How to Conduct the Air Monitoring Study: Discussion of Practical and Scientific Issues

Presented to NRCS Air Quality Group
by Albert Heber, Purdue University
Thursday, November 20, 2003
Beltsville, MD
John Thorne’s Questions for Scientists
NRCS Air Quality Group Meeting
November 18-20, 2003

• What emission data needs to be collected?
• What operational data needs to be collected?
• What will the mobile labs look like? Cost?
• How many people are needed to do the work?
• What are the farm selection criteria?
• What are the PI qualifications?
• How will the data be managed?
• What about data format?
Project Title Ideas

- **PELF**: Pollutant Emissions from Livestock Facilities
- **BAEBL**: Baseline Air Emissions from Barns and Lagoons
- **MAEPL**: Monitoring of Air Emissions from Poultry and Livestock
- **BELiPS**: Baseline Emissions from Livestock Production Systems
- **AELPH**: Air Emissions from Livestock and Poultry Housing
- **MEPAB**: Monitoring of Emissions of Pollutants to the Air from Barns
- **APEPL**: Air Pollutant Emissions from Poultry and Livestock
- **APEAF**: Air Pollutant Emissions from Animal Facilities
Personnel Allocation per PELF Lab
(Number of FTE = % x # of labs)

• Lead PI: 3%
• Co-PI: 5%
• PI: 10%
• Site Analyst: 50%
• Data Manager: 5%
• Quality Assurance Manager: 5%
• DAC Manager: 2%
• Gas Analyzer Manager: 2%
• PM Manager: 1%
• Micromet Manager: 2.5%
PELF Project Personnel (total)
Initial Estimates (assumes EPA analyzes data)

• Lead PI (1): 0.75 FTE
• Co-PI (4): 0.25 FTE x 4 = 1.0
• PI (24): 0.10 FTE x 24 = 2.4
• Site Analyst (24): 0.50 FTE x 24 = 12
• DAC Manager: 0.50 FTE
• PM Manager: 0.25 FTE
• Gas Analyzer Manager: 0.50 FTE
• Data Manager: 1.25 FTE
• QA Manager: 1.25 FTE
• Micromet Manager: 0.75 FTE
Proposed PELF Organizational Chart
PELF Site Selection Criteria

• Adjacent rooms/buildings.
• Prefer mechanical ventilation, single-speed fans.
• Representativeness
  – Management of buildings, manure, etc.
  – Typical design according to Extension Ag Engineers.
  – Age and size of facility, buildings, etc.
  – Diet and genetics.
  – Consider geographic distribution.
• Accurate field production records
• Collaborative and supportive producer
  – Willing to make changes to facilitate measurements
  – Willing to record extra information for the study.
• Little or no external sources near the farm.
• Distance to PI (<2.5 hours away)
Natural vs. Mechanical Ventilation

• Minimum ventilation mode
  – Many NV barns have MV assist in cold weather.
  – NV flow rate variable. MV flow rate fixed.
  – Lower emission rates expected in MV barns.

• Temperature control mode
  – Both NV and MV have thermostatically controlled airflow rates so mean flow is the same.
  – Mean emission rate should be the same.

• Maximum ventilation mode
  – NV buildings have large ventilation openings.
  – Airflow/emission variance will follow wind variance.
  – Higher emission rates expected in NV barns.

• NV airflow patterns less predictable and consistent.
• Larger errors in NV barn emission data offset the uncertainty in transferring MV data to NV barns.

• Use MV to evaluate NV barns.
  – Choose site with MV over same type with NV.
  – Install fans in a NV barn for the PELF test.
  – Eliminate natural ventilation phase in tunnel ventilated house
  – Similar to using a wind tunnel on surfaces.
PI Selection Criteria

Minimum Training and Education
- Lead PI and Co-PIs: Ph.D. in Engineering
- PIs: M.S. in Engineering, Site Analyst: B.S. in Engineering

Experience and knowledge:
- Livestock emission measurement methodology
  - Direct source measurements
  - Ambient measurements and micromet techniques
- Gas and PM sampling theory and technology
- Measurement theory and technology
- Instrumentation and data acquisition
- Data analysis and reporting
- Working knowledge of quality assurance and quality control principles
- Livestock production systems (swine, dairy, poultry)
- Animal waste collection and treatment systems
- Building environmental control
  - Fan technology and performance (single and variable-speed)
  - Natural ventilation systems
  - Psychrometrics, fluid dynamics, thermodynamics, heat transfer, etc.

