Building a Processes Based Model for Livestock Emissions

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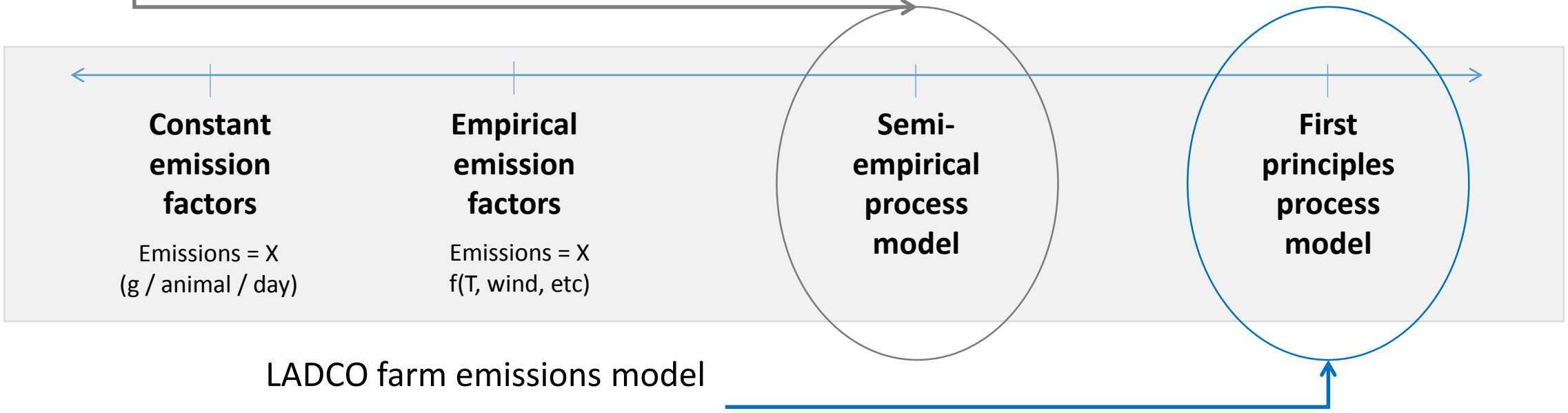
San Diego, California

History of Process Based Models

- National Academy of Sciences(2003) “Air Emissions From Animal Feeding Operations: Current Knowledge, Future Needs”
  - “The proposal would replace the current “emissions factor” approach with a “process-based modeling” approach. This can, if pursued vigorously, enhance both regulation and management of air emissions in the next two to five years.

Emission calculation methodology

- USEPA and Carnegie Mellon University statistical model based on measurement data (NAEMS study)
  - Science Advisory Board* recommends first-principles process-based model. EPA announced on April 15 2014 NACAA Agriculture committee call they are not pursuing at this time.

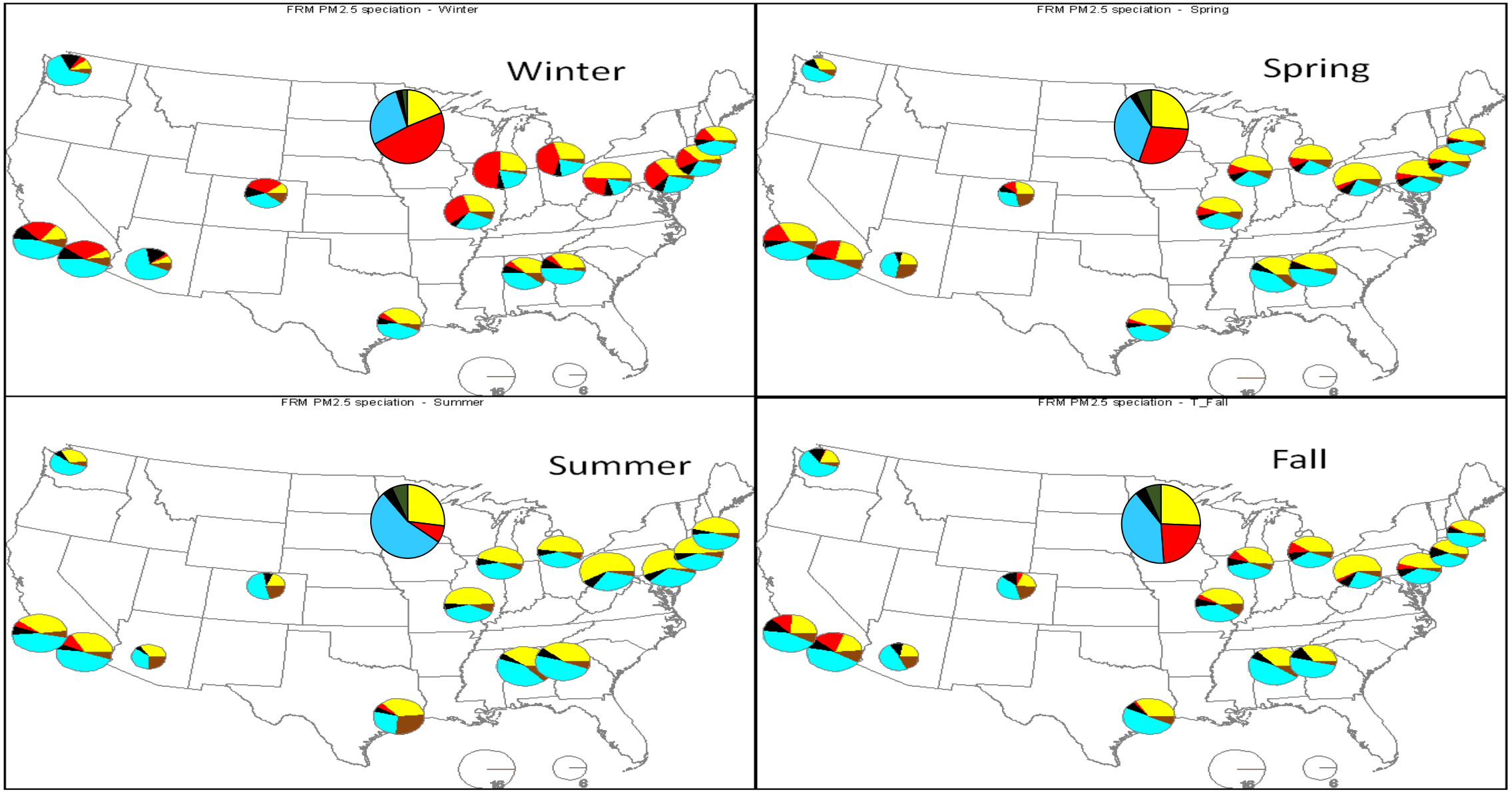


*http://yosemite.epa.gov/sab/sabproduct.nsf/0/ae6639dd6b79360e852579a4004e5529!OpenDocument&TableRow=2.3#2

Process Based Model Work at LADCO

- 2004 Early RPO work – Build a process based model with UC-Riverside and UC-Davis
  - Written in PostgresSQL – Very slow, well documented
- 2009 Improve Model Speed – Re-write in C, Vast improvement in processing Time
- 2013 Minnesota/MPCA take over project
  - Core processing flaws removed, and entire code refactored(reorganized), 10X faster.
  - Analysis of core processes in model for compliance with original science document.
  - Identification of key processing holes
  - Assessment of appropriate feedback to changes in key variables.
  - Provided documentation on what the model actually does (the science document documented what it should do)
  - Test results against real data (NAEMS) Too much for today.’s talk

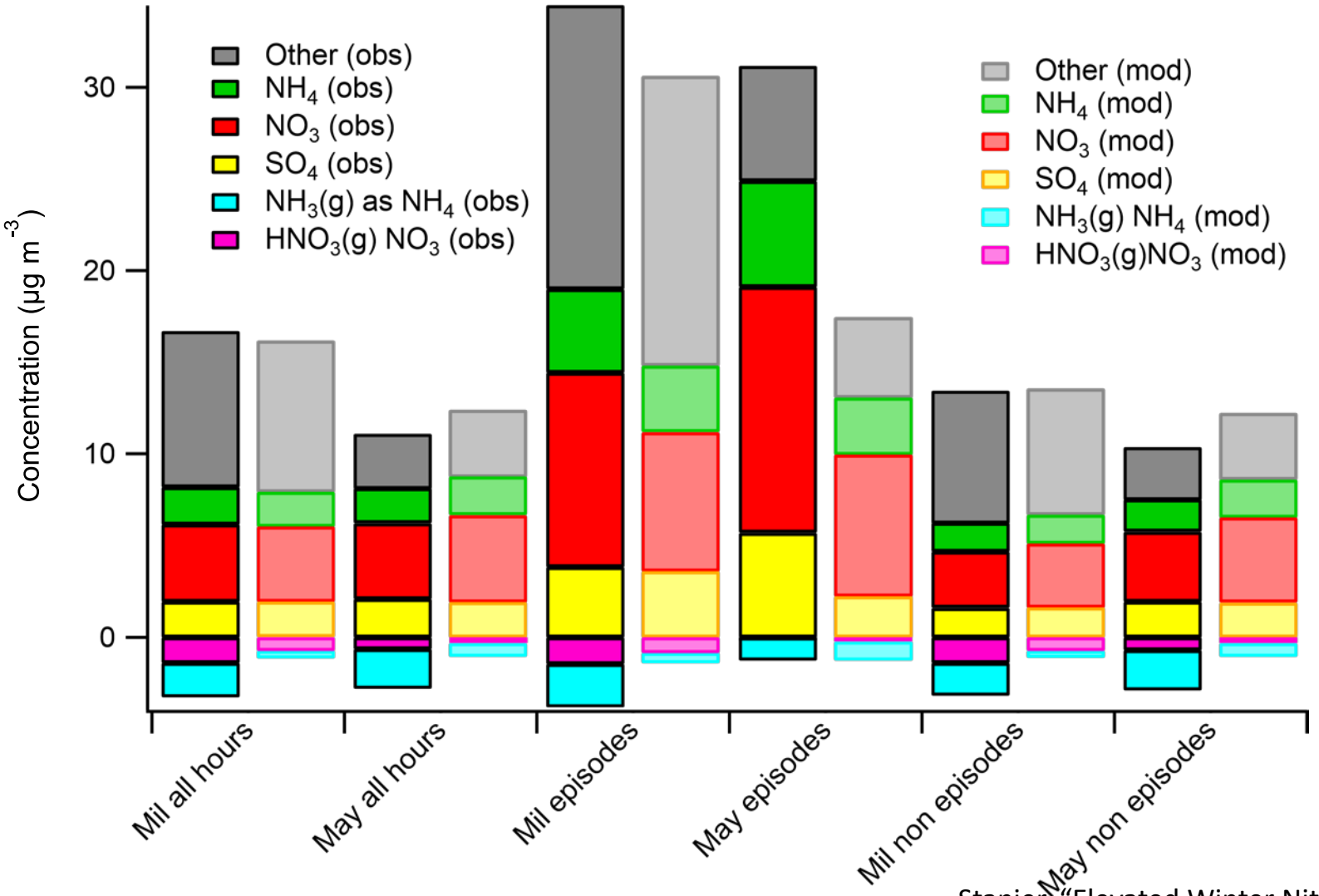
Ammonium nitrate is significant in the upper Midwest



