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# Comparison of measured and modeled ambient hydrogen sulfide concentrations near a 4000 head swine facility

**David Schmidt, M.S., Extension Engineer**

1390 Eckles Avenue, Department of Biosystems and Agricultural Engineering, University of Minnesota, St. Paul, MN 55108, schmi071@umn.edu

**Lakshmi Koppolu, Ph.D., Postdoctoral Fellow**

217 L.W. Chase Hall, Department of Biological Systems Engineering, University of Nebraska, Lincoln, NE 68583, lkoppolu2@unl.edu

**Gregory Pratt, Ph.D., Scientist**

Minnesota Pollution Control Agency, 520 Lafayette Road, St. Paul MN 55155

**Larry Jacobson, Ph.D., Professor**

1390 Eckles Avenue, Department of Biosystems and Agricultural Engineering, University of Minnesota, St. Paul, MN 55108, jacob007@umn.edu

**Dennis D. Schulte, Ph.D., Professor**

216 L.W. Chase Hall, Department of Biological Systems Engineering, University of Nebraska, Lincoln, NE 68583, dschulte1@unl.edu

**Steven Hoff, Associate Professor**

206B Davidson Hall, Department of Agriculture and Biosystems Engineering, Iowa State University, Ames, IA 50011, hoffer@iastate.edu

**Mara Moscato, Graduate Student**

1390 Eckles Avenue, Department of Biosystems and Agricultural Engineering, University of Minnesota, St. Paul, MN 55108

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*Abstract*. Air dispersion models are currently being used to regulate agriculture facilities and/or assess their environmental impact. As such, it is critical that these models accurately reflect these impacts. Meteorological conditions, hydrogen sulfide emissions, and downwind hydrogen sulfide concentrations at a four barn, 4000-head, swine finishing facility in Northeast Iowa were measured for a three week period in October 2003. Meteorological conditions and hydrogen sulfide emissions from the barns were used as inputs into two air dispersion models, INPUFF-2 and AERMOD. Model results were compared to measured results at eighteen receptor locations. Results indicate the models did not accurately predict spatial and temporal ambient concentrations. However, a rank order comparison of data (not matched in space and time) shows the models may be useful in predicting maximum concentrations over a period of time.

*Keywords:* Hydrogen Sulfide, Livestock, AFOs, Modeling, AERMOD, INPUFF-2

# INTRODUCTION

Air quality issues related to odor and gas emissions from Animal Feeding Operations (AFO's)is currently receiving national attention (NRC, 2003). Much of the attention is focused on process based models to predict the emissions and transport of these gases from the facilities. Several air dispersion models are available and currently being used to predict these ambient impacts; however, validation of these models for AFO's is limited. These models are typically designed for assessing impacts of industrial sources. AERMOD, one of the models used in this study, has undergone significant validation as part of the process of becoming officially accepted as an EPA regulatory model. However, agricultural building geometry, ventilation design and ventilation management are key differences between model inputs for industrial and agricultural sources that may impact the final results. Zhu et al (2000) showed some success using INPUFF-2 to predict odor dispersion from several livestock and poultry facilities using field validation with human panelists.

In general, there is a limited amount of field data available to help validate these models with feedlot sources because of the time and expense associated with gathering such data and because regulations requiring dispersion modeling for livestock facilities are relatively new. EPA guidance (EPA, 2001) requires model validation prior to acceptance as an regulatory model and notes that models are most reliable for 1) predicting longer time-averaged data and, 2) predicting magnitudes of maximum concentrations "occurring sometime, somewhere within an area". The guidance also suggests that the generally accepted "factor of two" model accuracy can often be in the range of ±10-40% when estimating maximum concentrations.

# Methodology

## Site Description
The farm used in this validation study is a four barn swine finishing site in North Central Iowa. The tunnel ventilated barns are each 12 m wide and 61 m long and oriented east and west with the roof peak at 4.6 meters. Buildings are spaced 20 meters apart. Tunnel ventilation fans are located on the east end of the barns. Each barn has a maximum capacity of 1000 finishing hogs. The site topography is flat with no trees, fences, hedgerows or other obstructions in the study area. Farmland near the site had been harvested prior to the study. The site is set 100 meters from the nearest road that runs on the west side of the building site.

