An Integrated Study of the Emissions of Ammonia, Odor and Odorants, and Pathogens and Related Contaminants from Potential Environmentally Superior Technologies (ESTs) for Swine Facilities

(Program OPEN: Odor, Pathogens, and Emissions of Nitrogen)

Evaluation Findings for the ESTs at AHA Hunt (SBR), Carroll's (ISSUES-ABS), Harrell's (ISSUES-PCS), Hickory Grove (Super Soils Composting), Howard Farm (Constructed Wetlands), and Vestal (ISSUES-RENEW); Lake Wheeler Road Field Laboratory (Gasifer);and Lake Wheeler Road Laboratory (Black Soldier Fly): for Ammonia, Odor and Odorants, and Pathogens

North Carolina State University, Raleigh, NC
Duke University, Durham, NC
University of North Carolina, Chapel Hill, NC

June 24, 2005

1. **Project Title:**

   An Integrated Study of the Emissions of Ammonia, Odor and Odorants, and Pathogens and Related Contaminants from Potential Environmentally Superior Technologies for Swine Facilities
   (Program OPEN: Odor, Pathogens, and Emissions of Nitrogen)

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Project Summary

The need for developing sustainable solutions for managing the animal waste problem is vital for shaping the future of North Carolina. As part of that process, the North Carolina Attorney General has concluded that the public interest will be served by the development, implementation, and evaluation of environmentally superior swine waste management technologies appropriate to each category of hog farms in North Carolina. This is being done through agreements (Agreements) between the Attorney General of North Carolina and Smithfield Foods, Inc and Premium Standard Farms, Inc, providing funds to the Animal and Poultry Waste Management Center (A&PWMC) at North Carolina State University, Raleigh, North Carolina.

During the past three and a half years, project OPEN (Odor, Pathogens, and Emissions of Nitrogen) funded by A&PWMC, has demonstrated the effectiveness of a new paradigm for policy-relevant environmental research in North Carolina’s animal waste management. This new paradigm is based on a commitment to improve scientific understanding associated with all aspects of environmental issues (air, water, soil, odor and odorants, and disease-transmitting vector and airborne pathogens) and, as part of a comprehensive strategy, to facilitate in the development, testing and evaluation of potential Environmentally Superior Technologies for the management of swine waste.

The progress that the OPEN team has made is a result of the scientific and intellectual leadership provided by the collaboration of scientists and engineers from three (3) universities (North Carolina State University, University of North Carolina at Chapel Hill, and Duke University), one (1) national laboratory (National Exposure Research Laboratory, U.S. Environmental Protection Agency), one (1) State of North Carolina Department (Division of Air Quality, and

Division of Water Quality, NC Department of Environment and Natural Resources), and one (1) private research organization (MCNC- North Carolina Supercomputing Center). Five ESTs have already been evaluated and are included in the Phase 1 report, these are Brown's of Carolina (BOC) Farm #93 – Upflow biofilteration system (EKOKAN) ; Corbett #1, 3 & 4 – Solids separation/gasification for energy and ash recovery centralized system (BEST); Goshen Ridge Farm- Solids separation/nitrification-denitrification/soluble phosphorus removal/solids processing system (Super Soils); Hickory Grove- Orbit High Solids Aerobic Digester (Orbit/HSAD); Lake Wheeler-Belt system.

For this current Phase 2 report, six ESTs were evaluated, these are AHA Hunt (SBR), Carroll's (ISSUES-ABS), Harrell's (ISSUES-PCS), Hickory Grove (Super Soils Composting), Howard Farms (Constructed Wetlands), and Vestal (ISSUES-RENEW). These technologies were evaluated during two seasons (cold and warm), and the results compared and contrasted with current lagoon and spray technologies at conventional swine farms (i.e. Moore Farm and Stokes Farm). Additional evaluation data was also collected for the Black Soldier Fly; and van Kempen/Koger gasifier, which were both located at the Lake Wheeler Road Field Laboratory (see Appendices A, and B).

This report will show that targeted emissions were reduced under some of the environmental conditions studied for the candidate technologies. However, based on the current research results and analysis, and available information in the scientific literature, some of the evaluated alternative technologies may require additional technical modifications to be qualified as Environmentally Superior as defined by the NC Attorney General Agreements.

Acknowledgements

This research is funded by the Animal and Poultry Waste Management Center (A&PWMC), Raleigh, NC. We sincerely acknowledge the help and support provided by Dr. Mike Williams, Project Officer, and Ms. Lynn Worley-Davis. We thank the technology PIs, farm owners, Cavanaugh & Associates, and Mr. Bundy Lane, C. Stokes, and P. Moore for their cooperation.

We acknowledge the discussions and gracious help provided by Dr. John Fountain, Dr. Richard Patty, Dr. Ray Fornes, and Dr. Johnny Wynne of North Carolina State University. We thank Wes Stephens, Mark Barnes, Guillermo Rameriz, and Rachael Huie. We also thank Mr. Hoke Kimball, Mr. Mark Yurka, and Mr. Wade Daniels all of NC Division of Air Quality for their support.

Introduction

This project is part of an overall research, development and demonstration effort to identify environmentally superior technologies for the treatment and management of swine waste. The project is being conducted for Smithfield Foods, Inc., Premium Standards Foods Inc. and the Attorney General of the State of North Carolina through agreements between these entities known as the "Smithfield Agreement" and the "Premium Standard Foods Agreement" (Agreements).

The agreements define "Environmentally Superior Technology or Technologies" as any technology, or combination of technologies that (1) is permittable by the appropriate governmental authority; (2) is determined to be technically, operationally, and economically feasible for an identified category or categories of farms [to be described in a technology determination]; and (3) meets the following performance standards:

1. Eliminates the discharge of animal waste to surface waters and groundwater through direct discharge, seepage, or runoff;
2. Substantially eliminates atmospheric emission of ammonia;
3. Substantially eliminates the emission of odor that is detectable beyond the boundaries of the parcel or tract of land on which the swine farm is located;
4. Substantially eliminates the release of disease-transmitting vectors and airborne pathogens; and
5. Substantially eliminates nutrient and heavy metal contamination of soil and groundwater.

Evaluation Summary

The results of these findings are summarized in three evaluation tables for each technology:

Table 1. Water holding structures emissions
Table 2. Barn (Fan ventilated or naturally ventilated) emissions
Table 3. Total emissions.

I. Evaluation of Environmentally Superior Technologies for Ammonia Project OPEN Science Team for Ammonia:

- *Project Director*
Viney P. Aneja[1]

- *Science Team Members*
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1. Evaluation of Environmentally Superior Technologies for Ammonia Emissions: AHA Hunt Farm

Sequencing Batch Reactor (SBR)

Alternative Technology: Sequencing Batch Reactor (SBR)

Location: AHA Hunt Farm (Bailey, NC)

Period of Operation:
The OPEN team monitored for evaluation during:
1st field experiment: 02/16 – 02/27/2004, and 03/03-03/08/2004
2nd field experiment: 04/19 – 04/30/2004

Technology contact: Tom Smith and Doug Goldsmith (252-249-3196)

NCSU Representative PI: Dr. John Classen (919-515-6800), Dr. Sarah Liehr (919-515-6761)

Statement of Task:

- Measurement of ammonia (NH_3) emissions from primary lagoon, secondary lagoon, equalization tank and sequencing batch reactor tank by using a flow-through chamber technology during two different campaigns (warm and cool seasons)
- Analysis of water samples from waste storage and treatment areas for Total Ammoniacal Nitrogen (TAN) and Total Kjeldahl Nitrogen (TKN) concentrations (one sample each day during the experimental period)
- On site monitoring of meteorological parameters at 10 meter height
- FTIR technology used to determine ammonia emissions from barns
- Parameters measured: NH_3 flux, storage lagoon temperature and pH, wind speed and direction, solar radiation, relative humidity and air temperature

Description of Alternative Technology:

The sequencing batch reactor is a large, open-top concrete tank or basin that is equipped with aerators and mixers. Waste is pumped into the reactor once each day. In the reactor, the waste cycles between aerated conditions, when the aeration and mixing equipment in running, and anoxic conditions, when the waste is not aerated. Nitrification, the conversion by microbes of ammonia to nitrate, occurs during aeration, while denitrification, the conversion of nitrate to nitrogen gas, occurs during the anoxic cycle. Much of the nitrogen in the waste is converted to nitrogen gas, which is released harmlessly into the atmosphere. At the same time, cycling between an aerated and anoxic environment creates conditions favorable for microbes to concentrate phosphorus from the waste stream into microbial cell mass.

Waste flows from the pig houses to a homogenization tank, where it is held before being pumped to the sequencing batch reactor. The homogenization tank is necessary because the pig houses are flushed repeatedly during the day, while the sequencing batch reactor is loaded only once a day. At this site, waste is pumped from the sequencing batch reactor to an existing lagoon. However, if this technology were used as the primary method of treating waste from a hog farm, a solids separation process would probably be used to remove the solid portion of the waste stream leaving the reactor. The remaining liquid would have to be sprayed on cropland, but the liquid would be relatively low in nutrients, and significantly less land would be needed than is the case with a lagoon. The solids would be rich in phosphorus and would have value as fertilizer or a soil amendment.

(Source: Waste management Programs, North Carolina State University, http://www.cals.ncsu.edu:8050/waste_mgt/)

- A conceptual flow-diagram of alternative technology;

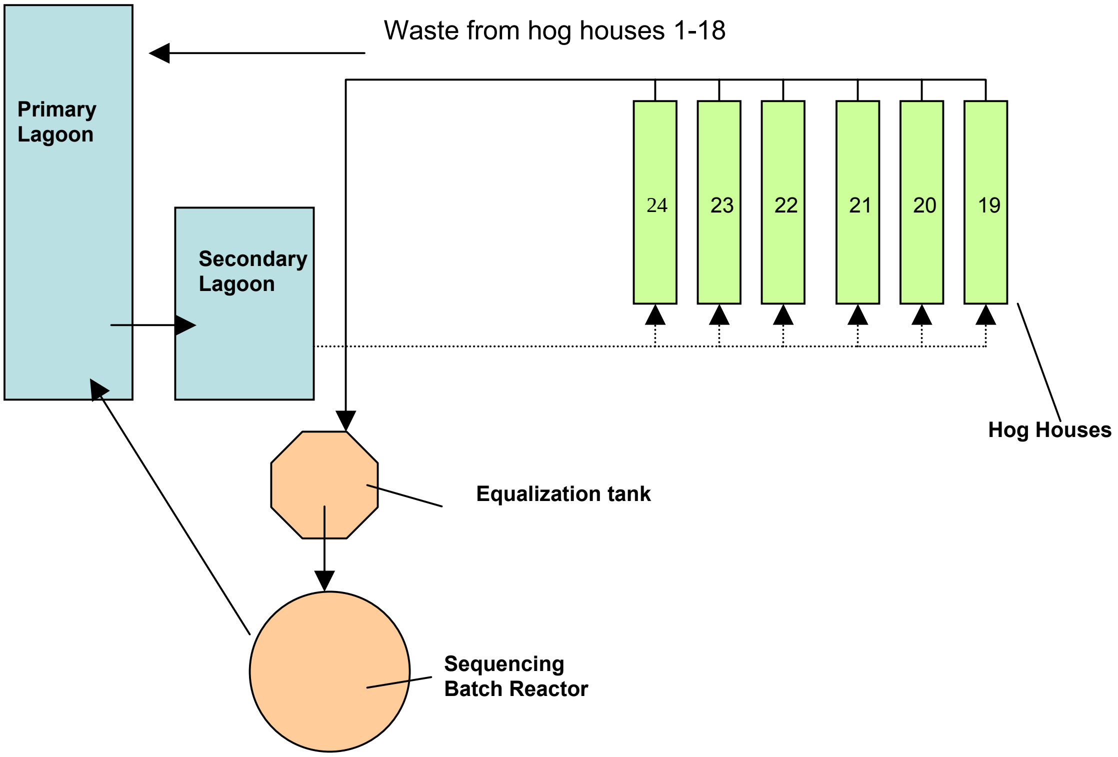


Figure 1.1 Conceptual flow diagram of SBR system (AHA Hunt farm).

(*Source; http //www.cals.ncsu.edu:8050/waste_mgt)*

- Possible points of emissions of ammonia on conceptual flow-diagram and parameters that are important in controlling emissions:

- Water holding structures: primary lagoon, secondary lagoon, equalization tank, and SBR tank - water temperature and water chemistry (pH and TAN) are the major controlling factors.

- Animal houses: house operational technology flushing sequence and frequency are controlling variables as well as pH and TAN.

An aerial photo of AHA Hunt with EST is given below:

Aerial photo of SBR site (AHA Hunt Farm).

- Table 1.1 Description of Animal Operation for houses 19-24 (value estimates provided by project investigators and/or animal contract company)

Sampling period (1st Evaluation) February 16-27, 2004

WEEK 1 **2/16-2/23**	**House 24 Finishing**	**House 23 Finishing**	**House 22 Finishing**	**House 21 Finishing**	**House 20 Finishing**	**House 19 Finishing**
# of pigs / house	600	529	632	529	605	610
Wks of finishing	1	2	3	4	5	6
Ave. Wt of pigs (lbs.)	50	60	70	80	90	100
Feed consumed (lb/pig/wk)	23.1	24.2	25.4	26.5	27.7	28.8
WEEK 2 **2/23-3/1**	**House 24 Finishing**	**House 23 Finishing**	**House 22 Finishing**	**House 21 Finishing**	**House 20 Finishing**	**House 19 Finishing**
# of pigs / house	599	529	630	527	600	608
Wks of finishing	2	3	4	5	6	7
Ave. Wt of pigs (lbs.)	60	70	80	90	100	110
Feed consumed (lb/pig/wk)	24.2	25.4	26.5	27.7	28.8	28.9
WEEK 3 **3/2-3/8**	**House 24 Finishing**	**House 23 Finishing**	**House 22 Finishing**	**House 21 Finishing**	**House 20 Finishing**	**House 19 Finishing**
# of pigs / house	598	525	625	526	591	602
Wks of finishing	3	4	5	6	7	8
Ave. Wt of pigs (lbs.)	70	80	90	100	110	120
Feed consumed (lb/pig/wk)	25.4	26.5	27.7	28.8	29.9	31.0

Table 1.2 Sampling period (2nd Evaluation): April 19 –30, 2004

WEEK 1 **4/19-4/25**	**House 24 Finishing**	**House 23 Finishing**	**House 22 Finishing**	**House 21 Finishing**	**House 20 Finishing**	**House 19 Finishing**
# of pigs / house	551	497	589	486	560	582
Wks of finishing	10	11	12	13	14	15
Ave. Wt of pigs (lbs.)	160	170	180	190	200	210
Feed consumed (lb/pig/wk)	33.3	34.4	35.5	36.7	37.8	38.9
WEEK 2 **4/26-4/30**	**House 24 Finishing**	**House 23 Finishing**	**House 22 Finishing**	**House 21 Finishing**	**House 20 Finishing**	**House 19 Finishing**
# of pigs / house	548	490	587	485	554	580
Wks of finishing	11	12	13	14	15	16
Ave. Wt of pigs (lbs.)	170	180	190	200	210	220
Feed consumed (lb/pig/wk)	34.4	35.5	36.7	37.8	38.9	40.0

Feed Nutrients

Table 1.3 Total elemental analysis of feed samples (5 samples in total, %N measurement is replicated 5 times, %P, Cu, Zn, measurements are replicated 3 times).

Date	%N	%P	Cu(ppm)	Zn(ppm)
February 19, 2004	2.72 ± 0.10	0.54 ± 0.01	74.4 ± 4.7	112.7 ± 2.3
April 19, 2004	2.65 ± 0.10	0.53 ± 0.01	66.0 ± 3.3	105.8 ± 1.3

Nitrogen Excretion based on feed analysis

*Computation of Nitrogen Excretion Based on Animal Feed Data using the standard technique of % N determined by feed analysis. This is applied to the waste from the six houses (houses 19 to 24) that flows around the EST (AHA Hunt farm: SBR Technology-Evaluation period, February 16 –March 8, 2004)***.** *Note: Sampling was only conducted the week of February 16 and March 2nd, therefore only those week's production data was used to calculate nitrogen excretion.*

- Animal population / Types:
  - Total number of pigs (finishing) in 6 finishing houses = 3486
  - Weighted average weight of the pigs =85.21 lb/pig = 38.65 kg/pig

- Nitrogen Intake
  - Average feed consumed = 12.3 kg/pig/wk
  - Average nitrogen content of the feed = 2.72% (from Feed Analysis)
  - Average nitrogen intake per pig = 0.33 kg-N/pig/wk

- Nitrogen Excretion
  - Average gain / feed or feed efficiency rate (ER) for feeder-finish operation, based on the 1999 Pig CHAMP data = 0.3
  - Average N excretion = (1-0.3) x 0.33 = 0.23 kg-N/pig/wk
  - Average N excretion on animal weight (*lw*) basis = 6.05 *kg-N/1000kg animal live weight(lw)/wk*

Computation of Nitrogen Excretion Based on Animal Feed (AHA Hunt farm: SBR Technology- 2nd Evaluation period, April 19 – 30, 2004)

- Animal population / Types:
  - Total number of pigs in 6 finishing houses = 3255

    - Weighted average weight of the pigs =190.38 lb/pig = 86.36 kg/pig

- Nitrogen Intake
    - Average feed consumed = 16.64 kg/pig/wk
    - Average nitrogen content of the feed = 2.65% (from Feed Analysis)
    - Average nitrogen intake per pig = 0.44 kg-N/pig/wk

- Nitrogen Excretion
    - Average gain / feed or feed efficiency rate (ER) for feeder-finish operation, based on the 1999 Pig CHAMP data = 0.3
    - Average N excretion = (1-0.3) x 0.44 = 0.31 kg-N/pig/wk
    - Average N excretion on animal weight (*lw*) basis = *3.57 kg-N/1000kg animal live weight(lw)/wk*

Nitrogen Excretion based on % crude protein

No feed analysis was performed for houses 1-18. % N is calculated based on estimates of % Crude Protein (CP), where % N = CP/6.25 (Personal Communication: Ms. Lynn Worley-Davis, APWMC . Nitrogen excretion was calculated individually for each house by averaging the nitrogen excretion over the two weeks. Note: Sampling was only conducted the week of February 16 and March 2nd, 2004. Therefore only those week's production data was used to calculate nitrogen excretion.