Seasonal $PM_{2.5}$ composition for select urban areas 2008-2010

Source: U.S. EPA

LADCO/IOWA Winter Nitrate Study

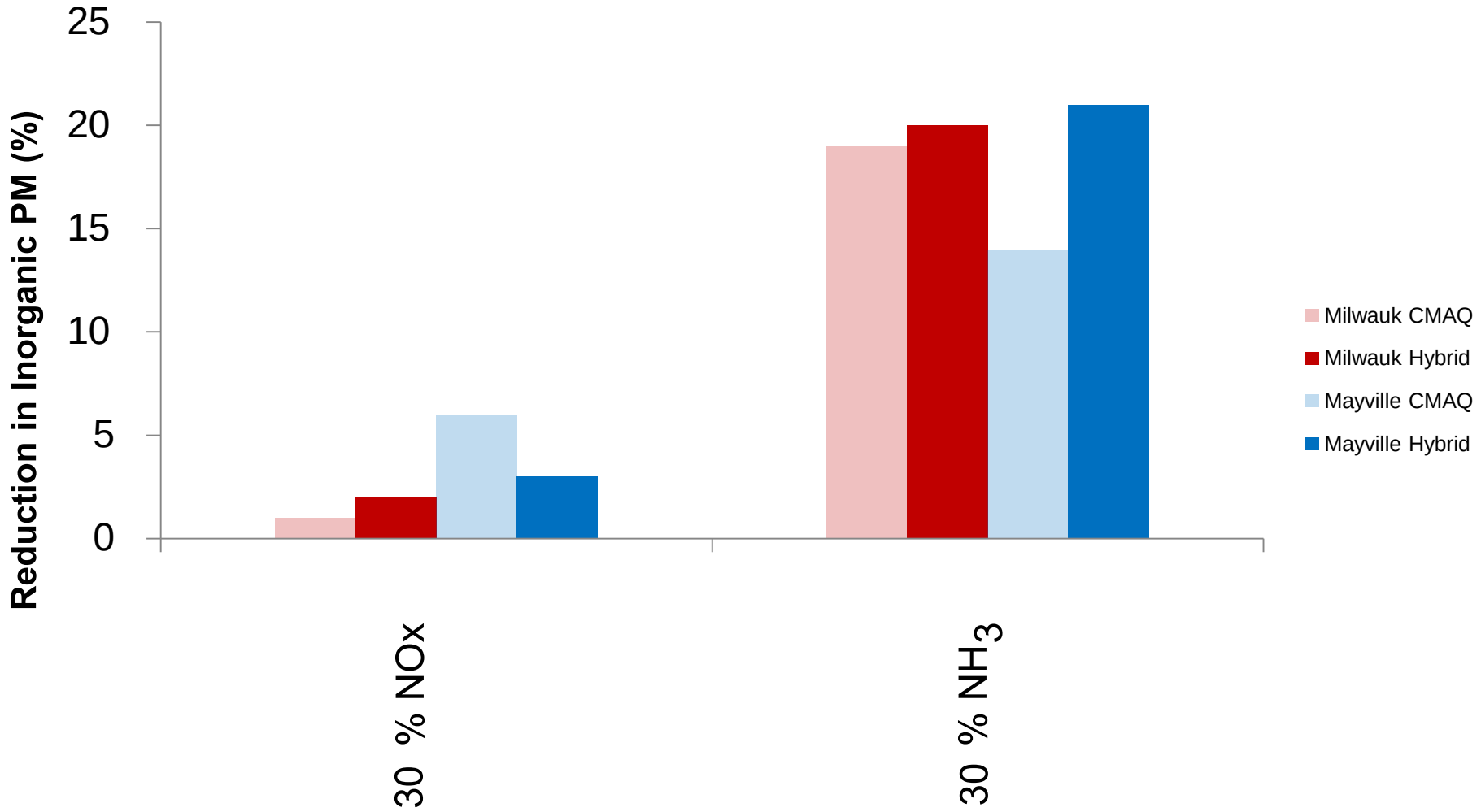


- CTM to measurement comparison study
- Model Skill: Comparison of Monitored Versus Modeled PM Speciation.
- Consistent under prediction of NH3 concentrations
- Total ammonia underprediction during almost all periods and sites.
- Shows as deficit in gas phase ammonia.
- Nitrate underprediction during episodes.

Stanier, "Elevated Winter Nitrate in the Upper Midwest" – University of Iowa 2003

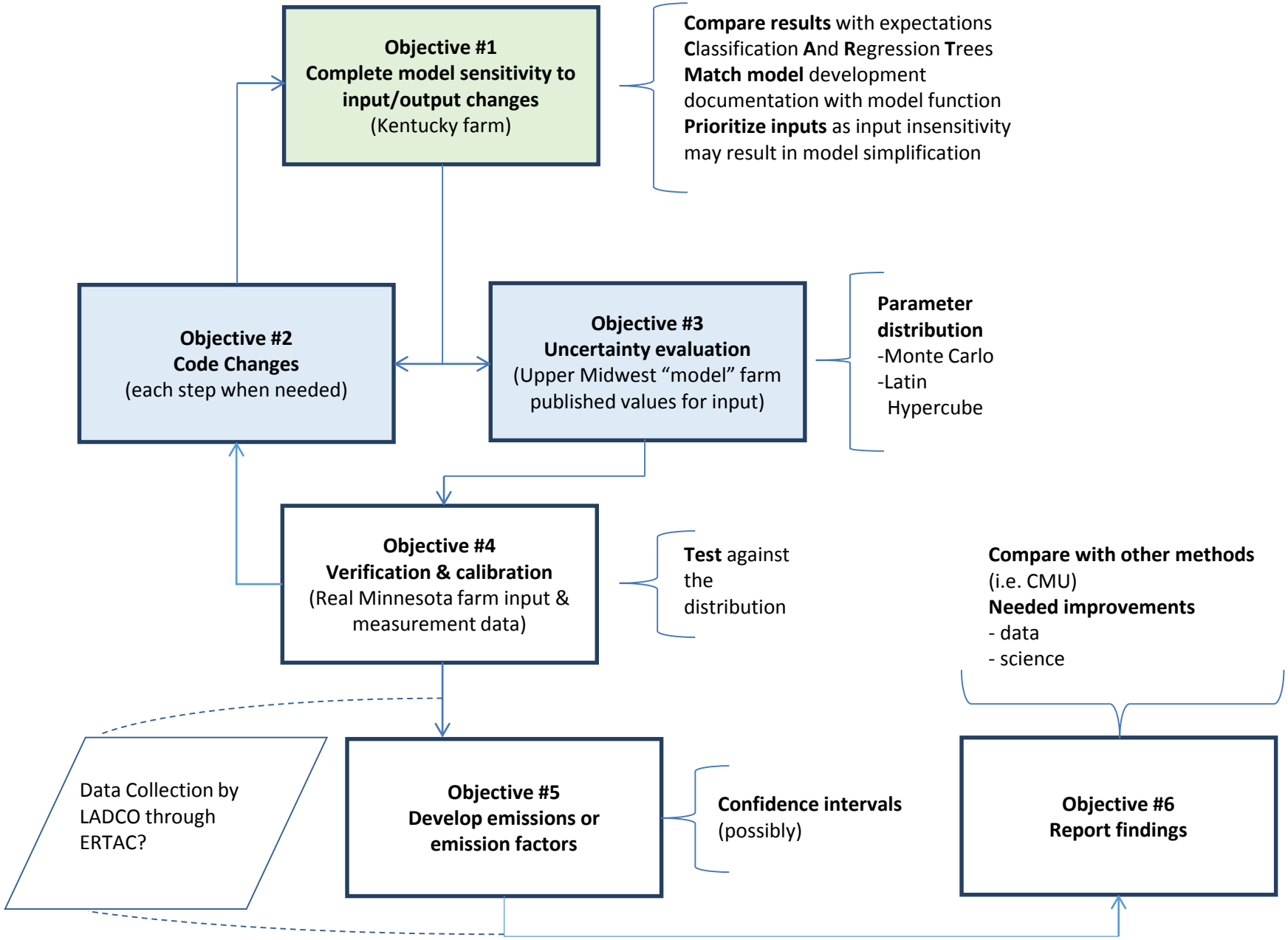
Thermodynamic Sensitivity / Model Skill

Direct CMAQ Sensitivities to Emissions versus ISORROPIA Model Hybrid of Modeled and Measured Values
(During hours with > 27 µg m^{-3} measured PM2.5)



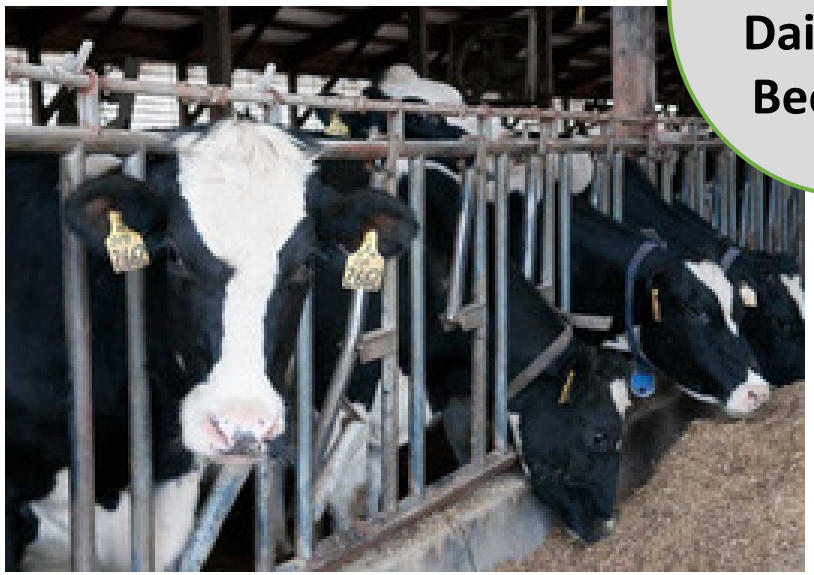
Stanier, “Elevated Winter Nitrate in the Upper Midwest” – University of Iowa 2014

