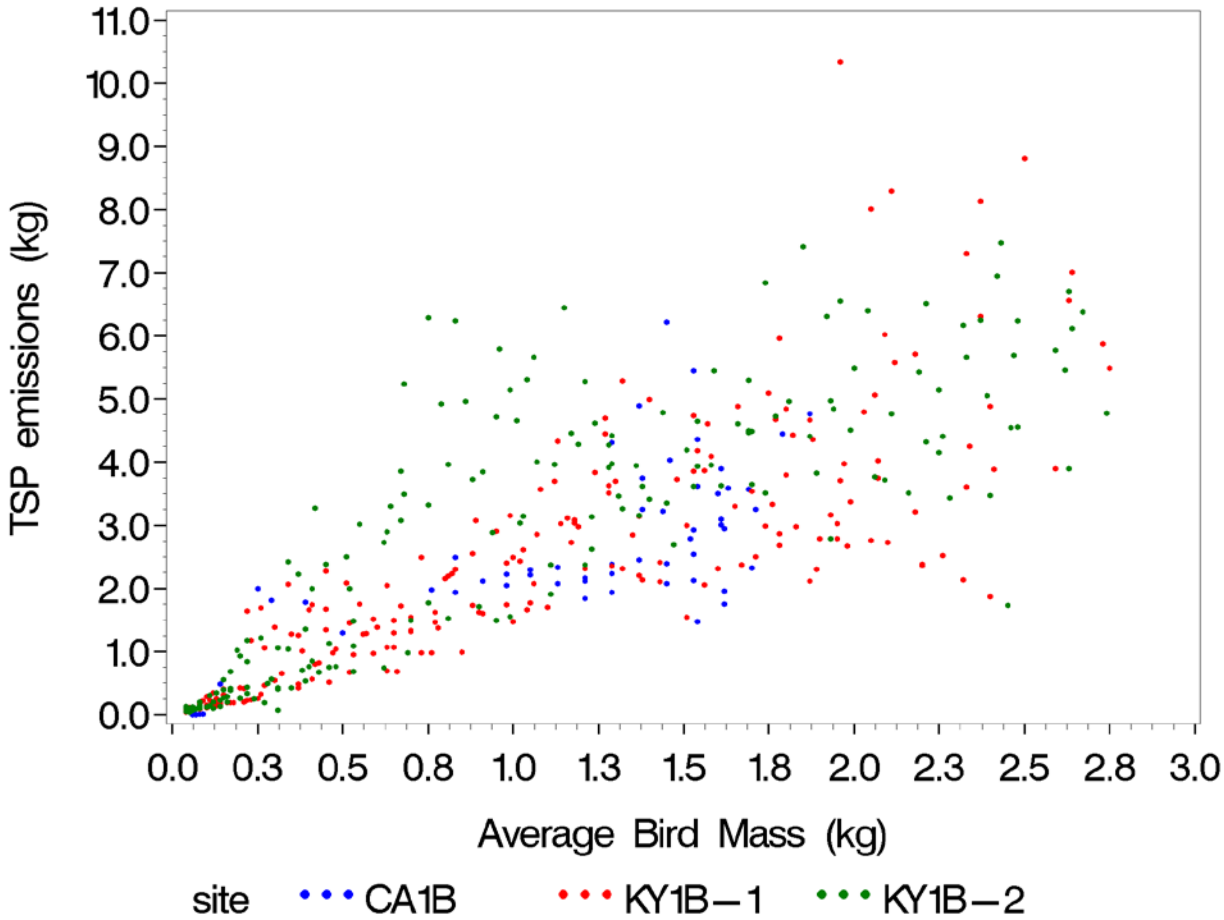


Figure 8-31. TSP Emissions vs. Average Bird Mass, Color-coded by Site

Plots of the build-up indicator parameters (i.e., *buildup, build, bld*) suggested average TSP emissions do not increase for flocks raised on built-up litter, because there is little difference in the minimum emissions levels between the litter conditions (Figure 8-32), and only a slight difference in average values. The EPA decided to include *build* as the functional form through which the variable *buildup* entered the mean trend function and test its significance using the p-value analysis to determine the final mean trend variables.

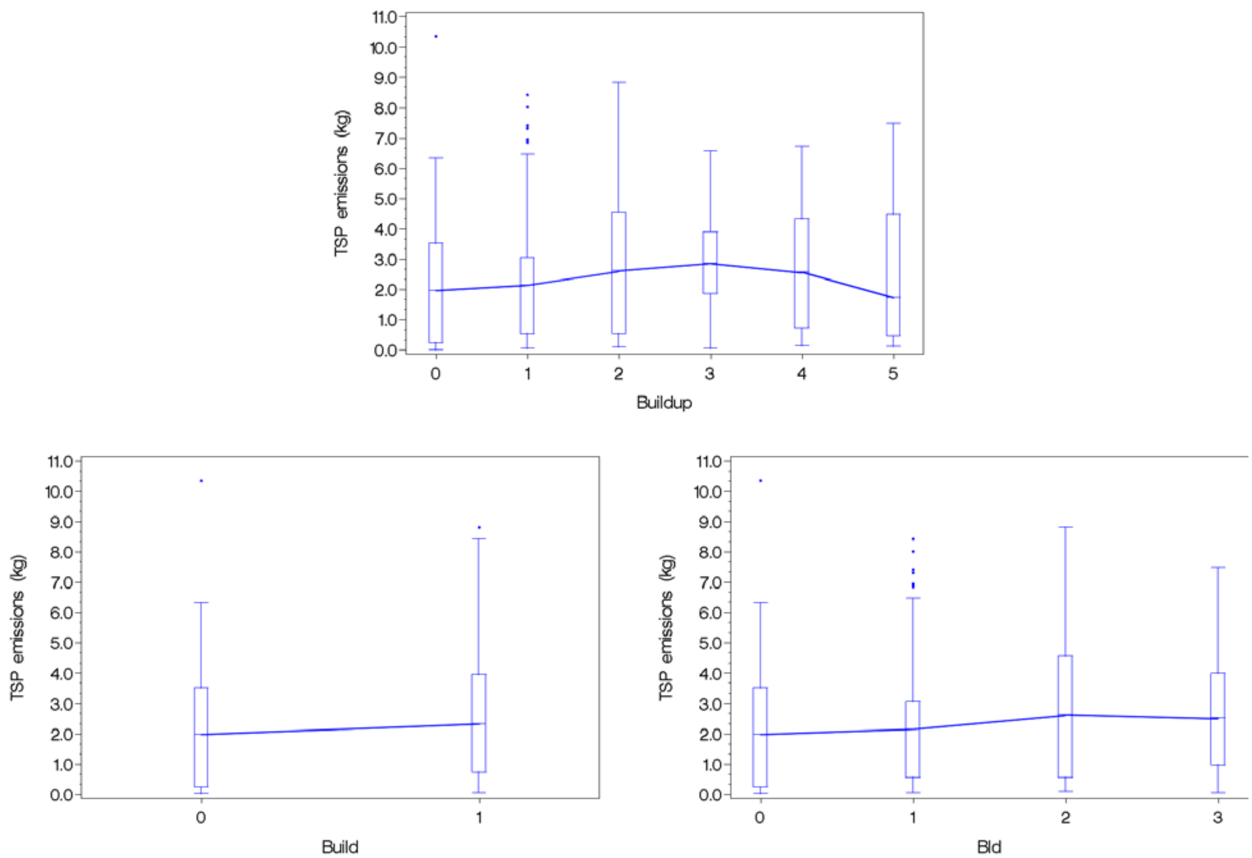
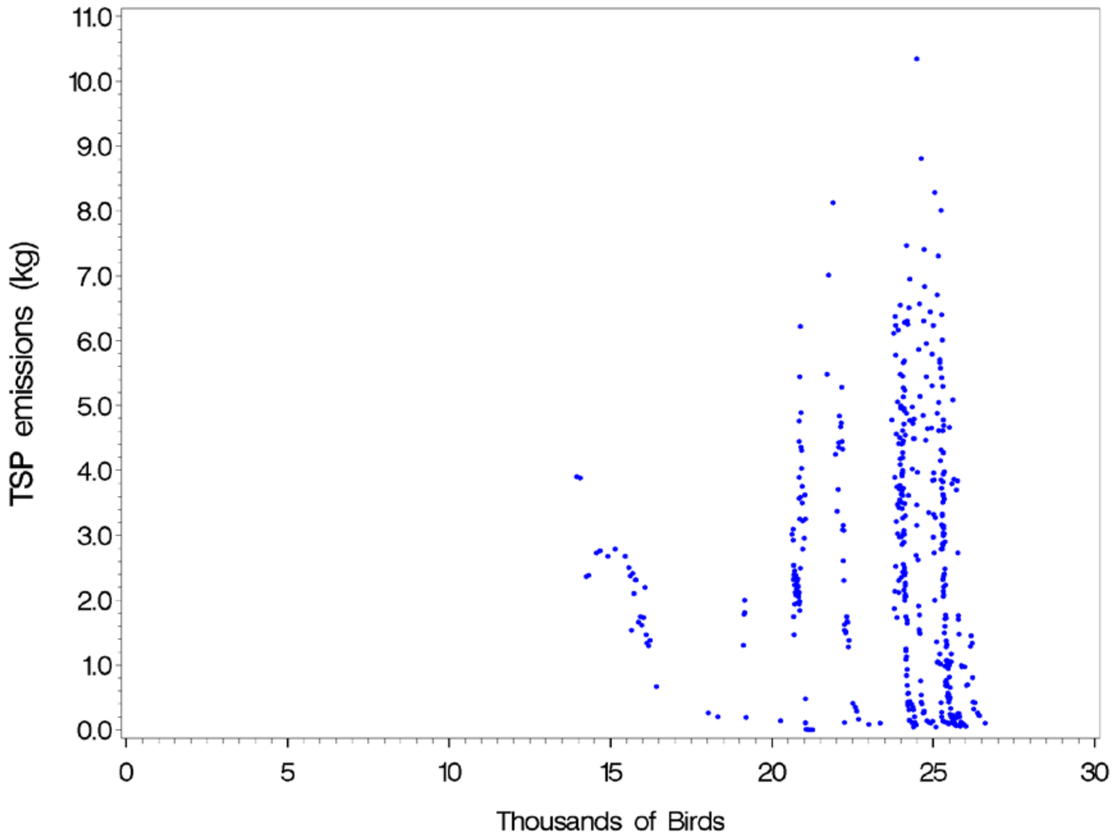


Figure 8-32. Box Plots of TSP Emissions vs. Categorical Variables for *buildup*

Figure 8-33, Figure 8-34, and Figure 8-35 show the scatter plots of TSP emissions versus the remaining predictors (i.e., number of birds, ambient temperature, ambient relative humidity, ambient pressure, house temperature and house relative humidity). Appendix F contains scatter plots of the predictor variables by average animal mass bin. The plots do not indicate that the EPA should use a functional form other than linear. Based on this visual analysis, and the absence of a process-based reason to do otherwise, the EPA chose a linear functional form in developing the TSP EEMs (See Table 8-36).