Table 1.4 Description of Animal Operation for houses 1-18 (value estimates provided by project investigators and/or animal contract company)   Sampling period (1st Evaluation) February 16- March 8, 2004

WEEK 1 2/16-2/22	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
# of pigs / house	322	341	579	605	595	589	556	497	253	502	498	565	611	645	-	-	-	278
Wks of finishing	19	18	17	16	15	14	13	12	11	10	9	8	1	-	-	-	-	20
Ave. Wt of pigs (lbs.)	240	230	220	210	200	190	180	170	160	150	140	130	60	50	-	-	-	250
Feed consumed (lb/pig/wk)	43.1	42.0	41.2	40.0	38.9	37.8	36.7	35.5	34.4	33.3	32.1	31.2	23.1	22.0	-	-	-	43.9
% N in feed*	2.32	2.32	2.32	1.97	2.29	2.29	2.29	2.29	2.34	2.29	2.34	2.06	2.75	2.75				2.32
WEEK 2 2/23-3/1	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
# of pigs / house	318	339	402	601	593	589	527	469	235	465	458	516	611	645	613	-	-	-
Wks of finishing	20	19	18	17	16	15	14	13	12	11	10	9	2	1	0	-	-	-
Ave. Wt of pigs (lbs.)	250	240	230	220	210	200	190	180	170	160	150	140	70	60	50	-	-	-
Feed consumed (lb/pig/wk)	43.9	43.1	42.0	41.2	40.0	38.9	37.8	36.7	35.5	34.4	33.3	32.1	24.2	23.1	22.0	-	-	-
% N in feed*	2.32	2.32	2.32	1.97	1.97	2.29	2.29	2.29	2.29	2.34	2.34	2.34	2.75	2.75	2.75	-	-	-
WEEK 3 3/2-3/8	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
# of pigs / house	204	233	324	441	491	586	525	469	234	463	457	514	611	645	613	600	-	-
Wks of finishing	21	20	19	18	17	16	15	14	13	12	11	10	3	2	1	0	-	-
Ave. Wt of pigs (lbs.)	260	250	240	230	220	210	200	190	180	170	160	150	80	70	60	50	-	-
Feed consumed (lb/pig/wk)	44.8	43.9	43.1	42.0	41.2	40.0	38.9	37.8	36.7	35.5	34.4	33.3	25.4	24.2	23.1	22.0		
% N in feed*	2.32	2.32	2.32	2.32	1.97	1.97	2.29	2.29	2.29	2.29	2.34	2.34	2.75	2.75	2.75	2.75	-	-

* % N calculated by use of Crude Protein (CP), where % N = CP/6.25

Table 1.5 Sampling period (2nd Evaluation): April 19 –30, 2004

WEEK 1 4/19-4/25	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
# of pigs / house	746	717	749	742	705	-	207	185	48	271	403	503	562	602	586	540	607	592
Wks of finishing	4	3	2	1	0	-	22	21	20	19	18	17	10	9	8	7	6	5
Ave. Wt of pigs (lbs.)	90	80	70	60	50	-	270	260	250	240	230	220	150	140	130	120	110	100
Feed consumed (lb/pig/wk)	26.5	25.4	24.2	23.1	22.0	-	45.9	44.8	43.9	43.1	42.0	41.2	33.3	32.1	31.2	29.9	28.8	27.7
% N in feed*	2.06	2.75	2.75	2.75	2.75		2.32	2.32	2.32	2.32	1.97	2.34	2.34	2.06	2.06	2.06	2.06	2.06
WEEK 2 4/26-4/30	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
# of pigs / house	742	715	748	742	696	710	-	-	-	270	402	500	556	592	573	528	595	569
Wks of finishing	5	4	3	2	1	0	-	-	-	20	19	18	11	10	9	8	7	6
Ave. Wt of pigs (lbs.)	100	90	80	70	60	50	-	-	-	250	240	230	160	150	140	130	120	110
Feed consumed (lb/pig/wk)	27.7	26.5	25.4	24.2	23.1	22.0	-	-	-	43.9	43.1	42.0	34.4	33.3	32.1	31.2	29.9	28.8
% N in feed*	2.06	2.06	2.75	2.75	2.75	2.75	-	-	-	2.32	2.32	2.32	2.34	2.34	2.34	2.06	2.06	2.06

*% N in feed calculated by use of Crude Protein (CP), where % N in feed = CP/6.25

Table 1.6 Nitrogen excretion values for each house for the 1st sampling period

House	N-excretion (kgN//wk/1000kglw)
1	4.25
2	4.15
3	4.07
4	3.97
5	3.87
6	3.76
7	3.65
8	3.54
9	3.43
10	3.32
11	3.21
12	3.12
13	2.34
14	2.23
15	2.23
16	2.12
17	No animals in the house
18	4.24
19	6.05
20	6.05
21	6.05
22	6.05
23	6.05
24	6.05

Total Nitrogen Excretion

1st sampling period: Average Total Nitrogen excretion for all 24 houses = 4.08 kgN/wk/1000kglw

Table 1.7 Nitrogen excretion values for each house for the 2nd sampling period

House	N-excretion (kgN//wk/1000kglw)
1	2.62
2	2.51
3	2.40
4	2.29
5	2.18
6	2.12
7	4.43
8	4.33
9	4.24
10	4.20
11	4.11
12	4.02
13	3.27
14	3.16
15	3.06
16	2.95
17	2.84
18	2.73
19	3.57
20	3.57
21	3.57
22	3.57
23	3.57
24	3.57

Total Nitrogen Excretion

2nd sampling period: Average Total Nitrogen excretion for all 24 houses = 3.29 kgN/wk/1000kglw

Meteorological Measurements

Monthly/Annual Climate Data Results at the nearest weather station
9.7 km from sampling site
(*Source: State Climatology Office)*

Summary of monthly precipitation (cm) from 1994 to 2004
WILSON 3 SW, NC (UCAN: 14409,COOP: 319476)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1994	9.80	7.34	15.37	4.27	9.09	6.05	15.27	6.02	7.34	7.09	4.17	2.72	94.51
1995	9.17	12.83	10.13	2.90	8.76	20.24	18.62	9.86	10.52	16.64		5.28	124.94
1996	11.13	5.99	7.77	6.50	12.60	9.88	22.10	4.78	25.83	9.50	7.59	9.91	133.58
1997	7.37	6.07	8.59	7.24	3.18	7.75	15.62	6.12	10.26	3.99	8.20	12.01	96.39
1998	18.21	15.14	16.31	8.86	5.84	4.17	14.40	16.79	11.30	6.45	6.48	10.97	134.92
1999	17.96	4.24	6.71	6.15	6.91	3.96	11.02	8.94	62.53	16.33	4.34	3.33	152.43
2000	14.12	5.08	6.53	8.00	3.00	7.52	11.48	13.39	17.60	0.00	6.35	3.58	96.65
2001	2.84	6.53	15.34	5.56	8.61	11.68	12.57	19.46	10.77	1.07	2.82	2.39	99.64
2002	14.50	3.86	6.83	5.36	3.86	10.67	15.93	19.86	9.50	12.42	11.58	9.47	123.85
2003	6.50	11.20	17.88	15.90	15.52	7.42	26.16	15.93	11.68	12.22	4.55	11.66	156.62
2004	4.55	**8.43**	5.03	**4.27**	25.68	14.76	15.95	11.28	15.93	3.66	9.42	2.90	89.94
AVG	11.16	7.83	11.15	7.07	7.74	8.93	16.32	12.11	17.73	8.57	6.23	7.13	121.35

AHA Precipitation Data Analysis (WILSON 3 SW, NC(UCAN: 14409, COOP: 319476)

Compared to the 10-year precipitation average of 7.8 cm for the month of February (1994-2003), AHA, conducted for February 16-27, 2004, showed a slightly higher precipitation average of 8.4 cm, a difference of 0.6 cm. Compared to the ten year precipitation average of 7.1 cm for the month of April, AHA, conducted for April19- 30, 2004, showed a lower precipitation average of 4.3 cm, a difference of 2.8 cm, however, the average is well within the range of the data for the last ten years.
The 10-year annual precipitation total (1994-2003) was 121.4 cm, while the annual precipitation total for 2004 was 89.9 cm, a difference of 31.5 cm. This was the lowest annual precipitation total in the last ten years.

Summary of monthly mean temperature (^{o}C) from 1994 to 2004

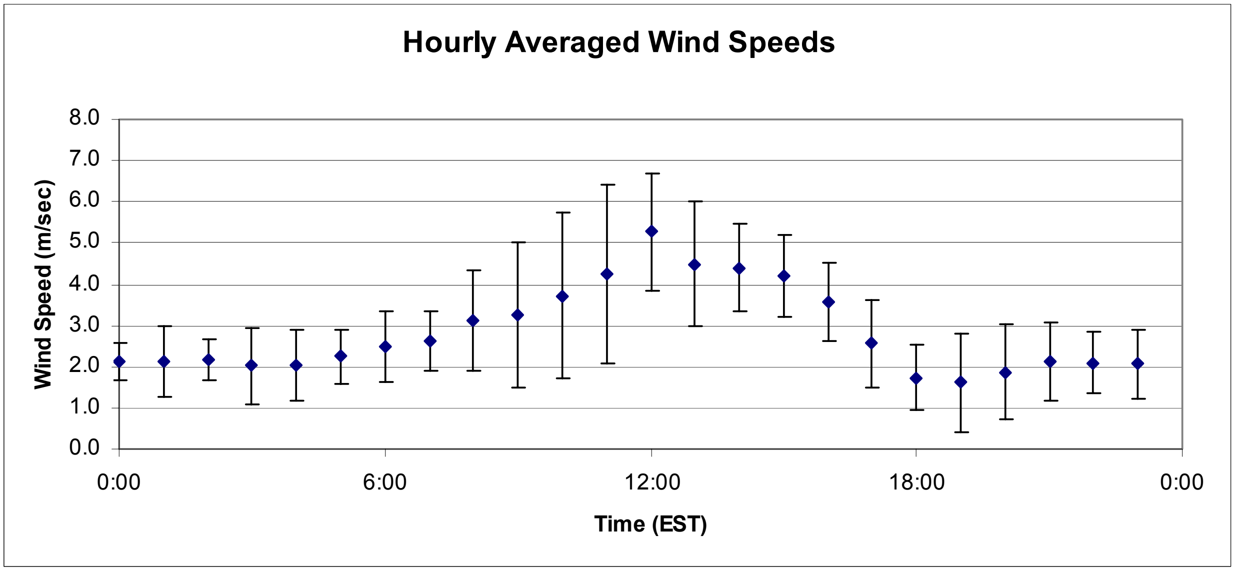
WILSON 3 SW, NC (UCAN: 14409,COOP: 319476)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1994	2.61	6.27	10.93	16.63	17.38	25.78	26.92	24.46	21.04	15.49	13.23	8.74	15.79
1995	5.98	4.36	11.01	15.83	19.78	23.43	26.89	26.06	21.15	17.15		4.27	15.99
1996	3.89	5.54	7.64	15.11	20.27	24.79	25.98	24.41	22.06	16.47	8.35	7.72	15.18
1997	5.36	8.29	12.72	13.19	17.92	22.33	26.58	24.54	22.07	16.08	9.46	6.47	15.42
1998	7.77	7.99	10.75	15.57	20.94	25.71	26.99	25.82	23.69	16.99	11.63	9.21	16.92
1999	8.14	7.61	8.92	16.43	19.34	23.50	27.12	26.52	21.65	15.60	13.69	6.86	16.28
2000	4.37	8.14	12.43	14.53	21.52	24.90	24.97	24.76	22.39	16.52	9.82	3.11	15.62
2001	4.74	8.21	9.46	16.23	20.02	25.35	24.53	25.43	21.09	15.98	13.93	9.86	16.23
2002	6.32	7.91	11.33	17.66	19.76	25.26	27.06	26.33	23.43	17.67	10.21	5.44	16.53
2003	3.42	5.51	11.84	14.71	19.91	24.04	26.17	26.49	22.48	16.07	14.43	5.99	15.92
2004	3.79	**5.23**	11.52	**16.59**	22.69	24.82	26.91	25.22	22.73	17.37	12.89	8.38	16.51
AVG	5.26	6.98	10.70	15.59	19.68	24.51	26.32	25.48	22.11	16.40	11.64	6.77	15.99

AHA Mean Temperature Data Analysis (WILSON 3 SW, NC(UCAN: 14409, COOP: 319476)

Compared to the 10-year temperature average of 7.0°C for the month of February (1994-2003), AHA, conducted for February 16 –27, 2004, showed a lower temperature average of 5.2°C, a difference of 1.8°C. This was the 2nd coldest in the ten year period (1994-2003).
Compared to the ten year temperature average of 15.6°C for the month of April, AHA, conducted for April 19-April 30, 2004, showed a slightly higher temperature average of 16.6°C. The 10-year annual temperature average (1994-2003) was 16.0°C, while the annual temperature average for 2004 was 16.5°C, a difference of 0.5°C. This was the 2nd highest annual temperature average in the last ten years.

- Site Meteorological data measured during the measurement periods:



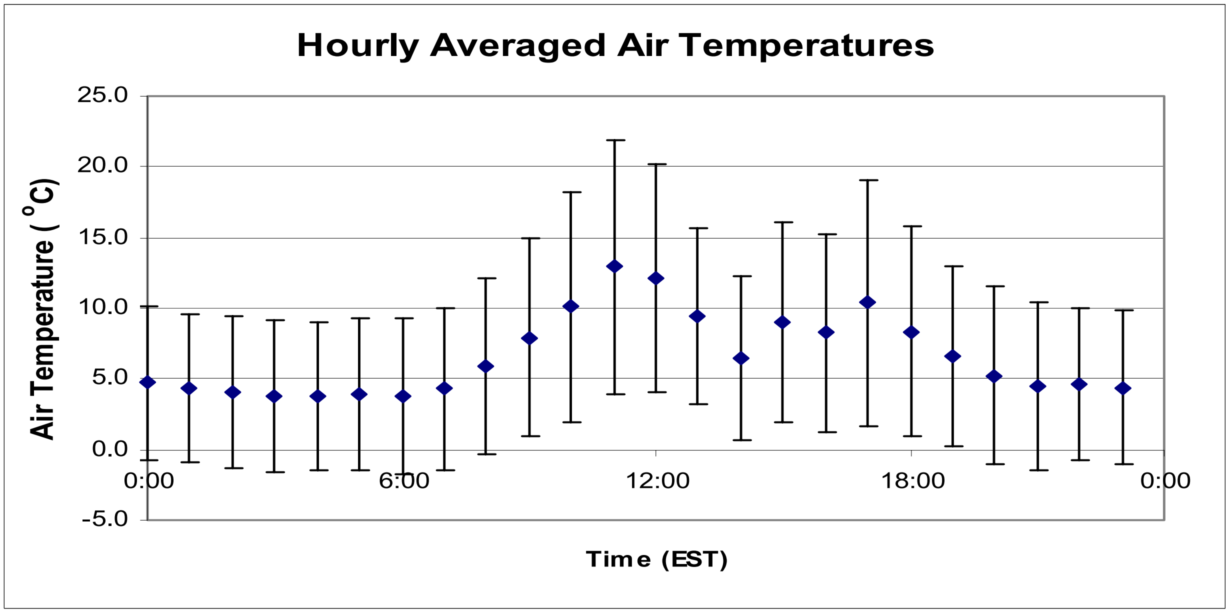


Figure 1.2 Site meteorological data during the 1st measurement period (February 16-20, March 3 & 8, 2004). Error bar indicates ±1 standard deviation of 15 minute averages.

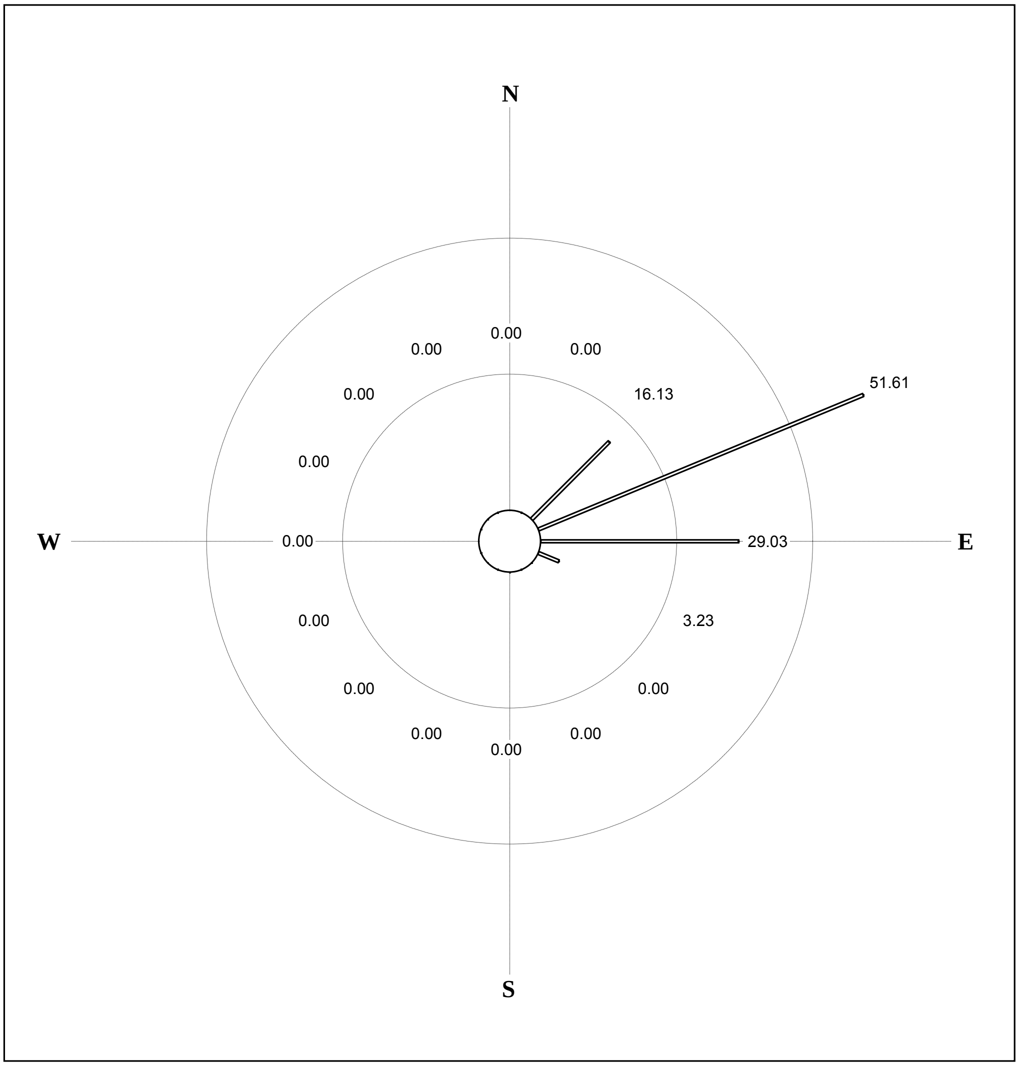
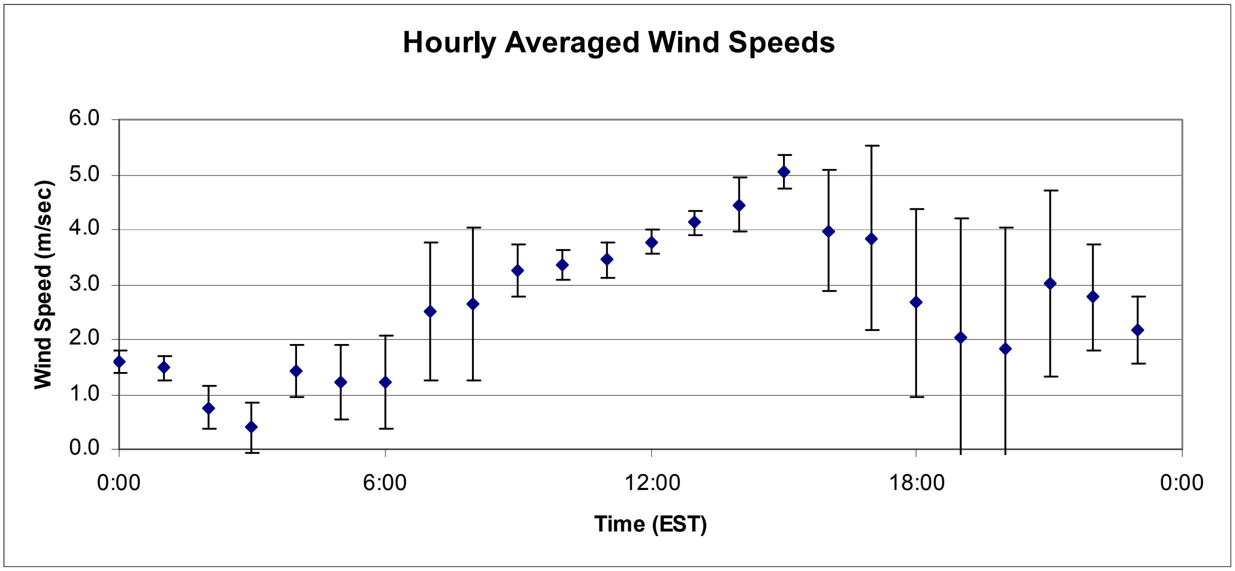