Ammonia model project objectives flow chart

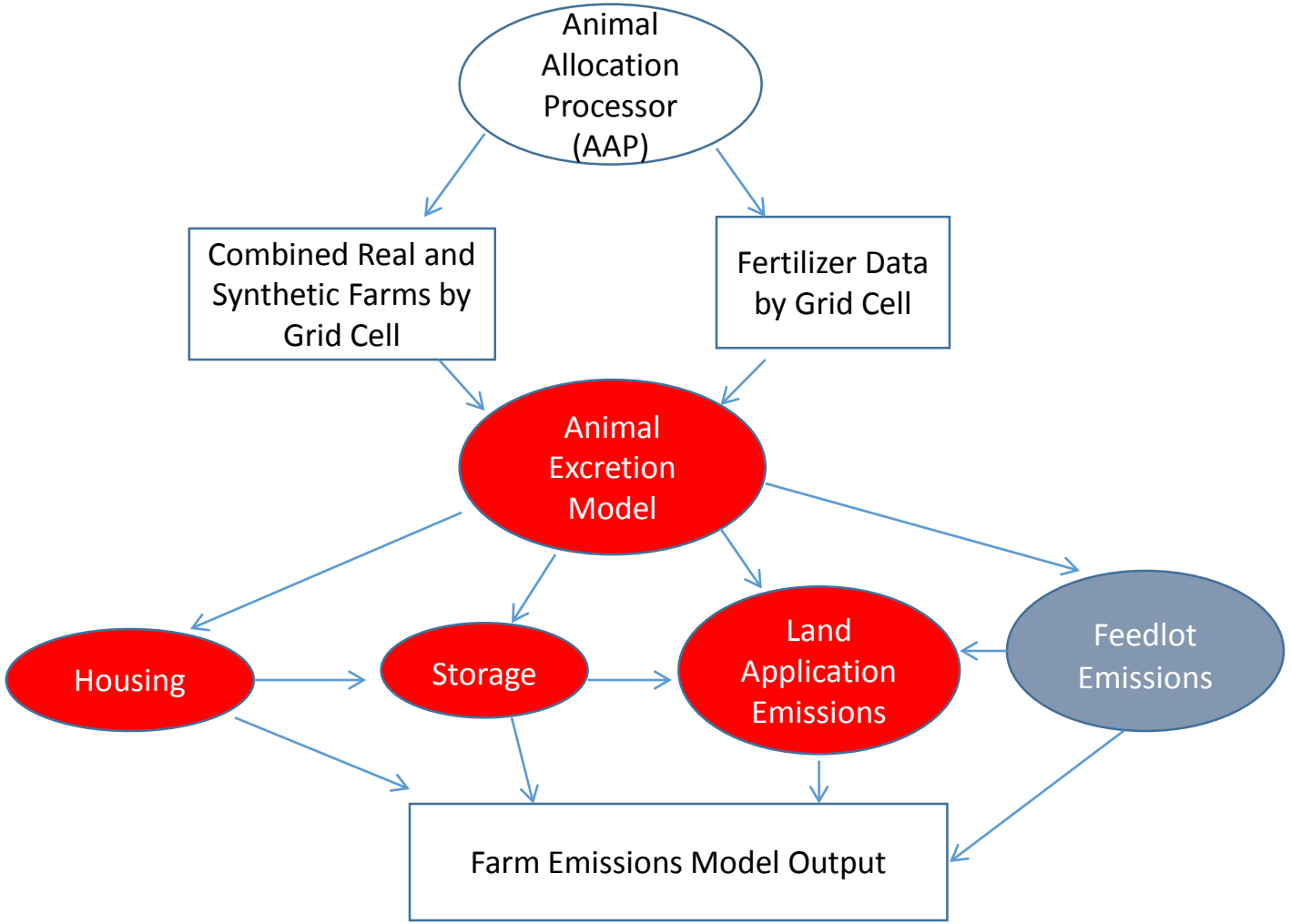


Animals

Swine
Poultry
Dairy cow
Beef cow

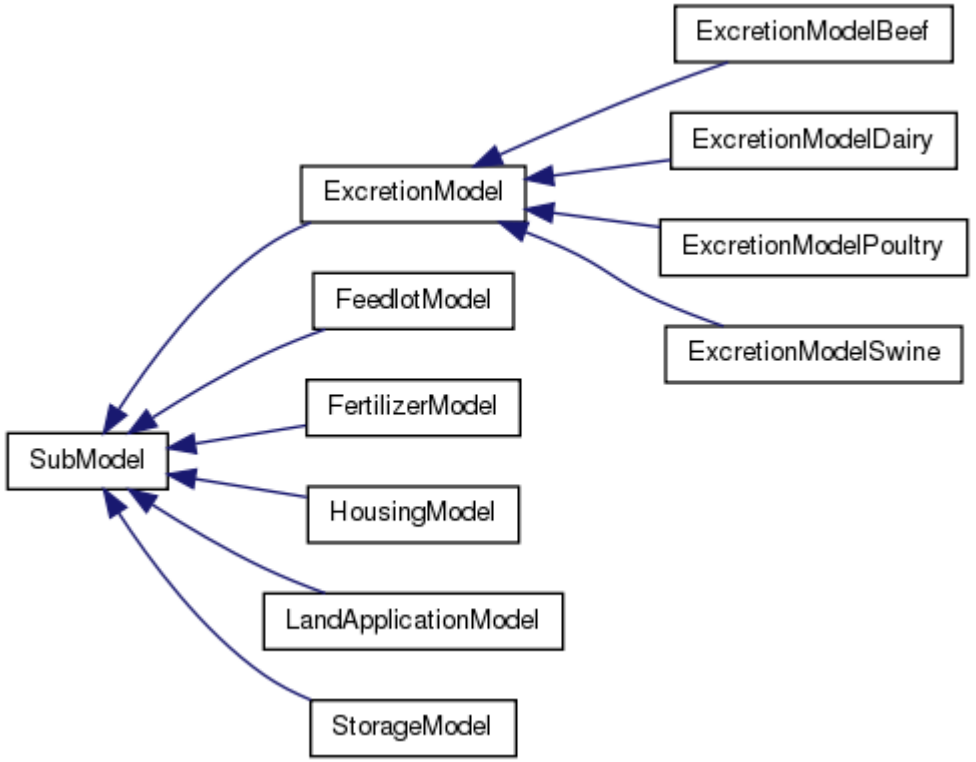


Schematic Flowchart of the Process-Based Ammonia Emission Model

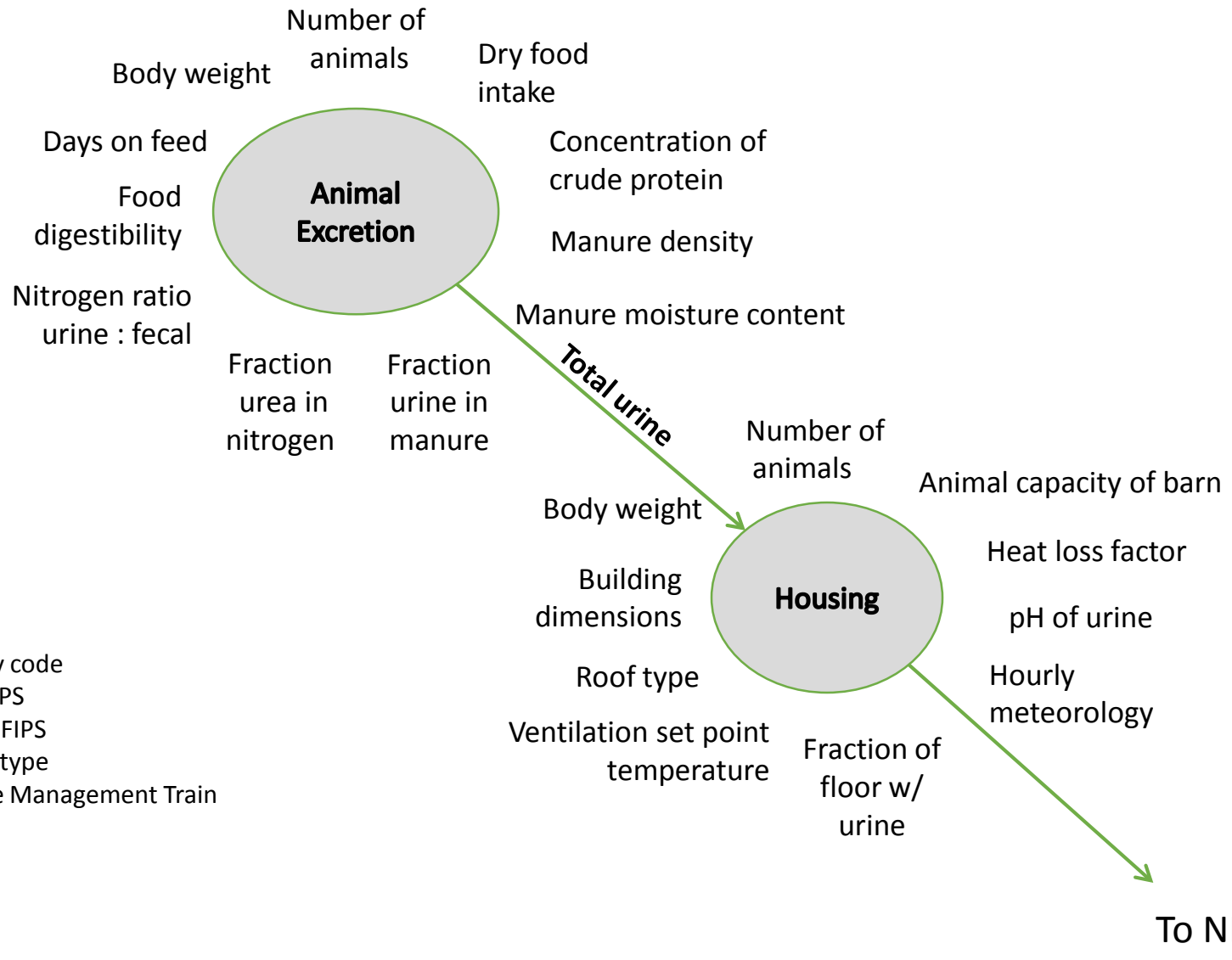


Current model structure and status

- **Excretion** is the most complete, separate for each animal type
- **Feedlot** is in initial stages, not called by the model
- **Fertilizer** is a placeholder, not in science document, not from livestock emissions.
- **Housing** is substantive for mechanical venting, one model for all animal types, handles urine on bare floor, animals indoors at all times
- **Land application** is incomplete
- **Storage** one model for all animal types, volume of manure and nitrogen concentration from excretion, sensitivity provides incorrect answers



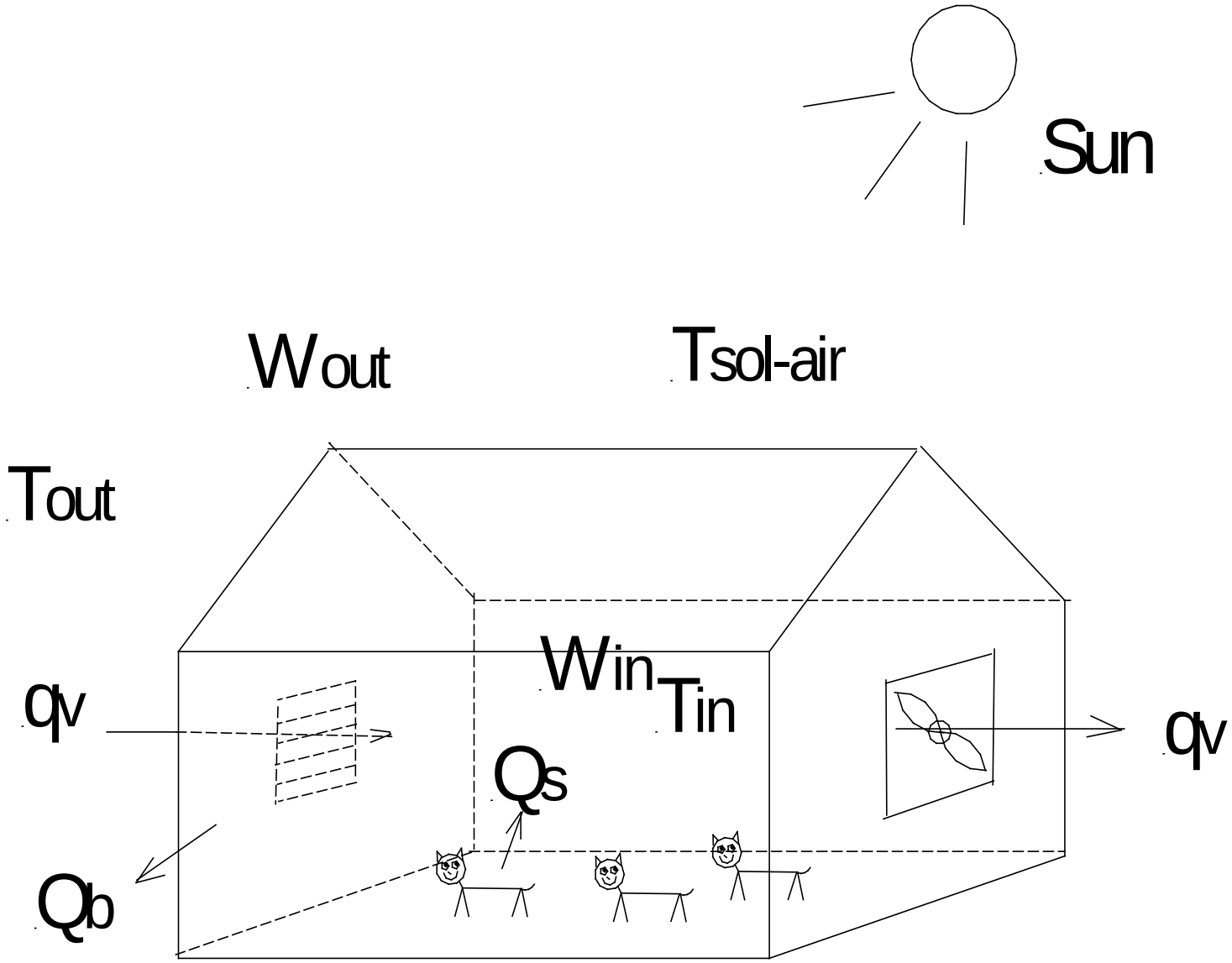
Model input variables for beef



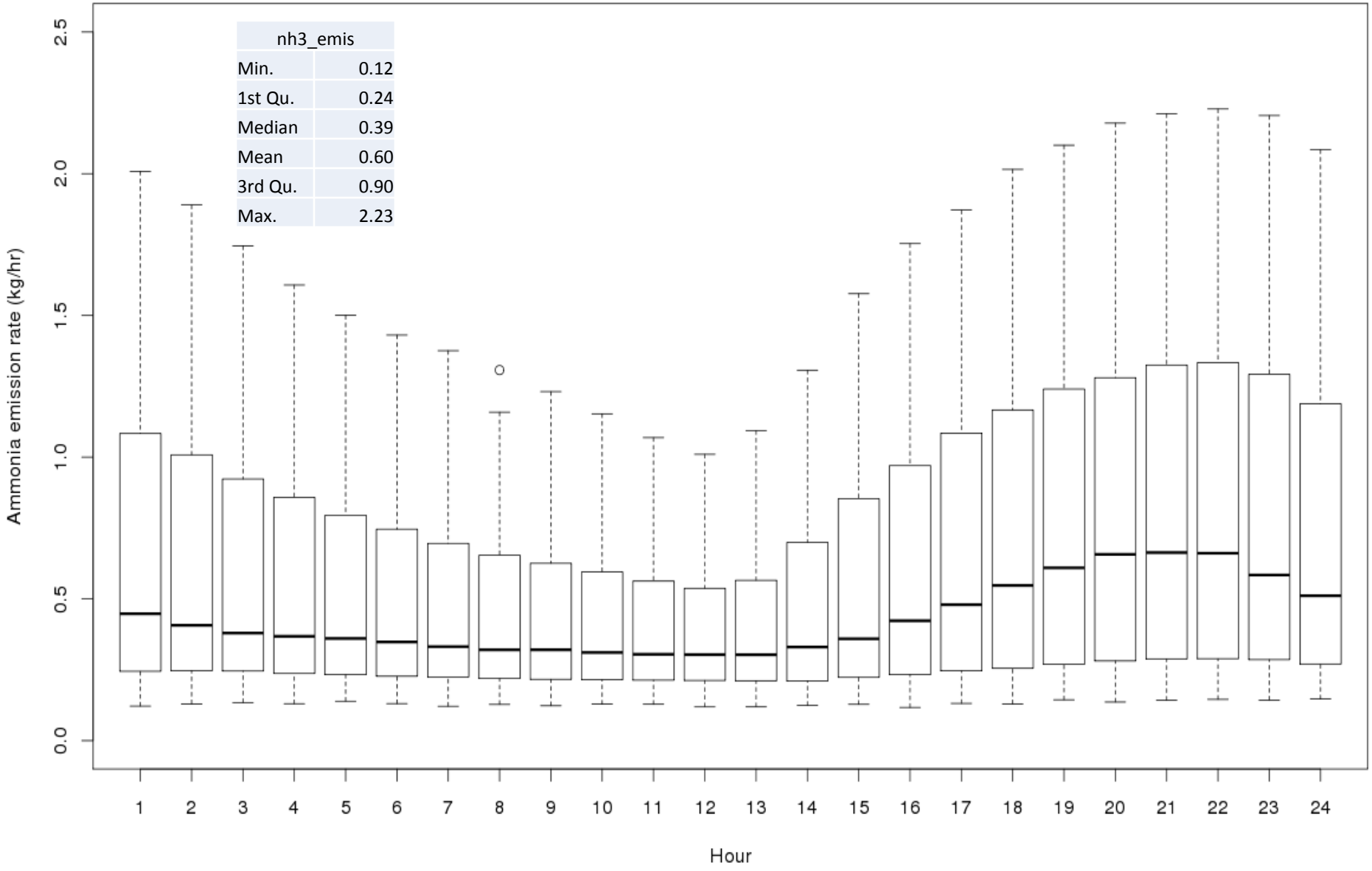
Facility id

- Country code
- State FIPS
- County FIPS
- Animal type
- Manure Management Train
- Farm id