Project experience and availability for this project
- Management and decision-making skills
- Should have final authority on site selections and site monitoring plans.
Purdue University’s Custom Designed Mobile Laboratories
Elkhart, IN can deliver 24 of these custom designed trailers for $10,600 ea. to West Lafayette, IN. Further distances will cost more.
Cargo Trailer Option
Off the shelf ~ $7,500
No insulation:
(a problem with off the shelf trailer)
What will PELF Cost?

- The following slides give the cost of similar emission measuring projects led by Purdue.
- Multiple sources of funding are given for each project to give a total figure.
- In each of these projects, support for data analysis was insufficient.
- Each project included odor sampling and evaluation with olfactometry.
- Each project had different objectives than PELF.
- Each lab monitored 1 or 2 barns simultaneously. However PELF labs could be set up to monitor more than 2 barns or barns and storages.
- Some facilities will cost more than others to monitor. The budget should reflect these differences. Examples:
  - Site location differences: 130 miles vs. 10 miles
  - Barn size: 600 ft x 100 ft laying house with 75 fans vs. 40 ft. x 40 ft. farrowing room.
  - Higher maintenance costs needed in poultry barns (more frequent visits)
  - Most efficient to have two sites managed by one site analyst
Purdue Study on Air Emission Control from Swine Buildings (4 labs, 8 barns)

- Field Tests of Alliance (A. Heber, D. Bundy), Monsanto EnviroChem, Inc.
- 7-12 months of air emissions from 4 sites with 2 barns each.
- Total barn-months = 72.
- Project collected PM, NH3, H2S, CO2 and odor emission data.
- The 1997 version of the Purdue Method (Heber et al., 2001) was developed in this project based on studies observed in Silsoe, England (Phillips et al., 1998).
- **Total cost: $1,000,000 (exact figure unknown) or about $250,000 per lab.**


Study of Emission Measurement Methods (1 lab, 1 barn)

- Real-time PM Monitor: A TEOM (A. Heber) Purdue Agricultural Alumni Foundation
- Seven months of air emissions from one laying house using two sets of gas analyzers, 4 TEOMs.
- Project collected PM, NH3, H2S, CO2 and odor emission data but focused on measurement methods thus making the project cost more.
- The 1997 version of the Purdue Method (Heber et al., 2001) was tested and improved in this project.
- **Total cost: $298,606**
6-State Study on Swine House Emissions (6 labs, 12 barns)

- This project is measuring PM10 (with 2 TEOMs), TSP (with Illinois sampler), NH3, H2S, CO2 and odor emissions for 15 months from two barns each at six sites. Total barn-months = 180.
- The 2002 version of the Purdue Method was used in this project and supplemented by the Illinois TSP method and the USDA/Kentucky portable fan test method.
- **Total support: $2,150,000 or $358,333/lab.**
Control of Air Pollution Emissions from Swine Houses (CAPESH) (1 lab, 2 barns)

- Measurement and Control of Dust, Odor and Gas Emissions from Swine Houses in Missouri (A. Heber, J. Ni), Premium Standard Farms
- Effect of Biocurtains on Aerial Pollutant Emissions from Swine and Poultry Buildings (A. Heber), National Center for Manure and Animal Waste Management
- Control of Air Emissions from Swine Houses by Misting Essential Oils and Water (A. Heber), Premium Standard Farms
- Control of Air Emissions from Swine Houses with Essential Oils (A. Heber), Premium Standard Farms
- This project measured PM10, TSP (with 3 TEOMs), CH4, NMHC, NH3, H2S, CO2 and odor emissions for 11 months from two barns
- The site was 450 miles from Purdue University. Missouri University provided local analyst support.
- The 2003 version of the Purdue Method was used in this project along with the USDA/Kentucky portable fan monitoring method and the Illinois BESS lab.
- **Total cost: $425,452**
Real-Time Emission Data to be Collected by PELF

- Ammonia – chemiluminescence
- NOx - chemiluminescence
- Hydrogen sulfide – Pulsed-Fluorescence
- Carbon dioxide – Photoacoustic Infrared
- FTIR for ambient gas measurements (not H2S)
- PM (PM$_{2.5}$, PM$_{10}$, TSP) – (TEOM)
  - Also integrated TSP samples with Illinois method.
- Building airflow (fan status, pressure, vane anemometer, FANS)
- Include ambient measurements of PM, gases
Operational Data to be Collected by PELF

- Heating, flushing, feeder, and fan operation
- Temperature and humidity
- Building static pressure
- Animal activity
- Lighting
- Wind speed and direction
- Solar radiation
- Animal inventory and mass
- Manure, feed and water analysis
- Milk production
- Egg production
Ambient PM Measurements? Yes.
Airflow Measurement

- Monitor fan operation
- Monitor static pressure
- Calculate airflow with published fan curve.

