Development of the Process Based NH_3 Model

ISSRC

University of California at Riverside

University of California at Davis

Environ

Iowa State University

Inter RPO Technical Workshop

Executive Summary

- **Project funded by the Lake Michigan Air Directors Consortium (LADCo) and Inter-RPO Funds.**
- **Goal – a processed based NH3 model and 2002 national ammonia emissions inventory**
- **Duration – 12/01/03 ~ 03/31/05**
- **Total Budget – $ 249,910.00**
- **Deliverable:**
  - Science document
  - Data document
  - Coding (design) document
  - Hands-on Training (March 17-18, 2005, Chicago, IL)
  - Final project report
  - 2002 National ammonia emissions inventory

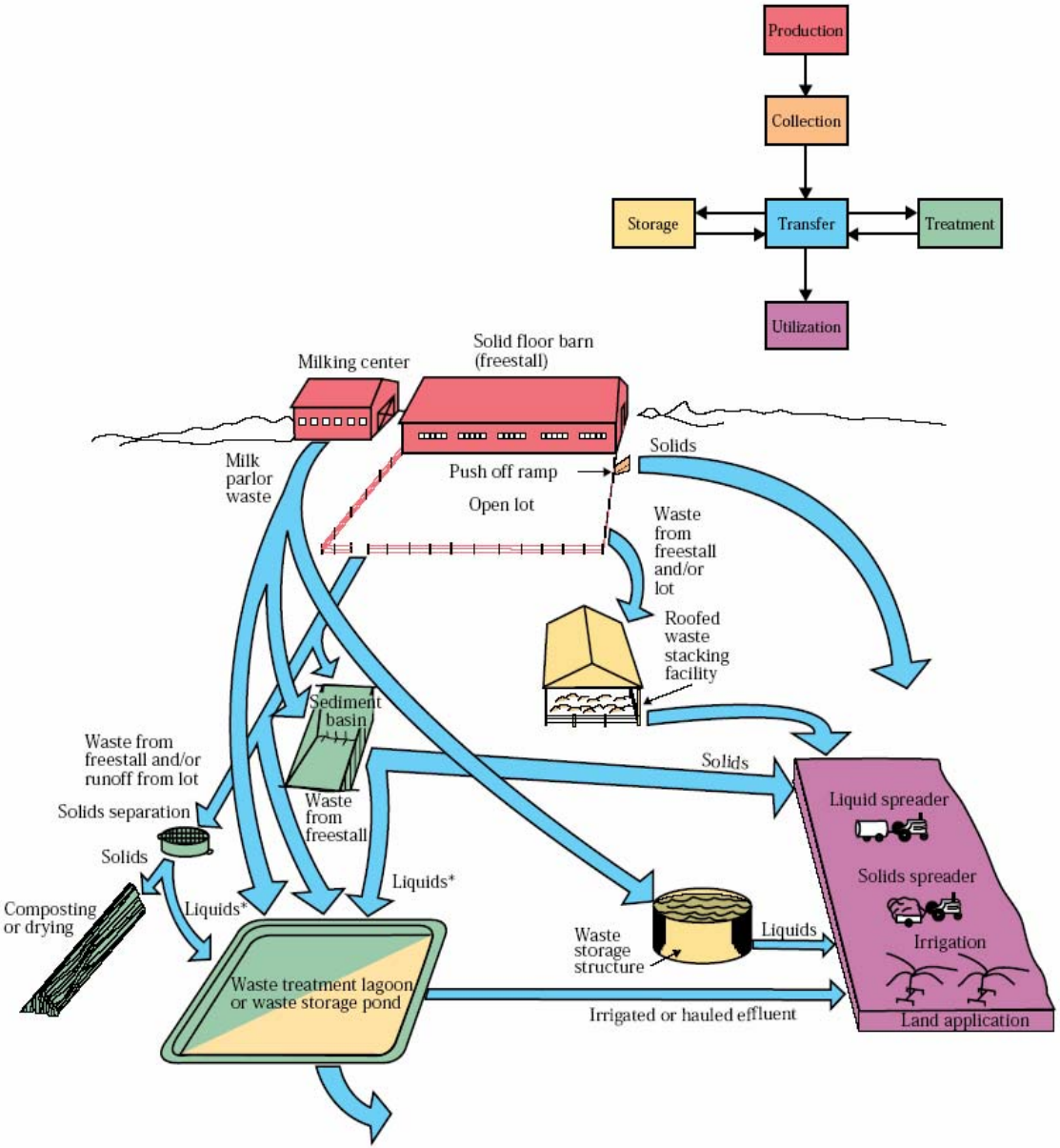
NH3 Model Development Team

- **ISSRC**
- **University of California, Davis**
  - Prof. Ruihong Zhang
  - Prof. James Fadel
  - Prof. Tom Rumsey
- **Virginia Tech University**
  - Prof. Jactone Arogo (formerly at North Carolina State University)
- **Iowa State University**
  - Prof. Hongwei Xin
  - Dr. Yi Liang
- **ENVIRON International Corporation**
  - Dr. Gerard Mansell
  - Stella Shepard
  - Mike Masonjones
- **University of California, Riverside**
  - Zion Wang
  - Yinqun Wang
  - Gail Tonnesen

Additional Scientific Contributors

- Ed DePeters (UC Davis)
- Ralph Ernst (UC Davis)
- Kirk Klasing (UC Davis)
- Jim Oltjen (UC Davis)
- Kent Parker (UC Davis)
- Peter Robinson (UC Davis)
- Anders Strathe (Denmark)
- Jeff Lorimor (Iowa State Univ.)
- Leo Timms (Iowa State Univ.)
- Dan Meyer (Iowa State Univ.)
- Charlie D. Fulhage (Univ. of Missouri)
- Richard Koelsch (U. of Nebraska)
- Don D. Jones (Purdue Univ.)
- Ted Funk (U. of Illinois)
- Larry Jacobson (U. of Minnesota)
- David Schmidt (U. of Minnesota)
- James P. Murphy (Kansas State Univ.)
- Joseph Harner (Kansas State Univ.)
- Harold Keener (Ohio State Univ.)
- Dick Nicolai (South Dakota State Univ.)
- Brian Holmes (Univ. of Wisconsin)

Animal Housing and Management Practices



* Liquids from lot runoff discharged to waste storage pond only

Processes Involved in Ammonia Emissions

- **Ammonia generation**
  - Urea hydrolysis via enzymes
  - Organic nitrogen mineralization via bacteria
  - Aqueous chemical reactions
- **Ammonia transfer from water phase to air phase**
  - Diffusion
  - Convection mass transfer