## Emission Monitoring
Two middle barns (barns B and C) of the four barn site were monitored continuously as part of an ongoing USDA/CSREES emission measurement project (Aerial Pollutant Emissions from Confined Animal Buildings Project http://manure.coafes.umn.edu/apecab/index.html ). Hydrogen sulfide concentrations from the pit and tunnel ventilation fans were measured using pulsed-fluorescence hydrogen sulfide analyzer (TEI 45C, Thermo Environmental Instruments, 8 West Forge Parkway Franklin, MA 02038). Concentrations from each of the fans were determined approximately every 120 minutes.  Building ventilation rates were determined by a complex procedure of continuous monitoring of the fan operation and fan calibration curves. Concentration data was combined with ventilation rates to determine hourly emission data. Details on emission measurement protocols can be found on the APECAB web site.

Ambient Monitoring
During the study period, eighteen receptors (hydrogen sulfide monitors) were located south-east of the buildings in three semi-circles approximately 100 m, 200 m and 300m from the buildings (figure 1). The positions of the buildings and the receptors were determined using standard Global Positioning System equipment. Hydrogen sulfide was measured using a chemcassette recorder (Model 7100, Zellweger Analytical, Lincolnshire, IL). The analyzer was capable of recording 15 minute average $H_2S$ concentrations. Data was recorded using a Squirrel data logger (Grant Instruments, UK).

Meteorological data was taken throughout the study period following EPA guidance (EPA, 2000). A 10 meter tower was used to gather wind speed and direction. Wind velocity and direction was measured using a vane anemometer (R.M. Young Wind Sentry,Model 03001). Relative humidity and temperature were measured using a Vaisala sensor (Model HMD60YO) and a shielded enclosure. Solar radiation was measured using a LI-COR Model LI200X pyrometer.

Model descriptions
Two models are currently being assessed in this project.

INPUFF-2 is a Gaussian puff model designed to simulate dispersion of airborne pollutants from semi-instantaneous to continuous point sources. The model can deal with multiple point sources and receptors simultaneously and uses Pasquill-Gifford stability class data to assess meteorological conditions. The model was chosen because it is easy to use and can readily be used with real-time meteorological data. For the purposes of this study, the building emission sources were divided into multiple point sources and assessed as several large stack diameter point sources.

AERMOD is a steady-state plume model using Gaussian distributions in the vertical and horizontal for stable conditions, and in the horizontal for convective conditions. AERMOD is under review and testing by EPA and is anticipated to become an approved regulatory model under US EPA guidance 40CFR 51, Appendix W. AERMOD handles multiple point, volume, and area sources with surface, near-surface, and elevated releases. The model is structured for using standard preprocessed meteorological data AERMET but real time data can also be processed and used in the model.
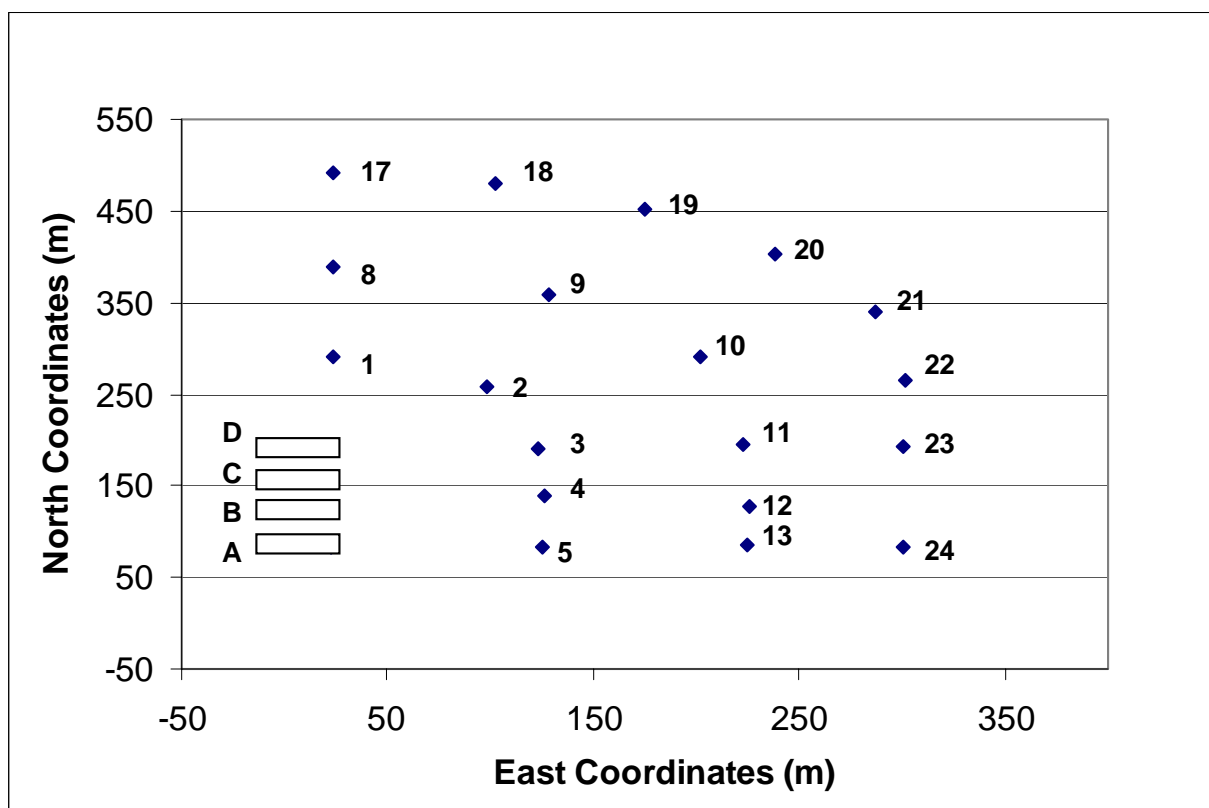
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Figure 1. Layout of barns and receptors in study area using GPS coordinates.