Figure 1.3 Wind rose depicting % wind direction during the 1st measurement period (February 16-20, March 3 & 8, 2004)



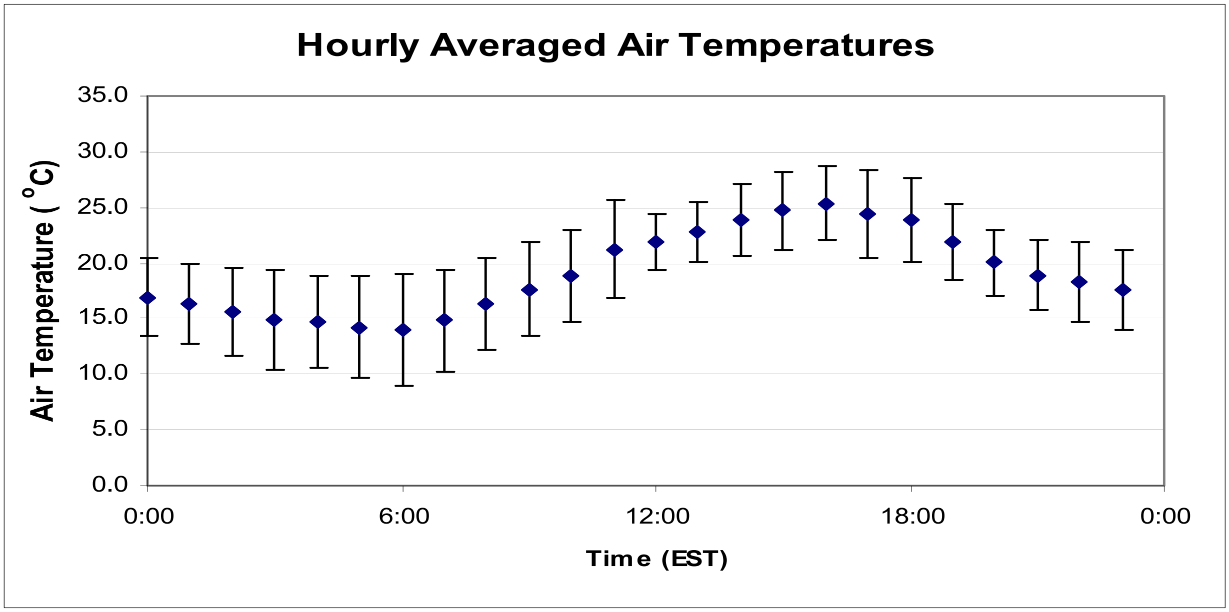


Figure 1.4 Site measurement data during 2nd measurement period (April 20-28, 2004). Error bar indicates ±1 standard deviation of 15 minute averages.

Note: No wind direction data for the 2nd measurement period.

Measurement of Ammonia Fluxes and Emissions

Emission Sources -

Major sources of NH_3 are the hog houses, primary storage and secondary storage lagoons. An open equalization tank and an open sequencing batch reactor (SBR) are also sources of NH_3. In all of the liquid waste environments, the NH_3 flux is expected to depend on ambient air temperature, water temperature, pH, wind speed and N in waste effluent. The flux chamber was deployed on lagoon type structures, open equalization tank and SBR tank. Measurements from the SBR tank were not possible during cycles when the aerators and mixers were operational due to the rapid movements within the tank. During the 1st evaluation, SBR measurements were taken during a period when the system was not operational.

The flux chamber measured NH_3 flux directly from their surfaces. For the houses, NH_3 emission was determined by using average NH_3 concentration across plumes from exhaust fans and estimated air flow rate from fans.

Dynamic-Chamber Technique for NH_3 flux measurement

The measurement schedule followed for determining the flux of ammonia from the water-holding structures using the dynamic-chamber technique is described in Table 1.8. Measured flux (presented as hourly averages) as a function of time is presented in Figures 1.7 and 1.8. Tabulated hourly average flux values for each water-holding structure are presented in Table 1.9. Table 1.9 also contains the overall average flux values for each water-holding structure for each evaluation period. Table 1.10 contains TAN and TKN concentrations of the effluent samples from the water-holding structures. Table 1.11 presents total emissions of ammonia (kg-N) per week for each water-holding structure calculated for each evaluation period and normalized to 1000 kg live weight of animals present.

AHA Hunt Farm (1st and 2nd Measurement Periods: February 16- February 20, March 3 & 8, 2004; April 20-28, 2004)

Table 1.8 NH_3 emission measurement schedule at AHA Hunt farm (1st and 2nd measurement period)

Sample dates	Parameters	Instruments	Sample plots	Remarks
Feb 16-18, 2004	NH_3 flux, lagoon T, lagoon pH, WD, WS, SR, air T, RH	One NH_3 analyzer, Meteorological instruments	Secondary lagoon- 2 different plots randomly selected.	Completed 2 diurnal measurements
Feb 18-20, 2004	NH_3 flux, lagoon T, lagoon pH, WD, WS, SR, air T, RH	One NH_3 analyzer, Meteorological instruments	Primary lagoon-2 different plots randomly selected.	Completed 2 diurnal measurements
March 3, 2004	NH_3 flux, tank water T, tank water pH, WD, WS, SR, air T, RH	One NH_3 analyzer, Meteorological instruments	An equalization tank	Completed 1 diurnal measurement
March 8, 2004	NH_3 flux, tank water T, tank water pH, WD, WS, SR, air T, RH	One NH_3 analyzer, Meteorological instruments	SBR tank	Completed 2 hour measurement

T = temperature; WD = wind direction; WS = wind speed; SR = solar radiation, RH = relative humidity

Water samples at each plot were collected every day for analysis of TAN and TKN concentrations at the laboratory.

Sample dates	Parameters	Instruments	Sample plots	Remarks
April 20-21, 2004	NH_3 flux,, tank water T, tank water pH, WD, WS, SR, air T,RH	One NH_3 analyzer, Meteorological instruments	An equalization tank	Completed 1 diurnal measurements
April 22-25, 2004	NH_3 flux , lagoon T, lagoon pH, WD, WS, SR, air T, RH	One NH_3 analyzer, Meteorological instruments	Primary lagoon-2 different plots randomly selected.	Completed 3 diurnal measurements
April 26-28, 2004	NH_3 flux , lagoon T, lagoon pH, WD, WS, SR, air T, RH	One NH_3 analyzer, Meteorological instruments	Secondary lagoon- 2 different plots randomly selected.	Completed 2 diurnal measurements

T = temperature; WD = wind direction; WS = wind speed; SR = solar radiation; RH = relative humidity

Water samples at each plot were collected every day for analysis of TAN and TKN concentrations at the laboratory.

Site photos during experimental period

1st Evaluation: Flux measurement of primary lagoon

2nd Evaluation: Overview of experiment at secondary lagoon

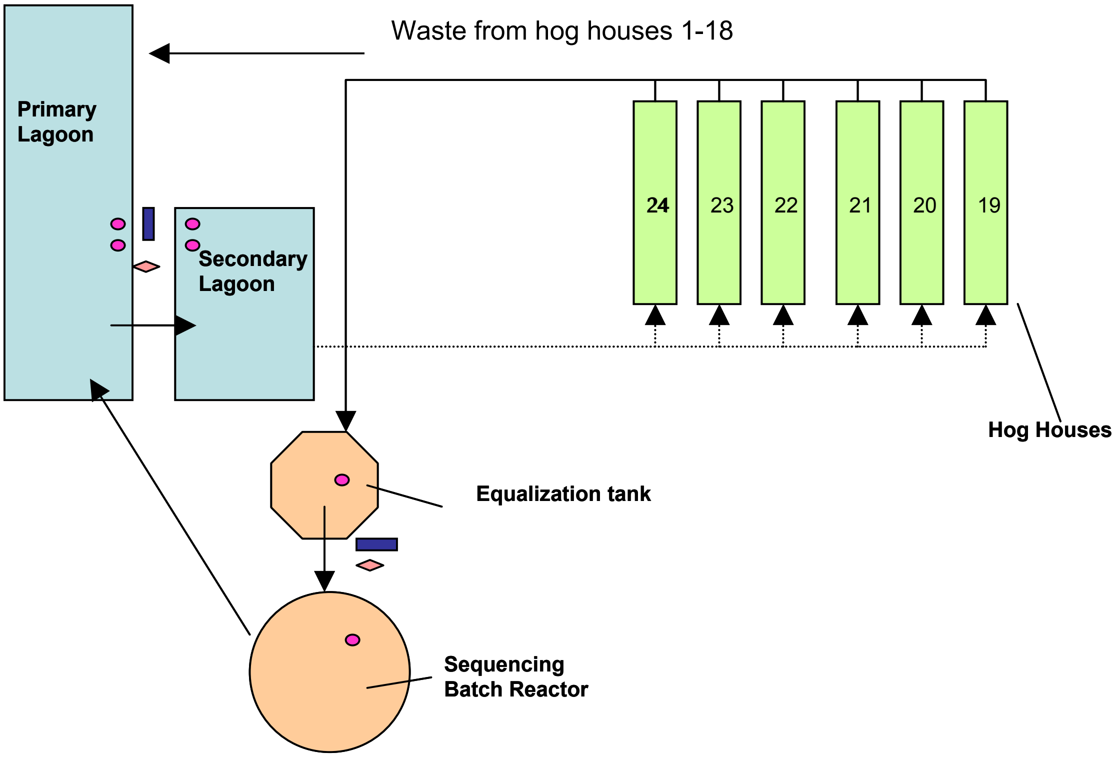
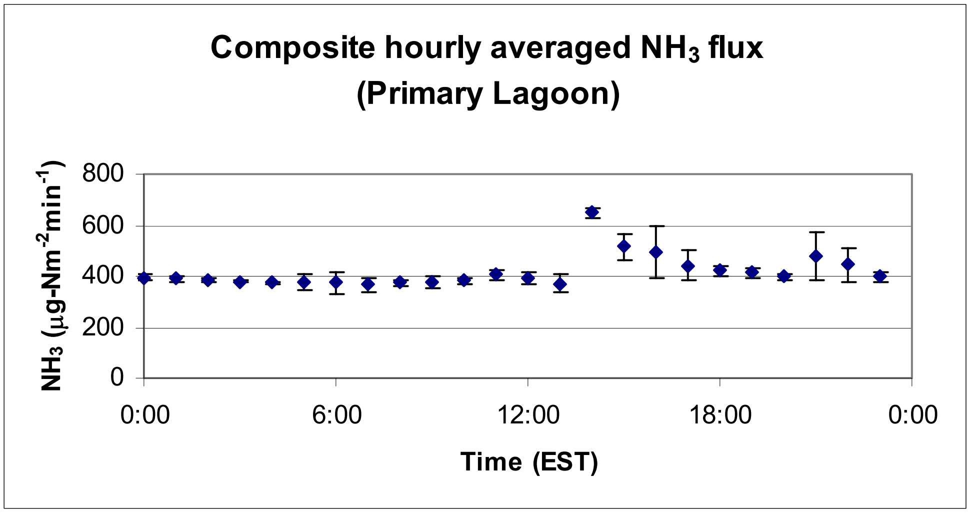
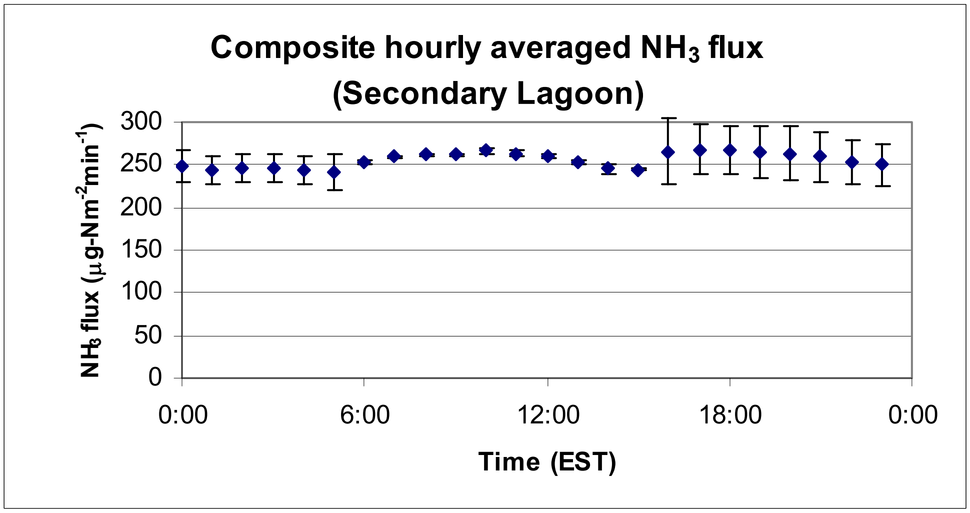
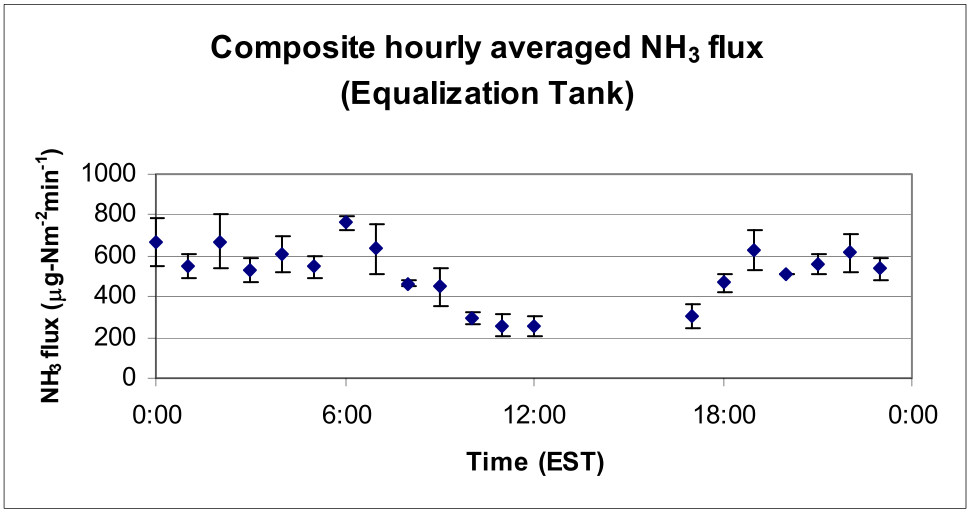


Figure 1.5 Experimental site layout and measurement locations.

1st Measurement period (February 16-20-March 3 & 8, 2004)







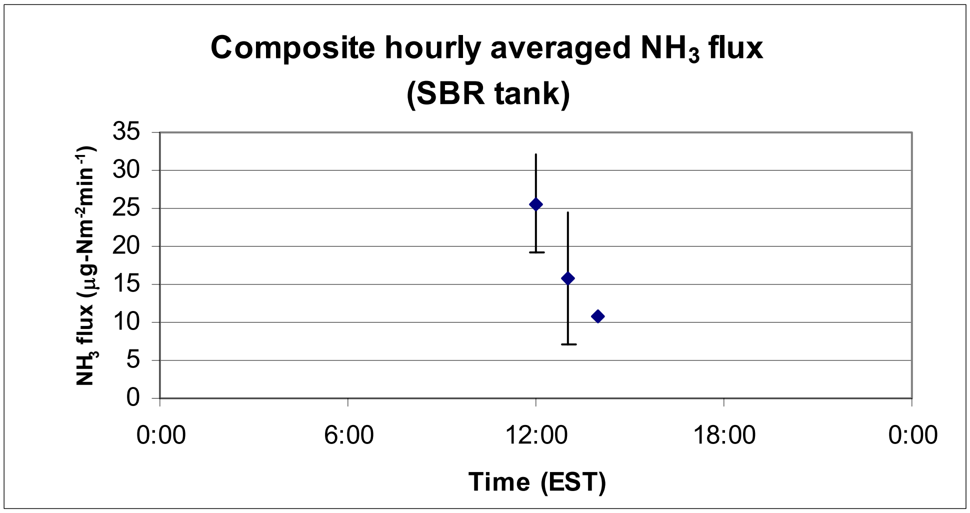
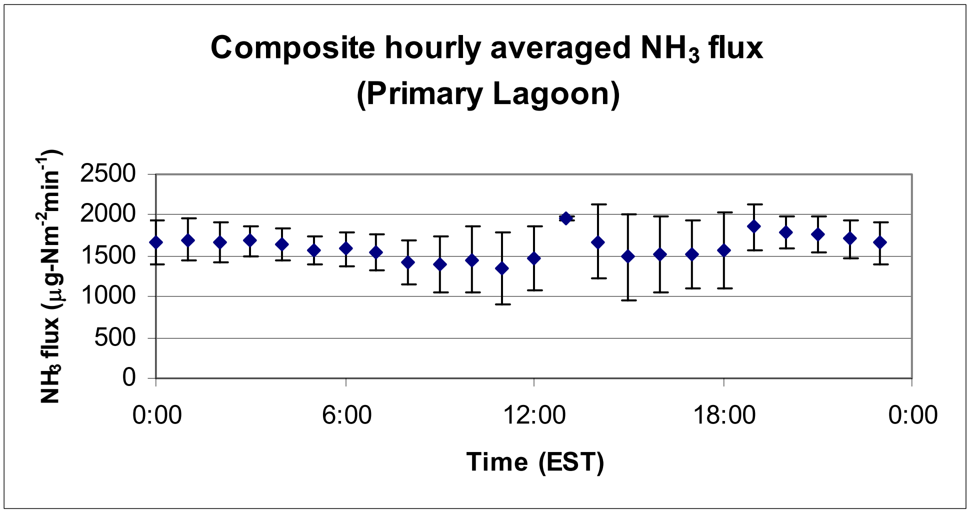
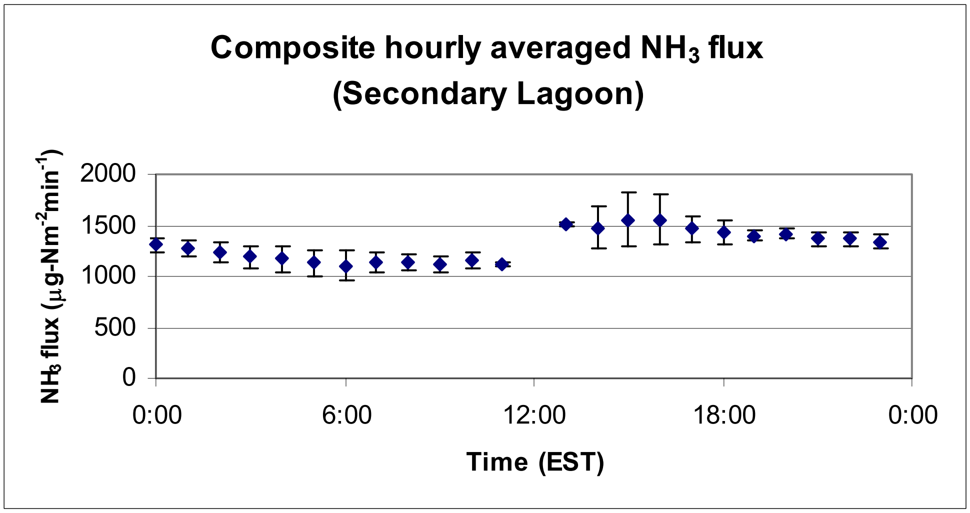


Figure 1.6 Diurnal variation of NH_3 flux from primary lagoon, secondary lagoon, equalization tank and SBR tank during the 1st measurement period. Error bar indicates ±1 standard deviation of 15 minute averages.