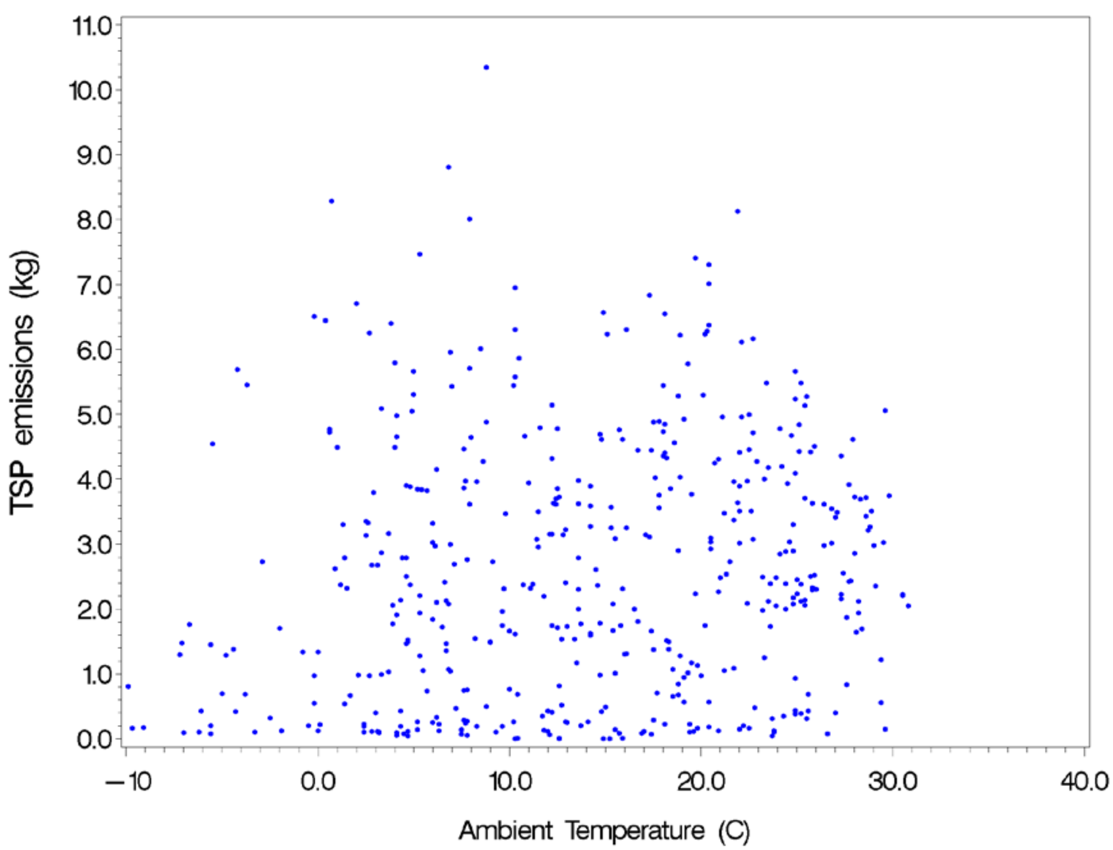


Figure 8-33. TSP Emissions vs. Predictor Variables *birds and *ta****

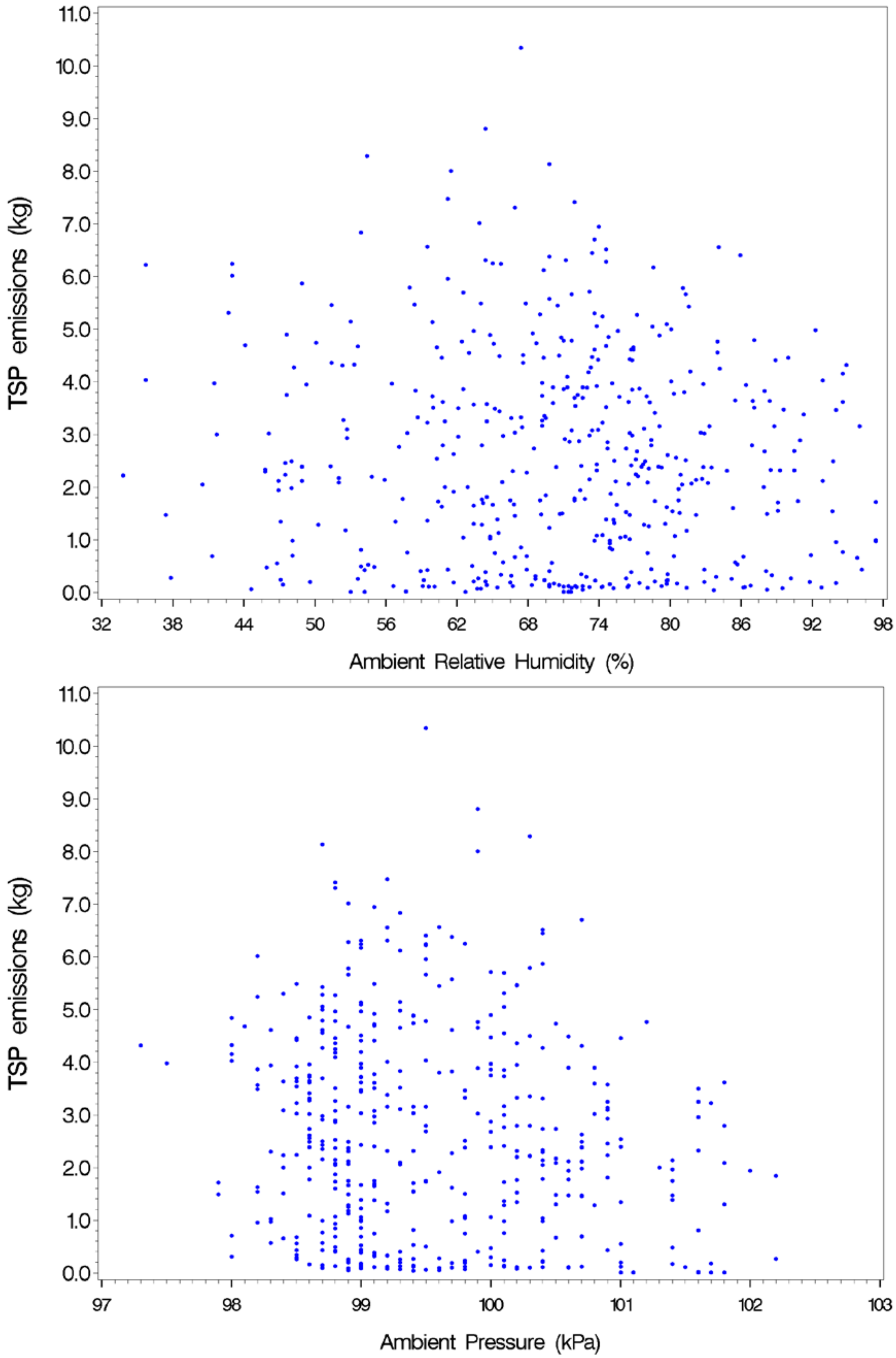


Figure 8-34. TSP Emissions vs. Predictor Variables *ha and *pa***

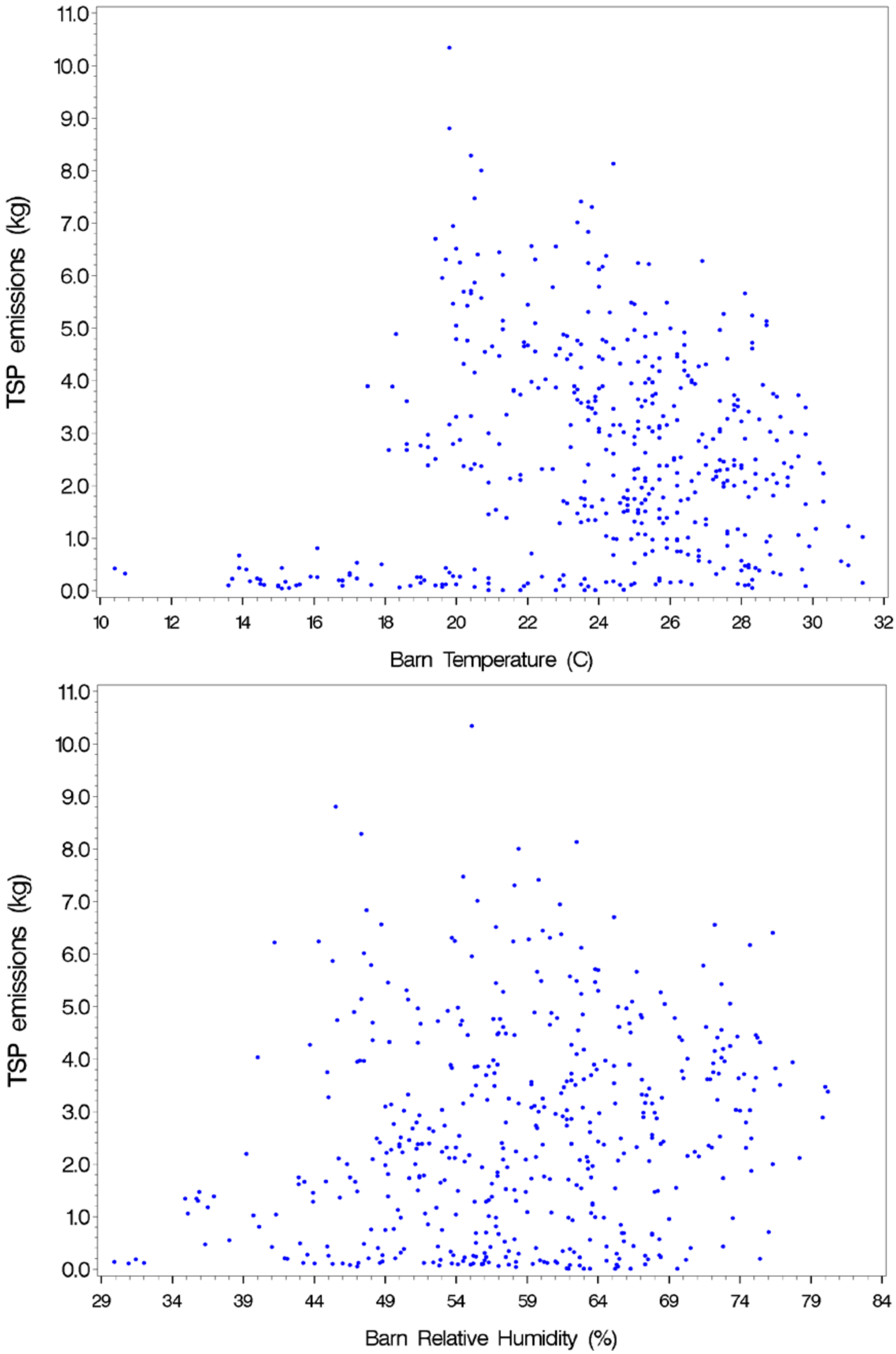


Figure 8-35. TSP Emissions vs. Predictor Variables *tc and *hc****

Table 8-36 summarizes the mean trend variables that describe the dependence of TSP emissions on the original predictor variables. The variables in column two were taken to be the main effect of the original predictors in column one of the table. For all predictors except *buildup* and *avem**, the mean trend variable was the same as the original variable. For *buildup*, the main effect was the indicator variable, *build*. For *avem**, the linear (*avem*) and quadratic ($avem^2$) terms were collectively considered the main effect for the EEM tested.

Table 8-36. Summary of Main Effect Mean Trend Variables for PM_{10}

Original Predictor Variable[a]	Main Effect Mean Trend Variable(s)
buildup	*build*
*birds**	*birds*
*avem**	*avem*, $avem^2$
*ta**	*ta*
*ha**	*ha*
*pa**	*pa*
*tc**	*tc*
*hc**	*hc*

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1).

8.4.3.2 *Creating Mean Trend Variables from Main Effects and Interactions*

The EPA created interaction terms and determined what level of interactions (e.g., two-way, three-way) to include in the set of candidate mean trend variables of Table 8-36. Initial testing of the R^2 of two-way and three-way terms conducted by the EPA suggested that consideration of two-way interactions was appropriate for development of TSP EEMs. The main effects and interaction terms for the versions of the three EEMs tested are presented in Table 8-37.

Table 8-37. Candidate Mean Trend Variables for the I, IA and IAC TSP EEMs

EEM	Main Effects	Two-Way Interaction Terms
I, Quadratic ($I\ EEM_Q$)	*build, birds, avem, avem*^{2}	*buildbirds, buildavem, buildavem*^{2}*, birdsavem, birdsavem*^{2}
IA, Quadratic ($IA\ EEM_Q$)	Same as $I\ EEM_Q$ plus: *ta, ha, pa*	Same as $I\ EEM_Q$ plus: *buildta, buildha, buildpa, birdsta, birdsha, birdspa, avemta, avem*^{2}*ta, avemha, avem*^{2}*ha, avempa, avem*^{2}*pa, taha, tapa, hapa*
IAC, Quadratic ($IAC\ EEM_Q$)	Same as $IA\ EEM_Q$ plus: *tc, hc*	Same as $IA\ EEM_Q$ plus: *buildtc, buildhc, birdstc, birdshc, avemtc, avem*^{2}*tc, avemhc, avem*^{2}*hc, tatc, tahc, hatc, hahc, patc, pahc, tchc*

8.4.3.3 *Centering and Scaling Predictors*

The EPA centered and scaled each continuous predictor variable prior to creating interaction terms by subtracting the mean of all observations in the base dataset from each value, then dividing by the standard deviation of the base dataset. The centering and scaling factors for the predictor variable for the TSP final EEMs are presented in Table 8-38.

Table 8-38. Centering and Scaling Reference Values for Continuous TSP Predictor Variables

Predictor Variable[a]	Centering Value	Scaling Value
*birds**	24	2.6
*avem**	1.0	0.77
*ta**	14	9.4
*ha**	71	13
*pa**	100	0.93
*tc**	24	4.0
*hc**	59	9.6

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1). Predictor variables are centered and scaled prior to the creation of higher-order terms (e.g., *eavem* or *avem*^{2}) and the creation of interaction terms (e.g., *avemta*).

8.4.4 Selecting Final Mean Trend Variables for TSP

Only a quadratic version of the I, IA, and IAC EEMs were tested. Table 8-39 contains the final mean trend variables for the selected form of each EEM after backward elimination of variables (see Section 7.5). Predictions based on the I EEM developed systematic bias for the intercept, γ_1, at all stages. The systematic bias was marginal, and did not indicate a serious issue with the EEM. Predictions based on the IA and IAC version of the EEM did not display systematic bias at any stage of the backward elimination process.

The selected form of the I EEM contained all the initial interaction terms. This EEM displayed the best fit-statistics against the cross-validation dataset (lowest RMSE and highest R^2), and the best estimate of the intercept, γ_1. The selected form of the IA EEM displayed the best fit-statistics against the base dataset (lowest BIC and -2LL values) and the cross-validation dataset (low RMSE and highest R^2). The selected form of the IAC EEM displayed the best fit-statistics against the base dataset (smallest 95 percent confidence interval width) and the cross-validation dataset (low RMSE and highest R^2).