**91 cm fan**

\[ y = -119x + 22022 \]

- \( R^2 = 0.999 \)

**122 cm**

**91 cm**
Building Static Pressure
Does the published fan curve still work for this fan? No.
Measuring Single-Speed Fan Airflow

- Fan performance curve, degradation
- Fan removal and test at BESS lab
- FANS tests (AMCA transfer standard)
- Small vane anemometers
- Fan operation (go downstream)
- Fan static pressure
Dirty is 8-13% < cleaned
Dirty is 14-24% < published
Cleaned is 7-13% < published
Airflow of Variable Speed Fans

- Fan removal and test at BESS lab
- Fan operation
- FANS tests to calibrate flow devices
- Full impeller anemometers (direct) in chimney
- Small vane anemometers (direct)
- Indirect method for belt drive fans
  - Static pressure
  - Impeller rpm
- Ancillary information
  - Fan performance curve
  - Speed control signal
  - Motor voltage

![Graph showing airflow and pressure over time](image)
• \( \text{NH}_3 \) methods
  - Chemiluminescence
  - Photoacoustic IR
  - Electrochemical
Gas Analyzer Calibrations

- Measurements are only as good as the calibrations of the analyzers.
- The following slides show some calibrations and control charts at Purdue University this year.
Calibration of CL NH₃ Analyzer using Programmable Diluter

\[ y = 4.814x - 0.4847 \]

\[ R^2 = 0.9996 \]
November 5 Sampling Run of CL NH3 Analyzer at a Laying House

Chemiluminescence NH₃ Control Chart

**Chemiluminescence NH₃ Control Chart**

- **Date**: 10/26, 11/9, 11/23, 12/7, 12/21, 1/4
- **Span conc., ppm**: 0, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200
- **Zero conc., ppm**: 0, 1, 2, 3, 4, 5, 6, 7, 8
- **Analyzer Voltage, VDC**: 0, 2, 4, 6, 8
- **Cal Gas concentration, ppm**: 0, 2, 4, 6, 8

**Maintenance needed**

**Calibration of INSITE NH₃ Analyzer**

- **y = 24.428x**
- **R² = 0.9997**

Nov. 5 calibration
October 16 Sampling Run of PIR at Laying House

MSA PhotoAcoustic IR NH$_3$ Control Chart

Date

Span conc., ppm

Zero conc., ppm

Graph showing data points for Span and Zero checks over dates 10/16, 10/24, 11/3, 11/7, 11/17, 11/26.

Y = 186.25x
R$^2$ = 0.9965

Y = 193.83x - 6.8209
R$^2$ = 1

Calibration of INSITE MSA-NH$_3$ Analyzer

Cal Gas concentration, ppm vs. Analyzer Voltage, VDC
August 8 Sampling Run of Pulsed Fluorescence H₂S Analyzer at Laying House

Pulsed Fluorescence H₂S Control Chart

Calibration of H₂S Analyzer

\[ y = 87.048x - 3.4362 \]

\[ R^2 = 0.9999 \]
August 8 Sampling Run of 10,000-ppm Photoacoustic IR CO$_2$ Analyzer at Laying House

![Graph showing gas concentration over time](attachment:graph.png)

- Calibration of CO2b Analyzer
  - $y = 851.13x - 1750.2$
  - $R^2 = 0.9994$

Date: 8/7, 8/21, 9/4, 9/18, 10/2, 10/16, 10/30, 11/13, 11/27, 12/11
August 8 Sampling Run of 2,000-ppm Photoacoustic IR CO₂ Analyzer at Laying House

Inset graph:
- Calibration of CO₂ Analyzer
- \( y = 244.91x - 487.39 \)
- \( R^2 = 0.9999 \)
Exhaust Air Chromatogram
Methane/NMHC Analyzer (FID)
Gas Concentration History