Housing



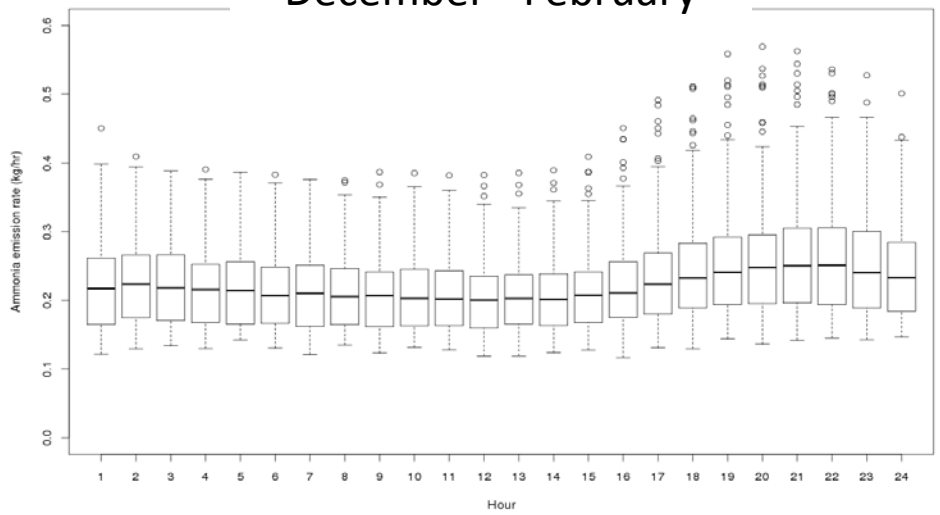
Kentucky beef housing hourly emissions
January to December 2005