Table 8-40 shows the fit statistics for the best version of each EEM. A check mark (✓) in the column for γ_0 indicates that the estimate is not significantly different from zero at the α = 0.05 significance level, while an "x" indicates that it is significantly different from zero. Similarly, a check mark or an "x" in the column for γ_1 indicates whether or not the estimate is significantly different from one.

Table 8-39. Final I, IA and IAC EEM Mean Trend Variables for TSP EEMs

EEM	Main Effects	Two-Way Interaction Terms
I	*build, birds, avem, avem*^{2}	*buildbirds, buildavem, buildavem*^{2}*,birdsavem, birdsavem*^{2}
IA	*build, birds, avem, avem*^{2}*, ta, ha*	*buildbirds, buildavem, buildavem*^{2}*,birdsta, avemta, avem*^{2}*ta, avemha, avem*^{2}*ha*
IAC	*build, birds, avem, avem*^{2}*, ta, ha, pa, tc, hc*	*buildbirds, buildavem, buildavem*^{2}*, buildta, buildha, buildpa, buildhc, birdsavem, birdsavem*^{2}*, birdspa, birdstc, birdshc, avemta, avem*^{2}*ta, avemha, avem*^{2}*ha, avemhc, avem*^{2}*hc, taha, tapa, hapa, tatc, hahc, pahc*

Table 8-40. Final I, IA and IAC EEM Fit Statistics for TSP

	Fit Statistics							
EEM	-2LL	BIC	% in PI	Width (kg)	RMSE (kg)	R^2	γ_0 (g)	γ_1
I	1,228	1,235	96	5.2	1.0	0.71	0.19 ✓	0.87 x
IA	1,171	1,178	98	4.9	0.83	0.80	0.16 ✓	0.94 ✓
IAC	1,130	1,138	100	4.4	0.75	0.84	0.07 ✓	0.95 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the α = 0.05 significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the α = 0.05 significance level.

8.4.5 Summary of Final Results for the I, IA and IAC EEMs for TSP

The covariance parameters for the final forms of the EEMs are listed in Table 8-41. The coefficients for the EEM mean trend variables are listed in Table 8-42. The value of each main effect variable (x_p) must be centered and scaled when using these terms in Equation 7-1. The centering and scaling factors for the predictor variables used in the final TSP EEMs are presented in Table 8-38.

Table 8-41. Covariance Parameter for Final TSP EEMs

Covariance Parameter	Estimate		
	I	IA	IAC
$\hat{\rho}$	0.6641	0.6704	0.6241
$\hat{\sigma}^2$	1.1696	1.0050	0.7724

Table 8-42. Regression Coefficient for Final TSP EEMs

p	x_p	$\hat{\beta}_p$		
		I	IA	IAC
1	*Intercept*	2.45	2.22	2.20
2	*build*	0.37	0.66	0.67
3	*birds*	0.09	0.02	0.10
4	*avem*	1.69	1.58	1.94
5	$avem^2$	-0.18	-0.03	0.08
6	*ta*	a	0.47	0.81
7	*ha*	a	-0.23	0.29
8	*pa*	a	a	0.05
9	*tc*	a	a	-0.26
10	*hc*	a	a	-0.97
11	*buildbirds*	0.22	0.48	0.38
12	*buildavem*	0.14	0.28	0.16
13	$buildavem^2$	-0.11	-0.31	-0.34
14	*buildta*	a	a	-0.23
15	*buildha*	a	a	-0.23
16	*buildpa*	a	a	-0.16
17	*buildhc*	a	a	0.47
18	*birdsavem*	0.26	a	0.40
19	$birdsavem^2$	-0.06	a	-0.11
20	*birdsta*	a	0.20	a
21	*birdspa*	a	a	0.00
22	*birdstc*	a	a	-0.05
23	*birdshc*	a	a	-0.04
24	*avemta*	a	0.08	0.05
25	$avem^2ta$	a	-0.23	-0.18
26	*avemha*	a	-0.24	0.03
27	$avem^2ha$	a	-0.08	0.11
28	*avemhc*	a	a	-0.44
29	$avem^2hc$	a	a	-0.13
30	*taha*	a	a	0.05
31	*tapa*	a	a	-0.16
32	*hapa*	a	a	0.08
33	*tatc*	a	a	-0.06
34	*hahc*	a	a	0.04
35	*pahc*	a	a	0.02

Note: Each main effect variable was centered and scaled prior to creating higher-order terms, exponential terms and interactions.
[a] This variable is not included in the EEM.

8.5 EEMs for VOCs

8.5.1 Selecting Datasets

Table 8-43 shows the data completeness for VOC emissions at the California and Kentucky sites. As explained previously in Section 5, issues with the monitoring equipment prevented the collection of continuous data for VOCs at the CA1B houses. Consequently, the EEMs for VOCs were based on data from the Kentucky sites only.

A total of 360 days of VOC emissions measurements were available and were evenly distributed across the seasons. Of the 360 VOC observations available, five lacked the necessary inventory, ambient and confinement predictor variables for EEM development. After these missing data records were removed, the base dataset available for developing the VOC EEMs consisted of 355 observations. The EPA then randomly withheld 78 observations (approximately 22 percent of the 355 observations) to serve as the cross-validation data set.

Table 8-43. Data Completeness for VOC EEMs

Season	Description	CA1B		KY1B-1	KY1B-2	All Houses
		House 10	House 12	House 5	House 3	
All seasons	Number of grow-out days	642	647	288	267	1,844
	Days VOC data available	0	0	200	160	360
	Percent complete	0%	0%	69%	60%	20%
Winter	Number of grow-out days	150	153	87	74	464
	Days VOC data available	0	0	54	43	97
	Percent complete	0%	0%	62%	58%	21%
Spring	Number of grow-out days	157	158	83	55	453
	Days VOC data available	0	0	69	32	101
	Percent complete	0%	0%	83%	58%	22%
Summer	Number of grow-out days	156	157	55	74	442
	Days VOC data available	0	0	18	41	59
	Percent complete	0%	0%	33%	55%	13%
Fall	Number of grow-out days	179	179	63	64	485
	Days VOC data available	0	0	59	44	103
	Percent complete	0%	0%	94%	69%	21%

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8.5.2 Choosing the Probability Distribution for VOCs

The EPA first evaluated the empirical distribution (i.e., histogram) of the observed daily emissions for VOCs in determining whether using the normal distribution could be justified. The histogram in Figure 8-36 shows that many of the observations for VOCs correspond to lower emissions values, with a single peak at values around 0.375 kg. The figure also shows that the number of observations decreases as emissions increase. Based on this histogram, the EPA determined that the empirical distribution was unimodal (single-peaked) and skew right.

The EPA separated the base dataset into bins according to values of average bird mass. Figure 8-37 shows histograms of VOC emissions within the following six evenly distributed bins of average bird mass (*avem**) values (in kg): 0.0 to 0.5, 0.5 to 1.0, 1.0 to 1.5, 1.5 to 2.0, 2.0 to 2.5 and 2.5 to 3.0. The figure shows that the histograms for bins 1, 2, 3, and 4 are skew right while those for bins 5 and 6 are symmetric. Further disaggregation according to the values of other variables shows a variety of empirical distributions for different sets of conditions, and the skew right pattern is by no means a consistent pattern. There are not enough observations under any specific set of conditions (e.g., bird mass and humidity ranges) to use the empirical distribution to determine the true distribution. Therefore, in the absence of strong evidence against doing so, the EPA used the normal distribution.