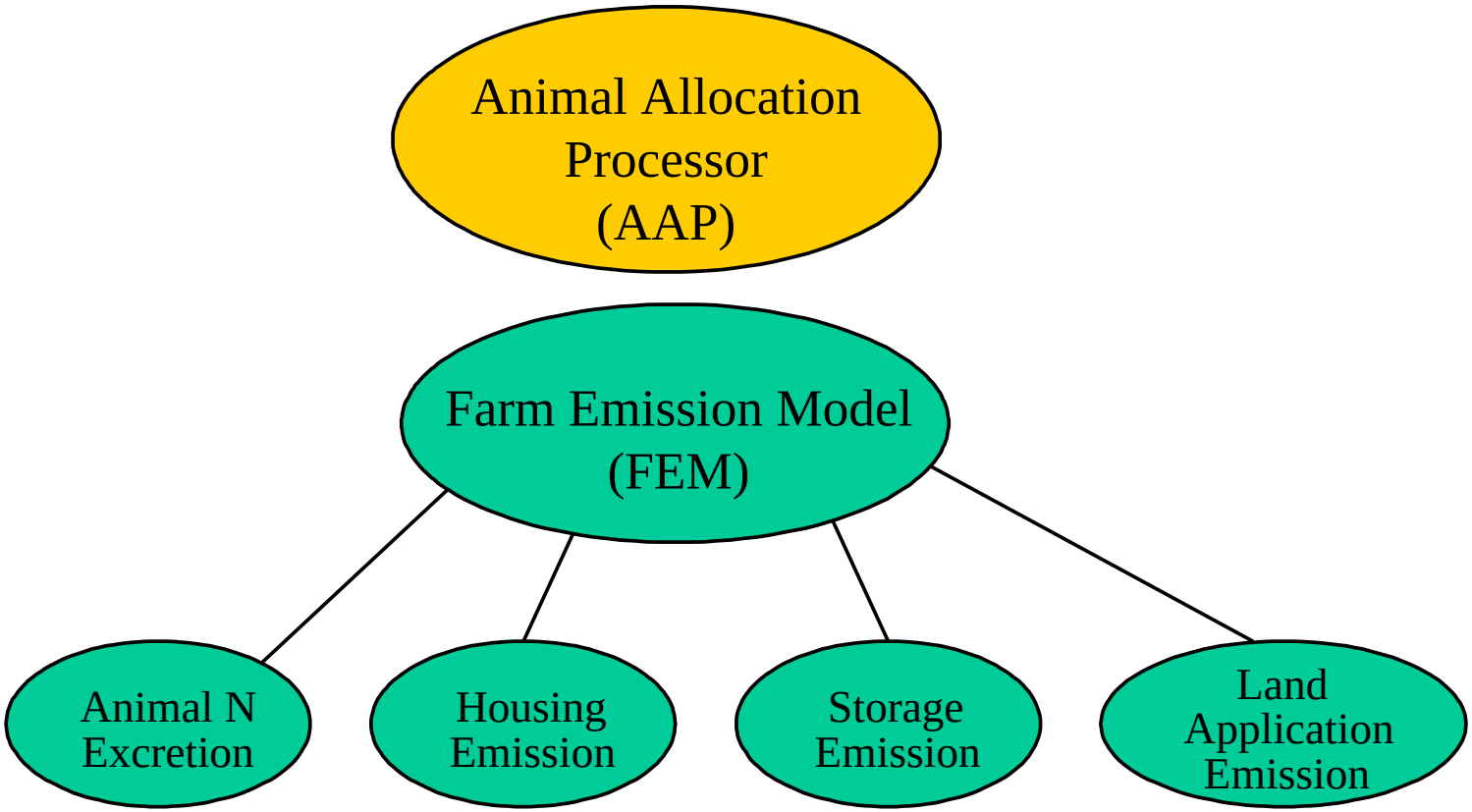
Processed Based NH3 Model w/ Fertilizer

- **NH3 Animal Allocation Processor**
- **NH3 Farm Emissions Model:**
  - Animal excretion model
  - Housing emissions model
  - Feedlot emissions model
  - Storage emissions model, and
  - Land emissions model
- **Animal types considered:**
  - Dairy cows
  - Beef cattle
  - Swine
  - Poultry (layers, broilers, and turkeys)
- **Commercial Fertilizer**

Process-based NH3 Model Overview

- **Original Design**
  - Discussed in the Coding (Design) document dated 11/14/04
  - Farm Emissions Model
  - Statistical Model
- **Revised Design**
  - Change in direction on 12/29/04
  - Detail of the changes are described in the two memorandums attached to the email (*"Status of the ammonia emissions model"*) sent out on 01/05/2004 to the NH3 listserv.
  - Animal Allocation Preprocessor
  - Farm Emissions Model

Process-based NH3 Model Flow Diagram



AAP/FEM Coding Specs

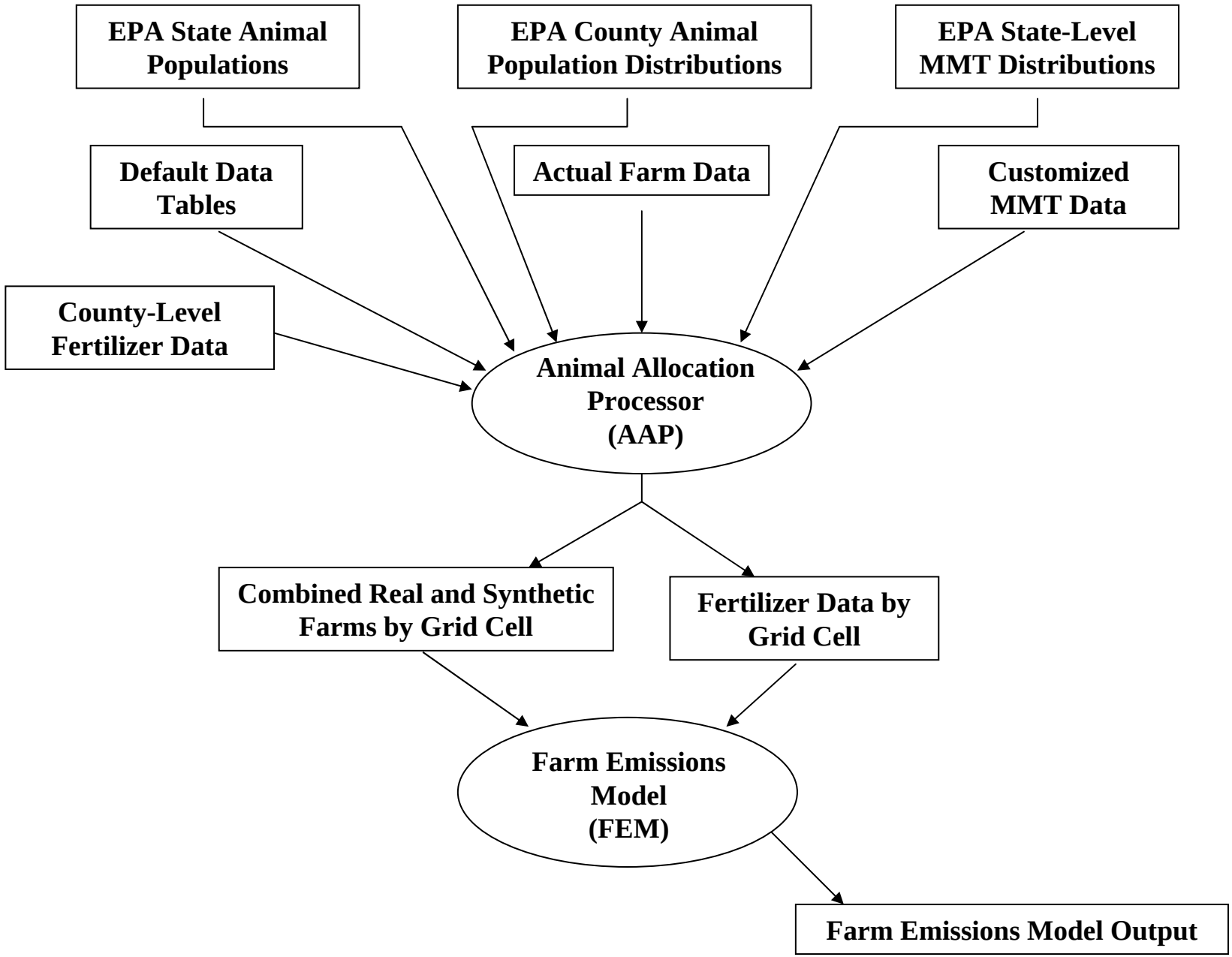
- **Code written as part of the CONCEPT Framework**
- **Conform to CONCEPT coding specs.**
- **Could also be run as a stand-alone model**
- **Languages used include:**
  - PostgreSQL (& plpgsql)
  - Perl

Animal Allocation Processor

- Distribute county-level animal head counts to defined Manure Management Trains (MMTs)
- Spatially allocate MMTs to grid cells using gridded surrogates (agricultural land)
- Format input data for Farm Emission Model (FEM)
- Actual Farm Data
- Fertilizers

Fertilizer Emissions

- Default (Placeholder) Approach
- Fertilizer Amounts by County
- Spatial Allocation Using Gridded Surrogates
- Processed through FEM in anticipation of improved estimation methodologies dependent on meteorology and environmental parameters


EPA State Animal Populations
EPA County Animal Population Distributions
EPA State-Level MMT Distributions
Default Data Tables
Actual Farm Data
Customized MMT Data
County-Level Fertilizer Data
Animal Allocation Processor (AAP)
Combined Real and Synthetic Farms by Grid Cell
Fertilizer Data by Grid Cell
Farm Emissions Model (FEM)
Farm Emissions Model Output