Kentucky beef housing emissions, hourly profile by season

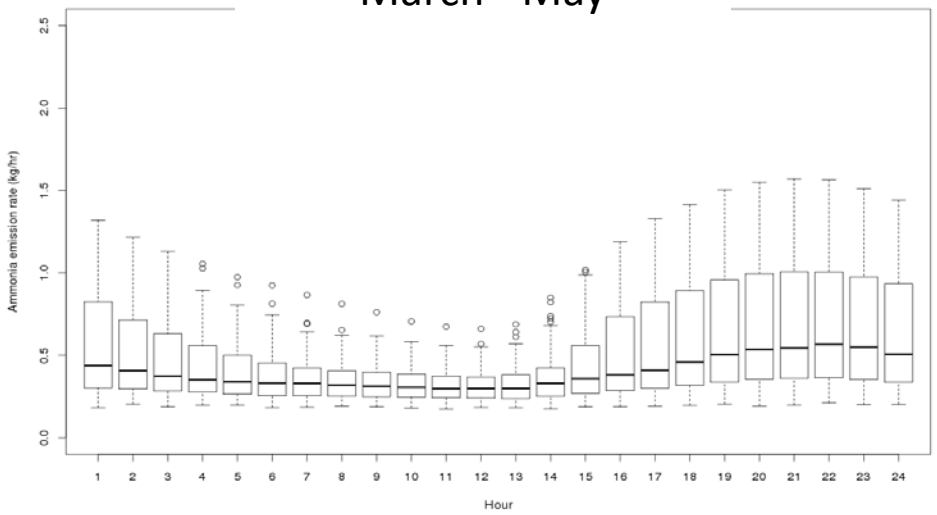
0.6 kg/hr

December - February



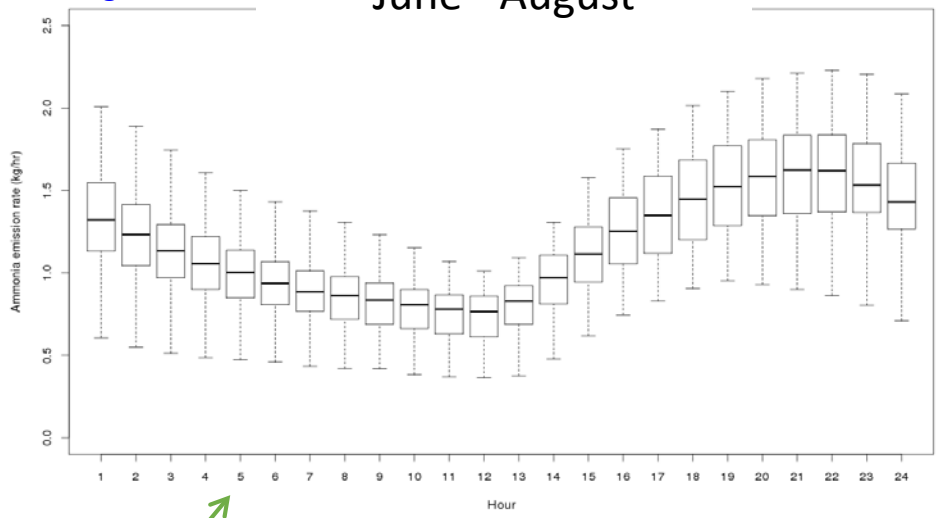
2.5 kg/hr

March - May



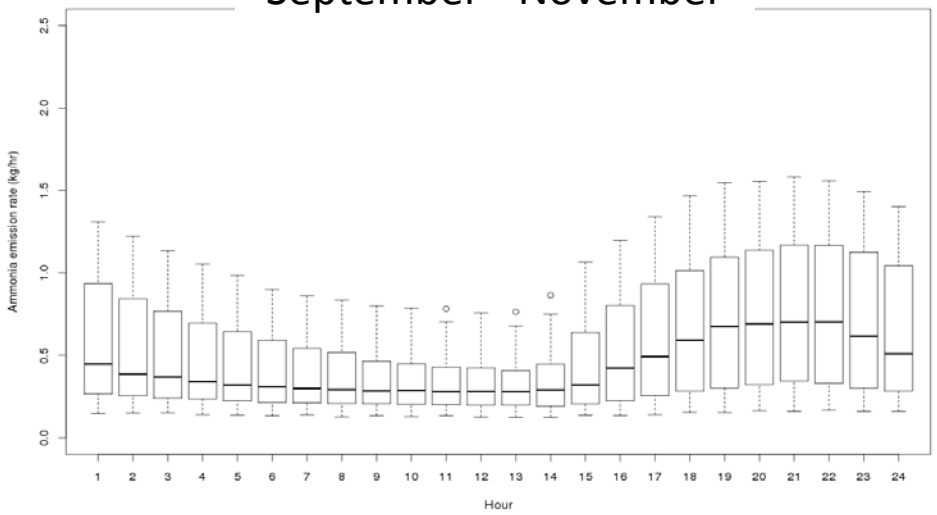
2.5 kg/hr

June - August



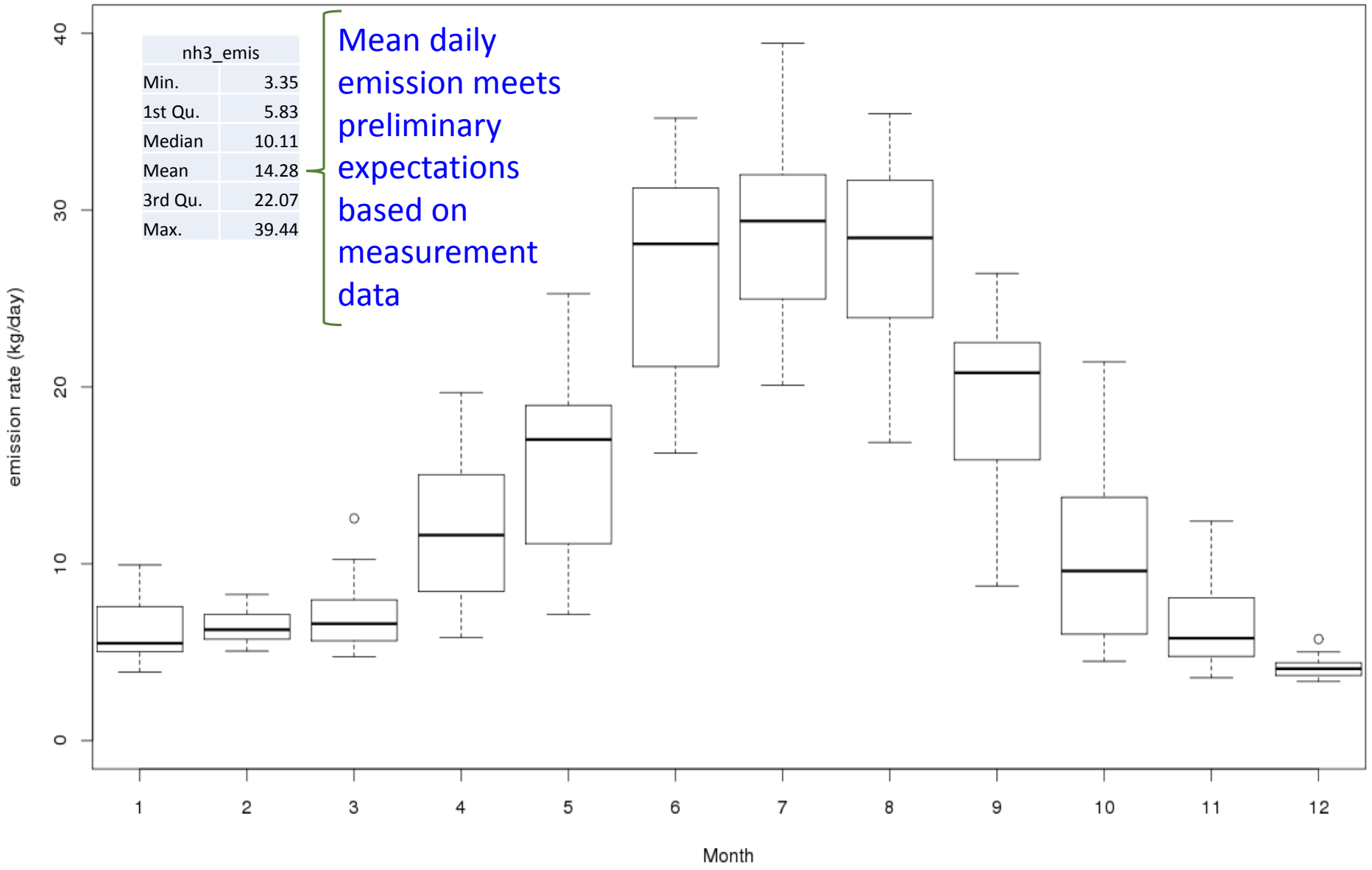
2.5 kg/hr

September - November

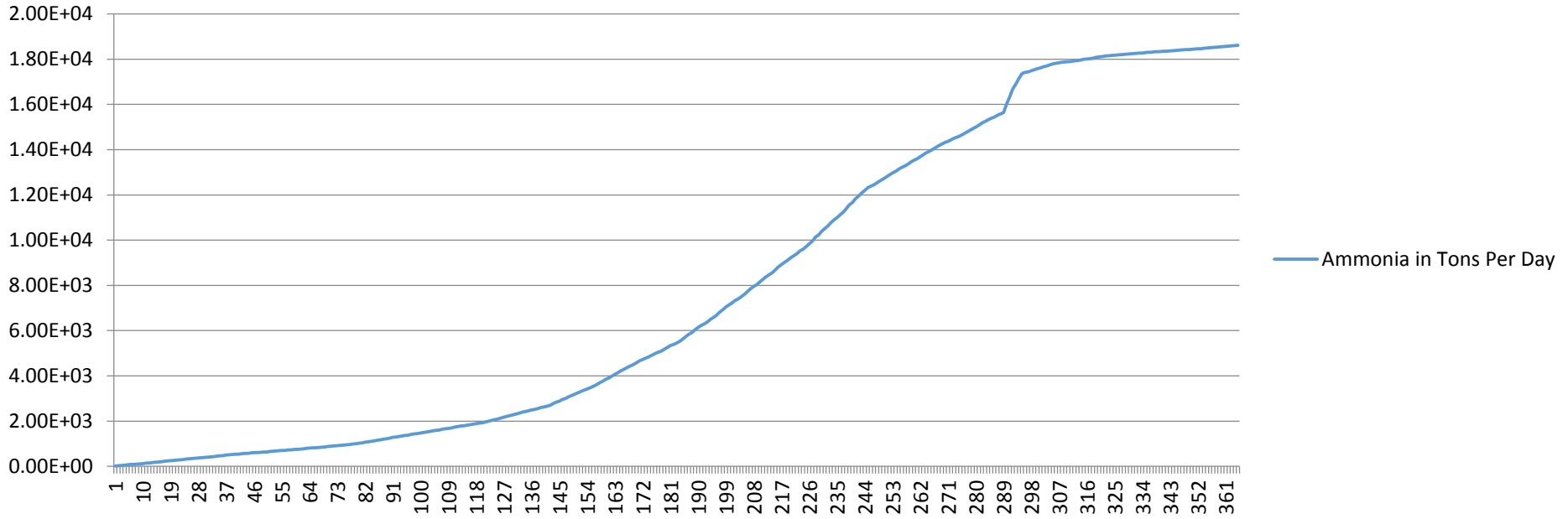


Shape of curve matches preliminary expectations based on measurement data

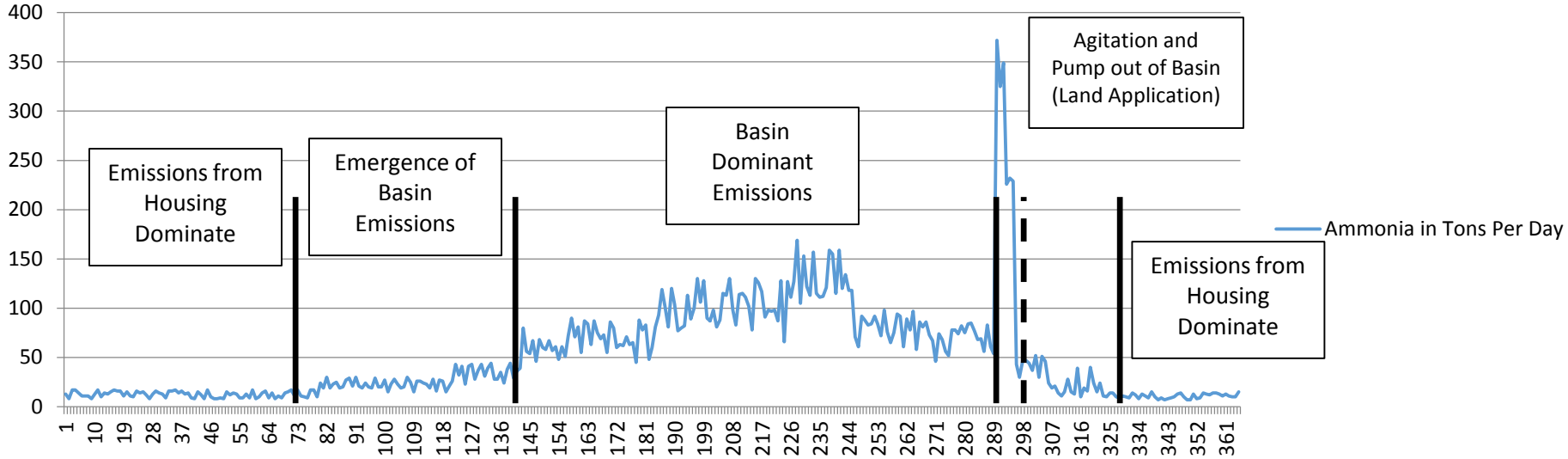
Kentucky beef housing daily emissions, monthly profile, year 2005



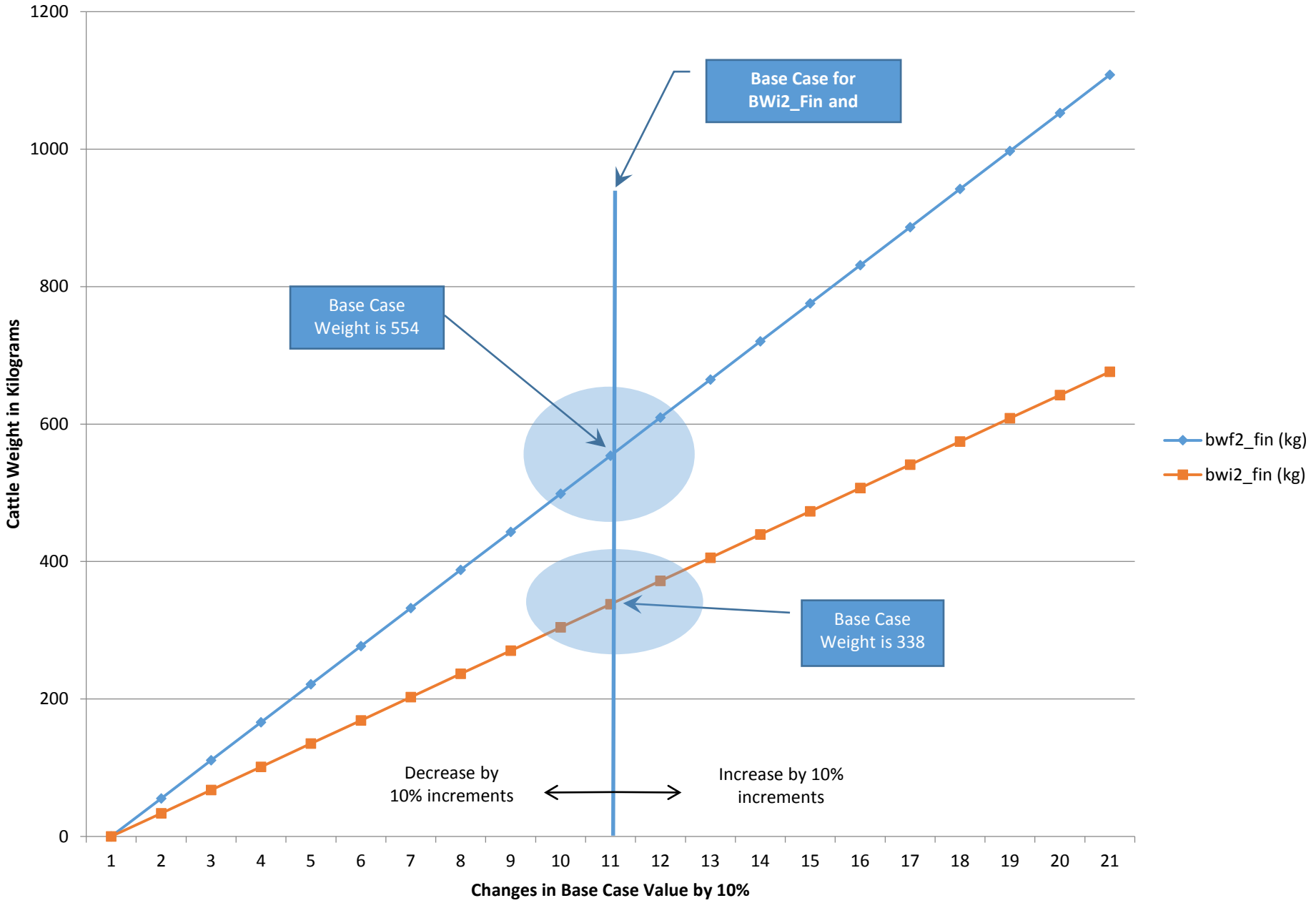
Cumulative Ammonia Emissions in Tons Per Day from a Minnesota Dairy



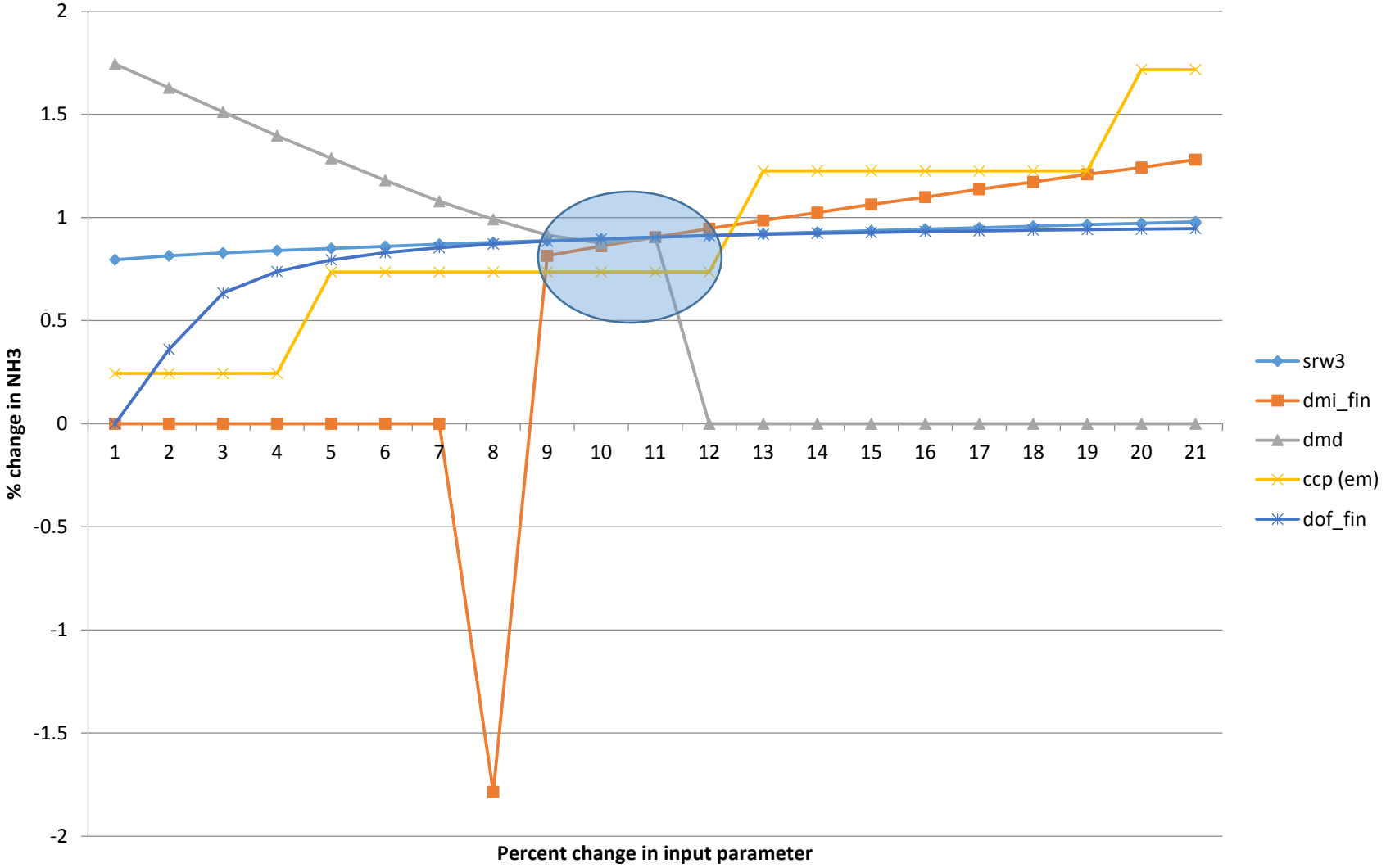
Daily Ammonia Emissions in Tons Per Day from a Minnesota Dairy