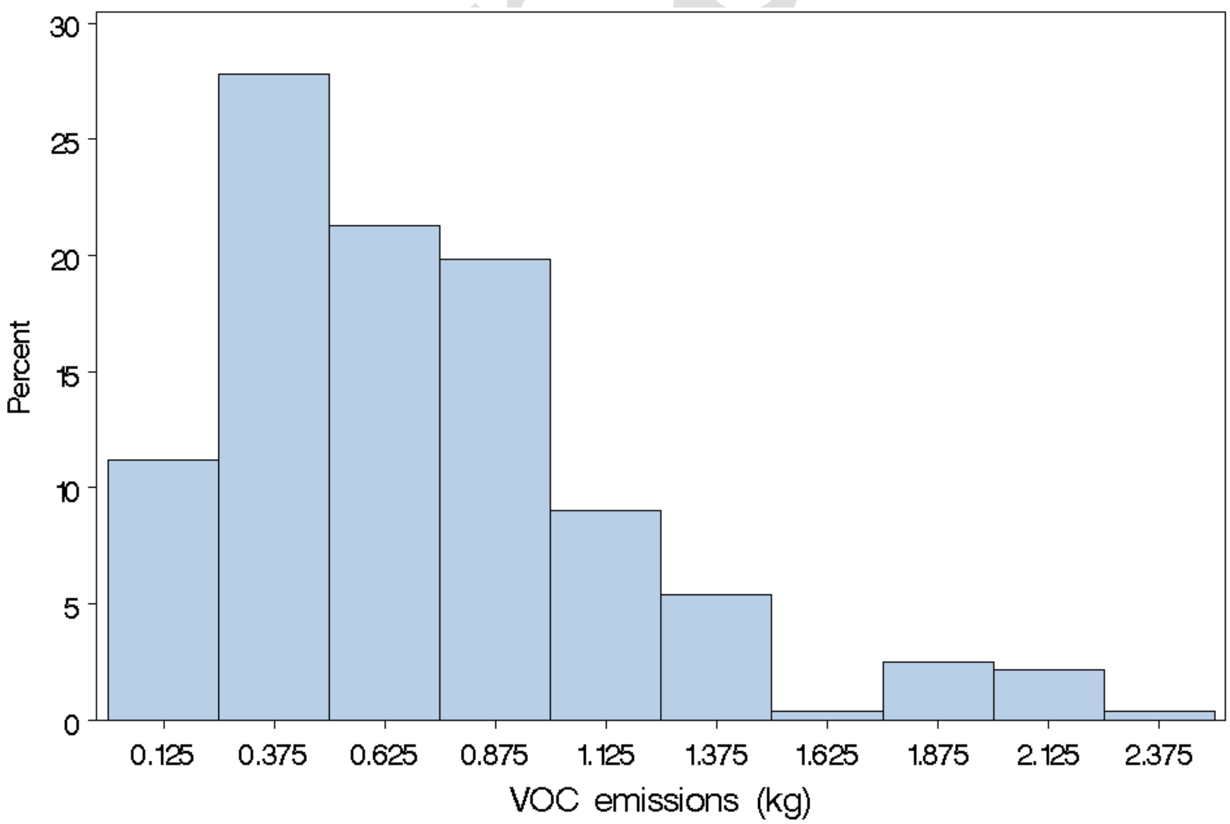


Figure 8-36. Histogram of VOC Emissions in the Base Dataset

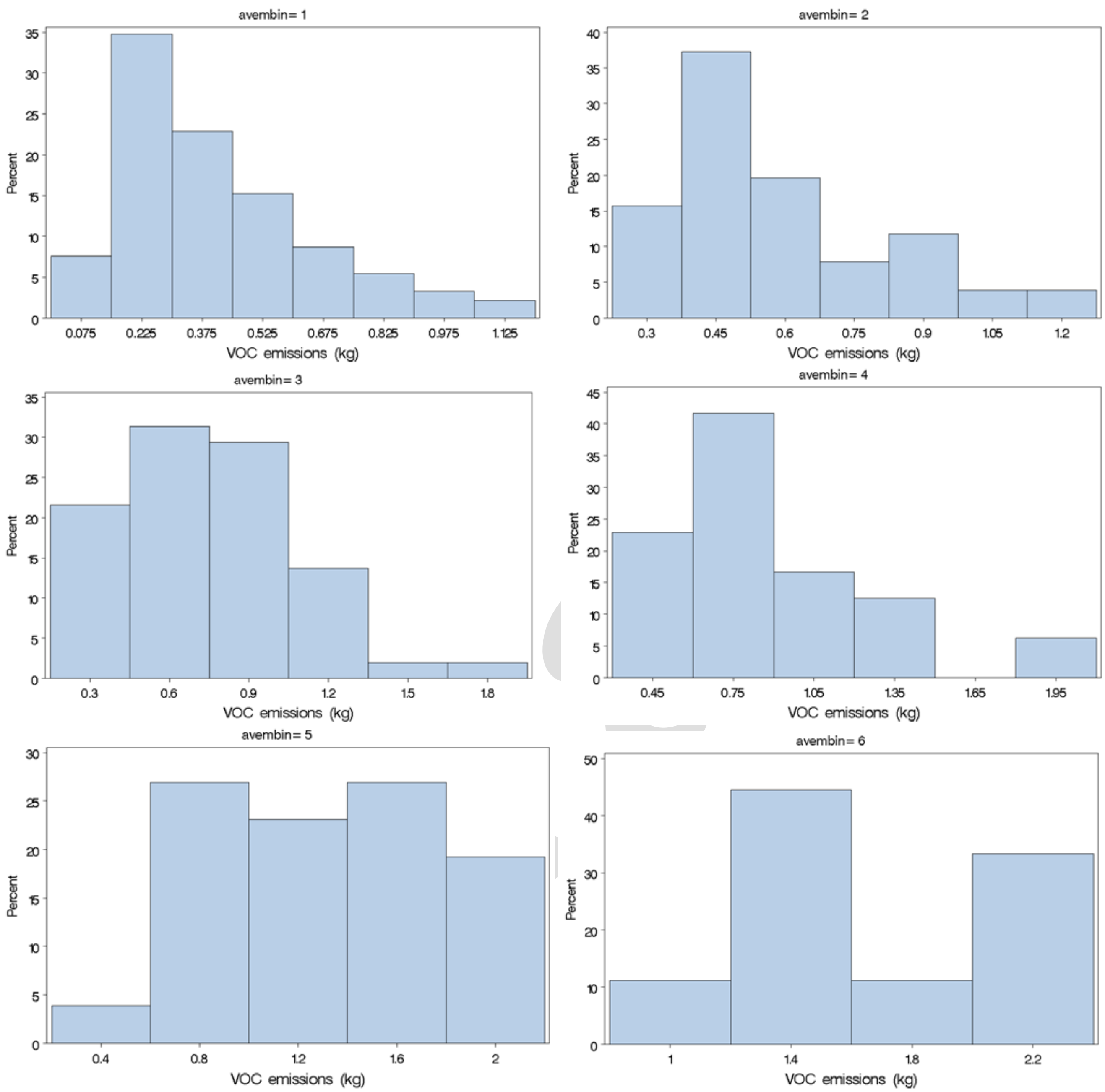


Figure 8-37. Histograms of VOC Emissions by *avem Bins**

8.5.3 Developing Candidate Mean Trend Variables for VOCs

8.5.3.1 *Choosing Predictor Variable Functional Forms*

Plots of VOC emissions versus average bird mass for all houses suggested a positive relationship, with a slight upward curvature. The gradual increasing trend suggested either a quadratic or a cubic form. Figure 8-38 includes linear, quadratic and cubic regressions of average mass overlaid on the VOC emissions as a point of reference for choosing a functional form. Because the appropriate form of the EEM was not apparent from the aggregated plot, the EPA reviewed plots disaggregated by house (Figure 8-39) and by flock (Appendix F) for further evidence of the functional form. Plots by house suggested a cubic form, especially in KY1B-1 House 5. Plots by flocks were less conclusive; suggesting that either a cubic or an exponential functional form would be suitable. Consequently, the EPA decided to test three versions of the I EEM (i.e., cubic, quadratic and exponential) to determine the best functional form for average mass.

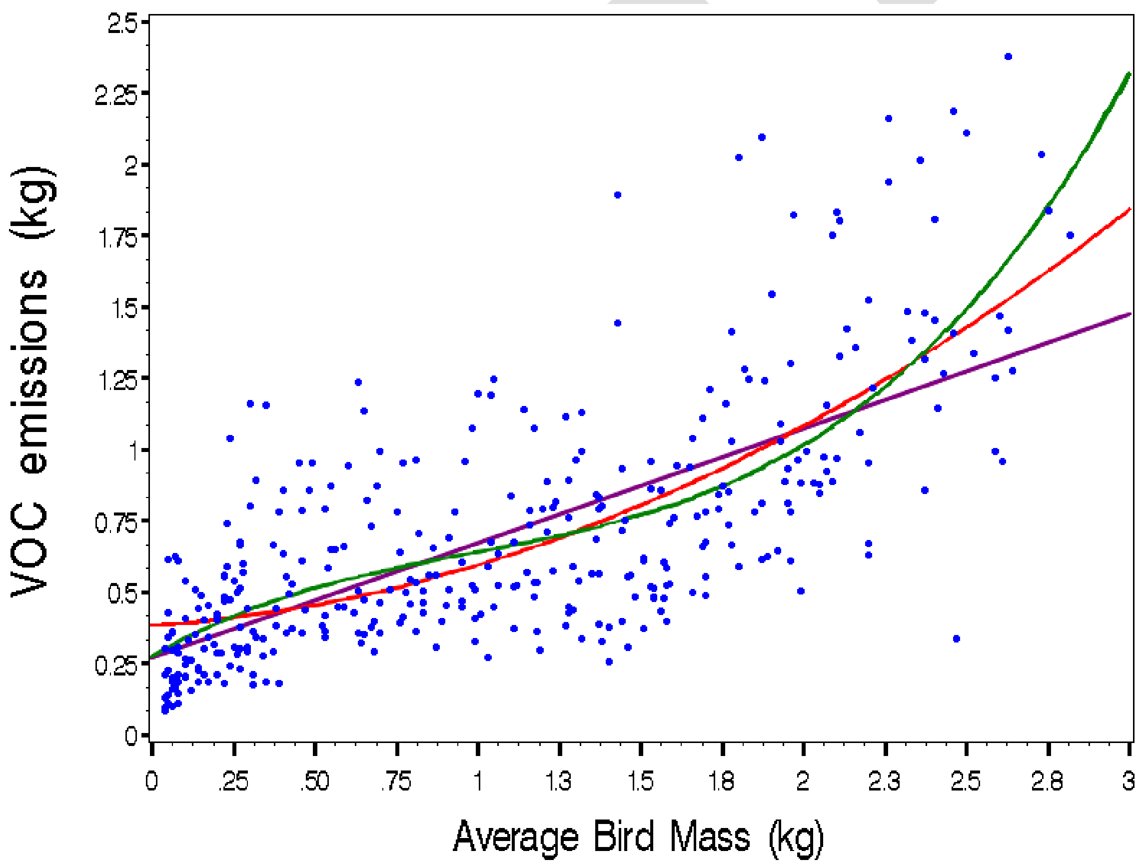


Figure 8-38. VOC Emissions vs. Average Bird Mass (Regression Overlays: purple = linear, red = quadratic, green = cubic)

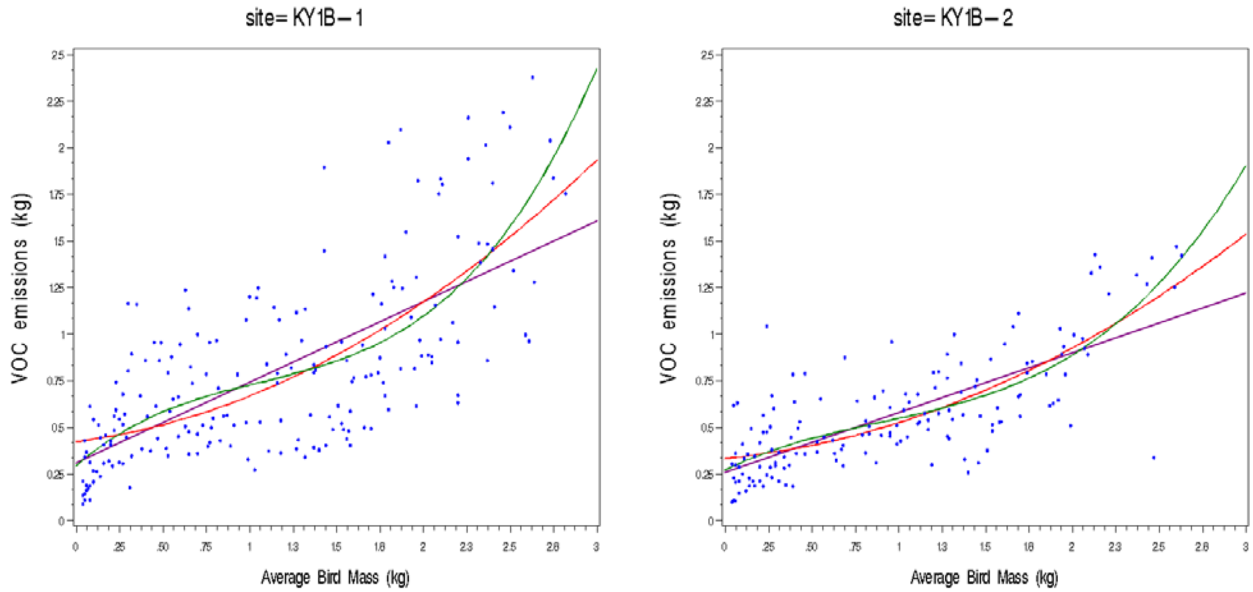


Figure 8-39. VOC Emissions vs. Average Bird Mass, by House (Regression Overlays: purple = linear, red = quadratic, green = cubic)

With regard to the effect of accumulated litter (*buildup*) on VOC emissions (see Section 7.3.1), the variance in VOC emissions values for lower weights, depicted in Figure 8-39, suggested a possible effect of litter condition on emissions. Plots of VOC emissions by average mass that are color-coded to indicate the level of *buildup* (Figure 8-40) suggested that higher VOC emissions correspond to built-up litter. However, the EPA was unable to draw a definitive conclusion from the scatter plot because only one full flock was raised on fresh bedding during the NAEMS.

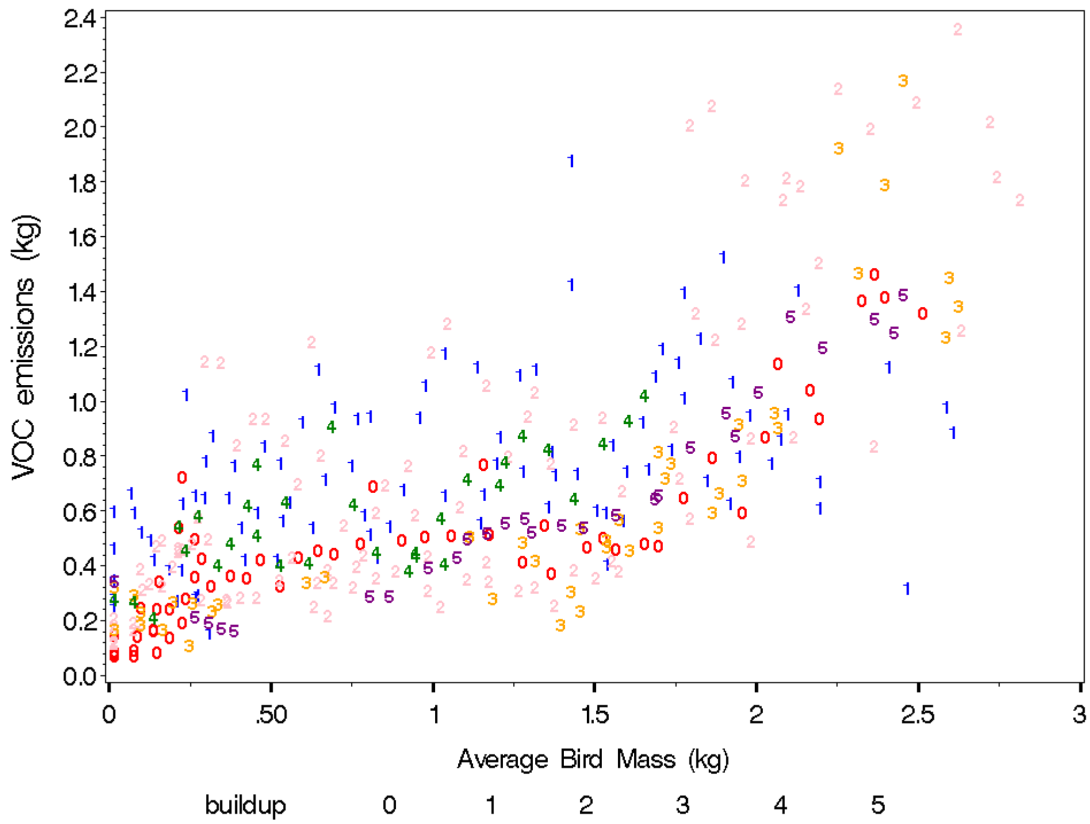


Figure 8-40. Overlay of *buildup* on VOC Emissions vs. Average Live Bird Mass

Plots of the build-up indicator parameters (i.e., *buildup*, *build*, *bld*) suggested that the average emissions increased for flocks raised on built-up litter. The trend is not as strong as with other pollutants, as there is only a small difference between the minimum emissions levels between the litter conditions (Figure 8-41), although the average emissions for the litter conditions does show a larger difference. To explore the issue, the EPA conducted preliminary tests to determine if a representation of build-up would significantly contribute to the mean trend variables for the VOC EEM. Consistent with the other pollutant EEMs developed, the EPA chose to include *build* in initial test EEMs, which showed *build* as a significant mean trend term. Consequently, the EPA decided to include *build* as the functional form through which the variable *buildup* enters the mean trend function and continue to test its significance using the p-value analysis to determine the final mean trend variables.