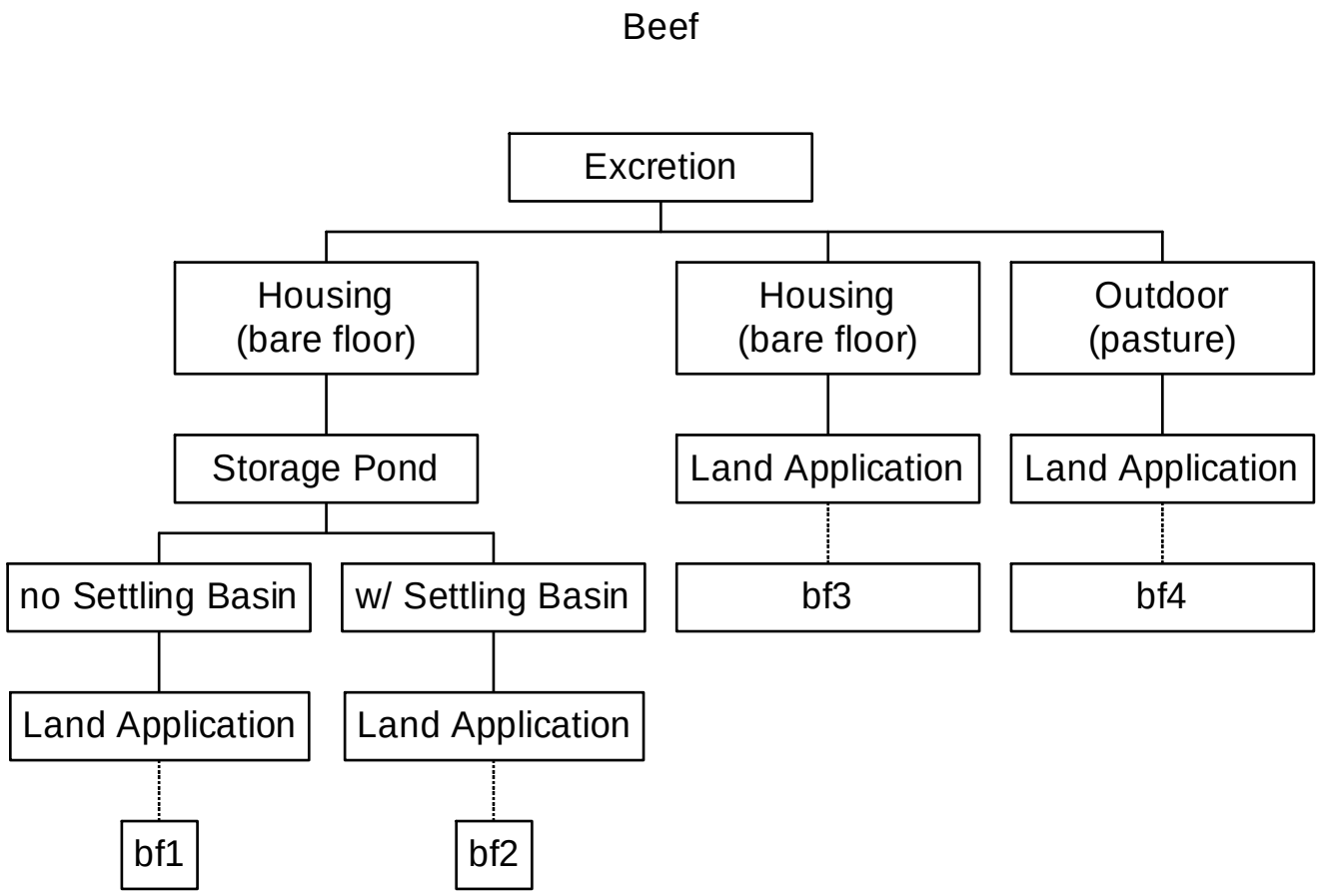
Mapping of Animal Subcategories

- **Dairy**
  - exact match (lactating, dry, heifer)
- **Beef**
  - EPA: not on feed heifers and steers, on feed heifers and steers, bulls, calves, beef cow
  - FEM: finishing, cow-calf pair, maintenance
- **Poultry & Layers**
  - EPA: broilers, turkeys, hens, pullets, chickens
  - FEM: broilers, male turkeys, female turkeys, layers
- **Swine**
  - EPA: swine 60, swine 60-119, swine 120-179, swine 180
  - FEM: finishing, weaning, gestating, lactating

EPA MMT

AnimalType	MMTID	SCC	SCC Description	MMT Description	Animal	RptFig#
Swine	1	2805039	Swine production - operations with lagoons (unspecified animal age)	Swine House with Lagoon Systems and no Solids Separation	Swine	1
Swine	4	2805039	Swine production - operations with lagoons (unspecified animal age)	Swine House with Lagoon Systems and Solids Separation	Swine	1
Swine	2	2805047	Swine production - deep-pit house operations (unspecified animal age)	Swine House with Deep Pit System	Swine	2
Swine	3	2805053	Swine production - outdoor operations (unspecified animal age)	Swine Outdoor Confinement	Swine	3
Poultry	1	2805007	Poultry production - layers with dry manure management systems	Poultry- dry layers	Layers	12
Poultry	2	2805008	Poultry production - layers with wet manure management systems	Poultry- wet layers	Layers	13
Poultry	1	2805009	Poultry production - broilers	Broiler house	Broilers	14
Poultry	2	2805009	Poultry production - broilers	Broiler outdoor confinement area	Broilers	16
Poultry	1	2805010	Poultry production - turkeys	Turkey house	Turkeys	15
Poultry	2	2805010	Poultry production - turkeys	Turkey Outdoor Confinement Area	Turkeys	16
Beef	1	2805001	Beef cattle - finishing operations on feedlots (drylots)	Beef Feedlot with Storage Pond, no Settling Basin	Beef	17
Beef	2	2805001	Beef cattle - finishing operations on feedlots (drylots)	Beef Feedlot with Storage Pond and Settling Basin	Beef	17
Beef	3	2805001	Beef cattle - finishing operations on feedlots (drylots)	Beef Feedlot with no Storage Pond or SettlingBasin	Beef	17
Beef	4	2805003	Beef cattle - finishing operations on pasture/range	Beef Operations on Pastures	Beef	18
Dairy	1	2805019	Dairy cattle - flush dairy	Flush Dairy with Solids Separation	Milking	4
Dairy	2	2805019	Dairy cattle - flush dairy	Flush Dairy without Solids Separation	Milking	4
Dairy	3	2805021	Dairy cattle - scrape dairy	Scrape Dairy without Soilds Separation	Milking	5
Dairy	4	2805021	Dairy cattle - scrape dairy	Scrape Dairy with Soilds Separation	Milking	5
Dairy	6	2805021	Dairy cattle - scrape dairy	Scrape Dairy- Daily Spread	Milking	7
Dairy	9	2805021	Dairy cattle - scrape dairy	Scrape Dairy- Slurry	Milking	9
Dairy	8	2805021	Dairy cattle - scrape dairy	Scrape Dairy- Solid Storage	Milking	10
Dairy	7	2805022	Dairy cattle - deep pit dairy	Dairy Barn with Deep Pit	Milking	8
Dairy	5	2805023	Dairy cattle - drylot/pasture dairy	Dairy Outdoor Confinement Area	Milking	11
Dairy	10	2805023	Dairy cattle - drylot/pasture dairy	Dairy Heifer and Dry cow drylot	Dry Cows	6

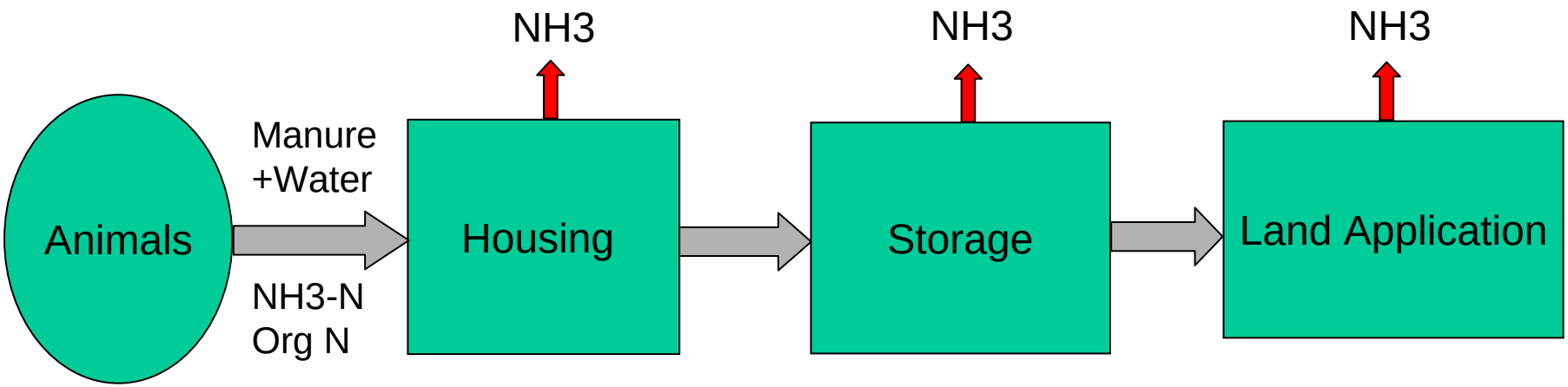
MMT – Beef


Beef
Excretion
Housing (bare floor)
Housing (bare floor)
Outdoor (pasture)
Storage Pond
Land Application
Land Application
no Settling Basin
w/ Settling Basin
bf3
bf4
Land Application
Land Application
bf1
bf2

Scientific Approach

- **Consider and analyze all physical, chemical and biochemical processes and reactions that take place and influence ammonia emission rate,**
- **Employ processed based mechanistic and empirical models (new and existing),**
- **Keep mass balances for the flow of nitrogen through each component of an animal waste management system.**

Farm Emissions Model



Dairy
Beef cattle
Swine
Layers
Broilers
Turkeys

Confinement
(Mechanically ventilated
or Naturally ventilated)
Open Feedlot

Under-floor pit
Outside storage
(liquid, solid)

Surface Application


Mechanically Ventilated Poultry House – Petaluma, CA

Considerations for Housing Model

Simulate variety of physical systems

- Ventilation: mechanical or natural
- In-house or outside manure storage
- Animal population can vary with time

Numerical solutions

- Equation solvers available and fast

Model parameters

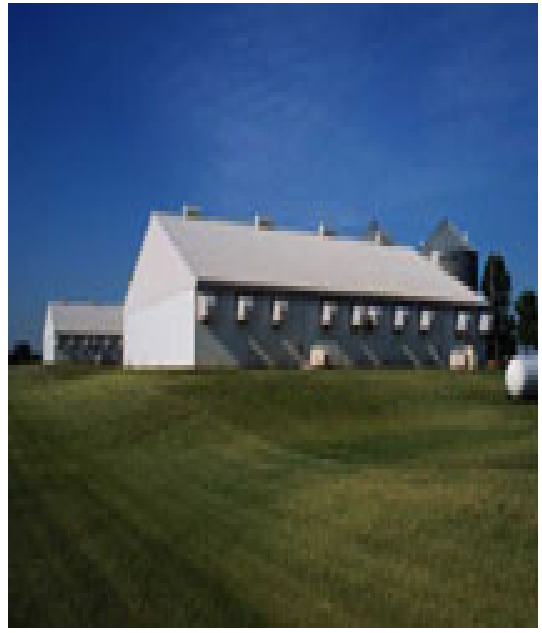
- Available from texts or literature

Mechanical Ventilation

Table 1. Recommended Ventilation Rates*

Housing	Weight	Cold Weather Rate cfm/unit	Hot Weather Rate cfm/unit
Sow and Litter	400	20	500
Nursery Pigs	12-30	2	25
	30-75	3	35
Finishing Pigs	75-150	7	75
	150-250	10	120
Gestating Sows	325	12	150
Boars & Breeding Sows	400	14	300

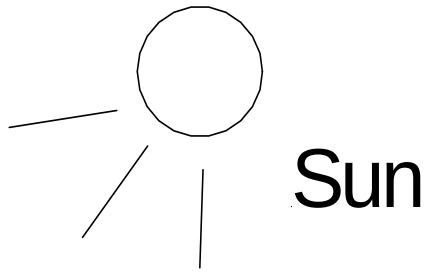
*From MWPS-8 "Swine Housing and Equipment Handbook," MidWest Plan Service, Ames, Iowa.