USEPA project: Air Sampling & Methodology for Confined Animal Housing Systems
Net vs. gross emission rates

Manure moisture content = 26.0%
Manure pH = 8.26
Advantages of Field Point

• Low cost, simplicity and flexibility
• Distributed I/O – next generation.
• Modularity and plug and play.
• Quick delivery by National Instruments.
• Short set up time.
Field Point Hardware

Pump exhaust tubes

Source: Larry Jacobson, Univ MN
Data Collection, Management, Processing and Analysis

• Collection
  – National Instruments Hardware and Software

• Management
  – Data format (consistent between sites)
  – Data storage and redundant backup

• Processing (with CAPECAB software)
  • Validate data (flag errors, etc.)
  • Calculates emission rates (minute averages)
  • Calculate basic statistics
    – Hourly and daily means
    – Variance (range, s.d.)
  • Deliver to EPA

• Analysis (by EPA)
  – Data interpretation and scientific insight
  – Emission factor development
  – Process-based modeling
Data Exchange and Software

Note: Framed, computers; Arrow, data flow direction; Underlined, software installed.
Data Processing Flow Diagram for the APECAB Project (3/31/03)

Notes: Framed, electronic files; Underlined, software; In “ ”, hard copies; Italicized, remarks
CAPECAB Data

• Databases
  – Raw (optional)
  – Calc
    • Flagging works off this database

• Data types
  – Tied to sample location
  – Not tied to sample location

• Time scale
  – One-minute base
  – Averages can be calculated as any multiples of 1 min.
Core CAPECAB Programs

- Convert
- Flagging
- Display
- Import/Export
  - Calculate
  - Animal Import
  - Miscellaneous Import
# Convert

Converts and transfers data from Labview text to raw or calc databases.

**Ana_Info File:**

<table>
<thead>
<tr>
<th>Convert!</th>
<th>Location</th>
<th>Length of Raw</th>
<th>Length of Calc</th>
<th>Number of Station Sets</th>
</tr>
</thead>
<tbody>
<tr>
<td>* CV</td>
<td>500</td>
<td>85</td>
<td>110</td>
<td>1</td>
</tr>
</tbody>
</table>

**Raw LV data**

- Raw
- Calc

- Write Records Directly to Calc Database

**Program Data**

1 analyzer set

**Site #**
Display: Show Graph

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Day</th>
<th>Show Parameters</th>
<th>Draw Manual Selections</th>
<th>Configure Advance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>10</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>3</td>
<td>1</td>
<td>Show Stations</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Noon to Noon</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Station: 500</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Minute</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ave</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Valid Percent</td>
<td>80</td>
<td></td>
</tr>
</tbody>
</table>

[Graph - mosite Site]

- Quick Pick
- Next QP
- Redraw QP
- Show Parameters
- Draw Manual Selections
- Configure Advance
- Year
- Month
- Day
March 2 data, MO
14 days of data
14 Daily Averages
Flagging

• Default setting for data is invalid and must be flagged.

• Invalid flags
  – Missing data (automatic if data is not there)
  – Offline (location not sampled is offline)
  – Stabilizing (analyzer equilibrating)
  – Calibration (not taking real data)
  – Sensor bad (data has to be thrown out)
  – Abnormal (obvious outlier)
  – User3

• Valid flags
  – Valid measurements
  – Valid interpolations
Import/Export

• Calculate
  – During Raw to Calc transfer
  – Calculations on the Calc database
• Animal Import (to raw or calc databases)
• Miscellaneous Import (other data)
# Equation Spreadsheets