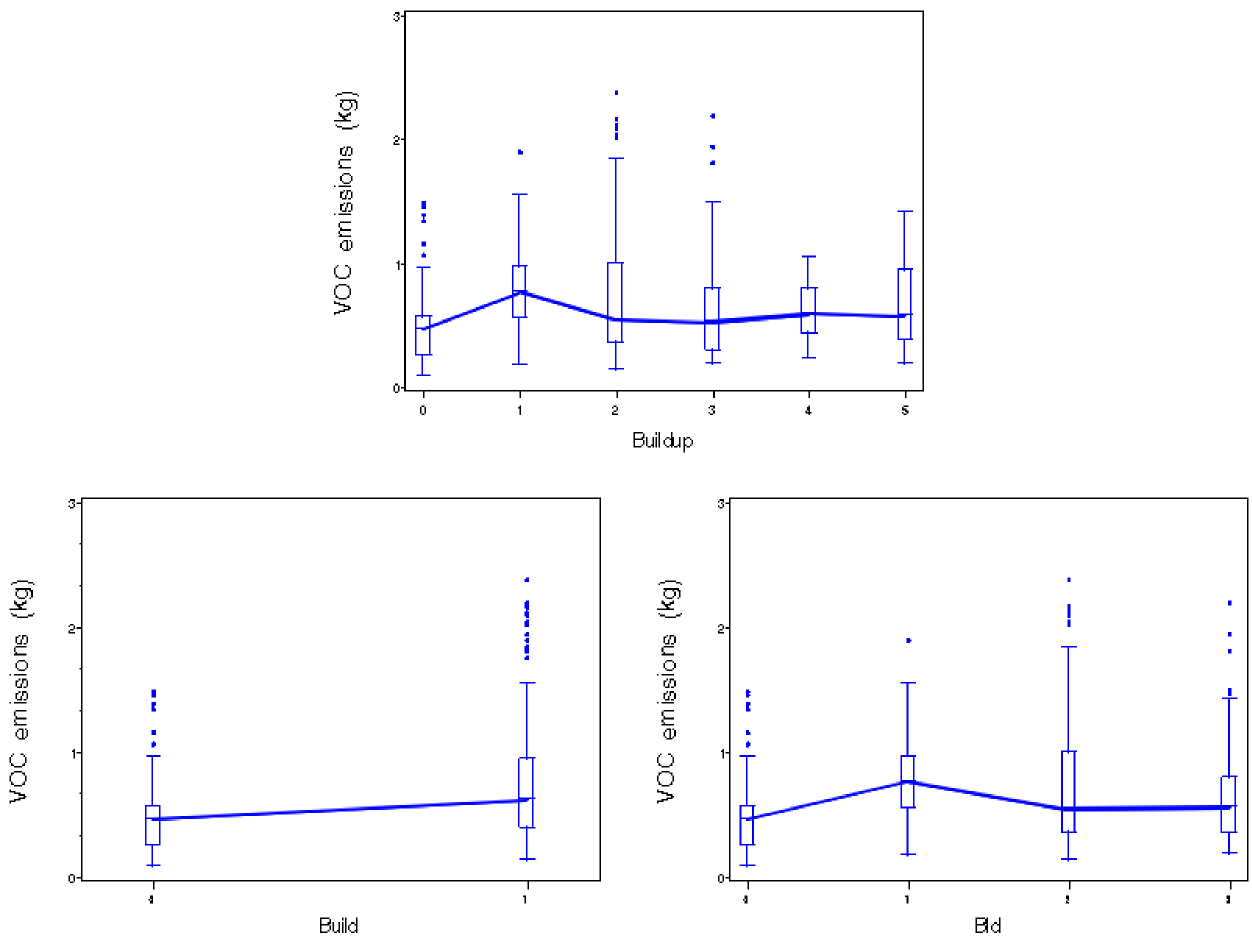
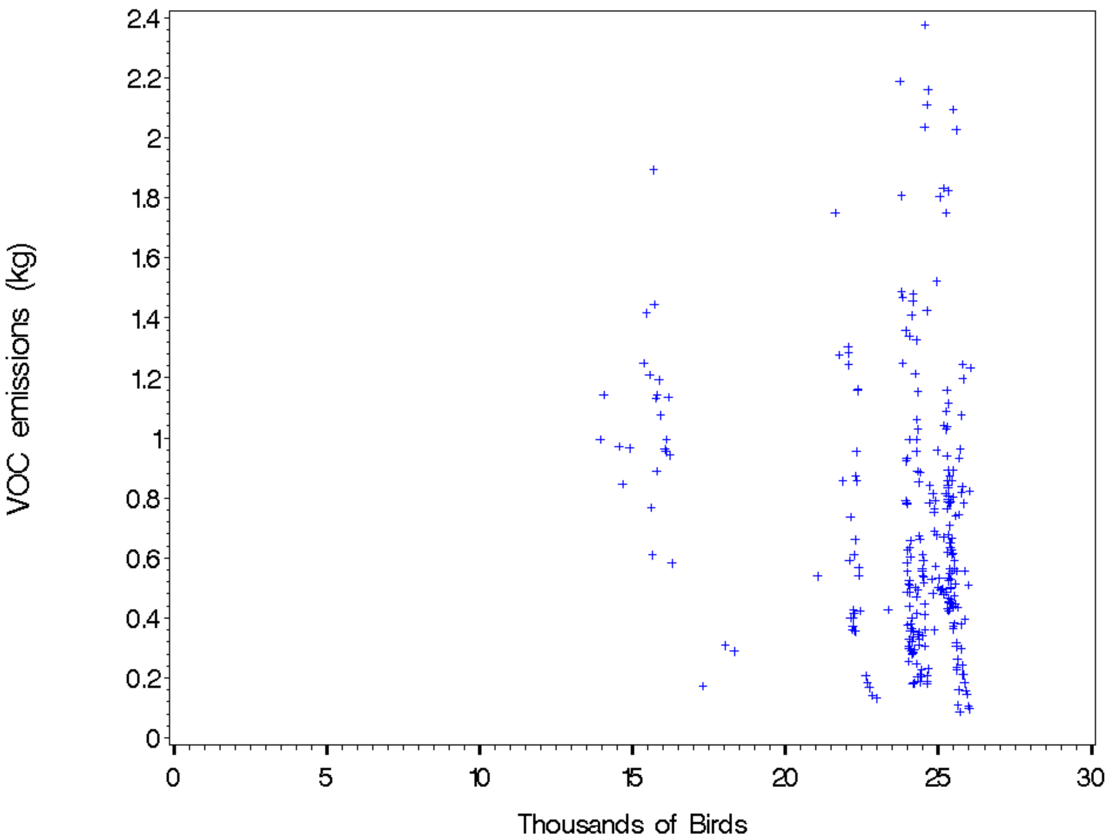


Figure 8-41. Box Plots of VOC Emissions vs. Categorical Variables for *buildup*

Figure 8-42, Figure 8-43 and Figure 8-44 show the scatter plots of VOC emissions by the remaining predictors (i.e., number of birds, ambient temperature, ambient relative humidity, ambient pressure, house temperature and house relative humidity). Appendix F contains scatter plots of the predictor variables by average animal mass bin. The plots do not indicate that the EPA should use a functional form other than linear. Based on this visual analysis, and the absence of a process-based reason to do otherwise, the EPA chose a linear functional form in developing the EEMs for VOCs.