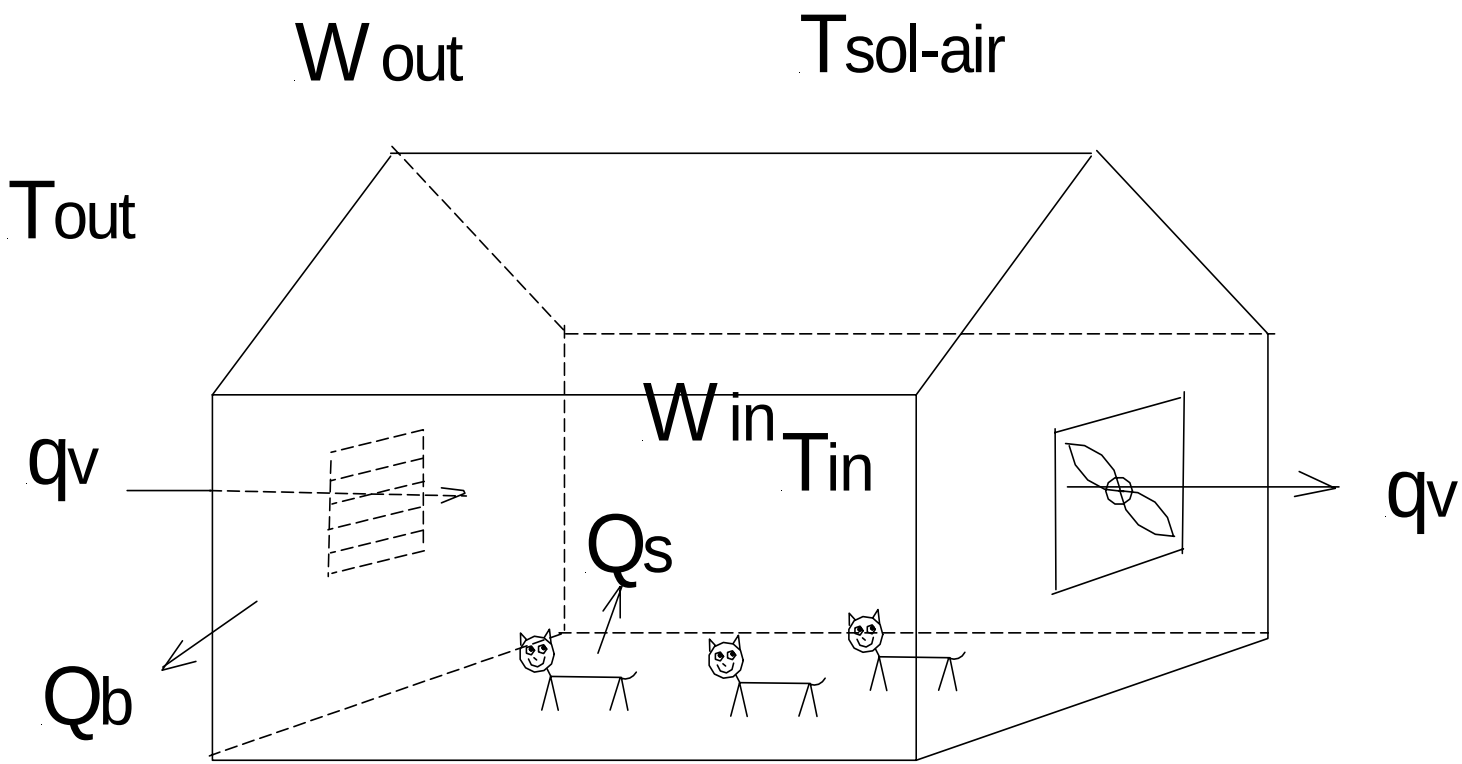


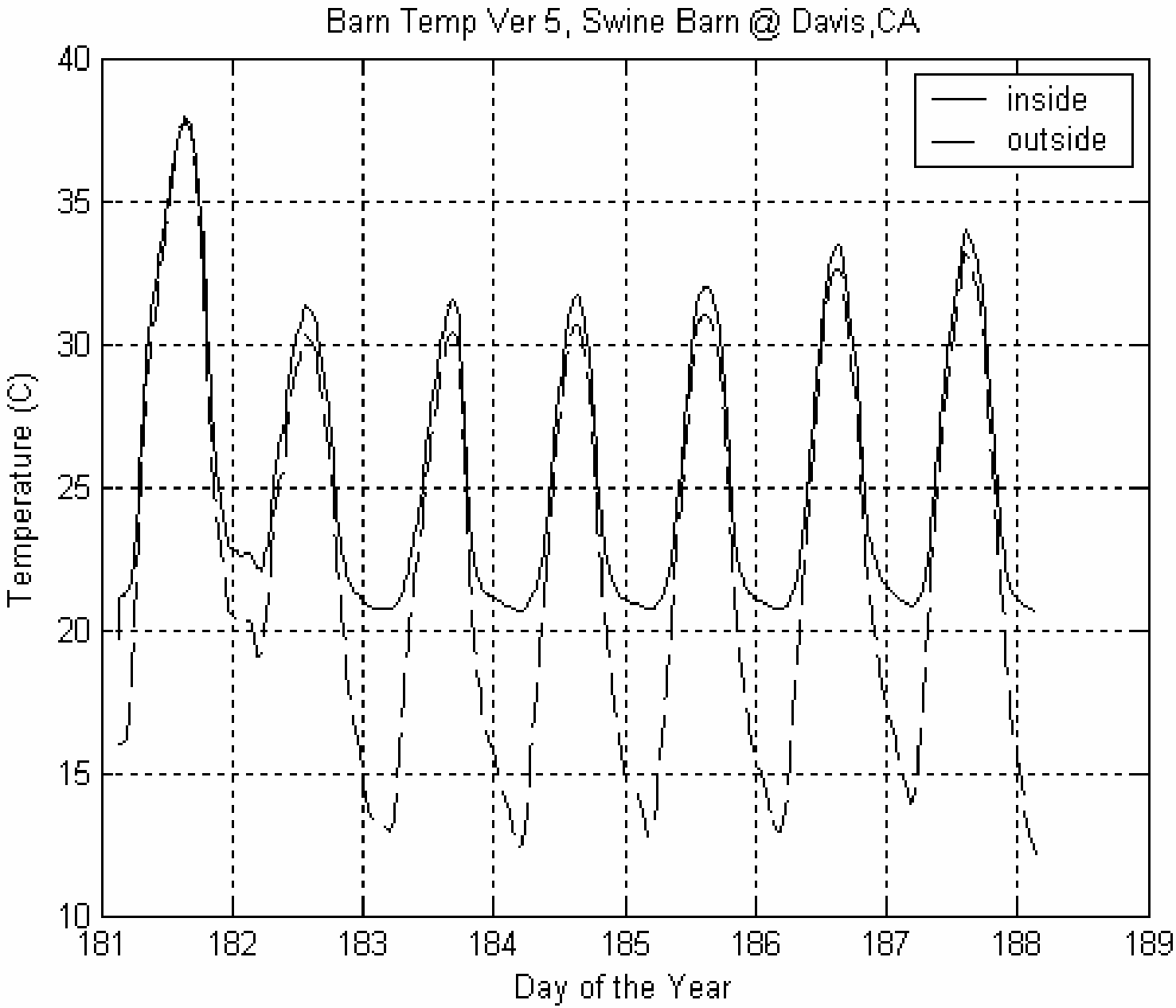
Mechanical Ventilation Model

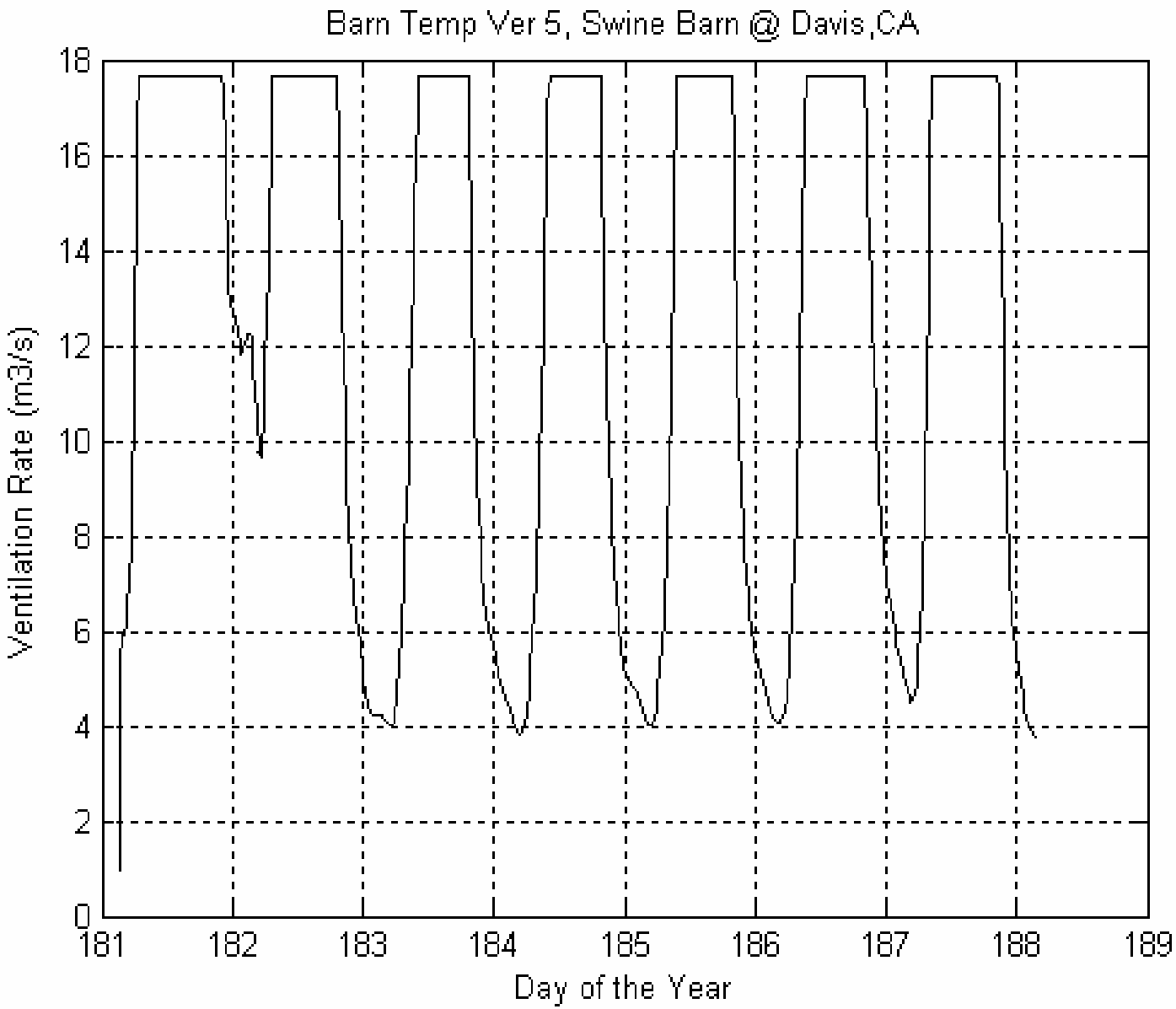
- Assumes air is well mixed within barn.
- Calculates ventilation rate as function of time.
- Calculates indoor air temperature as function of time.
- Utilizes control scheme similar to those used by the industry.