Source Characterization

Hourly emissions from the measured barns (B and C) are shown in Figure 2a and 2b and summarized in Table 1. Because buildings A and D were not monitored during this study period estimates of these emissions were required. For AERMOD, barns A and B were assigned the barn B hourly emissions while barns C and D were assigned the building C hourly emissions. For INPUFF-2, barn B and C emissions were averaged for each hourly time-step and this average was assigned to all buildings (A, B, C, and D).

With AERMOD, each barn was modeled as four equal volume sources with the total barn emissions divided equally between the four volume sources. INPUFF-2 modeled each building as four point sources with the cross-sectional area of the stacks at each "point" equivalent to one fourth of the area of the barn (figure 3).
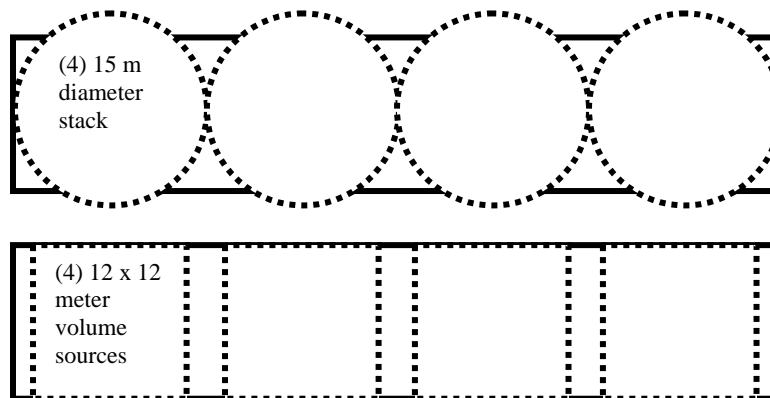
Figure 3. Schematic of individual barn and point (INPUFF-2) and volume (AERMOD) source representation.

Other critical modeling parameters for the validation procedure are shown in Table 1.

| Parameter | INPUFF | AERMOD |
|---|---|---|
| # point or volume sources | 16 (4 per barn) | 16 (4 per barn) |
| Initial lateral dimension, sigma y (m) | 5.8 | 7.1 |
| Initial vertical dimension, sigma z (m) | 1.1 | 1.1 |
| Stack Diameter (m) | 15 | - |
| Effective Emission Height (m) | 2.3 | 2.3 |
| Receptor Height (m) | 1 | 1 |
| Met Tower Height (m) | 10 | 10 |
| Terrain | Flat | Roughness = 0.05 |
| Bowen Ratio | - | 0.7 |