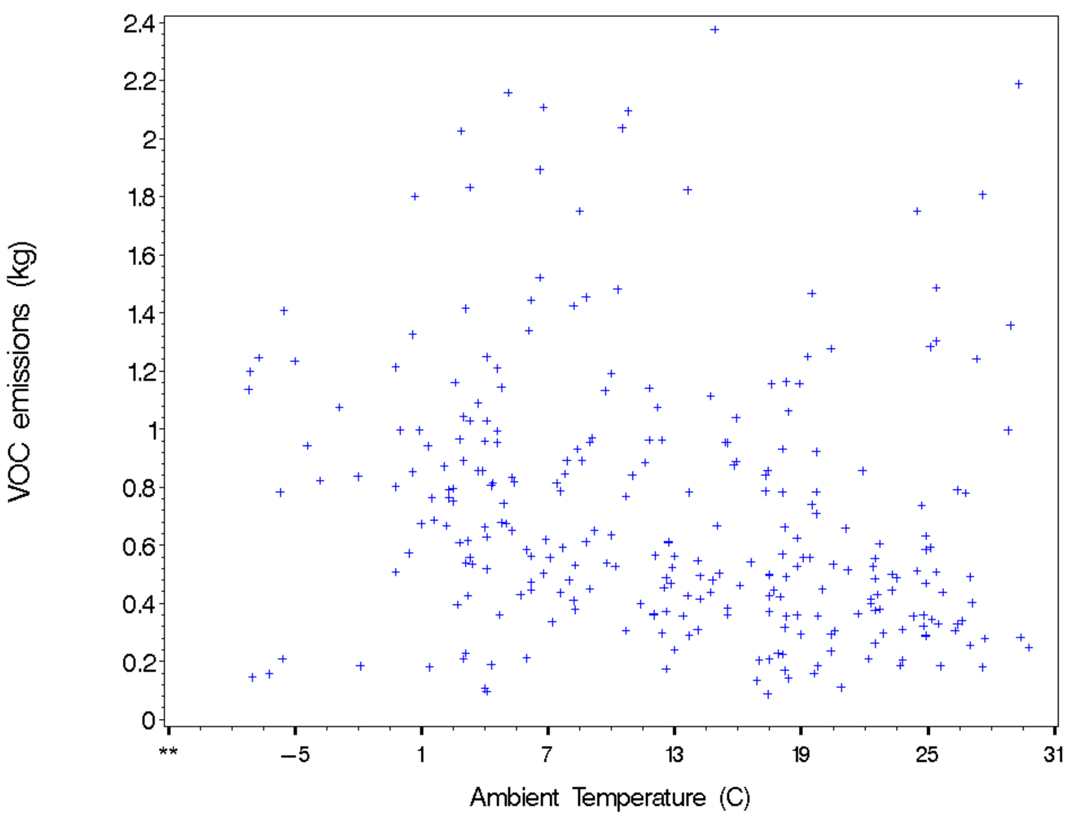


Figure 8-42. VOC Emissions vs. Predictor Variables *birds and *ta***

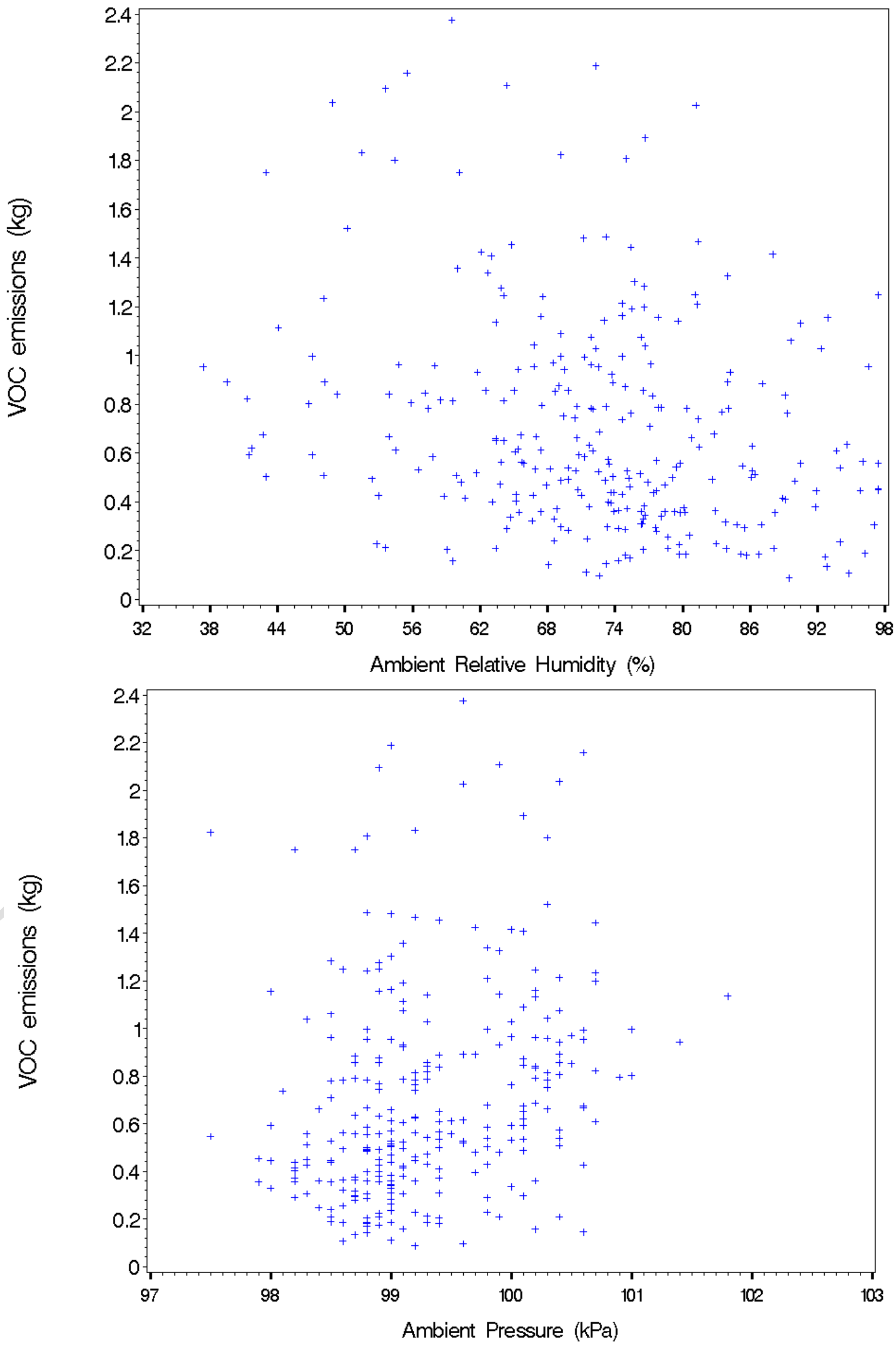


Figure 8-43. VOC Emissions vs. Predictor Variables *ha and *pa***

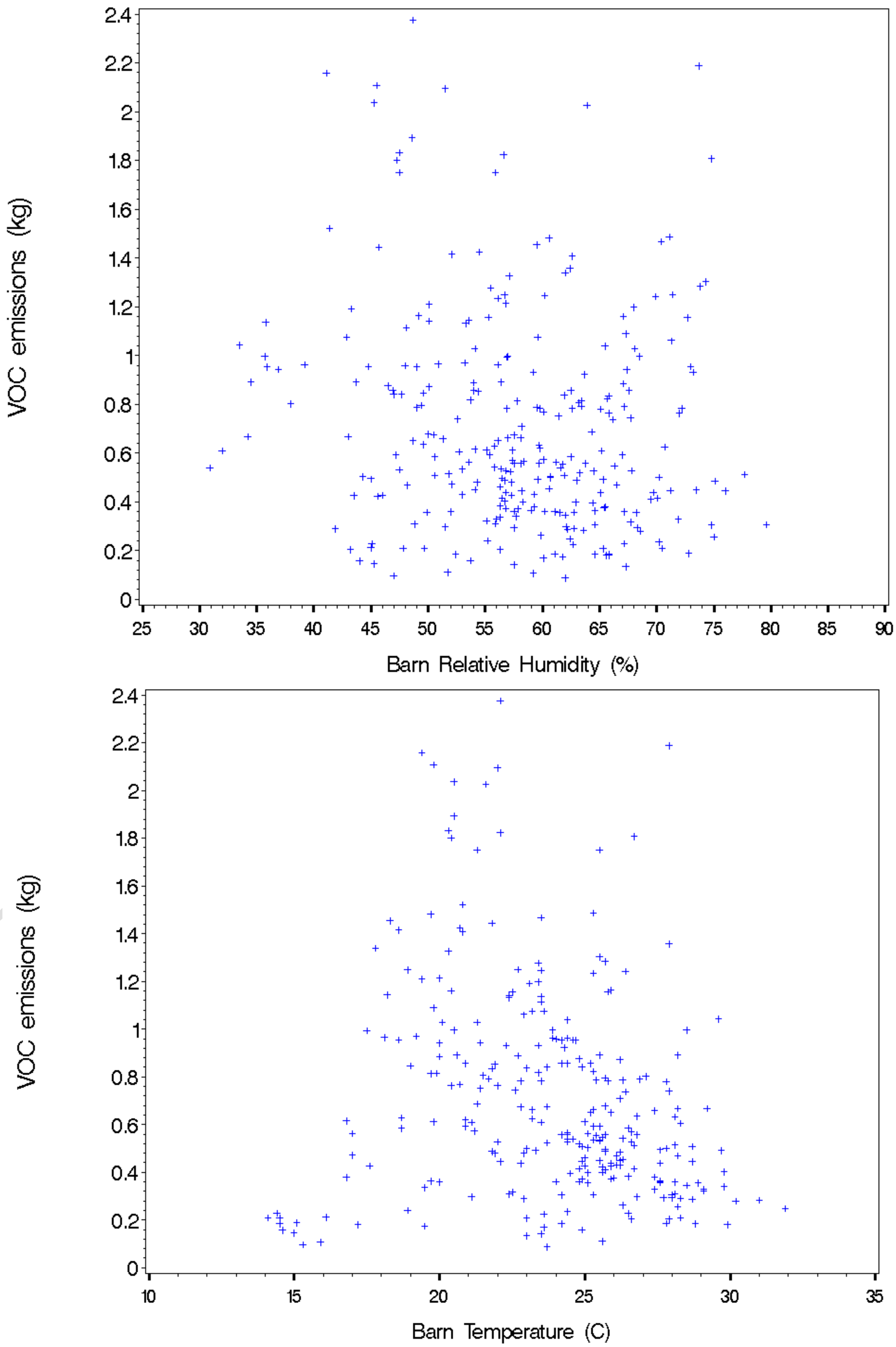


Figure 8-44. VOC Emissions vs. Predictor Variables *tc and *hc***

Table 8-44 summarizes the mean trend variables that describe the dependence of VOC emissions on the original predictor variables. The variables in column two were taken to be the main effect of the original predictors in column one of the table. For all predictors except *buildup* and *avem*, the mean trend variable was the same as the original variable. For *buildup,* the main effect was the indicator variable *build*. Forms of *avem** tested separately for EEM development included an exponential (*eavem*), quadratic (*avem* and $avem^2$), and cubic (*avem*, $avem^2$, and $avem^3$) form.

Table 8-44. Summary of Main Effect Mean Trend Variables for VOCs

Original Predictor Variable[a]	Main Effect Mean Trend Variables
buildup	*build*
*birds**	*birds*
*avem**	*avem*, $avem^2$ *avem*, $avem^2$, $avem^3$ *eavem*
*ta**	*ta*
*ha**	*ha*
*pa**	*pa*
*tc**	*tc*
*hc**	*hc*

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1).

8.5.3.2 *Creating Mean Trend Variables from Main Effects and Interactions*

The EPA created interaction terms and determined what level of interactions (e.g., two-way, three-way) to include in the set of candidate mean trend variables of Table 8-2. Initial testing of the R^2 of 2-way and 3-way terms conducted by the EPA suggested that consideration of two-way interactions was appropriate for development of VOC EEMs. The main effects and interaction terms for the versions of the three EEMs tested are presented in Table 8-45. Cubic versions of the IA and IAC EEMs are not shown in Table 8-45 because initial testing showed that none of the cubic terms for the EEMs were significant. A discussion of these initial tests for each of these EEMs is provided in Sections 8.5.4.2 and 8.5.4.3.

Table 8-45. Candidate Mean Trend Variables for the I, IA and IAC VOC EEMs

EEM	Main Effects	Two-Way Interaction terms
I, Cubic ($I\ EEM_C$)	*build, birds, avem,* $avem^2$, $avem^3$	*buildbirds, buildavem,* $buildavem^2$, $buildavem^3$, *birdsavem,* $birdsavem^2$, $birdsavem^3$
I, Quadratic ($I\ EEM_Q$)	*build, birds, avem,* $avem^2$	*buildbirds, buildavem,* $buildavem^2$, *birdsavem,* $birdsavem^2$
I, Exponential ($I\ EEM_E$)	*build, birds, eavem*	*buildbirds, buildeavem, birdseavem*
IA, Quadratic ($IA\ EEM_Q$)	Same as $I\ EEM_Q$ plus: *ta, ha, pa*	Same as $I\ EEM_Q$ plus: *buildta, buildha, buildpa, birdsta, birdsha, birdspa,avemta,* $avem^2ta$, *avemha,* $avem^2ha$, *avempa,* $avem^2pa$, *taha, tapa, hapa*
IA, Exponential ($IA\ EEM_E$)	Same as $I\ EEM_E$ plus: *build, birds, eavem, ta, ha, pa*	Same as $I\ EEM_E$ plus: *buildta, buildha, buildpa, birdsta, birdsha, birdspa, eavemta, eavemha, eavempa, taha, tapa, hapa*
IAC, Quadratic ($IAC\ EEM_Q$)	Same as $IA\ EEM_Q$ plus: *build, birds, avem,* $avem^2$, *ta, ha, pa, tc, hc*	Same as $IA\ EEM_Q$ plus: *buildtc, buildhc, birdstc, birdshc, avemtc,* $avem^2tc$, *avemhc,* $avem^2hc$, *tatc, tahc, hatc, hahc, patc, pahc, tchc*
IAC, Exponential ($IAC\ EEM_E$)	Same as $IA\ EEM_E$ plus: *build, birds, eavem, ta, ha, pa, tc, hc*	Same as $IA\ EEM_E$ plus: *buildtc, buildhc, birdstc, birdshc, eavemtc, eavemhctatc, tahc, hatc, hahc, patc, pahc, tchc*

8.5.3.3 *Centering and Scaling Predictors*

The EPA centered and scaled each continuous predictor variable prior to creating interaction terms by subtracting the mean of all observations in the base dataset from each value, then dividing by the standard deviation of the base dataset. The centering and scaling factors for the predictor variable for the final EEMs for VOCs are presented in Table 8-46.

Table 8-46. Centering and Scaling Reference Values for Continuous VOC Predictor Variables

Predictor Variable[a]	Centering Value	Scaling Value
*birds**	24	2.8
*avem**	1.1	0.76
*ta**	13	8.8
*ha**	72	12
*pa**	99	0.73
*tc**	27	3.5
*hc**	58	9.7

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1). Predictor variables are centered and scaled prior to the creation of higher-order terms (e.g., *eavem* or $avem^2$) and the creation of interaction terms (e.g., *avemta*).

8.5.4 Selecting Final Mean Trend Variables for VOCs

8.5.4.1 Inventory EEM

For the cubic version of the EEM, a full-reduced model F-test of the hypothesis that the coefficients $avem^3$, $birdsavem^3$, and $buildavem^3$ were simultaneously equal to zero produced a p-value of 0.43 which suggested that these terms should be removed from the EEM. This supported the conclusion that the functional form of *avem** is a lower-order polynomial rather than a cubic form. Therefore, the EPA only considered the quadratic and exponential forms (i.e., the cubic form of the EEM was not tested with the IA or IAC versions of the EEM).

Predictions based on the I EEM_Q form of the EEM developed systematic bias for γ_1 prior to completing the backwards elimination process. Predictions based on the I EEM_E completed the backward elimination process without any systematic bias.

The best version of the I EEM_Q occurred after the elimination of the $avem^2$ interaction terms (Table 8-47). This EEM displayed the best fit-statistics against the base dataset (lowest BIC and -2LL values) and the cross-validation dataset (lowest RMSE and highest R^2), without exhibiting systematic bias.

The selected form of the I EEM_E contains all the initial interaction terms. This version of the I EEM_E had the best fit-statistics against the test dataset and good fit statistics versus the cross-validation dataset, without systematic bias. The fit statistics for the selected I EEM_Q and I EEM_E are presented in Table 8-48. A check mark (✓) in the column for γ_0 indicates that the estimate is not significantly different from zero at the α = 0.05 significance level, while an "x" indicates that it is significantly different from zero. Similarly, a check mark or an "x" in the column for γ_1 indicates whether or not the estimate is significantly different from one.

Overall, the I EEM_Q and I EEM_E generally have similar fit statistics, with the I EEM_E having slightly better base dataset fit (smaller -2LL and BIC). The I EEM_E version was slightly better with respect to the percent of the data that is within the 95 percent prediction interval (% in PI) as this value should be as close to 95 percent as possible. Therefore, the EPA selected the exponential version of the I EEM for VOC emissions.

Table 8-47. Final Candidate I EEM Mean Trend Variables for VOCs

EEM	Main Effects	Two-Way Interaction terms
I EEM_Q	*build, birds, avem, avem*^{2}	*buildbirds, buildavem, birdsavem,*
I EEM_E	*build, birds, eavem*	*buildbirds, buildeavem, birdseavem*

Table 8-48. Final Candidate I EEM Fit Statistics for VOCs

Candidate EEM	Fit Parameters							
	-2LL	BIC	% in PI	Width (kg)	RMSE (kg)	R^2	γ_0 (kg)	γ_1
I EEM_Q	-19.0	-12.7	99	1.3	0.25	0.61	-0.01 ✓	0.93 ✓
I EEM_E	-29.2	-22.8	97	1.3	0.25	0.59	-0.01 ✓	0.92 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the α = 0.05 significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the α = 0.05 significance level.

8.5.4.2 *Inventory and Ambient EEM*

An initial test of the cubic version of the EEM showed a full-reduced model F-test of the hypothesis that the coefficients *avem*^{3}, *birdsavem*^{3}, *buildavem*^{3}, *avem*^{3}*ta*, *avem*^{3}*ha*, and *avem*^{3}*pa* were simultaneously equal to zero produced a p-value of 0.41, which suggested that these terms should be removed from the EEM. This further supported the conclusion that the functional form of *avem** is a lower-order polynomial rather than a cubic form. Therefore, the EPA only considered the quadratic and exponential forms.

The IA EEM_Q developed systematic bias for γ_1 prior to completing the backwards elimination process, and the IA EEM_E completed the backward elimination process without any systematic bias.