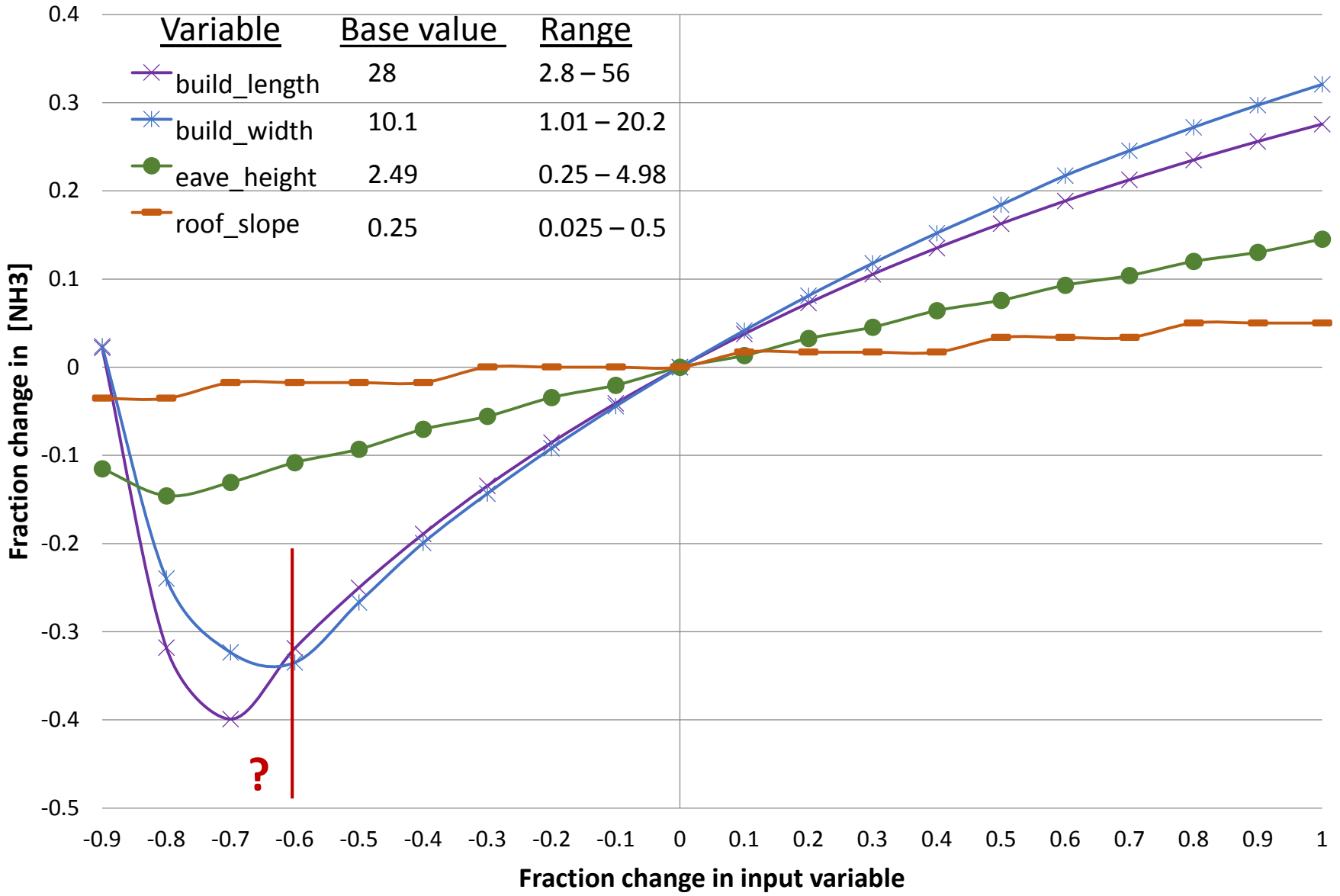
Distribution of Input Parameter Sensitivity Values for Finisher Cattle



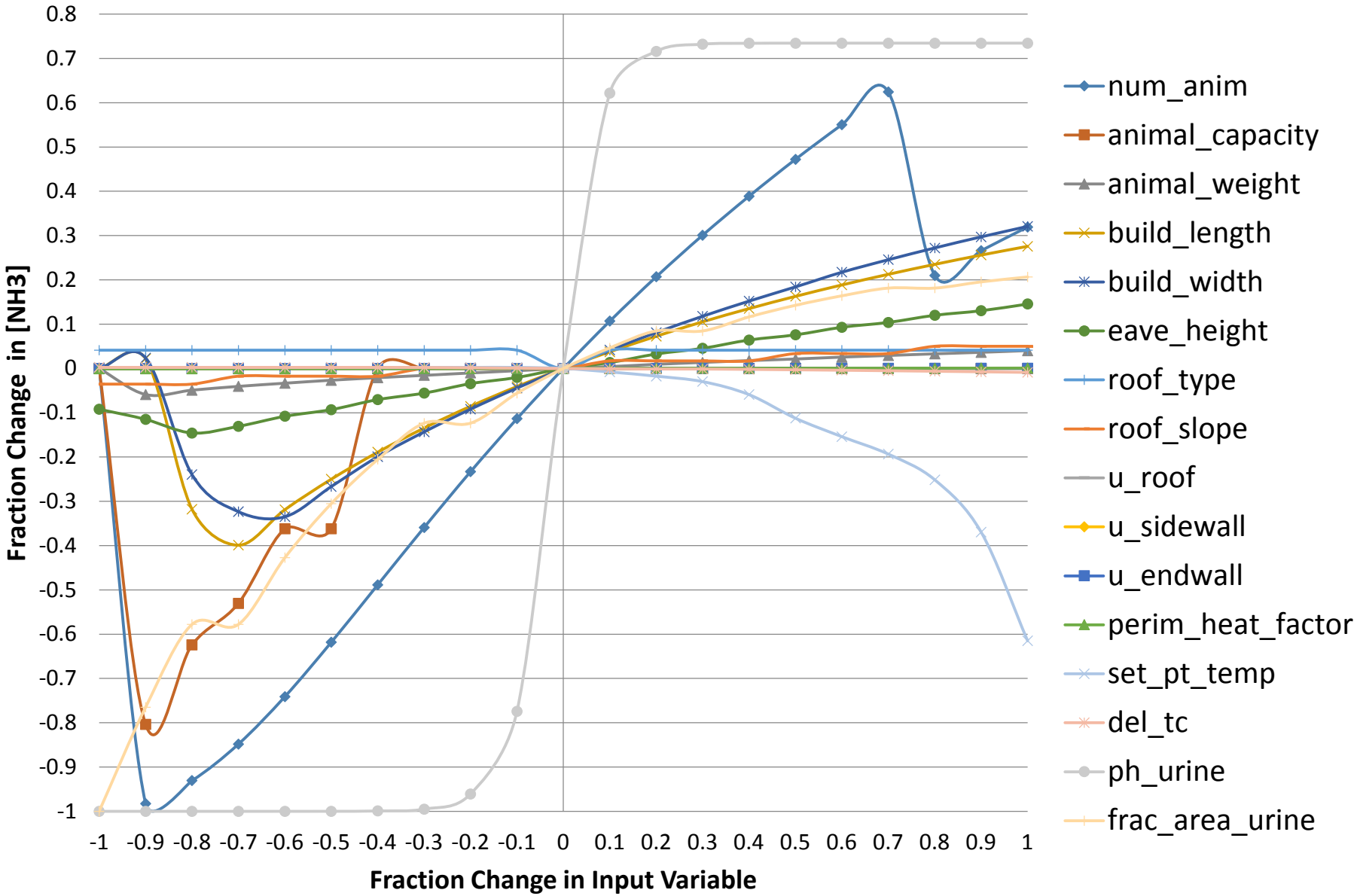
PreExcretion Submodel Emission Output Response to Changes in Standard Reference Weight (SRW3), Dry Matter Intake (DMI_fin, Dry Matter Digestibility (dmd), Crude Protein (ccp), Days on Feed (dof_fin).



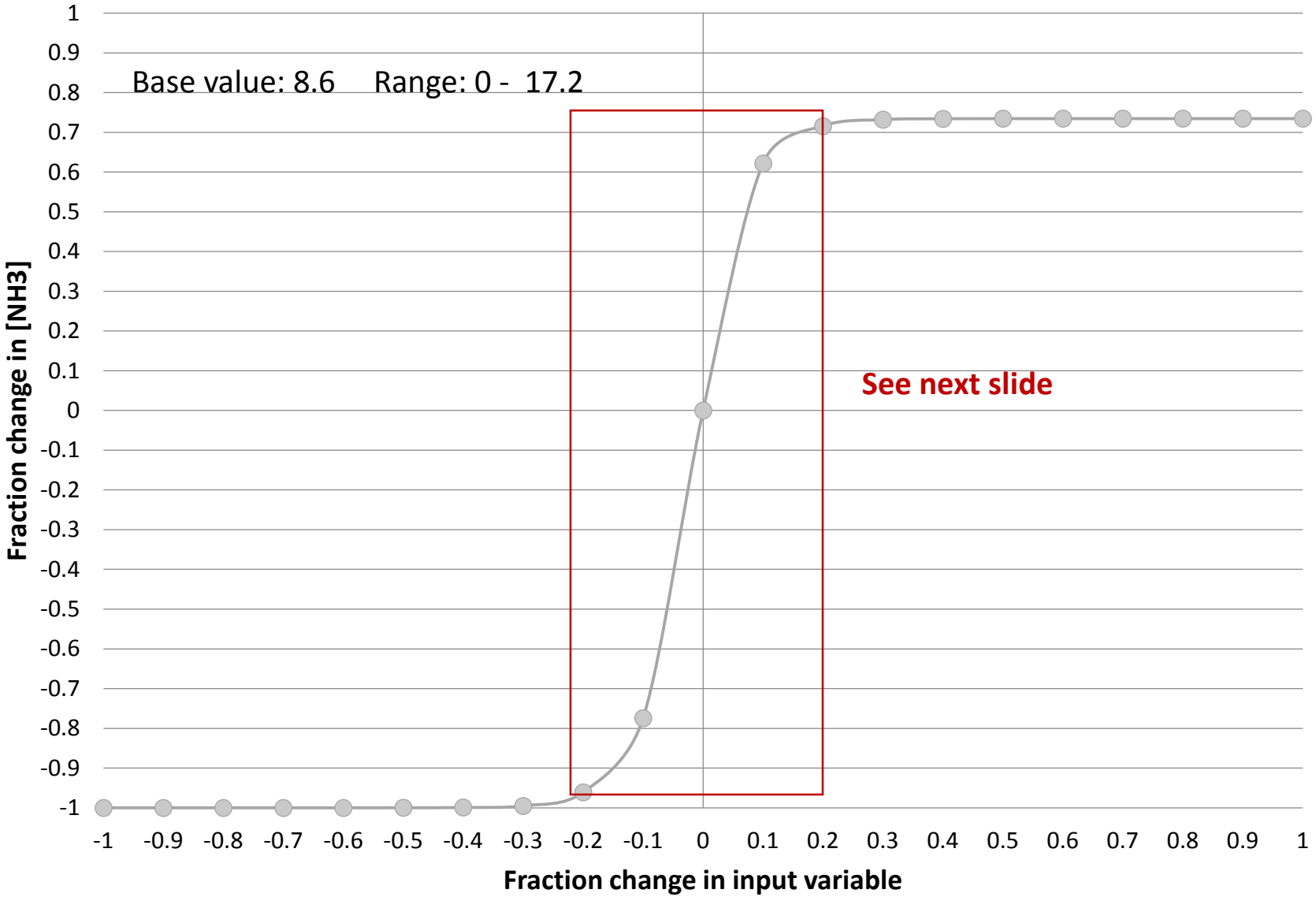
Building characteristics (gable roof)