## Results

Emissions

Hourly hydrogen sulfide emissions from barns B and C are shown in figure 3a and 3b and are summarized in Table 1. The peak emissions shown in figure 3 are during the agitation and pumping of the barns on Oct 20 through Oct 22. These dates were removed from the final comparative data set because of the land application occurring near the receptor locations during this time, which likely skewed the measured receptor values.
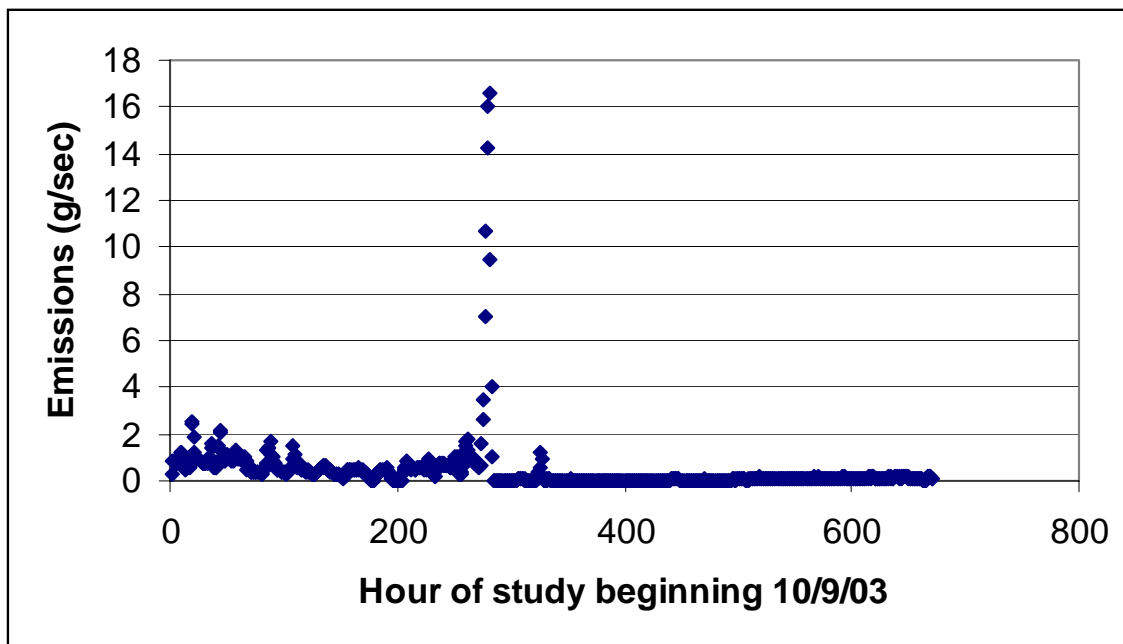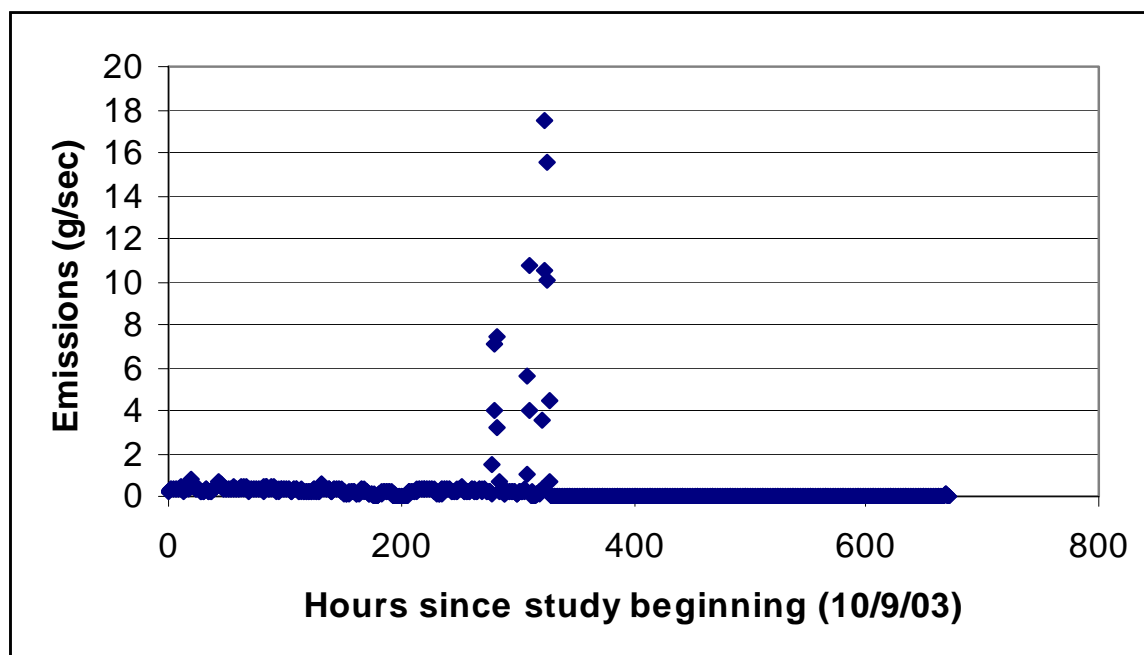
Figure 3a. Hourly time-steps vs. emissions for barn B.