The selected form of the IA EEM_Q and IA EEM_E are presented in Table 8-49. The selected IA EEM_Q displayed the best fit-statistics against the test dataset (lowest RMSE and highest R^2), without exhibiting systematic bias. The selected version of the IA EEM_E had the best fit-statistics against the base dataset (lowest BIC and -2LL values) and the cross-validation dataset (lowest RMSE and highest R^2). The fit statistics for the selected IA EEM_Q and IA EEM_E are presented in Table 8-50.

Overall, the IA EEM_Q and IA EEM_E had similar fit statistics for the test dataset, with the IA EEM_Q having a slightly better R^2 value. The IA EEM_E had better base dataset fit (smaller -2LL and BIC), as well as a better representation of the percent of the data that is within the 95 percent prediction interval. Therefore, the EPA selected the exponential version of the IA EEM for VOC emissions.

Table 8-49. Final Candidate IA EEM Mean Trend Variables for VOCs

EEM	Main Effects	Two-Way Interaction terms
IA EEM_Q	*build, birds, avem, avem^2, ta, ha, pa*	*buildbirds, buildavem, buildavem^2, buildta, buildha, buildpa, birdsavem, birdsavem^2, birdsta, birdsha, birdspa, avemta, avem^{2}ta*
IA EEM_E	*build, birds, eavem, ta*	*buildbirds, buildeavem, birdsta, eavemta*

Table 8-50. Final Candidate IA EEM Fit Statistics for VOCs

Candidate EEM	Fit Parameters							
	-2LL	BIC	% in PI	Width (kg)	RMSE (kg)	R^2	γ_0 (kg)	γ_1
IA EEM_Q	1.5	7.8	100	1.3	0.22	0.70	-0.004 ✓	0.94 ✓
IA EEM_E	-39.5	-33.1	97	1.3	0.24	0.63	-0.01 ✓	0.90 ✓

Note: An “x” in the columns for γ_0 and γ_1 indicate systematic bias. A check mark in the column for γ_0 indicates that the 95 percent confidence interval for the intercept contains zero and the estimate is not significantly different from zero. A check mark in the column for γ_1 indicates the 95 percent confidence interval for the slope contains one and the estimate is not significantly different from one.

8.5.4.3 *Inventory, Ambient and Confinement EEM*

An initial test of the cubic version of the EEM showed a full-reduced model F-test of the hypothesis that the coefficients *avem^3*, *birdsavem^3*, *buildavem^3*, *avem^{3}ta*, *avem^{3}ha*, *avem^{3}pa*, *avem^{3}tc* and *avem^{3}hc* were simultaneously equal to zero produced a p-value of 0.18, which suggested that these terms should be removed from the EEM. This further supported the

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conclusion that the functional form of *avem** is a lower-order polynomial rather than a cubic form. Therefore, the EPA only considered the quadratic and exponential forms.

Neither the IAC EEM_Q nor IAC EEM_E tested by EPA developed systematic bias prior to completion of the backwards elimination process. The mean trend variables for the selected version of the IAC EEM_Q and IAC EEM_E are presented in Table 8-51.

The selected form of the IAC EEM_Q displayed the best fit-statistics against the test dataset (lowest RMSE and highest R^2). The selected IAC EEM_E had the best fit-statistics against the cross-validation dataset (lowest RMSE and highest R^2) coupled with a small confidence interval width and approximately 95 percent inclusion in the confidence interval. The fit statistics for both the selected IAC EEM_Q and IAC EEM_E are presented in Table 8-52.

Overall, the IAC EEM_Q and IAC EEM_E had similar fit statistics against the cross-validation data set, with IAC EEM_E having slightly better base dataset fit (smaller -2LL and BIC). The IAC EEM_E version was also slightly better with respect to the percent of the data that is within the 95 percent prediction interval. Therefore, the EPA selected the exponential version of the IAC EEM for VOC emissions.

Table 8-51. Final Candidate IAC EEM Mean Trend Variables for VOCs

EEM	Main Effects	Two-Way Interaction Terms
IAC EEM_Q	*build, birds, avem, avem²*, *ta, ha, pa, tc, hc*	*buildbirds, buildavem, buildavem², buildtc, birdsavem, birdsavem², birdsta, birdsha, birdspa, birdstc, birdshc, avemta, avem²ta, avemha, avem²ha, tatc, tahc, patc, pahc, tchc*
IAC EEM_E	*build, birds, eavem, ta, ha, pa, tc, hc*	*buildbirds, buildeavem, buildpa, birdsta, birdsha, birdstc, birdshc, eavemtc, tatc, tahc*

Table 8-52. Final Candidate IAC EEM Fit Statistics for VOCs

Candidate EEM	Fit Parameters							
	-2LL	BIC	% in PI	Width (kg)	RMSE (kg)	R^2	γ_0 (kg)	γ_1
IAC EEM_Q	20	27	99	1.2	0.21	0.72	-0.03 ✓	0.96 ✓
IAC EEM_E	-34.6	-28.2	96	1.2	0.23	0.65	-0.07 ✓	0.98 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the $\alpha = 0.05$ significance level.

8.5.5 Summary of Final Results for the I, IA and IAC EEMs for VOCs

A summary of the final mean trend variables for the VOC EEMs is provided in Table 8-53. The covariance parameters for the final forms of the EEMs are listed in Table 8-53. The coefficients for the EEM mean trend variables are listed in Table 8-53. The value of each main effect variable (x_p) must be centered and scaled when using these terms in Equation 7-1. The centering and scaling factors for the predictor variable for the VOC final EEMs are presented in Table 8-46.

Table 8-53. Final EEM Mean Trend Variables for VOCs

EEM	Main Effects	Two-Way Interaction terms
I	*build, birds, eavem*	*buildbirds, buildeavem, birdseavem*
IA	*build, birds, eavem, ta*	*buildbirds, buildeavem, birdsta, eavemta*
IAC	*build, birds, eavem, ta, ha, pa, tc, hc*	*buildbirds, biuildeavem, buildpa, birdsta, birdsha, birdstc, birdshc, eavemtc, tatc, tahc*

Table 8-54. Covariance Parameter for Final VOC EEMs

Covariance Parameter	Estimate		
	I	IA	IAC
$\hat{\rho}$	0.7746	0.7784	0.7770
$\hat{\sigma}^2$	0.1009	0.09747	0.08368

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Table 8-55. Regression Coefficients for Final VOC EEMs

p	x_p	$\hat{\beta}_p$		
		I	IA	IAC
0	*Intercept*	0.031	0.19	-0.47
1	*build*	-0.69	-0.8	-0.65
2	*birds*	-0.82	-0.84	-0.72
3	*eavem*	0.59	0.53	1.12
4	*ta*	a	-0.23	-0.04
5	*ha*	a	a	0.02
6	*pa*	a	a	-0.1
7	*tc*	a	a	-0.18
8	*hc*	a	a	-0.1
9	*buildbirds*	0.626	0.9	0.88
10	*buildeavem*	0.38	0.4	0.21
11	*birdseavem*	0.13	a	a
12	*birdsta*	a	0.07	-0.07
13	*birdsha*	a	a	-0.04
14	*buildpa*	a	a	0.12
15	*eavemta*	a	0.12	a
16	*birdstc*	a	a	0.06
17	*birdshc*	a	a	0.11
18	*eavemtc*	a	a	0.2
19	*tatc*	a	a	0.04
20	*tahc*	a	a	0.04

Note: Each main effect variable was centered and scaled prior to creating higher-order terms, exponential terms and interactions.
[a] This variable is not included in the EEM.

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9.0 DEVELOPMENT OF DECAKING AND FULL LITTER CLEAN-OUT PERIOD EEMS

This section summarizes the analyses used to develop the EEMs for the decaking and full litter clean-out periods of broiler confinement houses. Due to the limited number of data values and lack of supporting information specifying how each house was operated during the period between flocks when the litter removal activities were conducted, the pollutant-specific EEMs developed in this section are emission factors (EFs) rather than predictive equations. The emissions factors provide an estimate of the emissions released over the entire decaking or full litter clean-out period, which begins after the birds have been sent to market and ends when the new chicks are placed in the house. The period covered by the EFs includes when the litter removal activities were conducted and when the house was sitting empty before a new flock was placed in the house.

Section 9.1 discusses the data that are available regarding litter removal periods. Section 9.2 discusses the analyses the EPA performed to develop the EFs for decaking and full litter clean-out periods.

9.1 Available Data for Litter Removal Periods

Compared to grow-out periods, the decaking and full litter clean-out periods account for a relatively small portion of the overall broiler production cycle. While the typical grow-out period lasts approximately 50 days, a typical decaking period lasts 6 to 14 days and a typical full litter clean-out period lasts 12 to 14 days. Because the litter removal periods account for a small number of days over the course of a year, the number of data values collected under the NAEMS for these periods is significantly less than for grow-out periods. Table 9-1 compares the total number of days the NAEMS investigators were on site for litter removal periods to the total number of days on site for the grow-out periods.

Table 9-1. Comparison of Days on Site for Litter Removal and Grow-out Period Days

House	Total Monitoring Days on Site	
	Litter Removal	**Grow-Out**
CA1B House 10	125	648
CA1B House 12	122	651
KY1B-1 House 5	87	307
KY1B-2 House 3	97	282
Total	**431**	**1,888**

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Over the course of the NAEMS, emissions and process parameter data were recorded for 24 decaking periods and 12 full litter clean-out periods (decaking is conducted more often than full litter clean-outs). The decaking periods monitored typically lasted between 3 and 22 days. There was an instance of a decaking period lasting 41 days at site KY1B-2, which contributed to the greater number of decaking observations for this site. However, this was due to a management change for the farm that halted broiler production rather than prolonged cleaning activity. The full litter clean-out periods observed during the NAEMS lasted between 6 to 25 days. Table 9-2 summarizes the total number of monitoring days available for each type of clean-out period. The average duration of decaking events at site CA1B were much shorter than decaking events at the Kentucky sites (Table 9-3), which accounts for the CA1B houses and the KY1B houses having a similar number of decaking days.

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Table 9-2. Comparison of Days on Sites for Decaking and Full Litter Clean-out Days

House	Total Monitoring Days on Site	
	Decaking	**Full Litter Clean-Out**
CA1B House 10	62	63
CA1B House 12	58	64
KY1B-1 House 5	62	25
KY1B-2 House 3	88	9
Total	**270**	**161**

Table 9-3. Duration of Grow-out and Clean-out Periods

Monitoring Site		Clean-Out Periods					
		Decaking			**Full Litter Clean-Out**		
		Frequency	**Average Duration (days)**	**Range of Duration (days)**	**Frequency**	**Average Duration (days)**	**Range of Duration (days)**
CA1B	H10	~ 5 time per year [a]	7.75	6 – 11	Every third flock (~2 times per year)	12.6	6 – 21
CA1B	H12	~ 5 time per year [a]	7.25	3 – 11	Every third flock (~2 times per year)	12.8	6 – 23
KY1B-1	H5	~4 times per year	15.5	12 – 22	Once per year	25	NA[b]
KY1B-2	H3	~4 times per year	22	15 – 41	Once per year	9	NA[b]

[a] Occurred 8 times during the study.
[b] Not applicable. Only one full litter clean-out event was monitored during the study.

As noted in Section 4, the EPA's review of the NAEMS data identified a small number of negative daily emissions values for H_2S, PM_{10}, and VOCs. The number of measured negative values is low (less than 5 percent) compared to the total number of emissions records available for H_2S, PM_{10}, and VOC over the litter removal periods. After discussion with the NAEMS Science Advisor, it was determined that the negative values were the result of instrumentation drift, and are valid values. However, to avoid possible complications with EF development (e.g., the EEM predicting negative emissions) the negative values were withheld from the datasets used to develop the EFs for the decaking and full litter clean-out periods.

Table 9-4 summarizes the number of daily emission values that are greater than or equal to zero that are available for EF development by litter removal activity and pollutant. The limited amount of data for decaking and full litter clean-out periods is partially the result of the substantially shorter duration of the litter removal periods compared to the grow-out periods (2 to 20 days for clean-out activities compared to 45 to 54 days for broiler grow-out). Additionally, because the PM monitors had to be removed during litter removal activities to prevent damage to the instruments, fewer valid PM emissions were available during those periods. Consequently, the measurements available for PM_{10}, $PM_{2.5}$ and TSP emissions are only for periods after the litter removal activities were completed and the house was empty before the next flock of birds was placed. Finally, the intermittent PM sampling schedule at site CA1B did not include measurement of $PM_{2.5}$ or TSP emissions during decaking and full litter clean-out periods. The EFs developed for $PM_{2.5}$ or TSP were based only on data collected at the Kentucky sites.