Housing Model



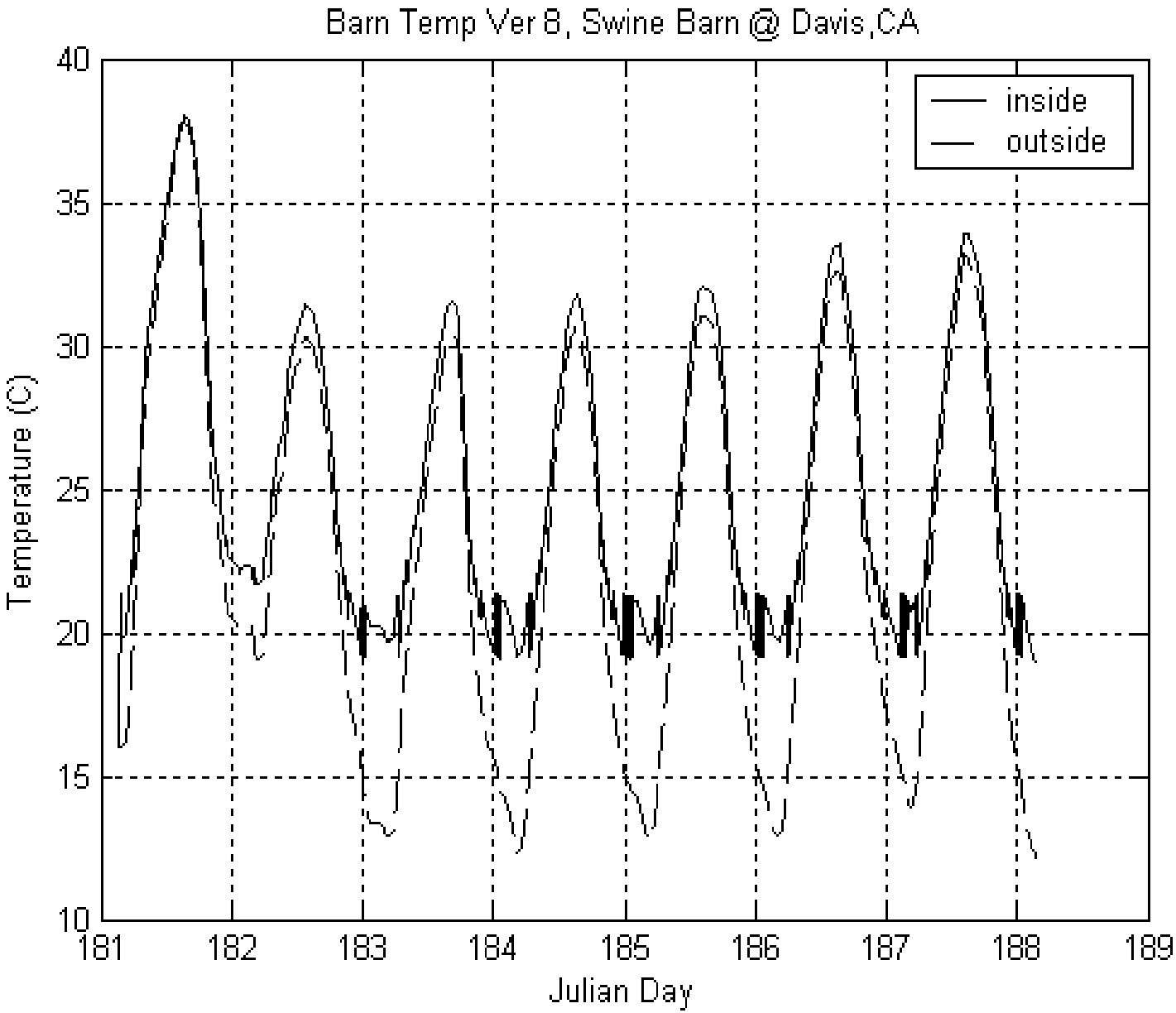


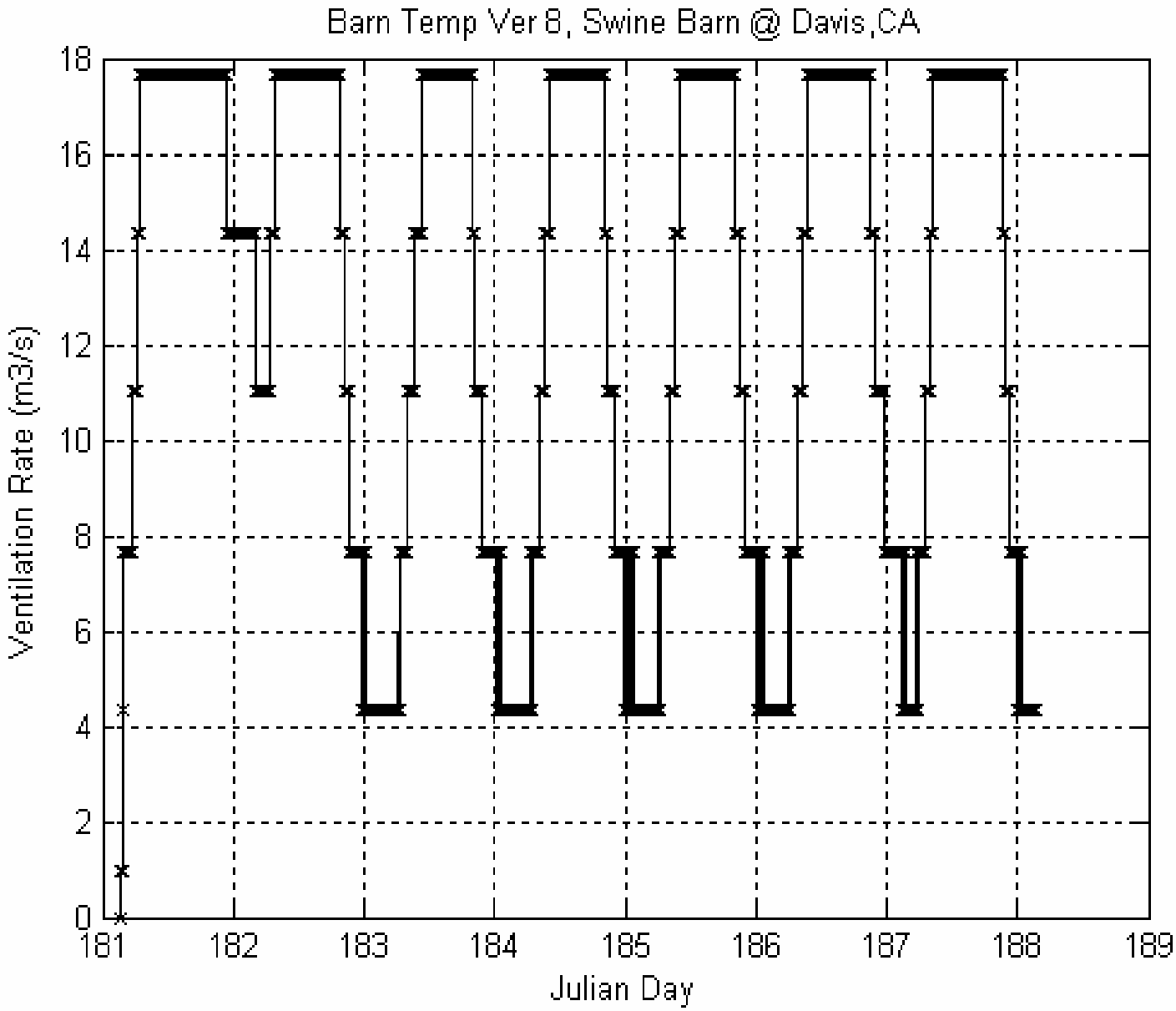

Barn Temp Ver 5, Swine Barn @ Davis,CA
inside
outside
Temperature (C)
Day of the Year
40
35
30
25
20
15
10
181
182
183
184
185
186
187
188
189


Barn Temp Ver 5, Swine Barn @ Davis,CA
Ventilation Rate (m3/s)
0
2
4
6
8
10
12
14
16
18
181
182
183
184
185
186
187
188
189
Day of the Year

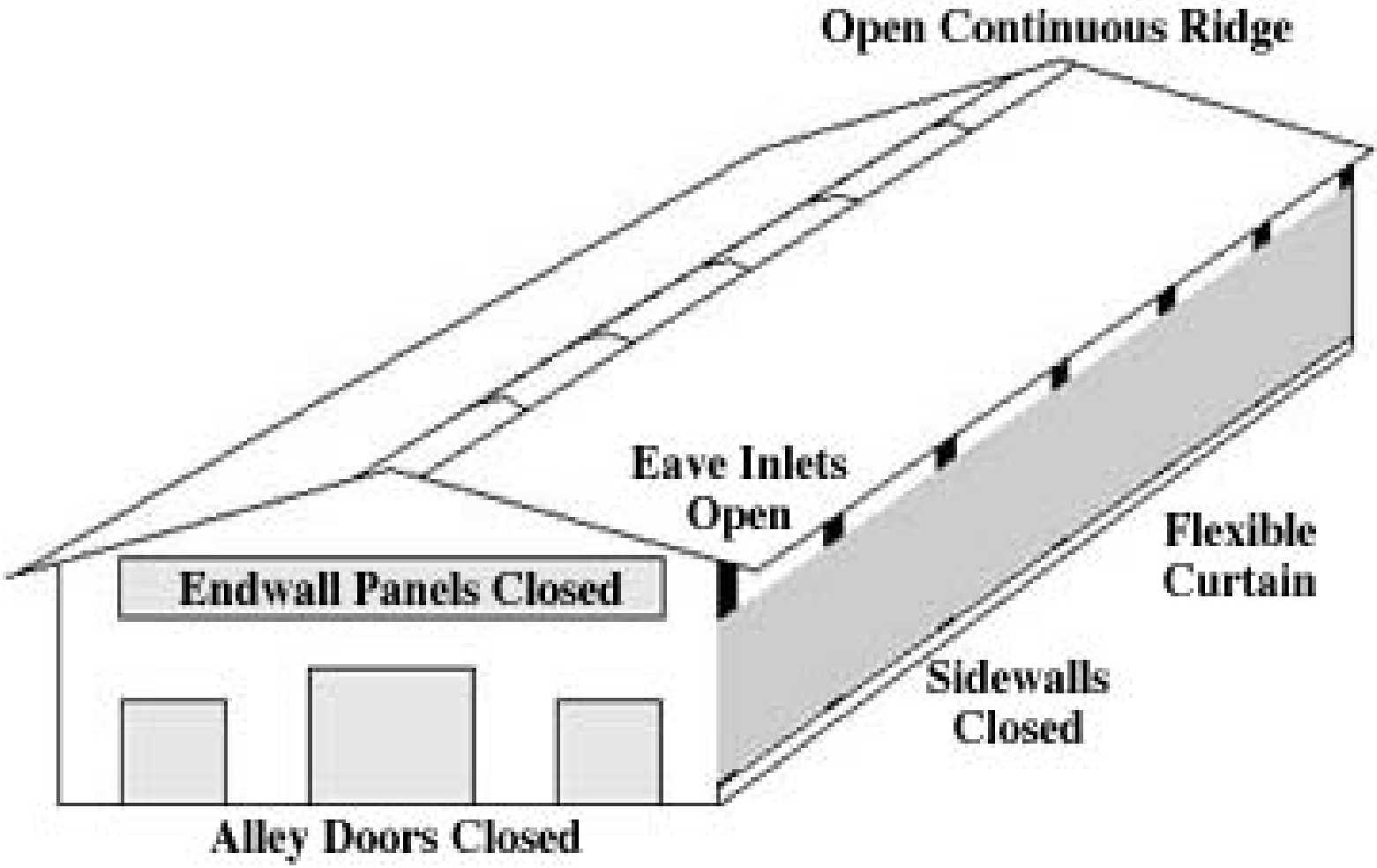
The same building was modeled using six constant speed fans

Fan	Capacity (m3/s)	Temp. fan on (C)	Temp fan off (C)
1	0.991	-10	100
2	3.34	20.0	18
3	3.34	21.25	19.25
4	3.34	22.50	20.5
5	3.34	23.75	21.75
6	3.34	25.00	23.


Barn Temp Ver 8, Swine Barn @ Davis,CA
inside
outside
Temperature (C)
Julian Day
40
35
30
25
20
15
10
181
182
183
184
185
186
187
188
189


Barn Temp Ver 8, Swine Barn @ Davis,CA
Ventilation Rate (m3/s)
Julian Day
0
2
4
6
8
10
12
14
16
18
181
182
183
184
185
186
187
188
189

Naturally Ventilated Freestall Dairy Barn


Open Continuous Ridge
Eave Inlets Open
Endwall Panels Closed
Flexible Curtain
Sidewalls Closed
Alley Doors Closed

Natural Ventilation Model

- Coupled steady state mass and energy balances to determine ventilation rate and indoor air temperature.
- Uses hourly ambient air temperature and wind speed/direction as inputs.
- Needs most of same building parameters as Mechanical ventilation (U values, animal sensible heat, etc.).