Figure 3b. Hourly time-steps vs. emissions for barn C.

Table 1. Summary of emissions from measured barns.

| Parameter | Pumping Included | | Pumping not included | |
|---|---|---|---|---|
| | Barn B g/s | Barn C g/s | Barn B g/s | Barn C g/s |
| Average | 0.30 | 0.45 | 0.18 | 0.32 |
| Min | 0.00 | 0.00 | 0 | 0.00 |
| Max | 17.50 | 16.59 | 0.79 | 2.50 |
| Median | 0.04 | 0.12 | 0.03 | 0.11 |

Selection of Meteorological Conditions

Hourly concentrations were modeled using AERMOD for the eighteen receptors throughout the measurement period. The resulting data was then post-processed to include only times when the wind was between 179°-271°. This procedure eliminated times when emissions from other nearby sources could impact the field monitors. INPUFF-2 was run for only those wind directions between 179°-271° for the same reason cited above. A total of 118 hours were included in the final analysis (538 hours were removed from the original 670 hours because of the limitations on wind direction and 14 hours were removed during the agitation and pumping).

Average hourly wind speed during the monitoring period ranged between 0 and 29 km/hr (0 and 28 mph).

Measured vs modeled

Receptor #3 measured vs modeled results are shown in figure 3. This graphical representation of measured vs modeled of Receptor #3 is representative of the other 17 modeled receptor locations primarily showing the inadequacy of the models to accurately predict hydrogen sulfide concentrations at specific locations at specific times. However, models are most useful at predicting long-term averages or maximum concentrations in a given area (EPA, 2000). As such, a modified data set was created based on the rank order of measured and modeled values (data sorted from low to high, column by column, to remove the element of time from the graphs and preserve the spatial relationship only in terms of source distance). These plots are shown in figure 4 and present the data for all receptors with receptor 1-5 combined and labeled "near" (approximately 100 meters from the barn edge), receptors 8-13 combined and labeled "middle" (approximately 200 meters from the barn edge) and receptors 13-24 combined and labeled "far" (approximately 300 meters from the barn edge). These new plots show the model predictions for both models and, as can be observed, indicate better correlation between modeled and measured when the requirements of space and time are relaxed.
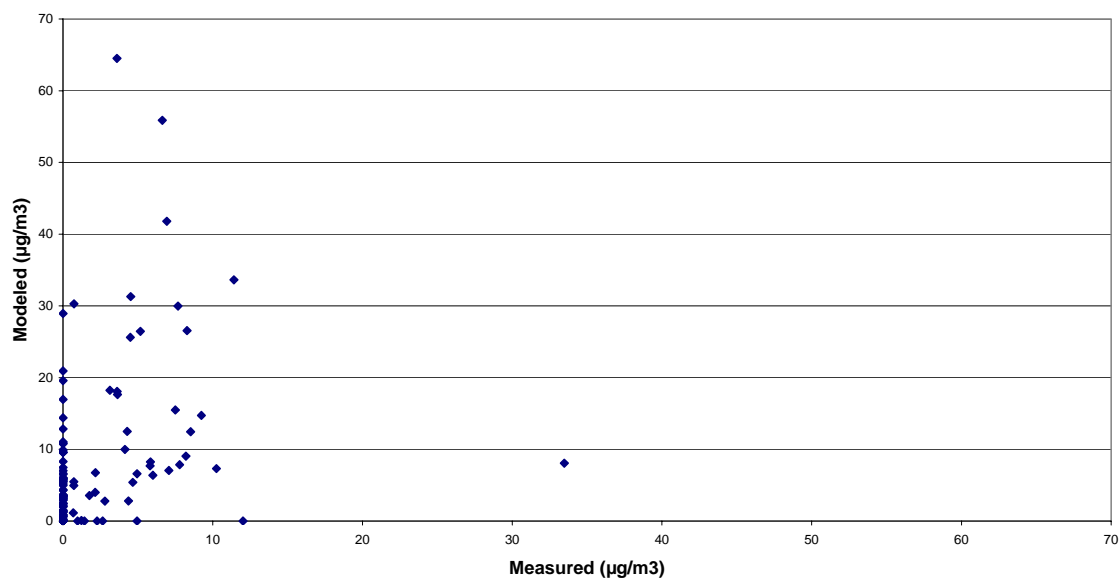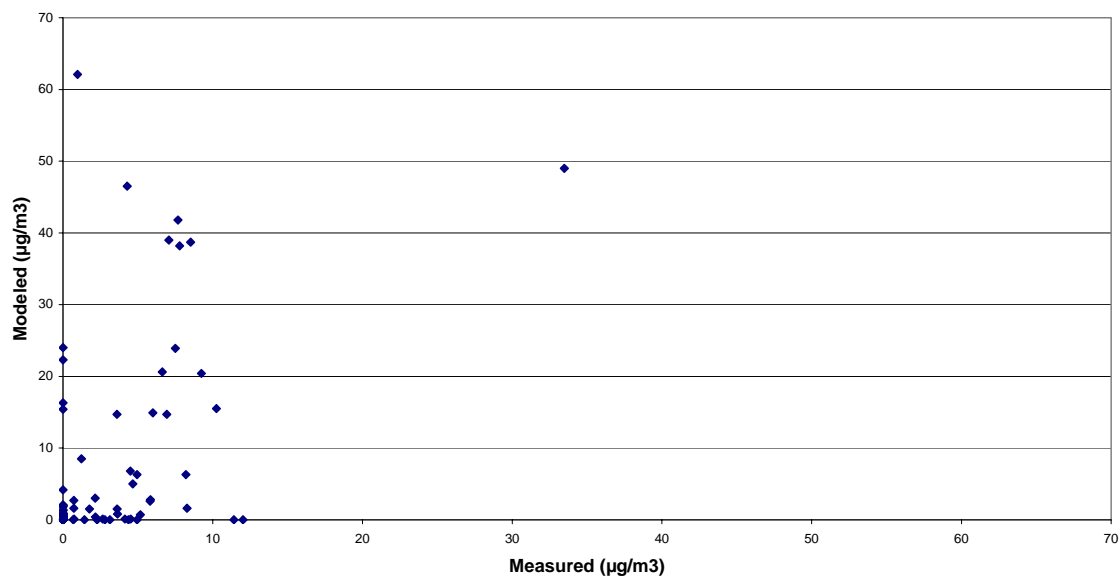
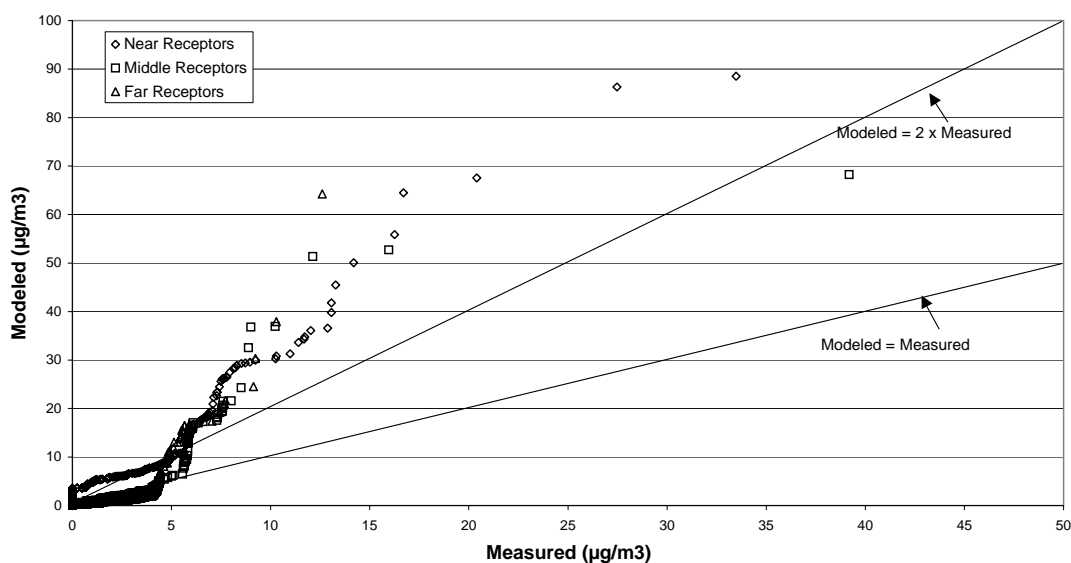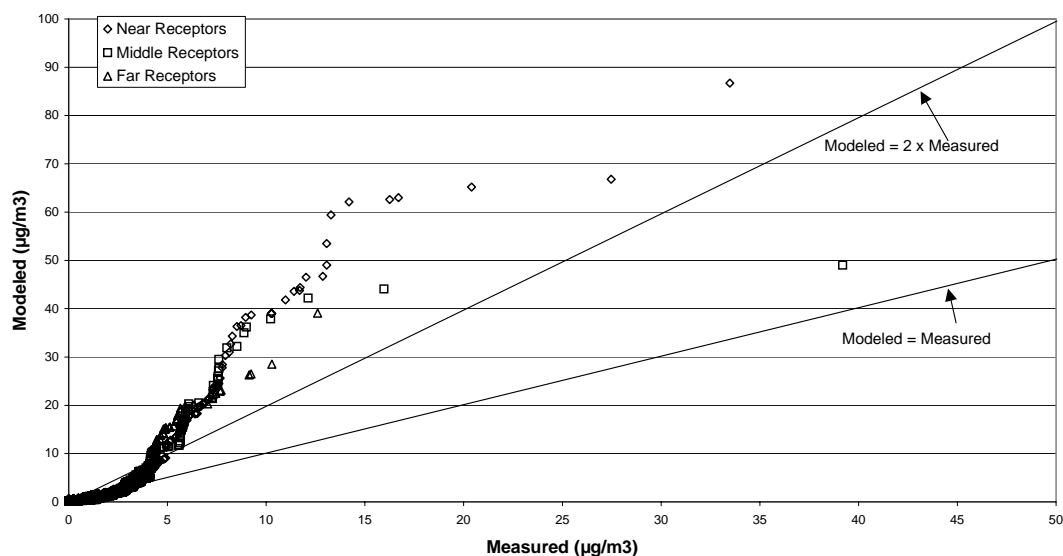Figure 3 a,b. Measured vs modeled for INPUFF-2 and AERMOD at receptor #3.