Beef housing variables
with model response in ammonia emissions

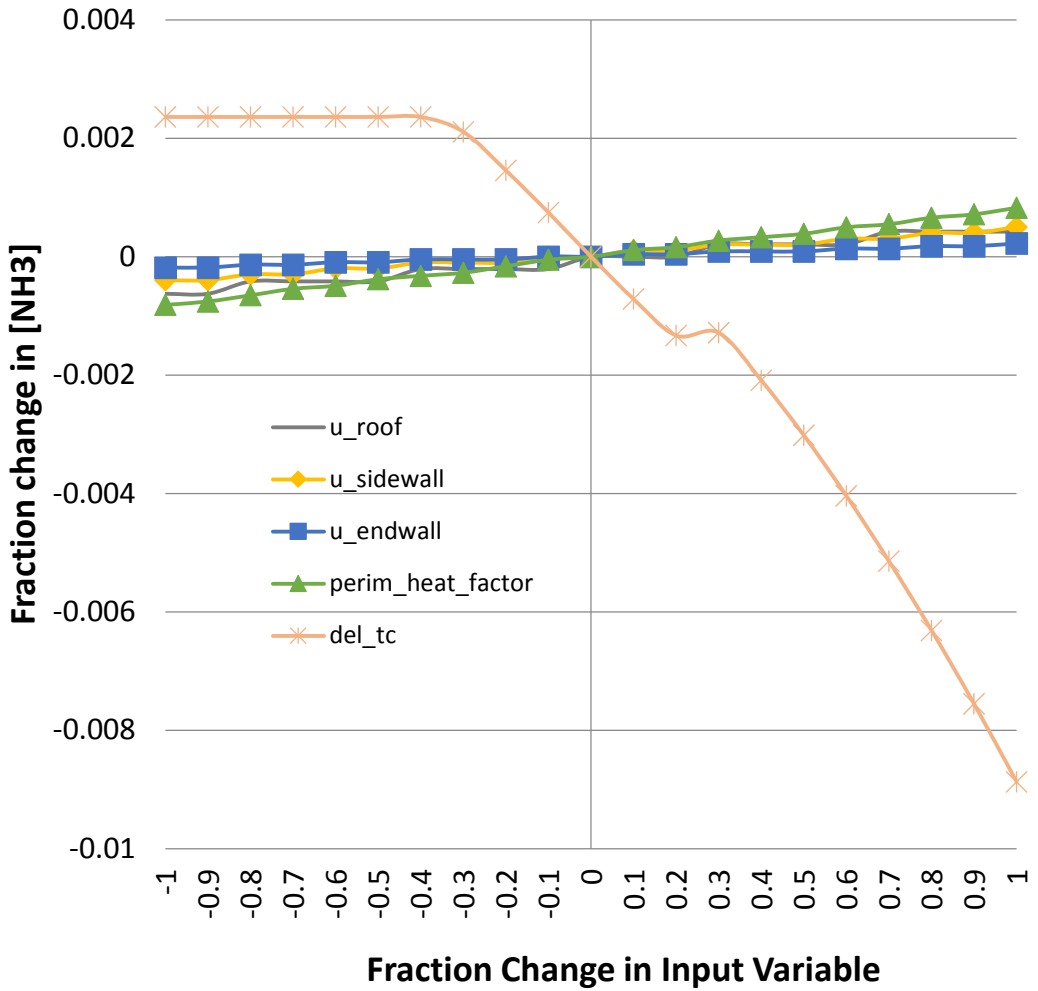


pH of urine

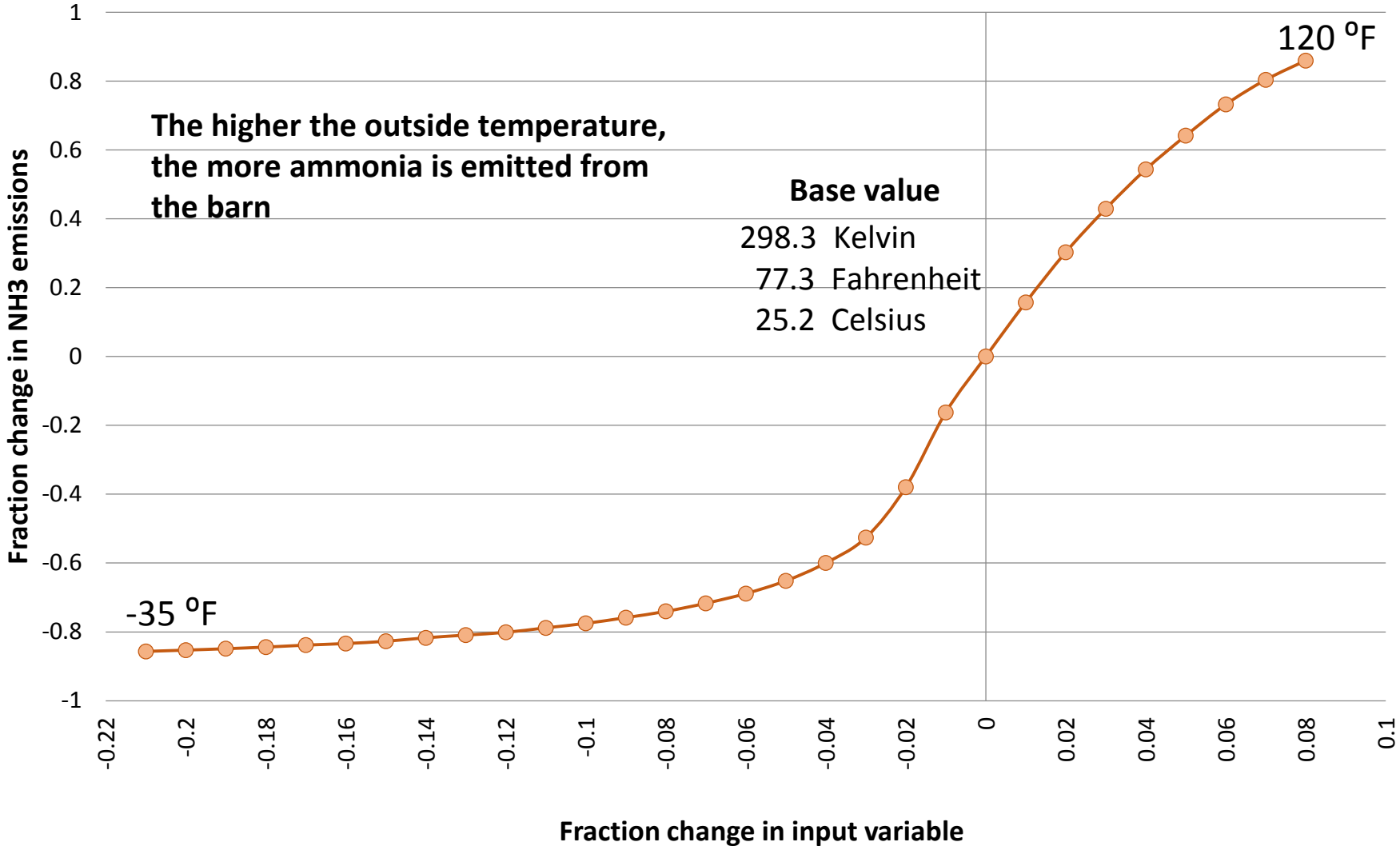

Base value: 8.6 Range: 0 - 17.2
See next slide
Fraction change in [NH3]
Fraction change in input variable
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
-1 -0.9 -0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

Housing variables changed with very small affect on ammonia emissions

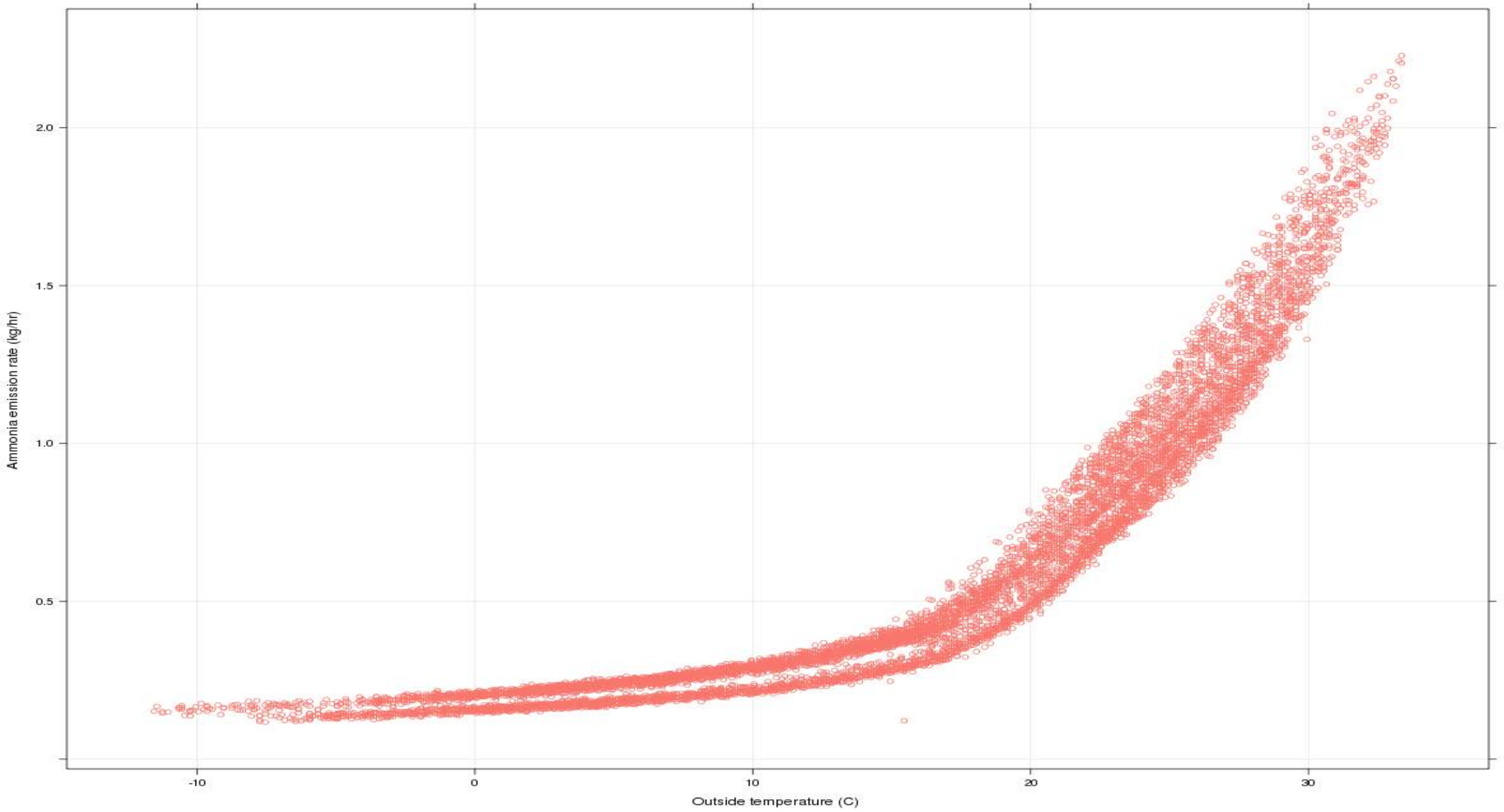
- Roof_type
  1 = gable, 2 = monoslope should get an error if another value
- U_roof, U_sidewall, U_endwall
  - Heat transfer coefficient of each surface refer to Panagakis and Axaopoulos (2004) very small values
- Perim_heat_factor
  - Perimeter heat loss factor (base value: 1.5 range: 0 - 3)
- Del_tc
  - Band width of ventilation control unit for mechanical ventilation only
    (base value: 4 range 0 – 8)