<table>
<thead>
<tr>
<th>Start</th>
<th>End</th>
<th>Purpose</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>fill c85 and get rid of negs</td>
<td>C85 = IfLessThanElse(c1,0,0,c1)</td>
</tr>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>Flag C85 with C1 flags</td>
<td>C85 = ValueFlag(c85,c1)</td>
</tr>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>Convert amb NH3 from ppm to mg/m3</td>
<td>L1 C85 = C85*17/0.0821/(273.15+C36)</td>
</tr>
<tr>
<td>01/03/2003 17:31</td>
<td>16/03/2003 00:00</td>
<td>Convert barn7 NH3 from ppm to mg/m3</td>
<td>L2 C85 = C85 * 17 / 0.0821 / (273.15 + C32)</td>
</tr>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>Convert barn8 NH3 from ppm to mg/m3</td>
<td>L3 C85 = C85 * 17 / 0.0821 / (273.15 + C32)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Start</th>
<th>End</th>
<th>Purpose</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>Create Interpolated Minute Data NH3 L1</td>
<td>c111 = Interpolate(c85,L1,170)</td>
</tr>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>Create Interpolated Minute Data NH3 L2</td>
<td>c112 = Interpolate(c85,L2,170)</td>
</tr>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>Create Interpolated Minute Data NH3 L3</td>
<td>c113 = Interpolate(c85,L3,170)</td>
</tr>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>Create Interpolated Minute Data H2S L1</td>
<td>c114 = Interpolate(c86,L1,170)</td>
</tr>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>Create Interpolated Minute Data H2S L2</td>
<td>c115 = Interpolate(c86,L2,170)</td>
</tr>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>Create Interpolated Minute Data CO2 L1</td>
<td>c117 = Interpolate(c87,L1,170)</td>
</tr>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>Create Interpolated Minute Data CO2 L2</td>
<td>c118 = Interpolate(c87,L2,170)</td>
</tr>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>Create Interpolated Minute Data CO2 L3</td>
<td>c119 = Interpolate(c87,L3,170)</td>
</tr>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>NH3 emission of barn7</td>
<td>c90=(c112-c111)*c83</td>
</tr>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>NH3 emission of barn8</td>
<td>c91=(c113-c111)*c84</td>
</tr>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>H2S emission of barn7</td>
<td>c92=(c115-c114)*c83</td>
</tr>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>H2S emission of barn8</td>
<td>c93=(c116-c114)*c84</td>
</tr>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>CO2 emission of barn7</td>
<td>c94=(c118-c117)*c83</td>
</tr>
<tr>
<td>01/03/2003 00:00</td>
<td>16/03/2003 00:00</td>
<td>CO2 emission of barn8</td>
<td>c95=(c119-c117)*c84</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Start</th>
<th>End</th>
<th>Purpose</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>08/27/2002 0:00</td>
<td>7/30/2003 23:59</td>
<td>filter fan1 noise measurement</td>
<td>C73=IfLessThan(C16,0.05,0)</td>
</tr>
<tr>
<td>08/27/2002 0:00</td>
<td>10/30/2002 17:20</td>
<td>convert fan1 sva to flow rate m3/s</td>
<td>C73=IFLESSTHAN(-0.0709<em>C73</em>C73+2.0907*C73-3.8813,0,0)</td>
</tr>
<tr>
<td>10/30/2002 17:24</td>
<td>7/30/2003 23:59</td>
<td>convert fan1 voltage to sva</td>
<td>C73=IfLessThan(18.552*C73-0.9157,0,0)</td>
</tr>
<tr>
<td>10/30/2002 17:24</td>
<td>7/30/2003 23:59</td>
<td>convert fan1 sva to flow rate m3/s</td>
<td>C73=IFLESSTHAN(-0.0709<em>C73</em>C73+2.0907*C73-3.8813,0,0)</td>
</tr>
<tr>
<td>08/27/2002 0:00</td>
<td>7/30/2003 23:59</td>
<td>filter fan2 noise measurement</td>
<td>C74=IfLessThan(C17,0.05,0)</td>
</tr>
<tr>
<td>08/27/2002 0:00</td>
<td>10/30/2002 17:20</td>
<td>convert fan2 sva to flow rate m3/s(no)</td>
<td>c74=c74</td>
</tr>
<tr>
<td>10/30/2002 17:24</td>
<td>7/30/2003 23:59</td>
<td>convert fan2 voltage to sva</td>
<td>C74=IfLessThan(18.336*C74-0.8928,0,0)</td>
</tr>
</tbody>
</table>
CAPECAB

- CAPECAB is fully functional now and is being used to analyze data since early summer. It is a work in progress and is getting better each month with added features and user friendliness.

- CAPECAB Papers for upcoming AWMA Meeting:

- Written by Matt Eisentratt, RSLS Group, Calgary, CA, for Purdue University with financial support from APECCAB partners.

- It cost $15,000 and 10 months to develop on custom basis. About $1,000 per site license. Highly recommended for use by PELF.