2^{nd} Measurement period (April 20-28, 2004)





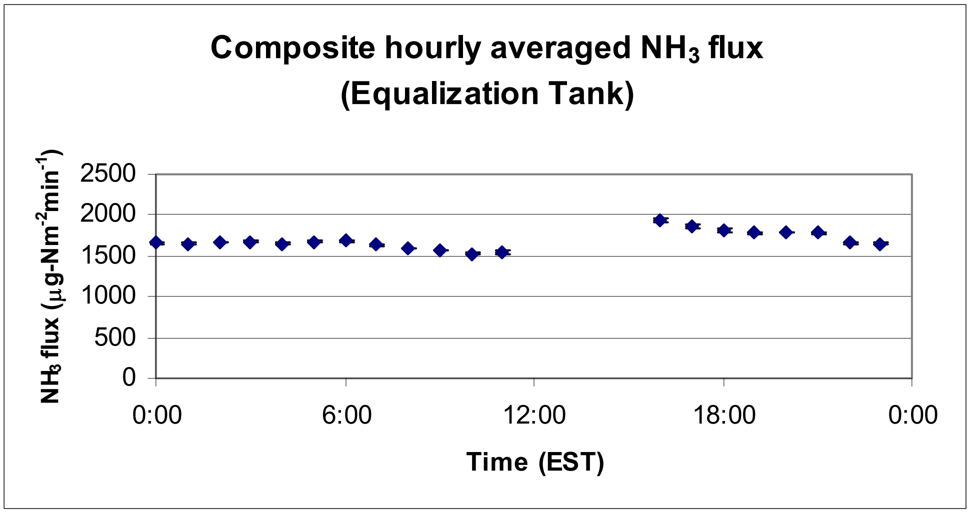


Figure 1.7 Diurnal variation of NH_3 flux from primary lagoon, secondary lagoon and equalization tank during the 2^{nd} measurement period. Error bar indicates ±1 standard deviation of 15 minute averages.

Table 1.9 Summary of hourly and overall averaged NH_3 flux from the water holding structures during the experimental periods.

AHA Hunt 1st Period

	NH_3 flux (1st period: 2/16-3/08/2004) (μg-N m^{-2} min^{-1})							
	Primary lagoon		Secondary lagoon		Equalization tank		SBR tank	
EST	hrly avg	stdev	hrly avg	stdev	hrly avg	stdev	hrly avg	stdev
0:00	394.9	12.3	248.6	18.6	667.0	119.6		
1:00	390.7	11.1	244.0	16.9	548.7	57.3		
2:00	388.1	8.0	245.6	16.7	670.7	134.3		
3:00	379.4	4.7	245.7	15.8	527.7	56.7		
4:00	372.7	4.2	243.3	16.5	606.8	89.8		
5:00	374.6	29.9	241.3	21.2	545.0	53.8		
6:00	373.5	41.1	252.9	2.9	761.2	35.2		
7:00	365.6	24.7	259.4	1.0	636.0	121.8		
8:00	374.4	11.2	261.8	0.7	463.9	16.8		
9:00	377.8	25.5	261.7	0.5	449.1	94.5		
10:00	383.2	11.2	266.2	2.7	294.7	29.7		
11:00	405.0	22.1	263.2	3.9	259.8	52.7		
12:00	395.8	23.7	260.2	3.1	256.5	50.8	25.6	6.5
13:00	371.8	34.3	253.6	2.3			15.8	8.7
14:00	647.9	22.6	245.1	5.2			10.8	
15:00	515.6	50.2	244.7	1.2				
16:00	493.8	100.0	265.1	38.8				
17:00	441.6	58.0	268.4	30.3	302.6	62.1		
18:00	420.8	17.5	267.0	29.1	468.0	46.3		
19:00	413.0	18.2	265.6	30.6	625.2	98.7		
20:00	396.9	12.7	263.5	31.3	510.8	3.1		
21:00	480.0	95.9	259.1	30.0	558.9	50.5		
22:00	445.1	66.4	253.5	25.6	615.0	90.5		
23:00	397.1	17.3	249.8	23.7	535.6	53.0		
average†	416.6		255.4		515.2		17.4	
stdev	63.9		9.0		143.7		7.5	
# of data	24		24.0		20		3	
average‡	406.9		254.9		521.8		17.9	
stdev	58.3		22.3		151.2		8.7	
# of data	178		149.0		78		7	
(15 min)	T_{lag}=5.4±2.5(n=347)							

† Statistics for hourly averages

‡ Statistics for 15 minute averages for the experimental period

AHA Hunt 2nd Period

	NH_3 flux (2nd period: 4/20-4/28/2004) (μg-N m^{-2} min^{-1})					
	Primary lagoon		Secondary lagoon		Equalization tank	
EST	hrly avg	stdev	hrly avg	stdev	hrly avg	stdev
0:00	1662.3	272.4	1305.0	71.5	1655.8	3.9
1:00	1702.1	247.3	1272.4	83.9	1649.6	12.0
2:00	1676.1	246.0	1238.0	104.6	1670.7	7.5
3:00	1681.2	189.6	1193.4	106.4	1671.2	14.4
4:00	1648.7	190.4	1168.8	120.7	1649.7	17.3
5:00	1569.6	163.2	1128.1	136.4	1675.9	12.0
6:00	1586.6	211.8	1102.8	143.4	1686.3	8.8
7:00	1539.8	228.5	1131.8	94.9	1630.7	20.3
8:00	1426.2	269.4	1135.9	76.3	1592.2	7.5
9:00	1407.7	342.5	1125.0	79.3	1570.5	5.1
10:00	1455.1	402.4	1161.9	76.5	1530.7	19.2
11:00	1356.3	441.0	1112.9	18.2	1542.8	15.5
12:00	1464.7	391.7				
13:00	1958.0	29.7	1516.2	21.1		
14:00	1677.9	462.1	1475.6	210.6		
15:00	1490.8	530.8	1553.5	264.6		
16:00	1525.1	467.3	1558.7	240.1	1928.3	28.3
17:00	1520.8	412.2	1461.8	127.5	1860.0	17.0
18:00	1559.0	464.0	1432.0	124.5	1811.2	19.1
19:00	1851.0	276.0	1400.6	53.0	1780.2	6.3
20:00	1796.3	197.5	1418.5	48.0	1783.9	4.9
21:00	1771.5	223.0	1370.2	70.1	1783.6	10.4
22:00	1707.2	241.1	1364.1	64.7	1665.5	13.2
23:00	1662.1	253.8	1340.5	69.3	1649.6	7.0
average†	1612.3		1302.9		1689.4	
stdev	147.7		155.0		104.7	
# of data	24.0		23		20	
average‡	1617.7		1300.3		1685.1	
stdev	336.1		187.3		96.3	
# of data	243.0		170		77	
(15 min)			T_{lag}=24.5±1.8(n=392)			

† Statistics for hourly averages

‡ Statistics for 15 minute averages for the experimental period

Table 1.10 Total Ammoniacal Nitrogen (TAN) and Total Kjeldahl Nitrogen (TKN) averages and their standard deviation from water-holding structures at AHA Hunt farm

	Primary lagoon		**Secondary lagoon**		**Equalization tank**		**SBR tank**	
	TKN (mg-N l^{-1})	TAN (mg-N l^{-1})	TKN (mg-N l^{-1})	TAN (mg-N l^{-1})	TKN (mg-N l^{-1})	TAN (mg-N l^{-1})	TKN (mg-N l^{-1})	TAN (mg-N l^{-1})
1st Period (Feb 16-20 & Mar 3)	794.3±7.6 n =3	629±226.4 n =3	304±17.0 n=2	281.5±4.9 n=2	1038.5±54.4 n=2	924.5±38.9 n=2	702.0 n=1	365.0 n=1
2nd Period (Apr 20-28)	983.3±212.3 n=3	855.0±41.2 n=3	288.3±11.0 n=3	223.0±10.6 n=3	702 n=1	631 n=1		

n represents the total number of effluent samples collected at each water-holding structure.

Table 1.11 Summary of total emissions from water-holding structures at SBR during the experimental periods.

1st Period

Water holding structure	Primary lagoon	Secondary lagoon	Equalization tank	SBR tank
Area (m^2)	20160	9207	104.2	364.2
Weekly NH_3 emission (kg-N/wk)	82.7	23.66	0.55	0.07
Total emission from tanks and lagoon (kg-N/wk)	106.97			
Total emission/pig (kg-N/pig/wk)	0.01			
Total emission/1000 kg-lw (kg-N/1000kg-lw/wk)	0.17			

2nd Period

Water holding structure	Primary lagoon	Secondary lagoon	Equalization tank
Area (m^2)	20160	9207	104.2
Weekly NH_3 emission (kg-N/wk)	328.74	120.68	1.77
Total emission from tanks and lagoon (kg-N/wk)	451.19		
Total emission/pig (kg-N/pig/wk)	0.04		
Total emission/1000 kg-lw (kg-N/1000kg-lw/wk)	0.56		

Average Ammonia Concentrations Using Open-Path Fourier Transform Infrared (OP-FTIR) Spectrometers

OP-FTIR spectrometer concentration measurements were obtained during February 24-25 and April 21-22, 2004. For both measurement periods, data was collected over the aerated SBR Tank and equilibration tank. Measurements were also made at the long side of one of the barns in the curtain opening, see Figure 1.8. For the February evaluation, the Aeration was on for the SBR tank during the entire measurement period. In April, measurements were obtained for ~one hour before the system was turned on. Figure 1.9 shows the 15 min average concentrations and standard deviations in mg--N/m3 for all locations in February, 2004. Figure 1.10 shows the 15 min average concentrations and standard deviations in mg--N/m3 for all locations in April, 2004. Table 1.12 lists the average daily concentrations of Nitrogen in mg/m3.

Figure 1.8 Locations of Measurements taken with the OP-FTIR Spectrometers.

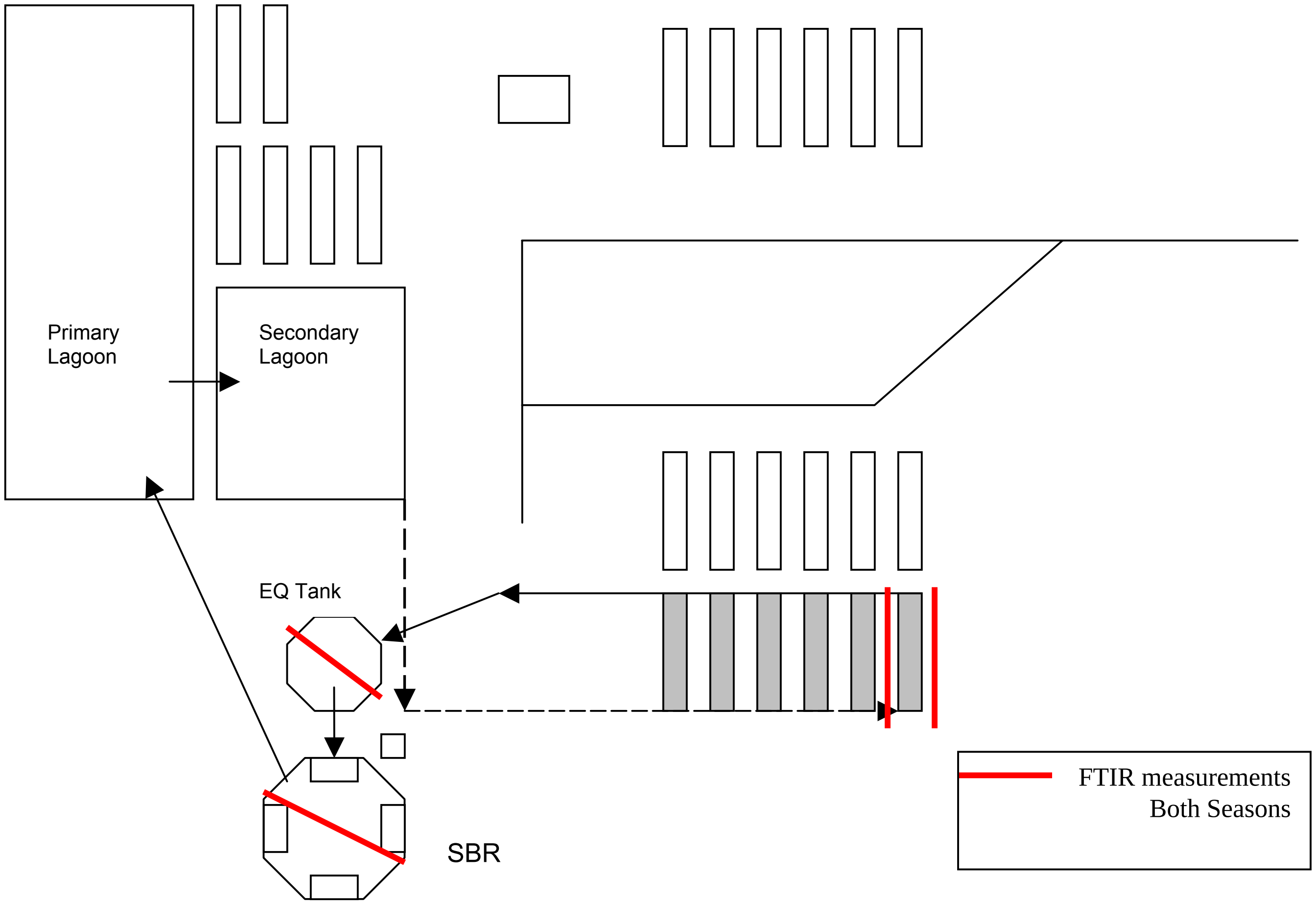


Figure 1.9 Fifteen-minute Average Concentrations and Standard Deviations Measured in February, 2004.

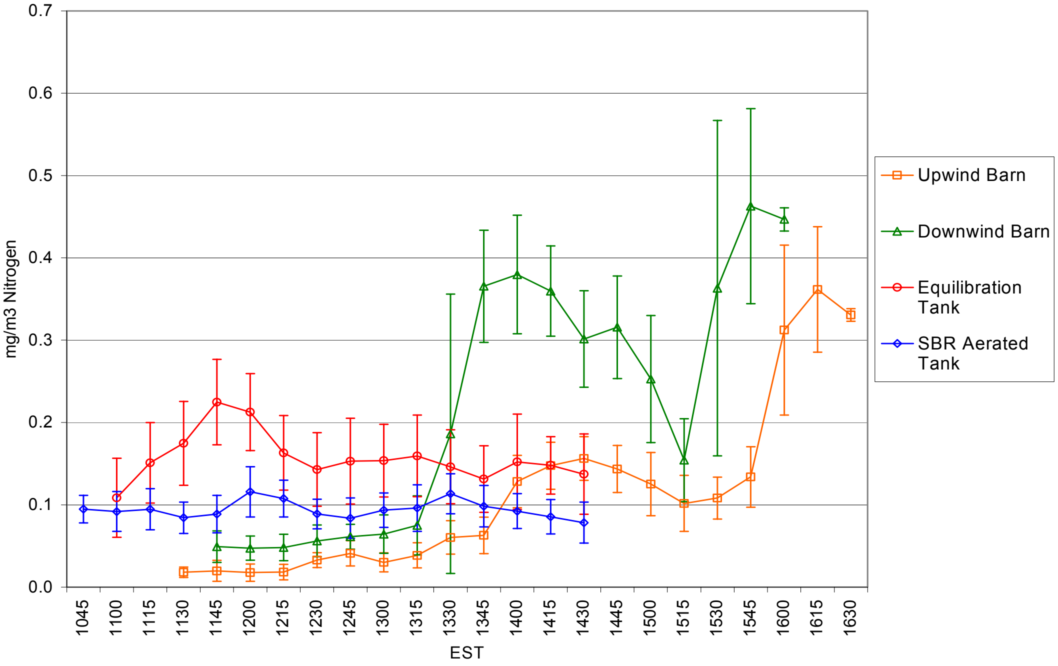


Figure 1.10 Fifteen-minute Average Concentrations and Standard Deviations Measured in April, 2004.

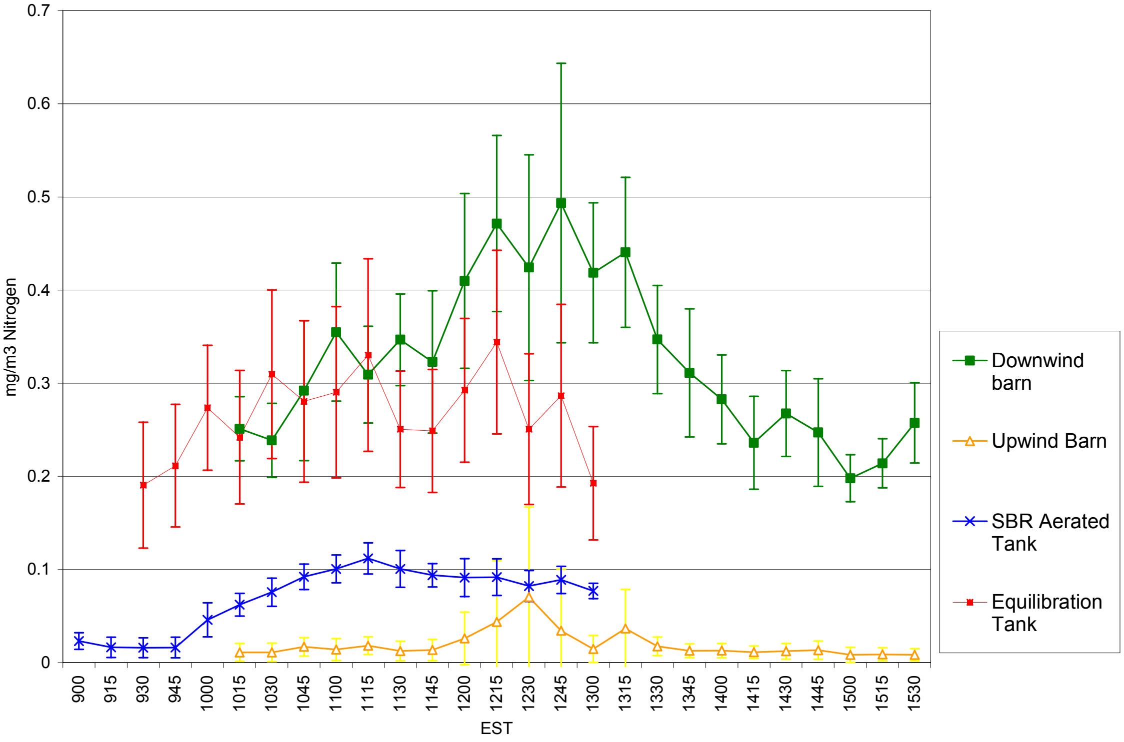


Table 1.12 Average Daily Concentrations of Nitrogen (mg N/m3)

Date	**Component**	
	Barn (mg N/ m3)	
2004	**Upwind Barn**	**Downwind Barn**
February 24	**0.114**	**0.222**
April 21	**0.020**	**0.324**
	Equalization Tank	
February 25	**0.157**	
April 22	**0.266**	
	SBR Aerated tank	
February 25	**0.094**	
April 22	**0.070**	

Estimated Ammonia Emissions from Barns

To calculate the average nitrogen flux from the naturally ventilated houses, air-flow measurements were made by sampling at one location along each of the four sections of the building on the upwind side while the OP-FTIR was deployed. Each location was sampled for 30-60 seconds and the high and low readings recorded for all four locations over a 5-7 minute period of time. The high and low wind velocity readings were used to calculate the average wind velocity. The curtain opening for each section was measured and the volume of air per second (ventilation rate) flowing through the upwind side of the barn was calculated as the sum of curtain openings times the average wind velocities for the four sections of the building. The net ammonia concentrations associated with emissions from the building were obtained by subtracting the upwind readings from the downwind readings using the OP-FTIR and then converting the difference to concentrations of ammonia. A moving average was then applied to the concentration data to reduce the effect of wind variations (times when the wind deviated from the predominate direction). Flux from the building was obtained by multiplying net ammonia concentration times the corresponding ventilation rate. The flux calculations were then normalized by the total live weight of swine in the house (1000 Kg LW) (Table 1.13).