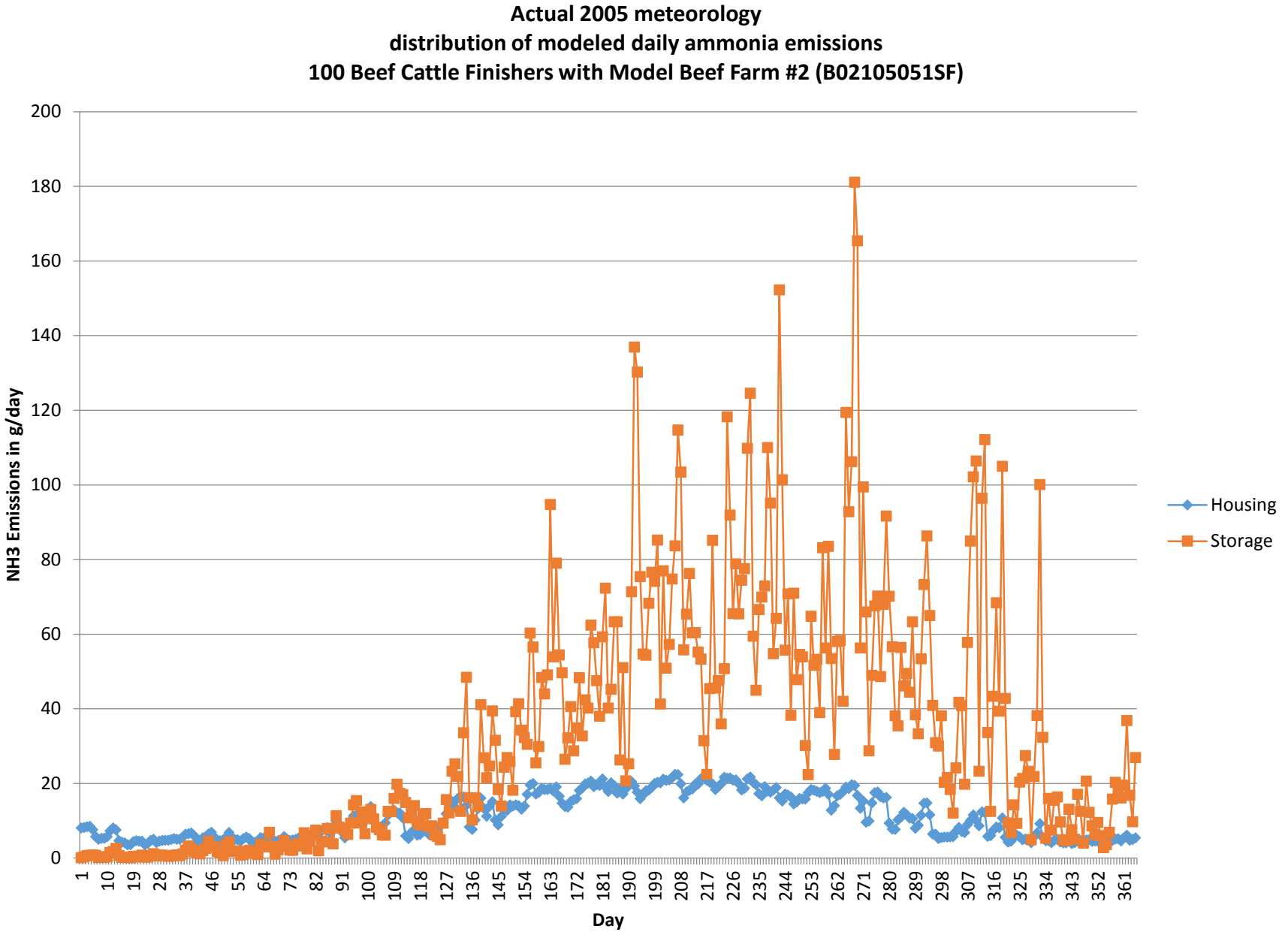


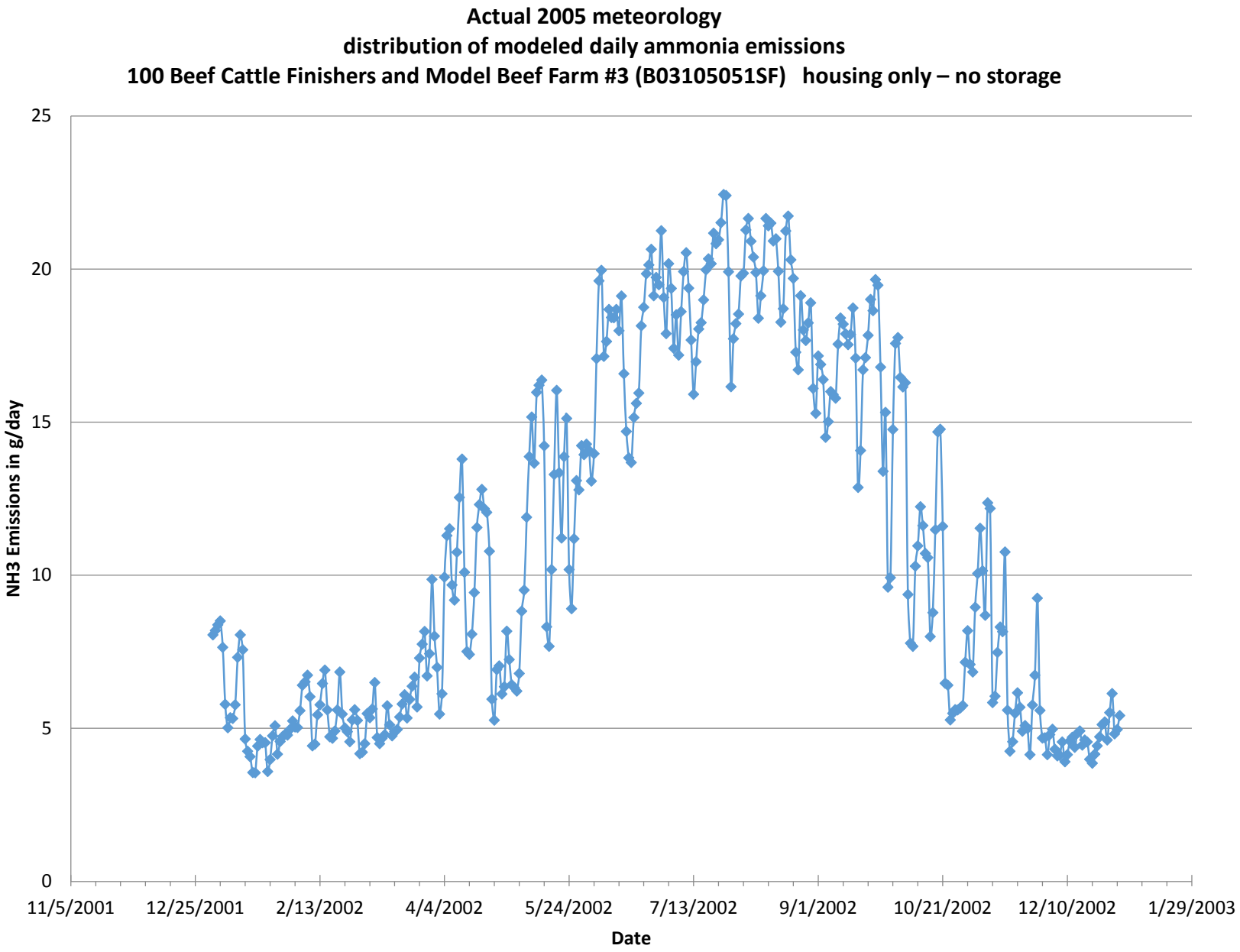
Meteorology: temperature (met temperature)



Kentucky farm correlation of outside temperature and ammonia emission rate




Actual 2005 meteorology
distribution of modeled daily ammonia emissions
100 Beef Cattle Finishers with Model Beef Farm #2 (B02105051SF)
NH3 Emissions in g/day
200
180
160
140
120
100
80
60
40
20
0
1
10
19
28
37
46
55
64
73
82
91
100
109
118
127
136
145
154
163
172
181
190
199
208
217
226
235
244
253
262
271
280
289
298
307
316
325
334
343
352
361
Day
Housing
Storage


Actual 2005 meteorology
distribution of modeled daily ammonia emissions
100 Beef Cattle Finishers and Model Beef Farm #3 (B03105051SF) housing only – no storage
NH3 Emissions in g/day
25
20
15
10
5
0
11/5/2001
12/25/2001
2/13/2002
4/4/2002
5/24/2002
7/13/2002
9/1/2002
10/21/2002
12/10/2002
1/29/2003
Date

Computation Time

Impact of Ordinary Differential Equation Solver

Run excretion and housing for one farm	minutes	seconds
Baseline: not running meteorology or ODE solver	0	0.043
Run with meteorology, but not ODE solver	1	19.171
Run with meteorology and the ODE solver	**1**	**25.540**
Run with meteorology and the ODE solver WITH enhancement	0	**8.374**

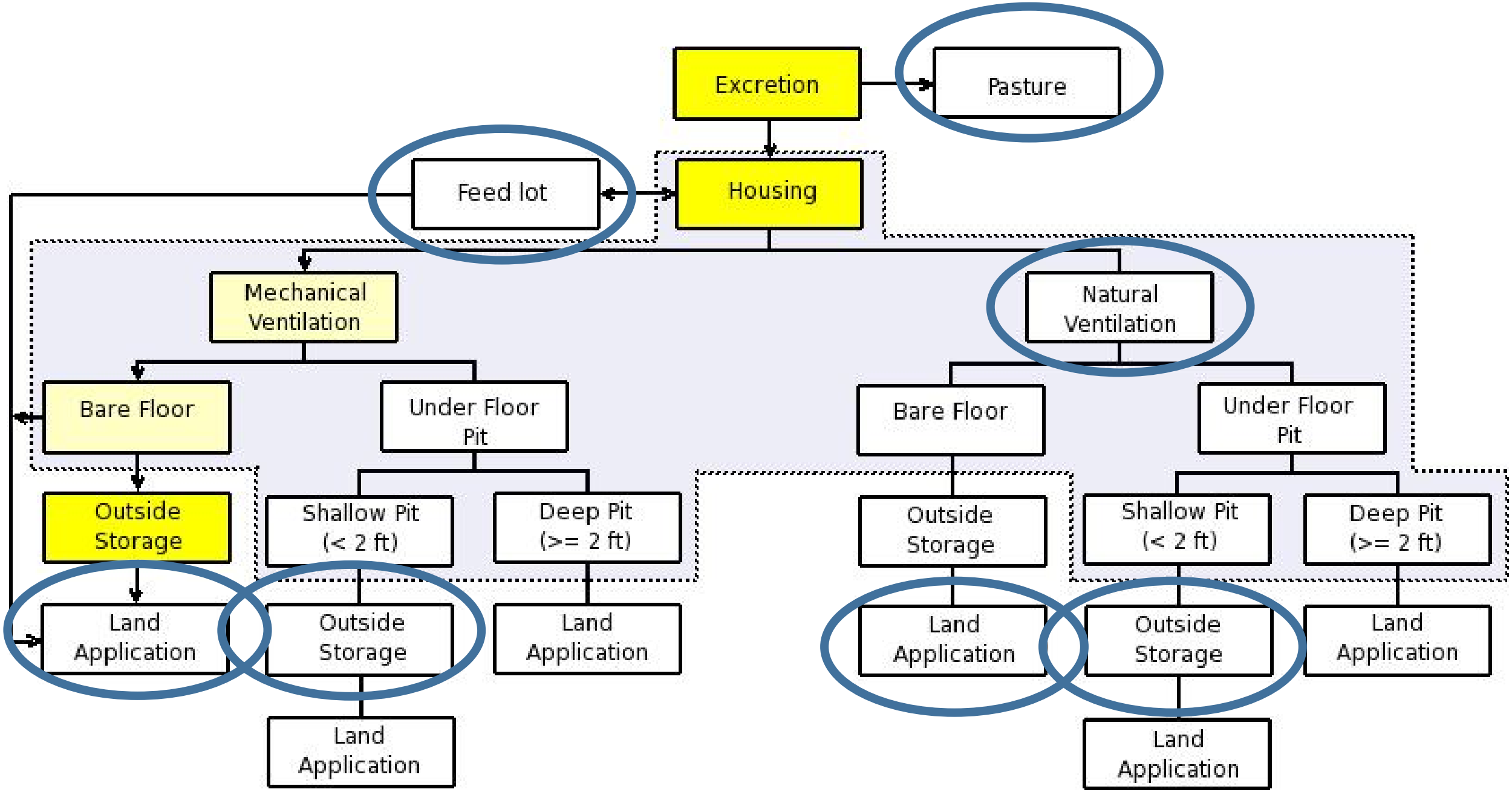
6.4 seconds

10x FASTER!!!!

1 million+ Farms in US with Animals
2000+ Hours to process annual emissions on single machine.

Model package – MPCA deliverables to LADCO

- ❖Model code—refactored, most recent version– C++
- ❖Default input data files (or examples)
- ❖Run scripts
- ❖Documentation (web browser application)
  - Code
  - Code function – what the model does
  - Requirements – what the science document says model should do
  - Enhancements list
  - Flow diagrams
    - Manure management practices
    - Data
  - References (Science document, published articles, other)
  - Sensitivity analysis
  - Validation of housing model for dairy and swine
    - upper MidWest NAEMS data
  - User's manual


Excretion
Pasture
Feed lot
Housing
Mechanical Ventilation
Natural Ventilation
Bare Floor
Under Floor Pit
Bare Floor
Under Floor Pit
Outside Storage
Shallow Pit (< 2 ft)
Deep Pit (>= 2 ft)
Outside Storage
Shallow Pit (< 2 ft)
Deep Pit (>= 2 ft)
Land Application
Outside Storage
Land Application
Land Application
Outside Storage
Land Application
Land Application

Objective #2. Make necessary FEM model code changes

Without a dedicated C++ developer, and sufficient funds for LADCO to hire a contractor, the means for success on this objective is more uncertain. Categorize and take initial stab at the following code changes to resolve outstanding issues from testing. Code changes beyond the abilities of the project team will be stored on a list for future efforts. **Depending on the type of necessary change, the project may be unable to proceed beyond this point.**

- **Bug fixes.** Eliminate errors to ensure all key input variables are operable, and soft-code to provide customization of user input values. The need for this type of change is most likely to occur during the implementation of objective #1.
- **Enhancements.** Add features to the model to make it better, i.e. new manure management trains and new land-spreading methods. The need for this type of change most likely will need outside support.
- **Maintenance.** Preserve the value of the FEM model after it is in operation. This is outside the scope of this project.
- **Re-factoring.** Improve the engineering without changing the functionality of the code, i.e. reduce the complexity of the code or improve readability. May be accomplished during bug fixes or enhancements, otherwise this is outside the scope of this project.

LADCO hiring intern in FY2016 to implement MPCA recommendations.