Figure 4a and 4b. Measured vs modeled of near, middle, and far receptors for (a) INPUFF-2 and (b) AERMOD not considering temporal variability.

## Discussion and Conclusions

Neither INPUFF-2 nor AERMOD predicted ambient concentrations that closely matched the measured concentrations for both time and space. When presented in rank order, AERMOD under-predicted measured concentrations at concentrations lower than 5 ppb for the middle and far receptors while the near receptors overpredicted in this range of concentrations. At higher

measured concentrations AERMOD had a tendency to over predict the ambient concentrations, typically more than a factor of 2. INPUFF-2 predicted well at concentrations below 5 ppb but also tended to over predict at all distances and concentrations. Uncertainty in emission measurements (and emission estimates for buildings A and D), measurement of meteorological conditions, and receptor measurements could be contributing factors in these comparative results.

Future Work
The validation of the INPUFF-2, AERMOD is the first step in a larger project. A third model, CALPUFF, will also be validated using this same data set. This larger project is attempting to develop a siting tool for livestock operations required to meet the MN state standard for hydrogen sulfide.

The steps for the development of such a tool are as follows:

1. Validate the accuracy of current dispersion models for predicting downwind hydrogen sulfide concentrations from livestock facilities. Choose the best model to use in predicting downwind concentrations from a set of model farms.
2. Develop a list of 30 to 40 model farms that represent typical AFO's in Minnesota – building sizes, building design, ventilation, and layout.
3. Model the minimum distances from these farms where downwind concentrations of hydrogen sulfide meet the state standard of 30 ppb 30 minute average twice per five days or 50 ppb 30 minute average twice per year, using average hydrogen sulfide emission factors and five years of MN meteorological data.
4. Present this information in a form that can be used by farmers and regulators in the siting of facilities to meet MN permitting standards.

## Acknowledgements

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