Table 1.13 Flux Calculations for the Barn (KgN/Week/1000Kg weight of pigs)

Date	Location	KgN/Week /1000 KG
02/24/04	1 Barn	0.0054
04/21/04	1 Barn	0.71

Assessment of Ammonia Emissions from Alternative Technology:

At each alternative technology and conventional site, the estimated ammonia emissions are limited to two two-week long periods, representing warm and cold seasons. But, since measurements at different sites are made at different times of the year, environmental conditions are likely to be different at different sites, even during a representative "warm" or "cold" season. There is a need for accounting for these differences in our relative comparisons of the various alternative and conventional technologies.

The estimated emissions from water-holding structures at an alternative technology for each measurement period are compared with the average estimated emissions from baseline sites, after the later are adjusted to the average environmental parameters (lagoon temperature and air temperature) observed at the former (alternative technology) site. A rational basis for this adjustment for somewhat different environmental conditions is the multiple regression model developed for ammonia emissions and measured environmental parameters at the two baseline sites. The model is described in appendix 2 of the three-year progress report. Such a comparison would not require highly uncertain extrapolations of emissions at alternative technology sites beyond the two measurement periods.

Absolute numbers are not used in assessing ammonia emissions from the proposed alternative technology. A normalized measure of emissions (normalized to calculated N-excreted; $\%E_{EST}$) is compared to a similar normalized measure of emissions ($\%E_{CONV}$) from a baseline site using the conventional lagoon technology for handling swine waste in North Carolina. The %E values are an estimate of rate of loss of N compared to N excreted. Two baseline sites are used to account for differences in housing ventilation across the sites with the proposed EST's. No method exists for adjusting baseline housing emissions to environmental conditions observed at an EST farm. Therefore, actual housing emissions measured at the baseline sites during comparable seasons of the year are used when generating the normalized measures of emissions from houses. It is acknowledged that the housing emissions for the baseline sites were not made under the exact meteorological conditions as the housing measurements for evaluation of an EST. The algorithm followed in deriving an index of performance ($\%\text{reduction} = [(\%E_{CONV} - \%E_{EST})/\%E_{CONV}] * 100$) by the EST in reducing ammonia emissions as compared to the conventional technology currently in use in North Carolina (baseline sites) is presented in Fig. 1.11 for water holding structures.

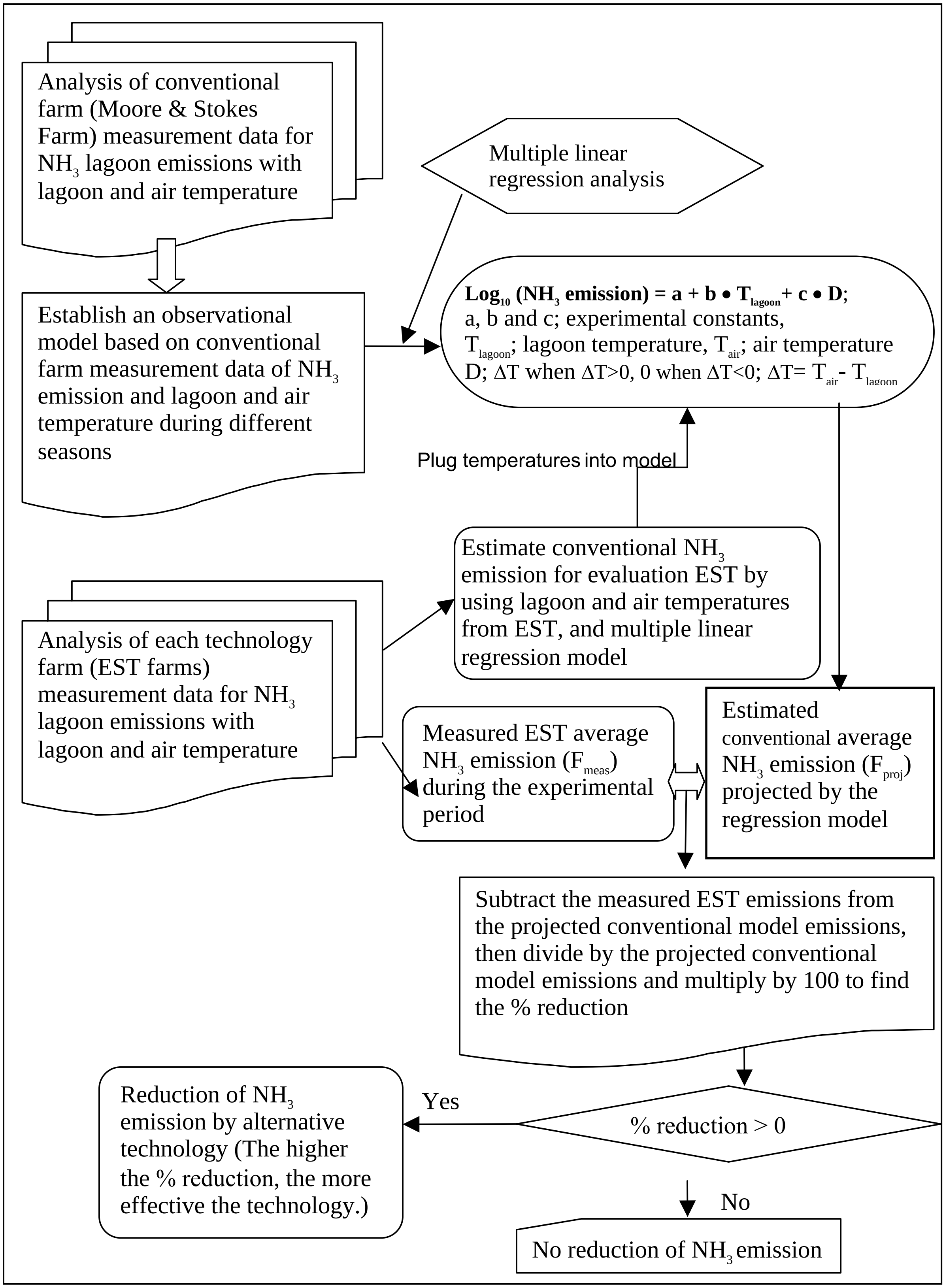


Figure 1.11 Algorithm flow chart for evaluation of alternative technology ammonia emission from water holding structures.

Evaluation of AHA Hunt farm (SBR)

We compare the lagoon NH_3-N emission from AHA Hunt farm with the projected average emission from lagoon at the conventional farm, using the observational statistical (multiple linear regression) model.

Table 1.14 gives animal weight, feed consumed, and N-excretion at baseline farms and AHA Hunt farm. Table 1.15 gives the NH_3-N emissions (kg-N/1000 kg-live weight/wk) data summary for the AHA Hunt farm and baseline farms for evaluation of EST at the former. The emissions from different components of an EST or baseline farm should be viewed relative to the estimated nitrogen excretion from animal population, weight and feed data.

Table 1.14 Summary of animal weight, and N-excretion at conventional farms (Stokes and Moore) and the EST (AHA Hunt; SBR) farm.

Farm Information	No. of pigs	average pig weight kg/pig	total pigs weight kg	N-excretion, E Kg-N/wk /1000kg-lw
Stokes (Sep.)	4,392	104.3	458,086	2.71
Jan.	3,727	88.5	329,840	2.51
Moore (Oct.)	7,611	52.3	398,055	4.39
Feb.	5,784	67.0	387,528	3.90
AHA Hunt (Feb-Mar)	10,909	59.2	645,813	4.08
Apr.	12,106	66.1	800,206	3.29

Table 1.15 Estimates of % reduction in NH_3-N emissions from different components and their sum total at the EST (AHA Hunt: SBR) and conventional farms (kg-N/wk/1000kg-*lw*). (% reduction = [(%E_{CONV}- %E_{EST})/%E_{CONV}]*100

(1) Primary Lagoon, Secondary Lagoon, Equalization Tank and SBR Tank Emissions

Period	Average lagoon temperature (°C)	Average D (°C)	Conventional model emissions F_{proj}	% E_{CONV}	SBR measured emission F_{meas}	% E_{EST}	% reduction
Feb 16- 27, Mar 3 & 8, 2004	5.4	1.1	0.11	3.4	0.17♣	4.2	-23.5
April 20-28, 2004	24.2	0.4	0.88	24.8	0.56♥	17.0	31.5

(2) Barn Emissions

Period	Stokes Farm measured emission	% E_{CONV}	SBR measured emission F_{meas}	% E_{EST}	% reduction
Feb 16- 27& Mar 3, 2004	0.25†	10.0	0.01	0.2	98.0
April 20-28, 2004	0.25†	10.0	0.71	19.5	-95.0

Total Emissions (1)+(2)

Period	conventional total emission	% E_{CONV}	SBR measured emission	% E_{EST}	% reduction
Feb 16- 27& Mar 3, 2004	0.36	13.4	0.80	4.4	67.2
April 20-28, 2004	1.13	34.8	2.32	36.5	-4.9

D is ΔT, the difference between the air temperature (T_{air}) and lagoon temperature (T_{lag}), when $T_{air} > T_{lag}$; D = 0 when $T_{air} < T_{lag}$. F_{proj} is baseline lagoon area adjusted NH_3 lagoon emission projected by the baseline multiple linear regression model corresponding to the average lagoon temperature and the average D during AHA Hunt (SBR) farm measurement periods. % E_{CONV} is the conventional model emissions relative to the N excreted. % E_{EST} is the measured emission from the EST relative to the N excreted. F_{meas} is sum of the NH_3 emission from water holding structures and NH_3 emission from barn house measured at AHA Hunt (SBR system) farm. ♣Emission from equalization tank and SBR tank was included (less than 1% of the total emission). ♥ Emission from equalization tank was included (less than 1% of the total emission). Soil flux measurements were not taken because there was no lagoon spray and land application during the experimental period. †: overall house emission measured at Stokes farm during January 2003. % reduction is used to describe how effective a technology is, in reducing NH_3 emissions. A number > 0 indicates a reduction in NH_3.The larger the % reduction, the more effective the technology is in reducing NH_3 emissions. Conversely a number < 0 indicates that there are has been no reduction in NH_3 emissions.

2. - Evaluation of Environmentally Superior Technologies for Ammonia Emissions: Carroll's

Aerobic Blanket System (ABS)

Alternative Technology: Aerobic Blanket System (ABS)

Location: Carroll's (Warsaw, NC)

Period of Operation:
The OPEN team monitored for evaluation during:
1st field experiment: 03/29 – 04/09/2004
2nd field experiment: 06/21 – 07/02/2004

Technology contact: Prince Dugba

NCSU Representative PI: Leonard Bull / Mike Williams

Statement of Task:

- Measurement of ammonia (NH_3) emissions from primary anaerobic lagoon and aerobic digester by using a flow-through chamber technology during two different campaigns (warm and cold seasons)
- Analysis of water samples from waste storage and treatment areas for Total Ammoniacal Nitrogen (TAN) and Total Kjeldahl Nitrogen (TKN) concentrations (one sample each day during the experimental period)
- On site monitoring of meteorological parameters at 10 meter height
- FTIR technology used to determine ammonia emissions from barns
- Parameters measured: NH_3 flux , storage lagoon temperature and pH, soil temperature, wind speed and direction, solar radiation, and air temperature

Description of Alternative Technology:
The waste stream in the proposed EST flows from the houses to a primary anaerobic lagoon equipped with the Aerobic Blanket System (ABS). The ABS consists of a fine mist of treated swine waste that is applied every 15 minutes to the surface of the anaerobic lagoon. During both evaluation periods, only half of the anaerobic lagoon was being treated by the ABS. The treated swine waste arises from an aeration treatment that takes place in an adjoining water-holding structure (aerobic digester). Waste from the anaerobic lagoon flows into an aerobic digester (IESS aeration system) that has a portion of the basin sectioned off with a plastic barrier. The aerated waste eventually flows into the sectioned-off portion of the aeration treatment basin and then is used to flush 2 of the 9 animal houses (other houses flushed with water from primary lagoon), and supplies the treated water for the ABS. During the first evaluation period, the IESS aeration system was not operational and treated waste for the ABS was derived by using two aeration treatment tanks. For the second evaluation, the aeration treatment basin was operating as designed. A schematic of the ABS system is shown in Fig. 2.1. Only waste from finishing houses

5 – 13 flows into the ABS-equipped anaerobic lagoon. Waste from the remaining farrow and nursery houses flows into a separate lagoon. These houses and their accompanying lagoon were not included in the evaluation of the EST.

- A conceptual flow-diagram of alternative technology;

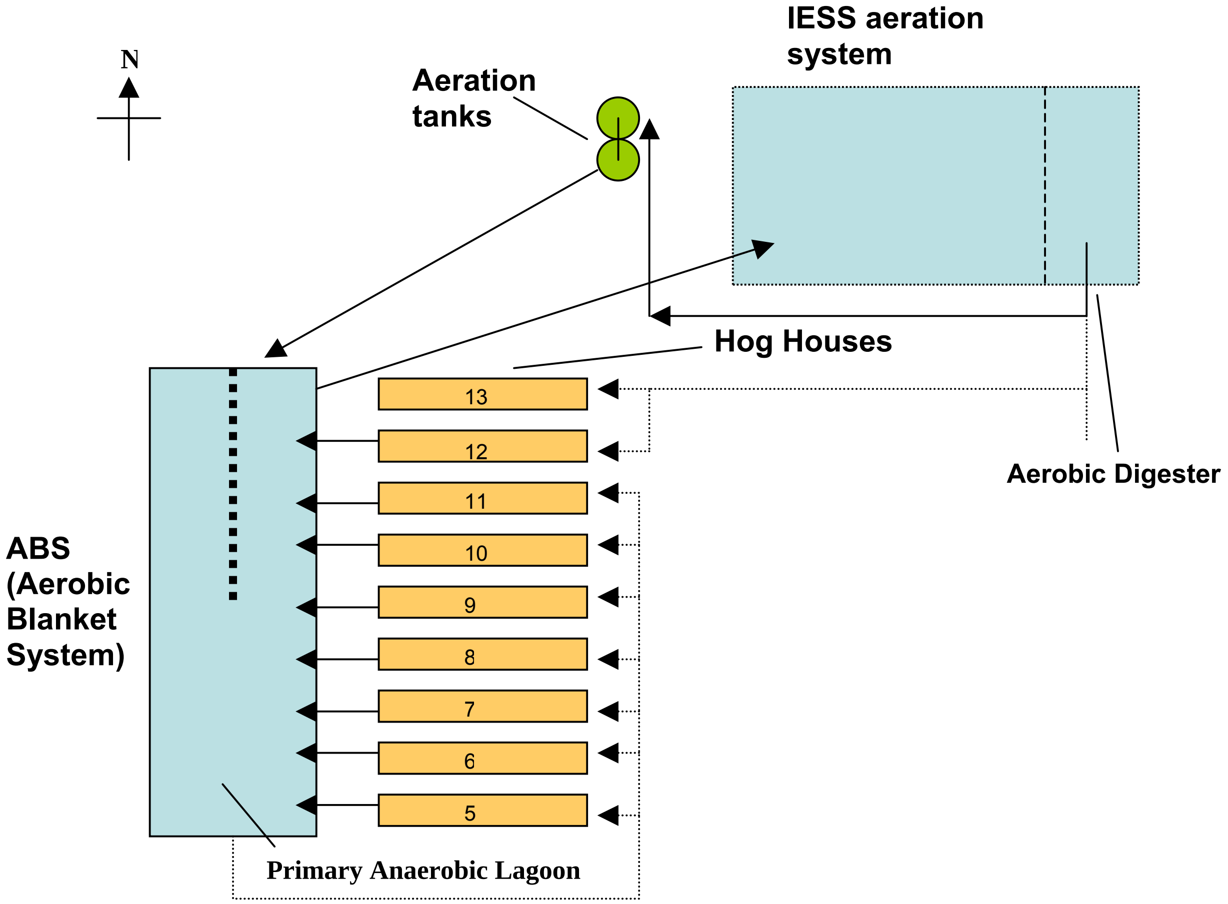


Figure 2.1 Conceptual flow diagram of Aerobic Blanket System (Carroll's).

(*Source; http //www.cals.ncsu.edu:8050/waste_mgt)*

- Possible points of emissions of ammonia on conceptual flow-diagram and parameters that are important in controlling emissions:

- Water holding structures: primary anaerobic lagoon equipped with ABS and IESS aerobic digester - water temperature and water chemistry (pH and TAN) are the major controlling factors.
- Animal houses: house operational technology flushing sequence and frequency are controlling variables as well as pH and TAN

- Treated swine waste used to in ABS: pH, TAN content of treated swine waste, frequency and duration of application

An aerial photo of Carroll's farm with EST is given below:

Aerial photo of ABS site (Carroll's farm).

- Table 2.1 Description of Animal Operation (value estimates provided by project investigators and/or animal contract company)

Sampling period (1st Evaluation) March 29- April 9, 2004

WEEK 1 3/29-4/4	**House 5 Finishing**	**House 6 Finishing**	**House 7 Finishing**	**House 8 Finishing**	**House 9 Finishing**	**House 10 Finishing**	**House 11 Finishing**	**House 12 Finishing**	**House 13 Finishing**
# of pigs / house	812	672	667	646	711	710	671	716	727
Wks in finishing	0	18	16	14	12	10	8	6	4
Ave. Wt of pigs (lbs.)	50.48	193.72	166.72	180.23	161.49	145.59	126.2	95.56	77.2
Feed consumed (lb/pig/wk)	16.4	39.3	32.1	32.1	32.1	32.6	29.0	24.3	21.0
WEEK 2 4/5-4/11	**House 5 Finishing**	**House 6 Finishing**	**House 7 Finishing**	**House 8 Finishing**	**House 9 Finishing**	**House 10 Finishing**	**House 11 Finishing**	**House 12 Finishing**	**House 13 Finishing**
# of pigs / house	812	669	665	642	707	703	666	706	727
Wks in finishing	1	19	17	15	13	11	9	7	5
Ave. Wt of pigs (lbs.)	66.09	212.97	185.97	197.17	180.19	164.29	142.15	111.18	92.82
Feed consumed (lb/pig/wk)	16.4	40.7	32.1	39.3	32.1	32.1	32.6	29.0	24.3

Table 2.2 Sampling period (2nd Evaluation): June 21 – July 2, 2004

WEEK 1 6/21-6/27	**House 5 Finishing**	**House 6 Finishing**	**House 7 Finishing**	**House 8 Finishing**	**House 9 Finishing**	**House 10 Finishing**	**House 11 Finishing**	**House 12 Finishing**	**House 13 Finishing**
# of pigs / house	806	749	811	882	754	732	632	680	692
Wks in finishing	11	7	5	3	1	0	20	18	16
Ave. Wt of pigs (lbs.)	155.54	139.34	108.99	82.3	60.65	45.6	238.78	206.34	187.76
Feed consumed (lb/pig/wk)	32.6	32.6	24.3	21.0	16.4	16.4	40.0	39.3	32.1
WEEK 2 6/28-7/2	**House 5 Finishing**	**House 6 Finishing**	**House 7 Finishing**	**House 8 Finishing**	**House 9 Finishing**	**House 10 Finishing**	**House 11 Finishing**	**House 12 Finishing**	**House 13 Finishing**
# of pigs / house	806	746	810	881	752	732	0	676	692
Wks in finishing	12	8	6	4	2	1	0	19	17
Ave. Wt of pigs (lbs.)	166.32	150.19	119.49	92.8	70.8	55.54	N/A	217.12	198.54
Feed consumed (lb/pig/wk)	32.1	32.6	29.0	24.3	21.0	16.4	N/A	40.7	39.3

- Feed Nutrients

Table 2.3 Total elemental analysis of feed samples (5 samples in total, %N measurement is replicated 5 times, %P, Cu, Zn, measurements are replicated 3 times).