Table 9-4. Number of Valid Non-Negative Daily Emissions Values for Litter Removal Periods

Litter Removal Activity	House	Count of Valid Non-negative Daily Emissions Values				
		NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP
Decaking	CA1B House 10	51	55	6	0	0
	CA1B House 12	48	52	4	0	0
	KY1B-1 House 5	58	57	11	19	20
	KY1B-2 House 3	82	67	45	45	41
	Total	**239**	**231**	**66**	**64**	**61**
Full Litter Clean-Out	CA1B House 10	30	23	9	0	0
	CA1B House 12	30	23	5	0	0
	KY1B-1 House 5	21	8	5	1	5
	KY1B-2 House 3	8	8	3	3	3
	Total	**89**	**62**	**22**	**4**	**8**

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9.2 EF Development for Decaking and Full Litter Clean-Out Periods

The EPA attempted applying ordinary least squares (OLS) regression analyses to develop predictive equations based EEMs for decaking and full litter clean-out periods. In OLS regression analyses, coefficients of the equation relating emissions to parameters (i.e., predictor variables) are estimated by determining numerical values for the parameters that minimize the sum of the squared deviations between the observed responses and the functional portion of the model. The EPA initially considered this approach because it is a widely accepted method for relating dependent variables (e.g., emissions) to independent variables (e.g., bird mass, house ventilation flow rate). However, the EPA rejected the use of OLS regression analyses for developing predictive equations based EEMs for litter removal periods because of the poor correlation of the resulting regression equations (i.e., R^2 values were less than 0.30).

The difficulty in applying the OLS regressions analyses to the litter removal period data was due to several characteristics of the available data. By design of the NAEMS, there are substantially fewer daily emissions values available for the decaking and full litter clean-out periods than for grow-out periods. Additionally, the emissions data that are available vary widely over the clean-out period as shown in Table 9-5. Applying the regression analyses to litter removal periods was further complicated because the data and supporting information do not specify how each house was operated during the period between flocks when the litter removal activities were conducted. For example, the available data do not indicate the date or time that the litter removal activities were initiated or completed, account for the manner in which the house doors and openings were managed, or identify the activities undertaken by farm personnel in the house during these periods. These factors could account for the variability in emissions and would likely improve the ability of a regression analysis to capture the emissions trends of the litter removal periods.

For the EEMs for litter removal periods, the EPA developed pollutant-specific emissions factors for the decaking and full litter clean-out periods. Typically, emissions factors relate pollutant emissions to an activity (e.g., kg of PM_{10}/kg of coal combusted). The EFs developed by the EPA relate pollutant emissions to the total weight of birds raised on the litter and the duration of the litter removal activity.

The emissions released during litter removal periods, which begin after the birds have been sent to market and end when the new flock is placed in the house, are directly related to the manure accumulated on the confinement floor, the amount of manure removed from the house by farm personnel, and the duration of the litter removal event.

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Table 9-5. Range of Emissions for Broiler Litter Removal Periods

Pollutant (units)	Litter Removal Activity	Daily Average Emissions per House (g/d)	Range of Observed Emissions	Standard Deviation
NH_3	Decaking	8,254.62	[0.00, 50,900.00]	8,511.14
	Full litter clean-out	4,739.67	[0.00, 30,569.63]	6,732.66
H_2S	Decaking	12.72	[0.00, 98.60]	16.95
	Full litter clean-out	6.58	[0.05, 63.50]	11.51
PM_{10}	Decaking	20.41	[0.00, 171.52]	37.43
	Full litter clean-out	16.09	[0.00, 71.29]	19.68
$PM_{2.5}$	Decaking	13.83	[0.00, 153.18]	27.90
	Full litter clean-out	5.12	[0.00, 13.76]	6.03
TSP	Decaking	55.66	[0.00, 361.23]	90.87
	Full litter clean-out	39.90	[0.00, 161.71]	53.29
VOC	Decaking	186.29	[0.00, 1,632]	267.86
	Full litter clean-out	296.66	[0.00, 1,234]	367.40

The total amount of manure accumulated at the end of each flock was not a part of the NAEMS monitoring program. To represent the accumulated manure in the house prior to commencement of litter removal activities, the EPA used the weight of birds raised on the litter since the last cleaning event (i.e., one flock). The specific amount of manure removed by each decaking and full litter clean-out event was not provided to the EPA. Section 3 summarizes the available data regarding the volume of manure removed on two occasions at site CA1B (the manure removed from each house was not part of the monitoring program at the Kentucky sites). Consequently, the amount of manure removed was not included in the development of EFs for litter removal periods.

To develop the EFs, the EPA calculated the average daily emissions rate (g/d) for each litter removal event by dividing the sum of the daily emissions by the total number of days of the event (i.e., total number of days the house is empty). The emissions rate values for each event were divided by the total weight of birds raised on the litter (kg) to yield an emissions factor expressed in terms of g of pollutant emissions/kg bird-day. The EFs for each pollutant and type of litter removal period were calculated by averaging the event-specific emissions factors, as follows:

$$EF_{Weight-Day} = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{[Total\ emissions]_j/[Number\ of\ days]_j}{[Total\ Weight]_j *}\right)$$

where j indicates a unique litter removal period and n is the number of litter removal events (24 decaking and 12 full litter clean-out periods).

The EPA evaluated three approaches for calculating the total weight of birds raised on the litter since the previous litter removal period:

*Cumulative Weight (CW) = Sum [(Daily bird inventory) * (Avg. daily weight (kg))]*

*Total Shipped Weight (SW) = (No. of birds shipped to market) * (Max. avg. weight (kg))*

*Max. Total Weight (MW) = (No. of birds placed) * (Max. avg. weight (kg))*

The cumulative weight was considered by the EPA because this value accounts for the actual weight of birds raised on the litter over the grow-out period. However, this approach requires the bird inventory and average weight values for each day of the grow-out period, which might not always be readily available for growers. The total shipped weight and maximum weight approaches require fewer data points to calculate an estimate of bird weight. The total shipped weight, based on the number of birds sent to market, was considered by the EPA because this value accounts for the mortality of the broilers over the course of the grow-out period. A high mortality rate would significantly affect emissions (i.e., fewer birds relates to less deposited manure). The total shipped weight was also considered because the broiler industry typically measures the production of a boiler house in terms of birds marketed. The maximum total weight, based on the number of birds placed in the house at the beginning of the grow-out period, was considered by the EPA because this value represents the highest possible measure of the weight of birds raised on the litter over the grow-out period. This approach to calculating maximum total weight would also account for a severe bird mortality event that occurred near the end of the grow-out period. In other words, the use of total shipped weight would underestimate the total bird weight raised on the litter in the event of a catastrophic loss prior to shipping. Table 9-6 summarizes the EFs developed for the decaking and full litter clean-out periods using the three weight calculation approaches. In general, the emissions factors suggest that decaking events have higher emissions than full litter clean-out events, with the exception of PM_{10} and VOC. This seems reasonable as the emissions factors take into account the days after the cleaning activity has taken place and the house is idle (i.e., no birds present). After decaking, the idle house will still have some residual biological materials that will continue to produce emissions. After a full litter clean-out, there is minimal residual manure to continue to produce emissions.

PM_{10} emission estimates for decking events are only slightly higher for one version of the emissions factors tested. This difference could simply be an artifact of the data, since the data only represent the period when the house was sitting idle after the cleaning activity. The higher VOC emission estimates for full litter clean-out could possibly be due to cleaning agents used providing an additional source. The NAEMS did not document the cleaning techniques of the broiler houses, so it is difficult to confirm this hypothesis.

To assess the predictive accuracy of the EFs, the EPA compared the measured emissions for litter removal periods to the emissions calculated using each type of EF. Due to the limited data available for litter removal periods, only two decaking events (one from site CA1B and one from a Kentucky site) and one full litter clean-out event (site CA1B) were withheld from the EEM development data set (a single full litter clean-out event was withheld because only two full litter clean-out periods were monitored at the Kentucky sites). Entire clean-out periods were withheld as the emissions factors developed were based on entire clean-out events rather than individual days. Additionally, the EPA's literature reviews and CFI described in Section 4 did not identify any studies that reported emissions from the litter removal periods.

Table 9-6. Emissions Factors for Broiler Litter Removal Periods

Pollutant	Type of Litter Removal Activity	EF (g pollutant/kg bird-day)		
		Cumulative Weight	Shipped Weight	Maximum Weight
NH_3	Decaking	0.006288	0.1380	0.1285
	Full litter clean-out	0.003108	0.0645	0.0629
H_2S	Decaking	0.000012	0.0003	0.0002
	Full litter clean-out	0.000005	0.0001	0.0001
PM_{10}	Decaking	0.000009	0.0002	0.0002
	Full litter clean-out	0.000011	0.0002	0.0002
$PM_{2.5}$	Decaking	0.000010	0.0002	0.0002
	Full litter clean-out	0.000003	0.0001	0.0001
TSP	Decaking	0.000038	0.0009	0.0008
	Full litter clean-out	0.000034	0.0007	0.0007
VOC	Decaking	0.000127	0.0026	0.0026
	Full litter clean-out	0.000182	0.0038	0.0037

For the assessment, the EPA calculated the three types of bird weight expressions, using the bird inventory data for the flocks, and the durations associated with the litter removal events data withheld for model validation. The measured emissions were compared to the emissions calculated by applying the weight and duration values to the EFs. Table 9-7 summarizes the absolute average difference in the measured and calculated emissions values. Based on this assessment, the EPA selected the EFs based on the cumulative bird weight for use in estimating pollutant emissions for litter removal periods.

Table 9-7. Difference in Measured Versus Estimated Emissions

Pollutant	Type of Litter Removal Activity	Absolute Difference in Emissions (g pollutant/kg bird-day)		
		Cumulative Weight	Shipped Weight	Maximum Weight
NH_3	Decaking	13,012.74	26,528.54	28,328.34
	Full litter clean-out	1,087.88	1,035.55	1,431.87
H_2S	Decaking	8.58	17.55	21.03
	Full litter clean-out	12.65	16.19	16.85
PM_{10}	Decaking	112.55	118.15	122.32
	Full litter clean-out	14.25	10.51	9.81
$PM_{2.5}$	Decaking	25.60	29.25	45.21
	Full litter clean-out	a	a	a
TSP	Decaking	214.90	228.66	288.86
	Full litter clean-out	a	a	a
VOC	Decaking	884.02	355.49	416.56
	Full litter clean-out	a	a	a

[a] No validation data available. CA1B did not have emission measurements of these pollutants for full litter clean-out events.

Using the EFs, the annual emissions for litter removal periods in a confinement house would be determined as the sum of the emissions calculated for each litter removal event that occurred during the year. For example, a farm would determine the cumulative bird weight of each flock raised on the litter in a confinement house between removal events based on daily inventory values and bird weights from site-specific growth curves. The farm also would record the duration of each decaking and full litter clean-out event that occurred in the house over the year. The event-specific emissions would be determined using the EFs and the cumulative bird weight and duration associated with each litter removal event. The farm's total annual emissions associated with litter removal periods would be the sum of house-specific emissions for each litter removal event that occurred over the year, as follows:

$$\text{Annual emissions}_{\text{Decaking}} = \Sigma((EF_{\text{Decaking}})*(CW)*(\text{Duration of decaking}))$$

$$\text{Annual emissions}_{\text{Full litter clean-out}} = \Sigma((EF_{\text{Full litter clean-out}})*(CW)*(\text{Duration of full litter clean-out}))$$

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Total annual $\text{emissions}_{\text{Litter removal periods}}$ = Annual $\text{emissions}_{\text{Decaking}}$ + Annual $\text{emissions}_{\text{Full litter clean-out}}$

The daily emissions for a given litter removal event at a house would be calculated by multiplying the emissions factor by the cumulative weight only.

Table 9-8 provides an example calculation of the annual and daily emissions values for a confinement house. In this example, the total annual emissions (i.e., the sum of the event-specific emissions) is 656.39 kilograms. The daily emissions (kg/d) for the five flocks are 15.97, 16.59, 16.09, 16.11 and 8.08, respectively.

Table 9-8. Example Flock Characteristics

Flock No.	Cum. Bird Weight (1,000 kg)	Type of Litter Removal After Flock	Duration (days)	Emissions Factor (g pollutant/kg bird-day)	NH_3 Emissions	
					(kg/event)	(avg. kg/d)
1	2,540	Decaking	8	0.006288	127.77	15.97
2	2,638	Decaking	10	0.006288	165.88	16.59
3	2,559	Decaking	7	0.006288	112.64	16.09
4	2,562	Decaking	9	0.006288	144.99	16.11
5	2,601	Full litter clean-out	13	0.003108	105.10	8.08
				Total annual emissions (kg) =	656.39	

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10.0 REFERENCES

EPA (U.S. Environmental Protection Agency). 2001. Emissions from Animal Feeding Operations (Draft). EPA Contract No. 68-D6-0011. Washington, D.C. Available on-line at http://epa.gov/ttn/chief/ap42/ch09/draft/draftanimalfeed.pdf.

National Research Council. 2003. Air Emissions from Animal Feeding Operations: Current Knowledge, Future Needs. National Academy Press, Washington, DC. ISBN: 0-309-08705-8; Available on-line at www.nationalacademies.org.

USDA 2009, 2007 Census of Agriculture, USDA, National Agricultural Statistics Service. Washington, D.C. available on-line at http://www.agcensus.usda.gov/Publications/2007/Full_Report/usv1.pdf.

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