Ammonia Emissions from a Commercial Broiler House

Worley, J.W. 2002. ASAE Paper 024118

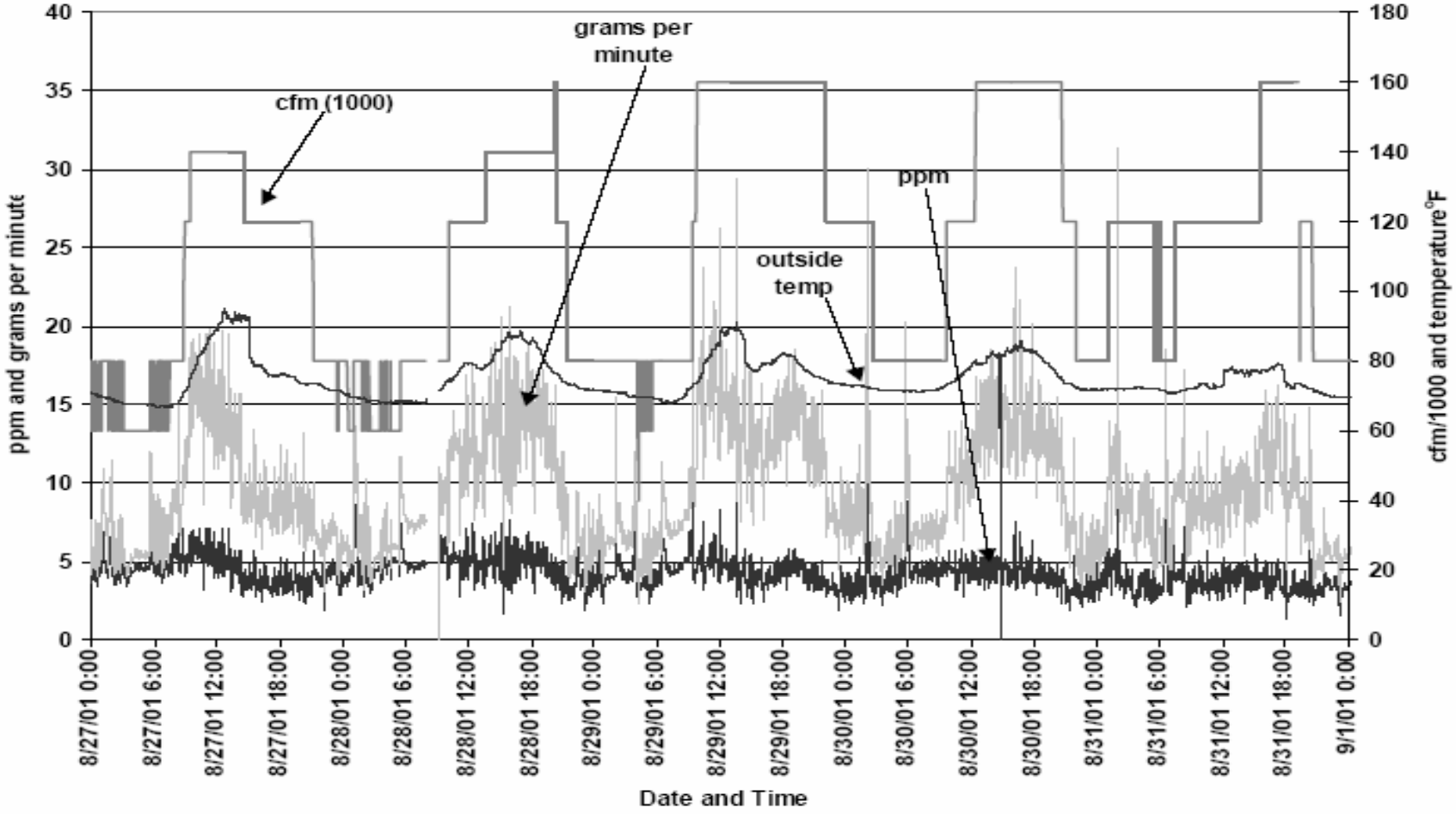


Figure 1. Raw data measured within the building in summer conditions

Storage Emission Model

- **Under-floor Pit Storage Model**
- **Outside Liquid Manure Storage Model**
- **Output from each**

  Ammonia Emission Rate (kgN/day)

Factors considered

- **Manure properties**
  - Volume, pH, ammonia concentration, mineralization rate (first order reaction)
- **Storage structures**
  - Volume and surface areas, dimensions
  - Treatment lagoon vs. storage pond
  - Storage period
- **Environmental Conditions**
  - Manure temperature
  - Ambient temperature
  - Air velocity
  - Precipitation and evaporation

AAP Input File Name: Post-excretion Storage - Beef

Emission Unit	TblNH3Post
Element	**Element Description**
RECORD TYPE	**A code that identifies the type of record (SB)**
COUNTRY_CODE	**The name of the country**
FIPS	**The FIPS code for the state and county**
AJC	**Alternate Jurisdiction Code. Used to define tribal areas and alter**
START DATE	**Start date of the period**
END DATE	**End date of the period**
OpenFeedlotManure	
StorageLiquidManure	
SurfaceArea	
SolidManure	
LiquidManure	
StoragePeriod	
StorageType	
StorageGeometry	
Diameter	
BottomLength	
BottomWidth	
BottomDiameter	
SideSlope	
ManureMoisture	
ManurePH	
VolumeEmptied	
TimeStep	
MineralizationRate	
TempCoeff	

AAP Input File Name: Post-excretion Storage - Poultry

Emission Unit	TblNH3Post
Element	**Element Description**
RECORD TYPE	**A code that identifies the type of record (SP)**
COUNTRY_CODE	**The name of the country**
FIPS	**The FIPS code for the state and county**
AJC	**Alternate Jurisdiction Code. Used to define tribal areas**
START DATE	**Start date of the period**
END DATE	**End date of the period**
SolidManure	
storageLiquidManure	
StoragePeriod	
StorageType	
StorageGeometry	
Diameter	
BottomLength	
BottomWidth	
BottomDiameter	
SideSlope	
ManureMoisture	
ManurePH	
VolumeEmptied	
TimeStep	
MineralizationRate	
TempCoeff	

Land Application Emission Model

- **Surface application model**
- **Output**
  - Ammonia emission rate (kgN/day)

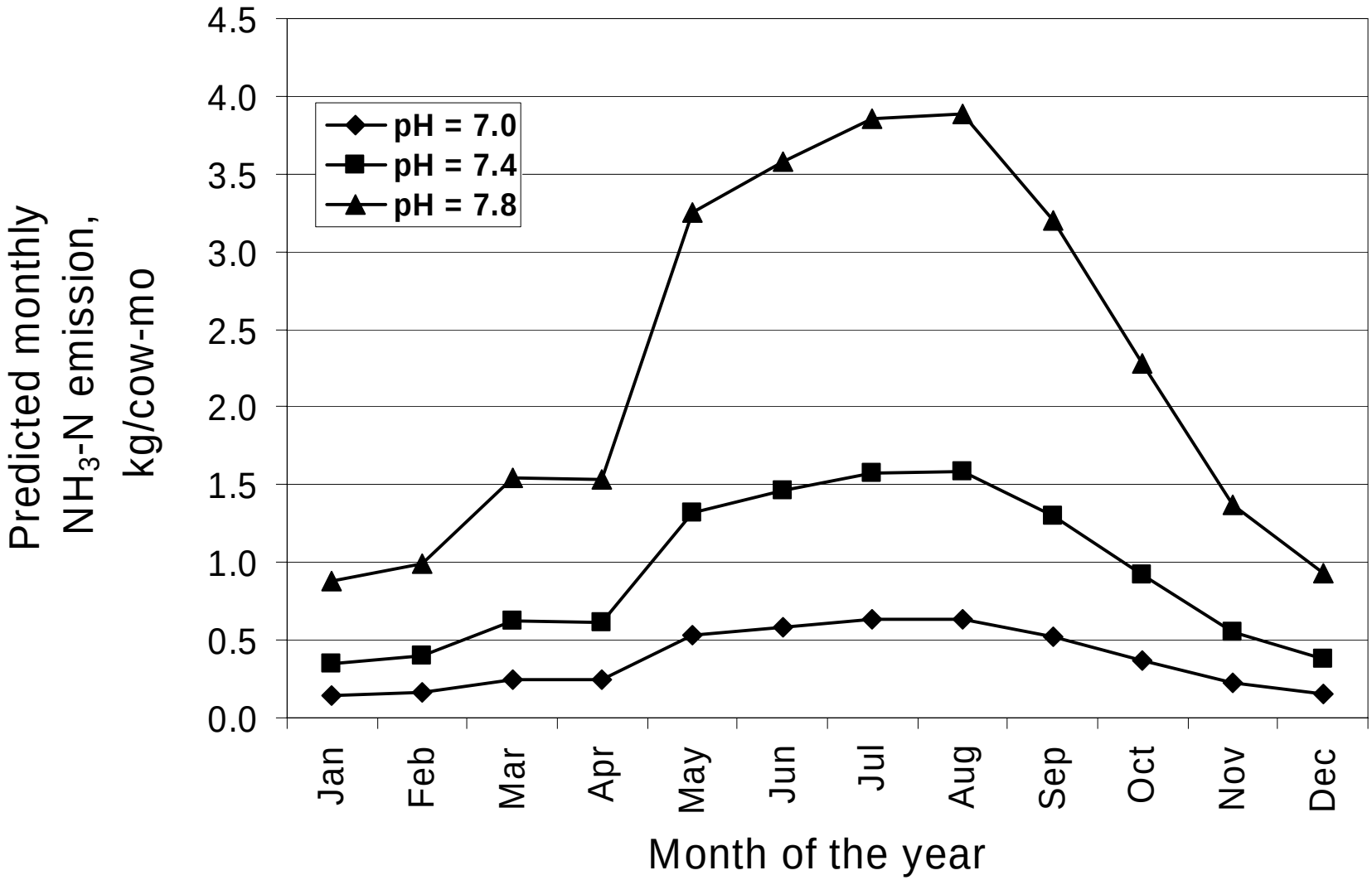
Factors considered

- **Manure properties**
  - Volume, pH, ammonia concentration, mineralization rate (first order reaction)
- **Land specifications**
  - Crop type and N uptake rate
  - Dimensions
  - Manure application rate and time
  - Soil type and infiltration rate
- **Environmental Conditions**
  - Soil temperature
  - Ambient temperature
  - Air velocity
  - Precipitation and evaporation