Date	%N	%P	Cu(ppm)	Zn(ppm)
March 29, 2004	2.56 ± 0.11	0.55 ± 0.01	19.7 ± 1.8	125 ± 2
June 21, 2004	2.67 ± 0.11	0.59 ± 0.01	22.8 ± 2.2	123 ± 2

Nitrogen Excretion

Computation of Nitrogen Excretion Based on Animal Feed Data (Carroll's farm: ABS Technology-Evaluation period, March 29 – April 9, 2004) Note: Sampling was only conducted the week of March 29, therefore only that week's production data was used to calculate nitrogen excretion.

- Animal population / Types:
  - Total number of pigs (finishing) in 9 finishing houses = 6332
  - Weighted average weight of the pigs =130.48 lb/pig = 59.19 kg/pig

- Nitrogen Intake
  - Average feed consumed = 12.89 kg/pig/wk
  - Average nitrogen content of the feed = 2.56% (from Feed Analysis)
  - Average nitrogen intake per pig = 0.33 kg-N/pig/wk

- Nitrogen Excretion
  - Average gain / feed or feed efficiency rate (ER) for feeder-finish operation, based on the 1999 Pig CHAMP data = 0.3
  - Average N excretion = (1-0.3) x 0.35 = 0.23 kg-N/pig/wk
  - Average N excretion on animal weight (*lw*) basis = 3.90 *kg-N/1000kg animal live weight(lw)/wk*

Computation of Nitrogen Excretion Based on Animal Feed (Carroll's Farm: ABS Technology-Evaluation period, June 21 – July 2, 2003) Note: Sampling was only conducted the week of June 28, therefore only that week's production data was used to calculate nitrogen excretion.

- Animal population / Types:
  - Total number of pigs in 9 finishing houses = 6095
  - Weighted average weight of the pigs =131.7 lb/pig = 59.74 kg/pig

- Nitrogen Intake
    - Average feed consumed = 13.21 kg/pig/wk
    - Average nitrogen content of the feed = 2.67% (from Feed Analysis)
    - Average nitrogen intake per pig = 0.35 kg-N/pig/wk

- Nitrogen Excretion
    - Average gain / feed or feed efficiency rate (ER) for feeder-finish operation, based on the 1999 Pig CHAMP data = 0.3
    - Average N excretion = (1-0.3) x 0.34 = 0.24 kg-N/pig/wk
    - Average N excretion on animal weight (*lw*) basis = *4.13 kg-N/1000kg animal live weight(lw)/wk*

Meteorological Measurements

Monthly/Annual Climate Data Results at the nearest weather station
8.5 km from sampling site
(*Source: State Climatology Office)*

Summary of monthly precipitation (cm) from 1994 to 2004
WARSAW 5 E, NC (UCAN: 14389,COOP: 319081)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1994	11.66	4.57	-	1.96	6.27	24.92	23.32	13.74	12.57	8.26	11.18	3.76	122.20
1995	8.94	11.13	10.72	1.35	8.41	40.26	12.09	3.40	4.90	11.56	10.39	4.19	127.33
1996	7.52	-	12.62	6.05	4.70	7.34	26.52	-	-	18.29	5.74	8.41	97.18
1997	8.10	7.34	8.03	8.00	6.63	7.14	16.94	8.36	19.13	5.21	13.06	11.33	119.25
1998	16.38	19.33	11.73	13.26	9.98	5.66	12.93	27.43	6.73	0.81	3.76	13.03	141.05
1999	18.36	5.56	6.96	11.66	8.20	13.21	13.74	28.45	62.31	7.16	5.72	4.06	185.39
2000	14.35	4.57	16.31	11.63	4.06	11.86	14.86	9.91	20.45	0.00	6.86	3.30	118.16
2001	2.08	9.42	18.44	1.45	11.89	16.59	7.21	14.00	-	2.92	3.30	2.59	89.89
2002	15.14	4.80	17.78	5.59	6.07	12.12	8.74	13.97	3.91	7.90	10.97	6.88	113.87
2003	4.09	12.42	16.00	14.10	15.19	13.61	45.87	9.09	10.36	13.00	5.21	12.27	171.22
2004	2.92	13.23	2.44	**14.86**	15.95	**11.81**	8.51	24.13	14.40	5.89	12.70	4.19	131.04
AVG	10.66	8.79	13.18	7.50	8.14	15.27	18.22	14.26	17.55	7.51	7.62	6.98	128.55

Carrolls Precipitation Data Analysis WARSAW 5 E, NC (UCAN: 14389,COOP: 319081)

Compared to the 10-year precipitation average of 7.5 cm for the month of April (1994-2003), Carroll's, conducted for March 29th- April 9, 2004, showed a much higher precipitation average of 14.9 cm, a difference of 7.4 cm, however this is within the range for the last ten years. Compared to the ten year precipitation average of 15.3 cm for the month of June, Carroll's, conducted for June 21- July 2, 2004, showed a lower precipitation average of 11.8 cm, a difference of 3.5 cm, however, the average is in the range of the data for the last ten years. The 10-year annual precipitation total (1994-2003) was 128.6 cm, while the annual precipitation total for 2004 was 131.0cm, a difference of 2.4 cm.

Summary of monthly mean temperature (^oC) from 1994 to 2004
WARSAW 5 E, NC (UCAN: 14389,COOP: 319081)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1994	5.91	8.69	-	18.35	19.72	26.38	27.92	25.43	21.88	15.78	14.13	9.81	17.63
1995	6.80	5.97	12.28	17.14	20.77	23.75	27.31	26.38	22.31	18.64	9.32	4.86	16.29
1996	5.68	-	8.74	16.18	21.36	24.74	26.33	-	-	17.56	9.87	9.44	15.55
1997	6.45	9.53	14.97	14.38	18.48	22.51	27.08	24.73	22.21	16.42	10.71	7.89	16.28
1998	8.88	9.18	11.55	15.87	21.08	26.29	27.41	25.79	24.22	16.65	12.76	10.31	17.50
1999	9.24	8.78	9.82	17.24	19.43	23.38	26.72	26.66	22.57	16.55	14.73	7.84	16.91
2000	5.06	9.21	13.23	15.51	-	25.04	25.03	25.23	22.52	16.18	10.17	3.64	15.53
2001	6.03	9.81	10.23	16.60	20.38	24.77	24.57	25.67		15.73	14.84	10.82	16.31
2002	7.84	8.69	12.75	18.82	19.66	24.91	26.87	26.26	24.12	18.95	10.29	5.95	17.09
2003	3.47	7.11	12.91	15.25	20.56	24.40	26.07	26.49	22.12	16.52	14.72	6.14	16.31
2004	4.54	5.94	12.50	**16.40**	22.91	**24.96**	26.45	24.39	22.81	17.33	13.07	6.94	16.52
AVG	6.53	8.55	11.83	16.53	20.16	24.62	26.53	25.85	22.74	16.90	12.16	7.67	16.54

Carrolls Mean Temperature Data Analysis WARSAW 5 E, NC (UCAN: 14389,COOP: 319081)

Compared to the 10-year temperature average of 16.5°C for the month of April (1994-2003), Carroll's, conducted for March 29th- April 9, 2004, showed a slightly lower temperature average of 16.4°C , a difference of 0.1°C. Compared to the ten year temperature average of 24.6°C for the month of June, Carroll's, conducted for June 21- July 2, 2004, showed a slightly higher temperature average of 25.0°C, a difference of 0.4°C.
The 10-year annual temperature average (1994-2003) was 16.5°C, this is the same as the temperature average for 2004.

- Site Meteorological data measured during the measurement periods:

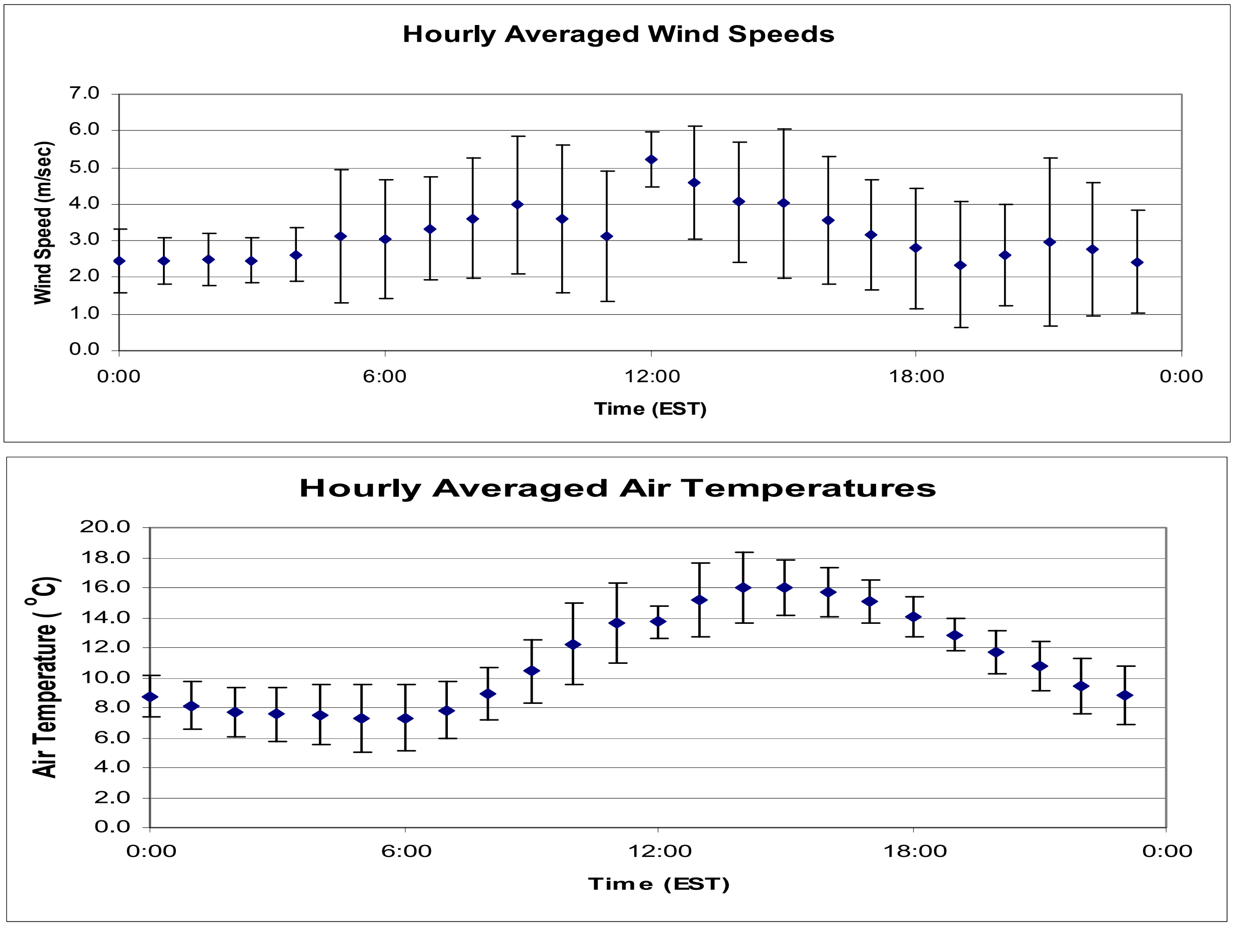


Figure 2.2 Site meteorological data during the 1st measurement period (March 29- April 2, 2004). Error bar indicates ±1 standard deviation of 15 minute averages.

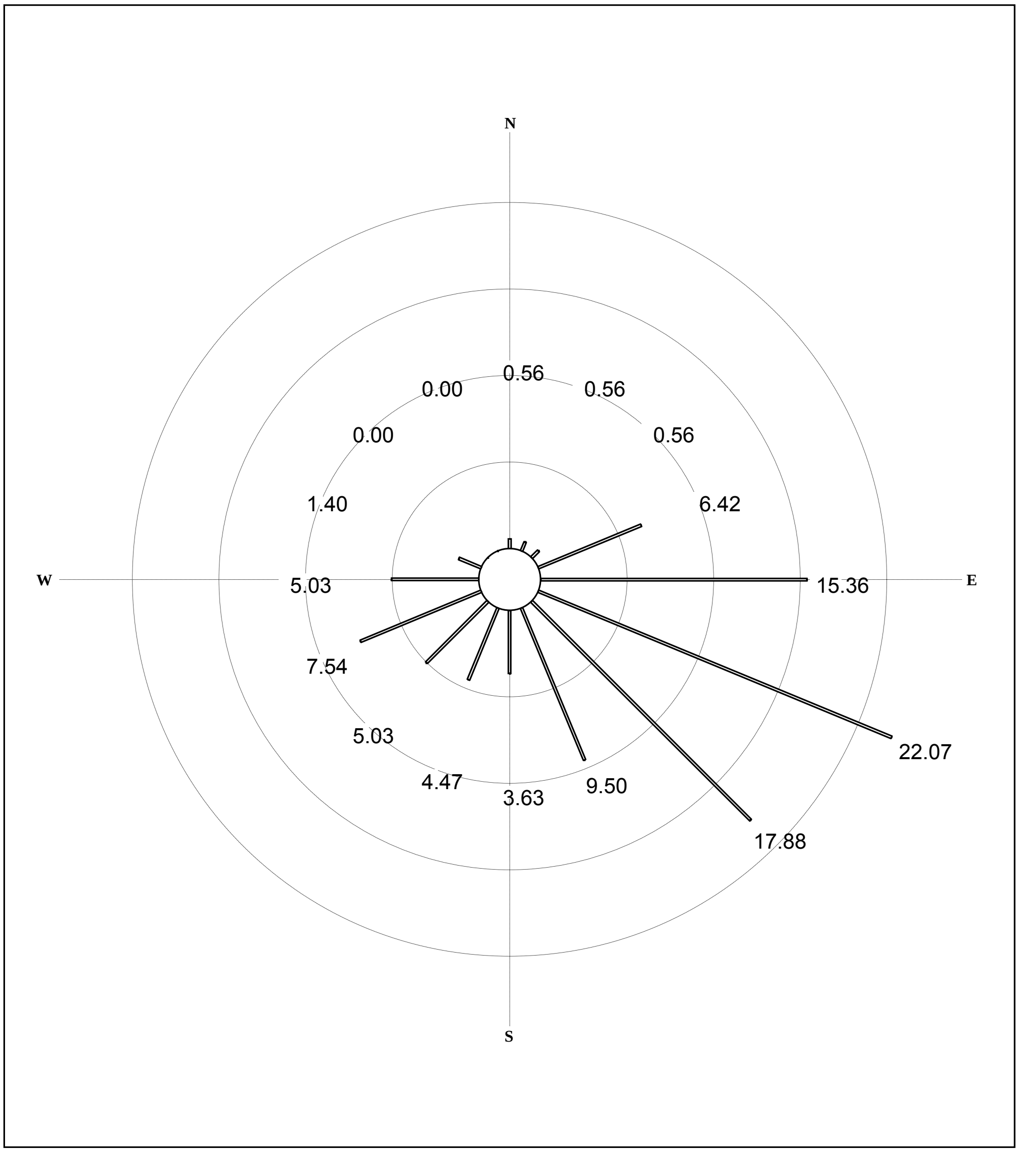
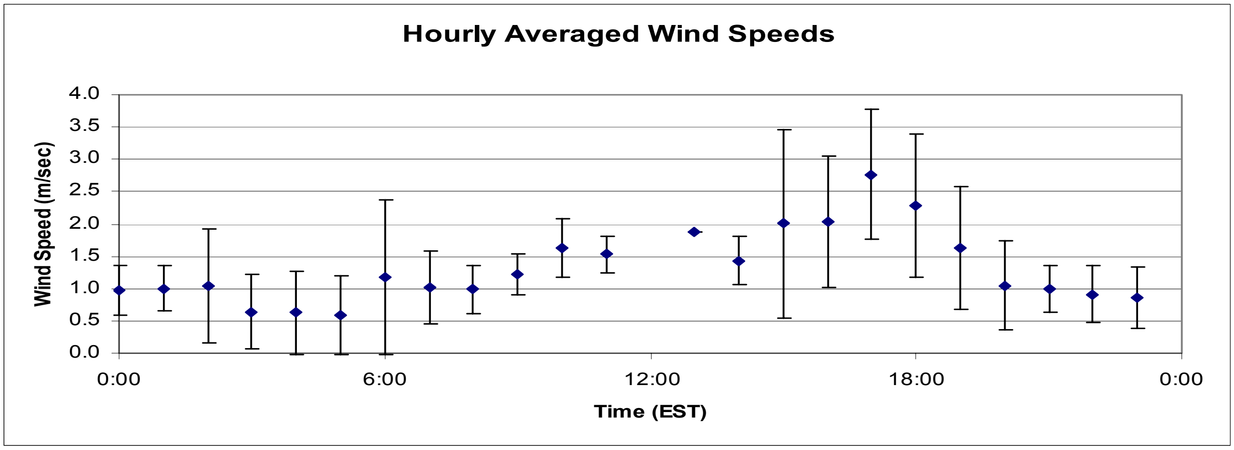


Figure 2.3 Wind rose depicting % wind direction during the 1st measurement period (March 29- April 2, 2004).



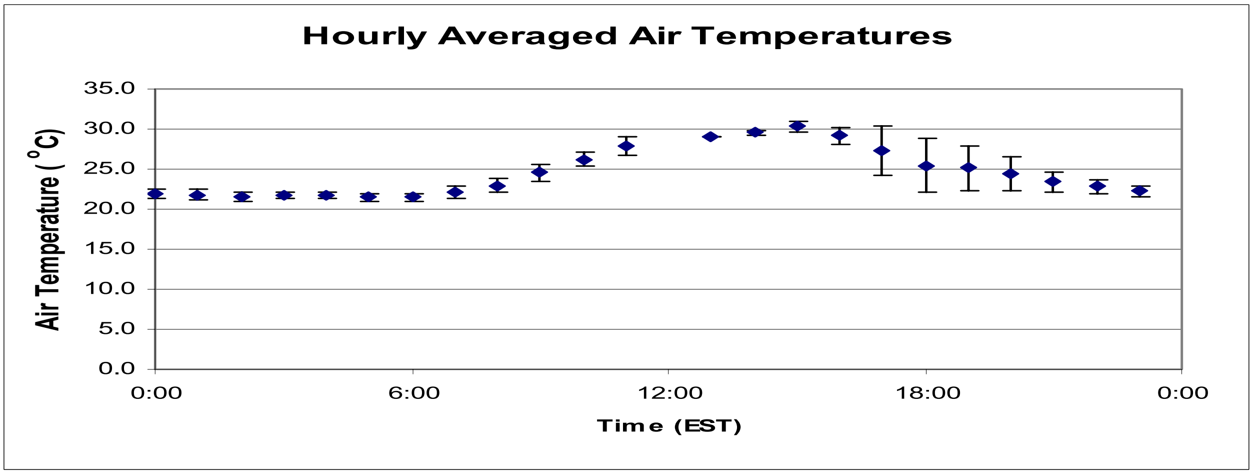


Figure 2.4 Site measurement data during 2nd measurement period (June 28- July 2, 2004). Error bar indicates ±1 standard deviation of 15 minute averages.

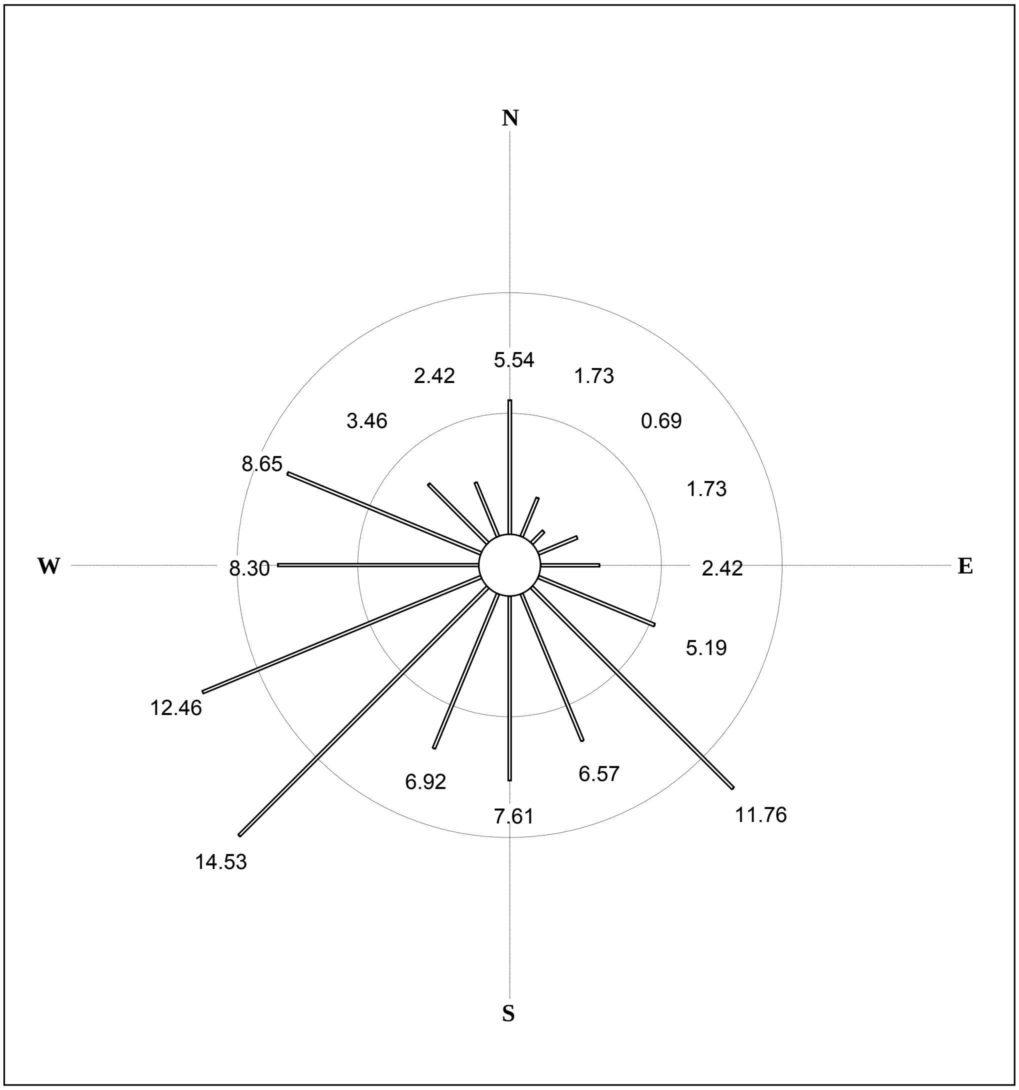


Figure 2.5 Wind rose depicting % wind direction during 2nd measurement period (June 28-July 2, 2004).

Measurement of Ammonia Fluxes and Emissions

Emission Sources -

Major sources of NH_3 are the hog houses, ABS lagoon and IESS lagoon, and biogenic emissions from soils during land applications. In all of the liquid waste environments, the NH_3 fluxes are expected to depend on ambient air temperature, water temperature, pH, wind speed and N in waste effluent. The flux chamber was deployed on water-holding structures measuring NH_3 fluxes directly from their surfaces. For the houses, NH_3 emission was determined by using average NH_3 concentration across plumes from exhaust fans and estimated air flow rate from fans.

Dynamic-Chamber Technique for NH_3 flux measurement

The measurement schedule followed for determining the flux of ammonia from the water-holding structures using the dynamic-chamber technique is described in Table 2.4. Measured flux (presented as hourly averages) as a function of time is presented in Figures 2.7 and 2.8. Tabulated hourly average flux values for each water-holding structure are presented in Table 2.5. Table 2.5 also contains the overall average flux values for each water-holding structure for each evaluation period. Table 2.6 contains TAN and TKN concentrations of the effluent from the water-holding structures. Table 2.7 presents total emissions of ammonia (kg-N) per week for each water-holding structure calculated for each evaluation period and normalized to 1000 kg live weight of animals present.

- Carrolls Farm(1st and 2nd Measurement Periods: March 29- April 9, 2004; June 21- July 2, 2004)

Table 2.4 NH_3 emission measurement schedule at Carroll's farm (1st and 2nd measurement period)

Sample dates	Parameters	Instruments	Sample plots	Remarks
March 29-31, 2004	NH_3 flux, lagoon T, lagoon pH, WD, WS, SR, air T, RH	One NH_3 analyzer, Meteorological instruments	West side of aerated lagoon-2 different plots randomly selected.	Completed 2 diurnal measurements
March 31-April 1, 2004	NH_3 flux, , lagoon T, lagoon pH, WD, WS, SR, air T,RH	One NH_3 analyzer, Meteorological instruments	East side of aerated lagoon-2 different plots randomly selected.	Completed 1 diurnal measurements
April 1-2, 2004	NH_3 flux, lagoon T, lagoon pH, WD, WS, SR, air T, RH	Two NH_3 analyzers (1 for emission and 1 for ambient), Meteorological instruments	Primary anaerobic lagoon-2 different plots randomly selected.	Completed 1 diurnal measurements

T = temperature; WD = wind direction; WS = wind speed; SR = solar radiation; RH = relative humidity

Water samples at each plot were collected every day for analysis of TAN and TKN concentrations at the laboratory.

Sample dates	Parameters	Instruments	Sample plots	Remarks
June 28-29, 2004	NH_3 flux, lagoon T, lagoon pH, WD, WS, SR, air T, RH	One NH_3 analyzer, Meteorological instruments	East side of aerated lagoon- 2 different plots randomly selected.	Completed 1 diurnal measurements
June 29-30, 2004	NH_3 flux, lagoon T, lagoon pH, WD, WS, SR, air T, RH	One NH_3 analyzer, Meteorological instruments	West side of aerated lagoon- 2 different plots randomly selected.	Completed 1 diurnal measurements
June 30- July 2, 2004	NH_3 flux, lagoon T, lagoon pH, WD, WS, SR, air T,RH	One NH_3 analyzer, Meteorological instruments	Primary anaerobic lagoon- 2 different plots randomly selected.	Completed 2 diurnal measurements

T = temperature; WD = wind direction; WS = wind speed; SR = solar radiation; RH = relative humidity

Water samples at each plot were collected every day for analysis of TAN and TKN concentrations at the laboratory.

Site photos during experimental period

1st Evaluation: Primary anaerobic lagoon with ABS “off”

2nd Evaluation: Primary anaerobic lagoon with ABS “on”

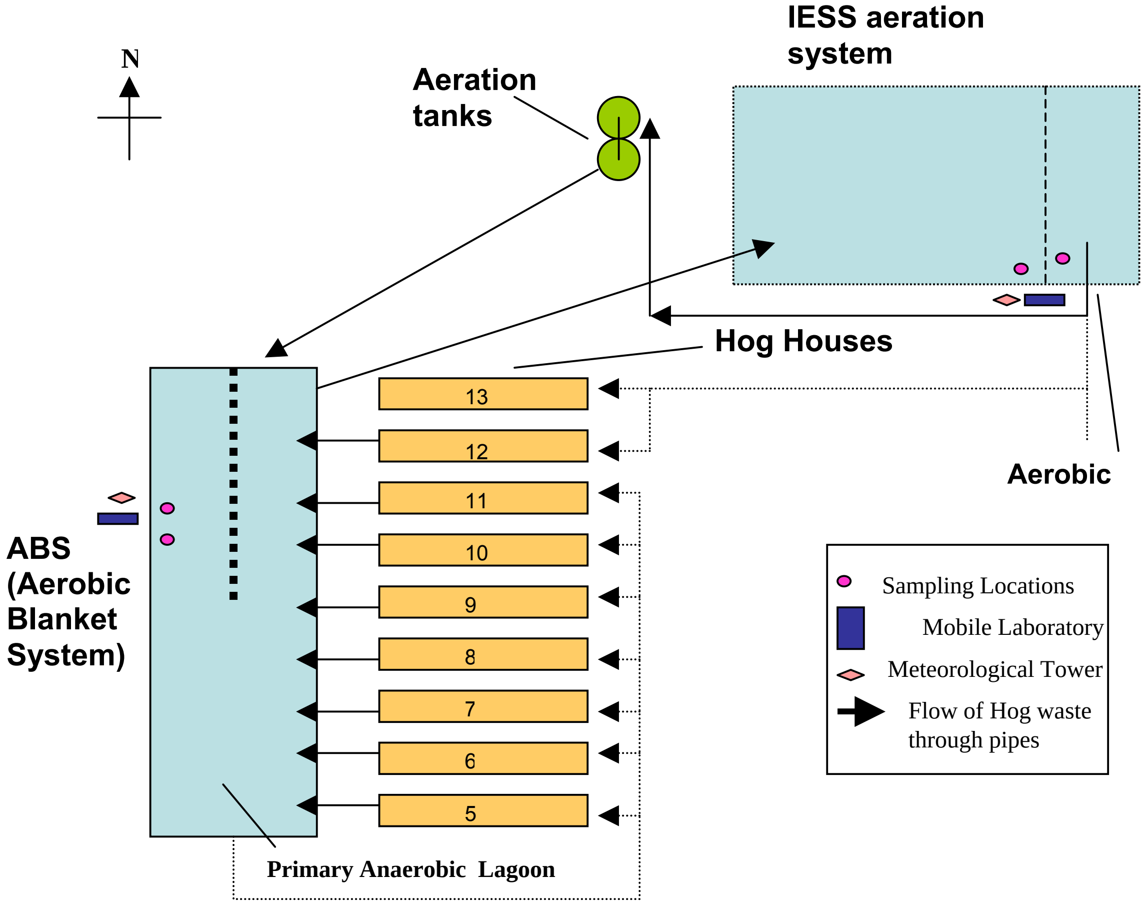


Figure 2.6 Experimental site layout and measurement locations.

1st Measurement period (March 29- April 2, 2004)

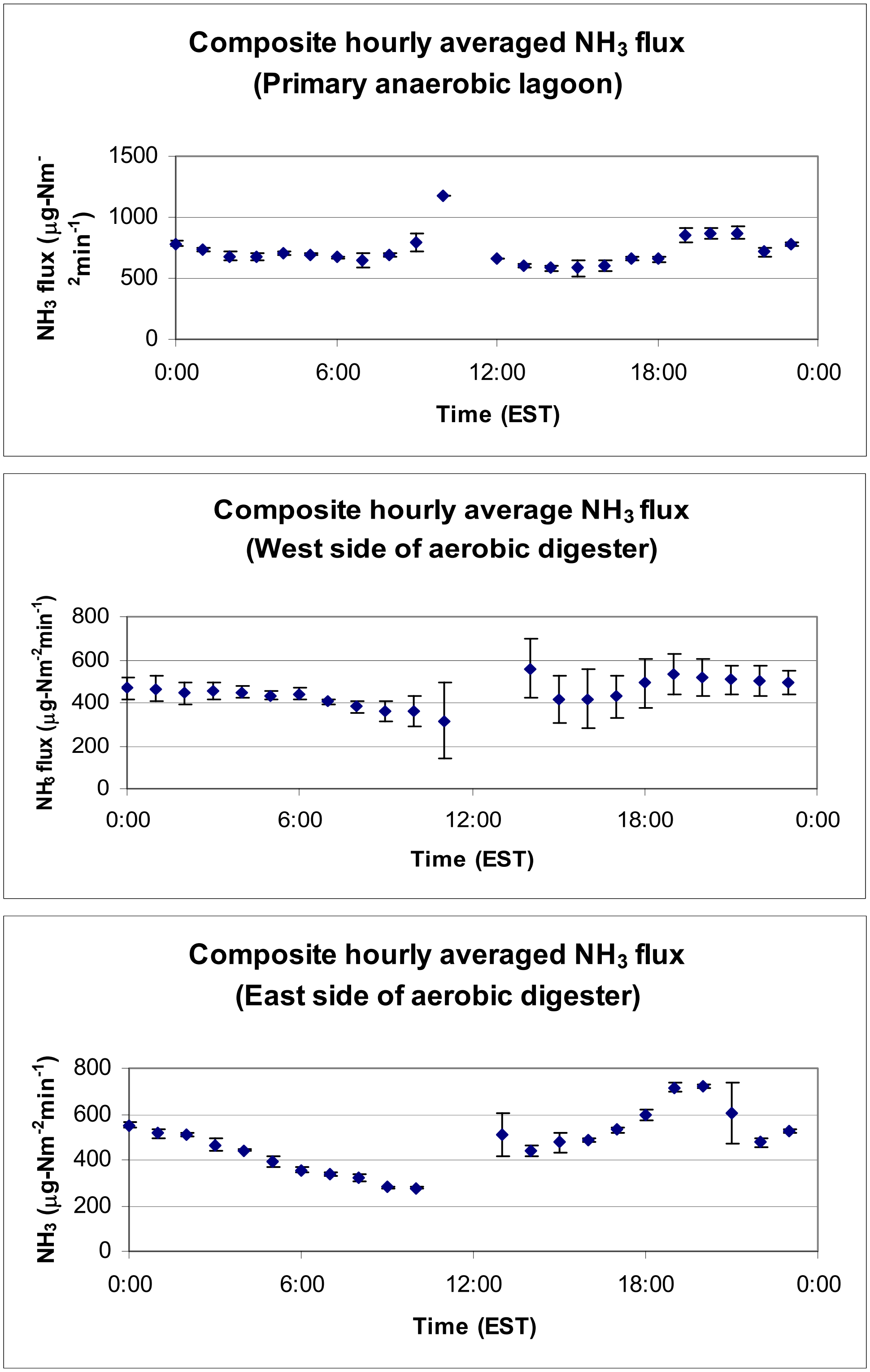


Figure 2.7 Diurnal variation of NH_3 flux from primary anaerobic lagoon, west side of aerobic digester and east side of aerobic digester during the 1st measurement period. Error bar indicates ±1 standard deviation of 15 minute averages.

2nd Measurement period (June 28-July 2, 2004)

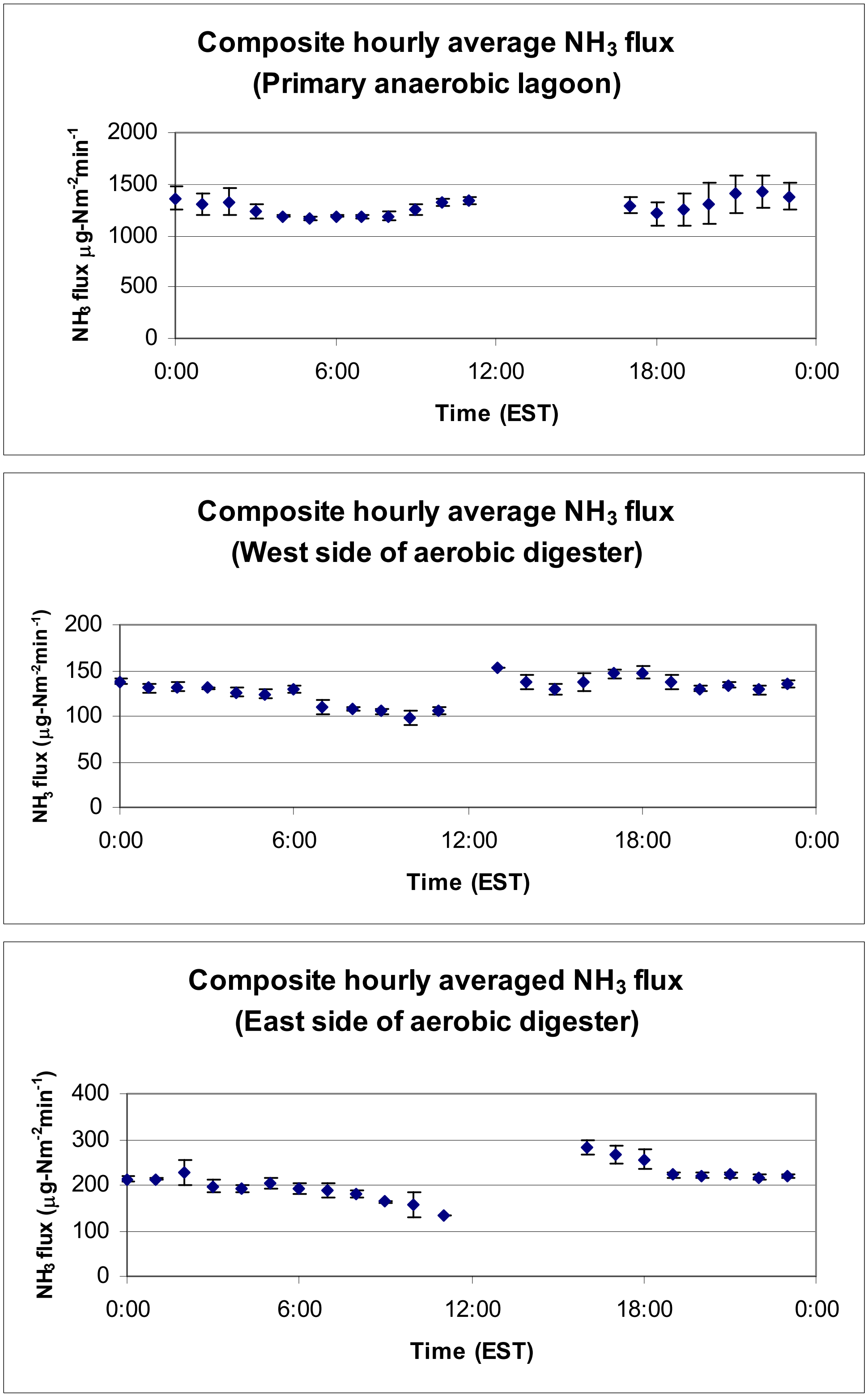


Figure 2.8 Diurnal variation of NH_3 flux from primary anaerobic lagoon, west side of aerobic digester and east side of aerobic digester during the 2nd measurement period. Error bar indicates ±1 standard deviation of 15 minute averages.