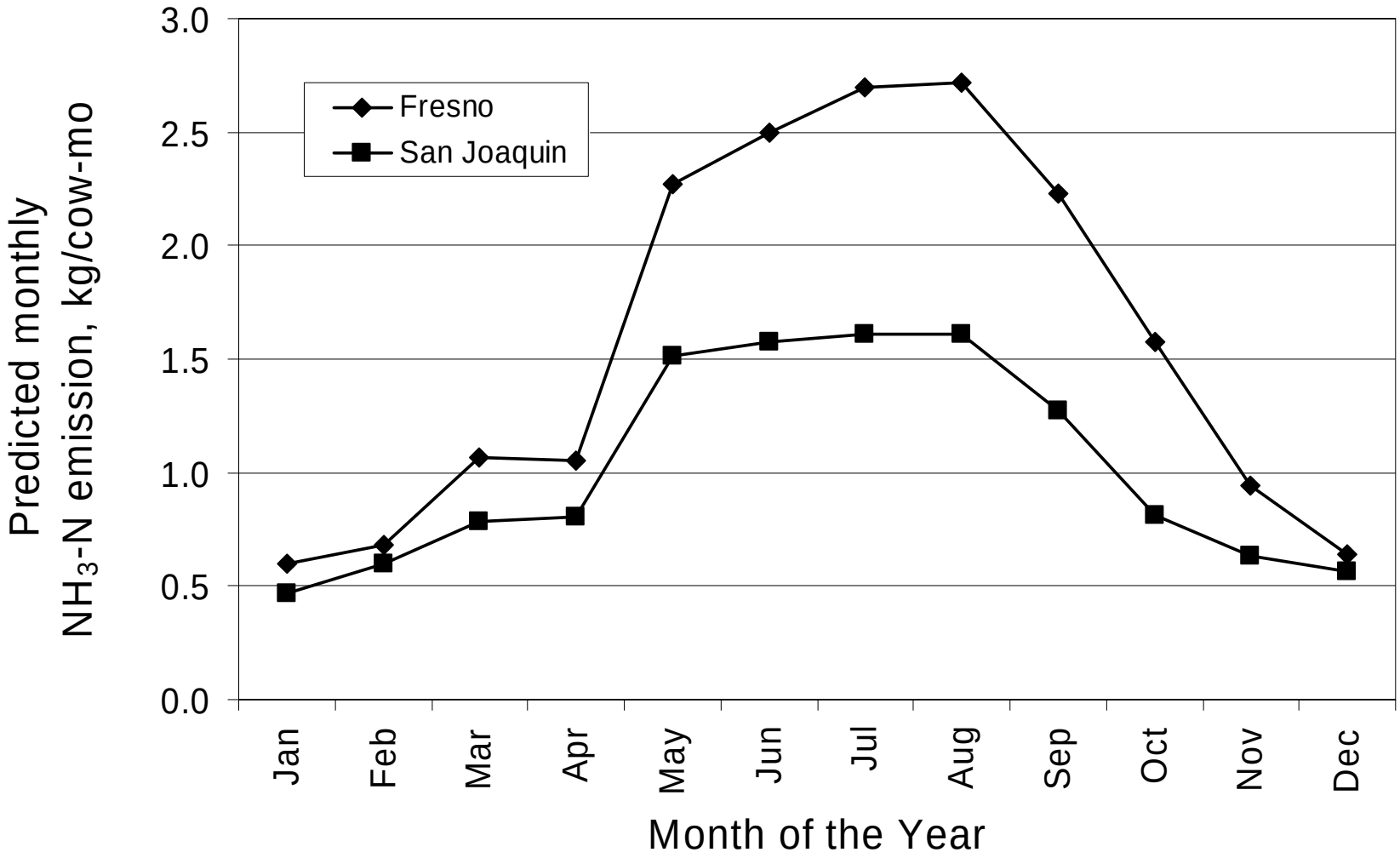
AAP Input File Name: Post-excretion Land Application - Dairy

Emission Unit	TblNH3Post
Element	**Element Description**
RECORD TYPE	**A code that identifies the type of record (LD)**
COUNTRY_CODE	**The name of the country**
FIPS	**The FIPS code for the state and county**
AJC	**Alternate Jurisdiction Code. Used to define tribal area**
START DATE	**Start date of the period**
END DATE	**End date of the period**
NPH	
Mdensity	
CropType	
Grain	
Silage	
Soybean	
Wheat	
Alfalfa	
Bermuda	
Soil_application	
DryMineralizationRate	
WetMineralizationRate	Mineralization rate (k) for wet soil

Predicted NH_3 Emissions from Dairy Lagoon under Different pH
(H=25ft and TAN=450mg/L, Fresno)



Predicted NH_3 Emissions from Dairy Lagoons in Fresno and San Joaquin



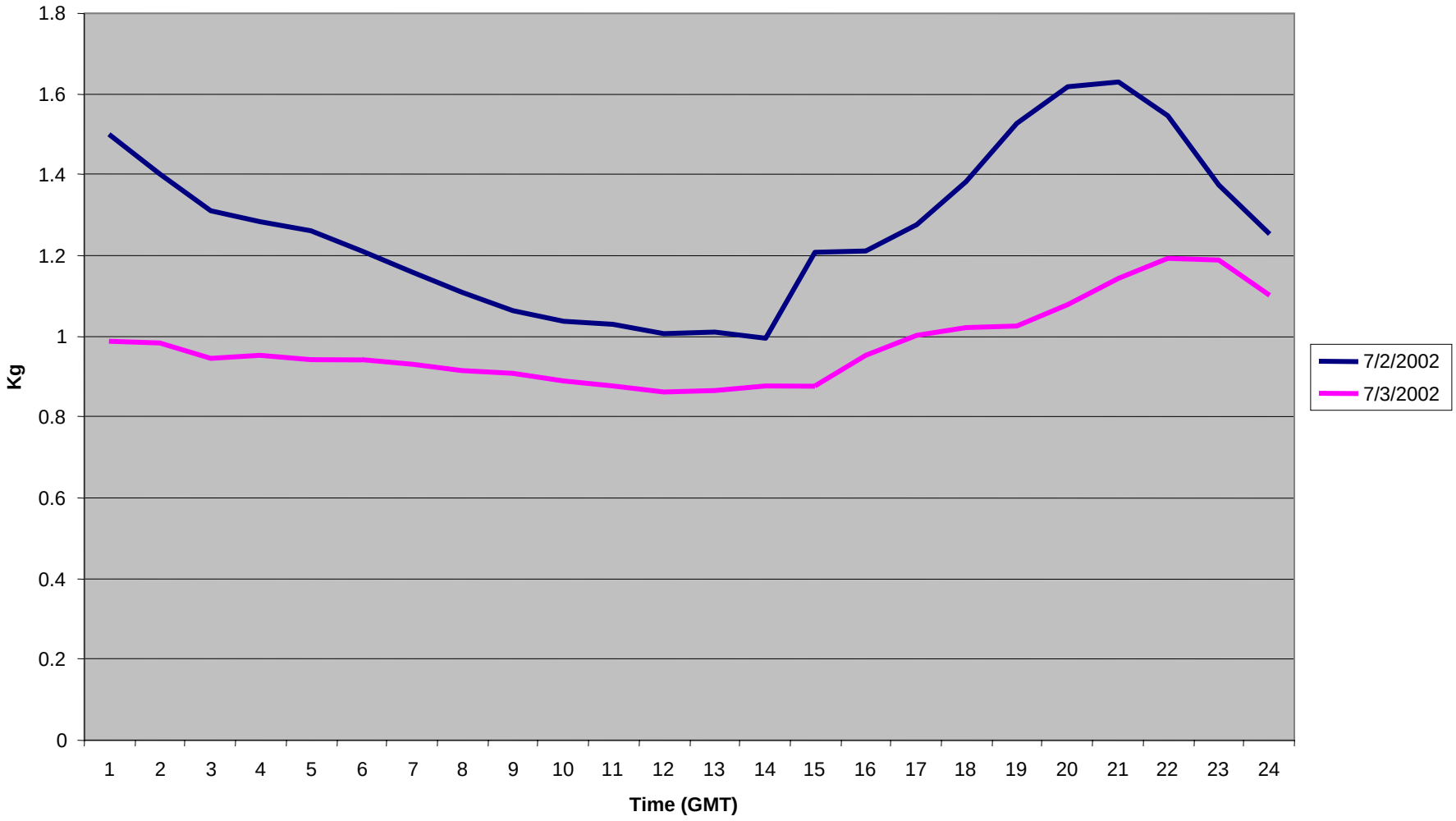
NH3 Emissions Calculation in FEM

- **FEM computes NH3 emissions with animal numbers by each MMT for each grid cell:**
  - Reads in ascii outputs from AAP
  - Reads in meteorology file from CONCEPT met tables
  - Run Animal Excretion Model
  - Based upon MMTID:
    - Run Housing Emissions Model
    - Run Storage/Feedlot Emissions Model
    - Run Land Emissions Model
  - Output total NH3 based on animal type & MMTID
  - Output commercial fertilizer NH3 emissions estimates

FEM Input/Output

- **Input Data**
  - AAP ASCII outputs (see handout for output format)
  - Meteorological Data
    - Lat/lon
    - Wind velocity and direction
    - Relative Humidity, Rain,
    - Frictional velocity, etc.
- **Output Data**
  - Based upon animal type & MMTID
  - Format:
    - CONCEPT ready format
    - NIF 3.0 format
    - ASCII csv format

NH3 Estimates from Farm Emissions Model (FEM)



Future Direction

- **More science is needed(Poultry Housing) Improved Science**
- **Validation Work with Measurement Data.**
  - Probems: Most Measurement studies do not collect the important variables. (only money from MWRPO)
- **Sensitivity analysis: Define the variables that are most influential over reasonable ranges.**
- **Start Outreach and community comments.**
  - Presentation to the AAQTF next week.
  - Outreach to MWRPO states USDA/State DA