Table 2.5 Summary of hourly and overall averaged NH_3 flux from the water holding structures during the experimental periods.

Carroll's 1st Period

	NH_3 flux (μg-N m^{-2} min^{-1}) (1st period: 3/29-4/2/2004)					
	West side of aerobic digester		East side of aerobic digester		Primary anaerobic lagoon	
EST	hrly avg	stdev	hrly avg	stdev	hrly avg	stdev
0:00	469.9	50.5	550.6	11.3	786.6	18.2
1:00	466.5	56.2	513.9	17.7	731.1	15.7
2:00	443.2	50.9	509.9	6.6	683.7	41.0
3:00	454.6	40.7	463.8	27.7	671.9	30.8
4:00	447.4	27.7	442.7	6.8	707.9	9.9
5:00	434.2	21.6	391.0	24.3	694.1	6.3
6:00	442.2	25.0	356.1	13.6	670.7	6.5
7:00	405.4	13.5	339.4	6.3	644.2	60.2
8:00	382.7	27.6	322.9	15.7	695.8	17.1
9:00	360.4	43.6	279.5	6.0	793.9	79.7
10:00	358.3	70.0	276.5	2.0	1175.4	
11:00	316.5	176.0				
12:00					655.4	
13:00			507.9	96.0	605.3	17.7
14:00	559.9	136.7	439.1	24.0	582.5	24.5
15:00	416.6	111.9	477.3	42.0	582.9	68.2
16:00	418.0	136.4	487.9	9.4	597.4	45.7
17:00	428.5	99.9	529.9	14.7	668.7	14.4
18:00	492.7	113.3	594.7	23.5	659.6	21.8
19:00	534.7	96.0	717.1	19.9	855.7	59.0
20:00	517.3	84.6	721.3	6.1	871.9	43.7
21:00	506.5	66.9	602.7	135.9	874.3	52.5
22:00	503.6	69.7	476.3	18.1	715.7	37.3
23:00	492.6	53.1	525.9	7.7	779.9	11.2
average†	447.8		478.5		726.3	
stdev	60.9		121.1		130.6	
# of data	22.0		22		23	
average‡	446.7		480.2		713.1	
stdev	93.0		123.1		106.3	
# of data	170.0		85		86	
(15 min)			T_{lag}=15.0±1.3(n=441)			

† Statistics for hourly averages

‡ Statistics for 15 minute averages for the experimental period

Carroll's 2nd Period

	NH_3 flux (μg-N m^{-2} min^{-1}) (2nd period: 6/28-7/2/2004)					
	West side of aerobic digester		East side of aerobic digester		Primary anaerobic lagoon	
EST	hrly avg	stdev	hrly avg	stdev	hrly avg	stdev
0:00	137.9	3.0	212.5	5.5	1364.0	108.2
1:00	131.0	4.7	213.1	2.6	1304.0	105.3
2:00	131.7	4.8	226.8	28.5	1330.2	132.7
3:00	130.5	1.3	196.8	13.0	1240.4	66.9
4:00	125.9	4.7	193.5	7.9	1186.3	9.1
5:00	124.4	5.7	203.9	11.2	1162.5	20.4
6:00	129.2	3.2	193.1	12.1	1188.5	7.5
7:00	109.5	7.7	186.7	15.3	1181.1	21.8
8:00	107.4	1.7	181.6	8.2	1189.0	48.5
9:00	105.2	2.7	162.9	1.7	1249.0	53.7
10:00	97.7	7.5	156.7	27.8	1316.1	33.8
11:00	105.4	3.9	133.9		1337.4	32.8
12:00						
13:00	153.0					
14:00	136.7	7.5				
15:00	130.0	5.9				
16:00	137.6	10.3	281.5	14.7		
17:00	146.1	5.6	266.9	18.9	1293.0	77.8
18:00	147.9	7.2	255.8	21.9	1212.7	108.6
19:00	137.3	7.7	222.4	6.3	1246.8	154.5
20:00	130.0	2.7	220.2	5.8	1312.8	192.4
21:00	134.2	3.5	222.6	5.8	1402.9	182.7
22:00	128.6	5.2	216.9	5.0	1429.3	158.2
23:00	134.8	4.3	219.5	5.7	1380.4	131.2
average†	128.3		208.4		1280.3	
stdev	14.4		35.7		81.9	
# of data	23.0		20		19	
average‡	127.5		209.4		1295.8	
stdev	14.4		32.9		135.6	
# of data	89.0		75		116	
(15 min)			T_{lag}=29.1±1.2(n=287)			

† Statistics for hourly averages

‡ Statistics for 15 minute averages for the experimental period

Table 2.6 Total Ammoniacal Nitrogen (TAN) and Total Kjeldahl Nitrogen (TKN) averages and their standard deviation from water-holding structures at Carroll's farm.

	West side of aerobic digester		**East side of aerobic digester**		**Primary anaerobic lagoon**	
	TKN (mg-N l^{-1})	TAN (mg-N l^{-1})	TKN (mg-N l^{-1})	TAN (mg-N l^{-1})	TKN (mg-N l^{-1})	TAN (mg-N l^{-1})
1st Period (Mar 29- Apr 2)	331.0 n=1	253.0 n=1	393.0±39.6 n=2	279.5±16.3 n=2	749.0±1.4 n=2	605.5±3.5 n=2
2nd Period (Jun 28-Jul 2)	387.0 n=1	235 n=1	91.8±44.1 n=2	35.0±9.8 n=2	481.0±4.6 n=3	384.0±4.6 n=3

n represents the total number of effluent samples collected at each water-holding structure.

Table 2.7 Summary of total emissions from water-holding structures at ABS during the experimental periods.

1st Period

Water holding structure	East side of aeration lagoon	West side of aeration lagoon	ABS lagoon
Area (m^2)	3304.8	6010.2	5068.8
Weekly NH_3 emission (kg-N/wk)	14.9	29.1	36.4
Total emission from tanks and lagoon (kg-N/wk)	80.4		
Total emission/pig (kg-N/pig/wk)	0.01		
Total emission/1000 kg-lw (kg-N/1000kg-lw/wk)	0.22		

Note: aeration system was not operating during the 1st evaluation period

2nd Period

Water holding structure	East side of aeration lagoon	West side of aeration lagoon	ABS lagoon
Area (m^2)	3304.8	6010.2	5068.8
Weekly NH_3 emission (kg-N/wk)	4.2	12.7	66.2
Total emission from tanks and lagoon (kg-N/wk)	83.1		
Total emission/pig (kg-N/pig/wk)	0.01		
Total emission/1000 kg-lw (kg-N/1000kg-lw/wk)	0.23		

Average ammonia concentrations using Open-Path Fourier Transform Infrared (OP-FTIR) Spectrometers

OP-FTIR spectrometer concentration measurements were obtained during March 30-31 and June 22-23, 2004. For the March measurement period, data was collected over the spray side and non-spray side of the lagoon. During both March and June, the sprayers were turned on for a few minutes every 15 minutes. Measurements were obtained along with a record of when the spray was on and when it was off. The concentrations during each 15-minute time interval were compared when the spray was on and when the spray was off, there was no statistical difference found in the measurements regardless of whether the spray was on or off.

Measurements of fan concentrations were also made at either end of the row of nine houses across the centerline of the fans. For the June measurement period, data was collected over the spray side of the lagoon. Measurements were also made at either end of the row of the first five houses with the centerline of the fans to measure fan concentrations, see Figure 2.9. Figure 2.10 shows the 15-minute average concentrations and standard deviations in mg--N/m3 for all locations in March, 2004. Figure 2.11 shows the 15-minute average concentrations and standard deviations in mg--N/m3 for all locations in June, 2004. Table 2.8 lists the average daily concentrations of nitrogen in mg/m3. Figures 2.12 and 2.13 compare the concentrations of nitrogen when the spray was on off in March and June, respectively.

Figure 2.9 Locations of Measurements taken with the OP-FTIR Spectrometers.

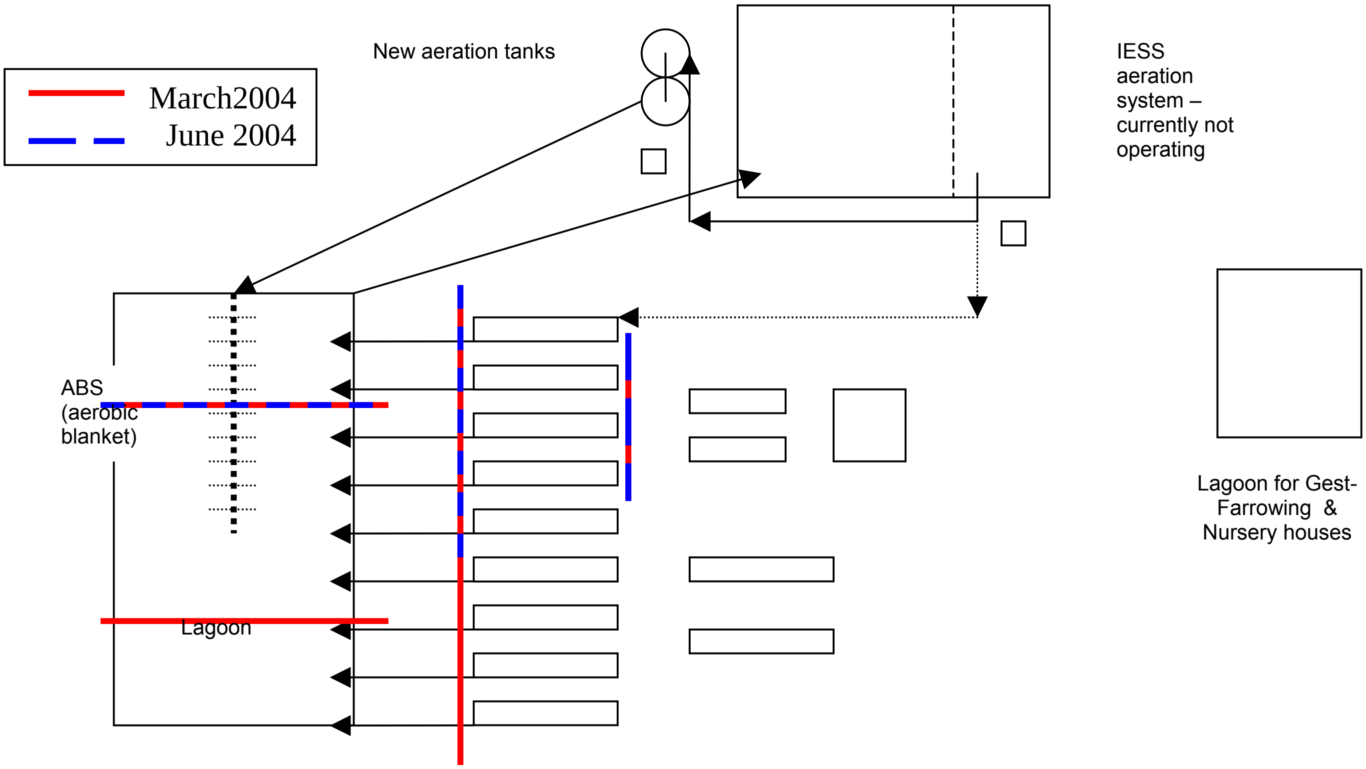


Figure 2.10 Fifteen- minute Average Concentrations and Standard Deviations measured in March, 2004.

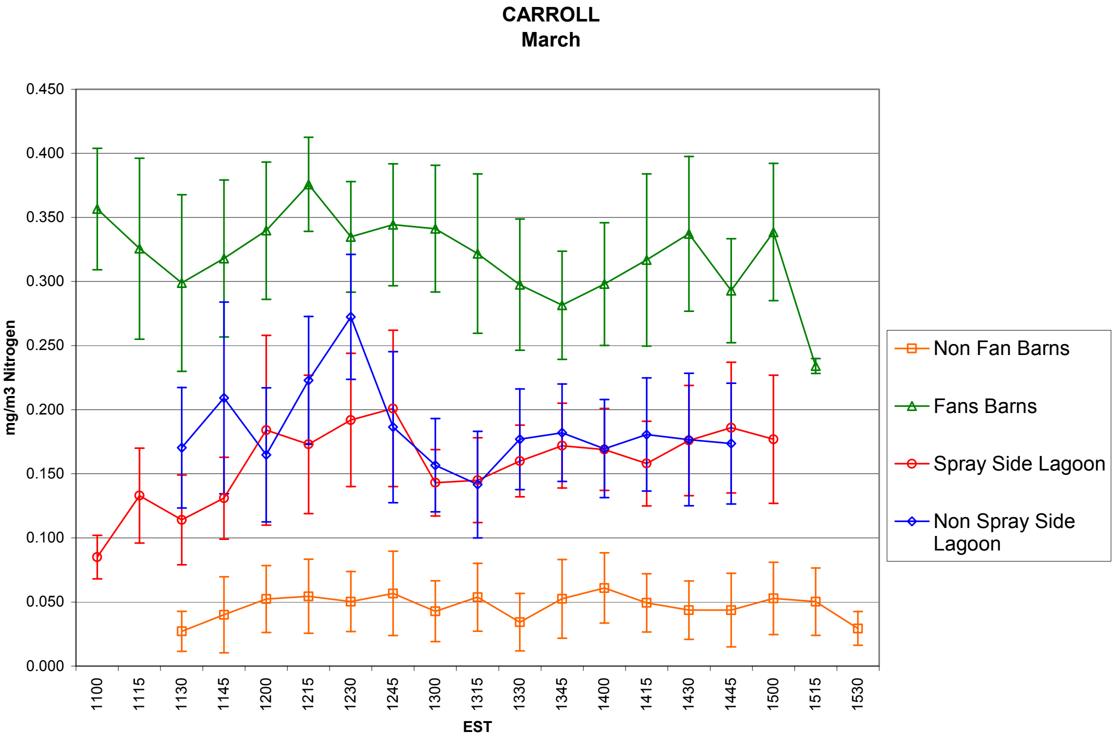


Figure 2.11 Fifteen- minute Average Concentrations and Standard Deviations measured in June, 2004.

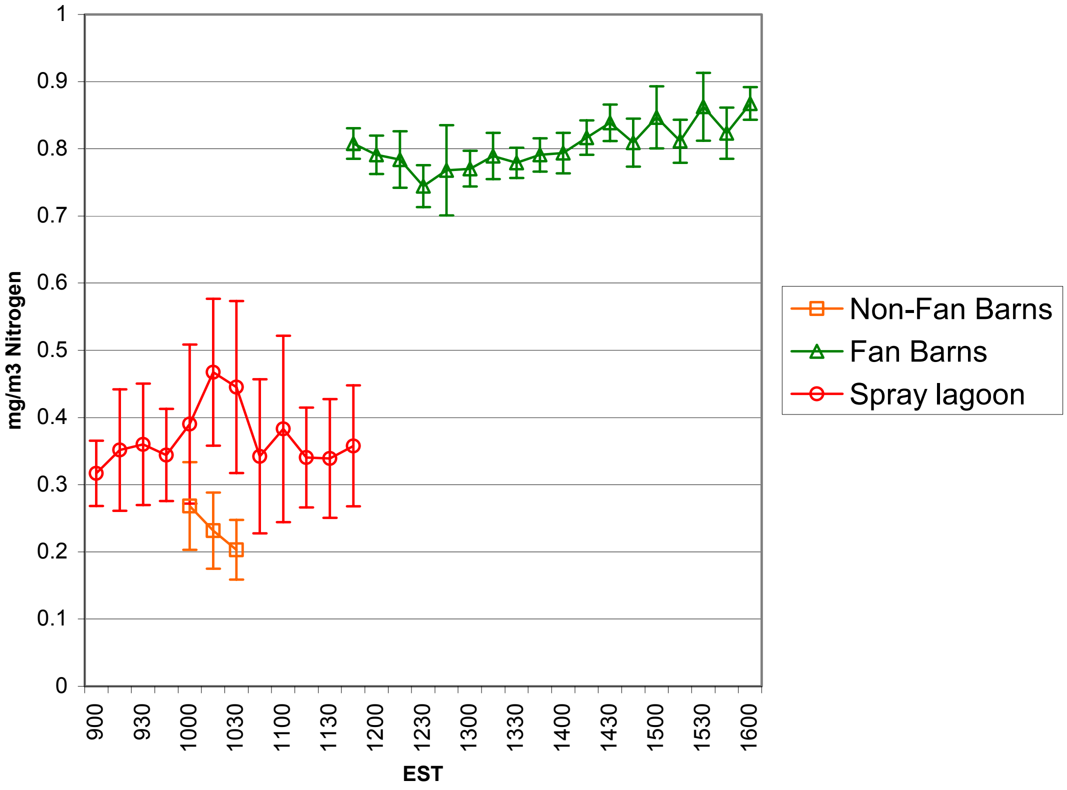


Table 2.8 Average Daily Concentrations of Nitrogen in mgN/m3.

Date	**Component**	
	Barn (mg N/ m3)	
2004	**Fan Side Barn**	**Non Fan Side Barn**
March 30	**0.320**	**0.047**
June 22	**0.805**	**0.234**
	Anaerobic Lagoon	
	Misted Side	**Non Misted Side**
March 31	**0.159**	**0.185**
June 23	**0.370**	**---**

Figure 2.12 March Concentrations of Nitrogen when the Mist was On vs. Mist was Off.

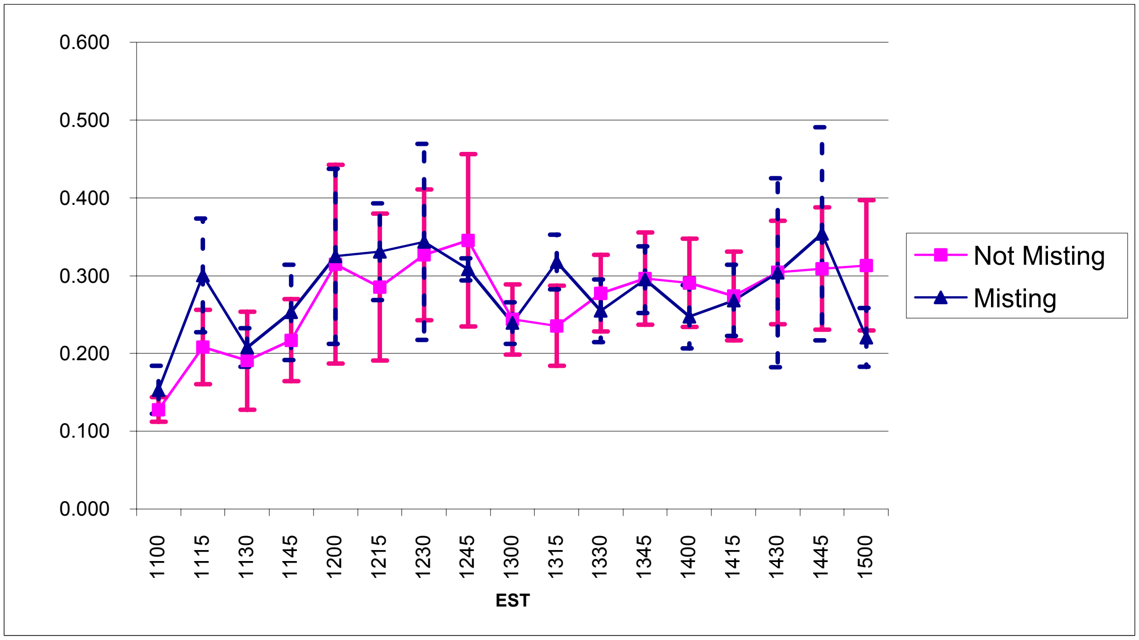
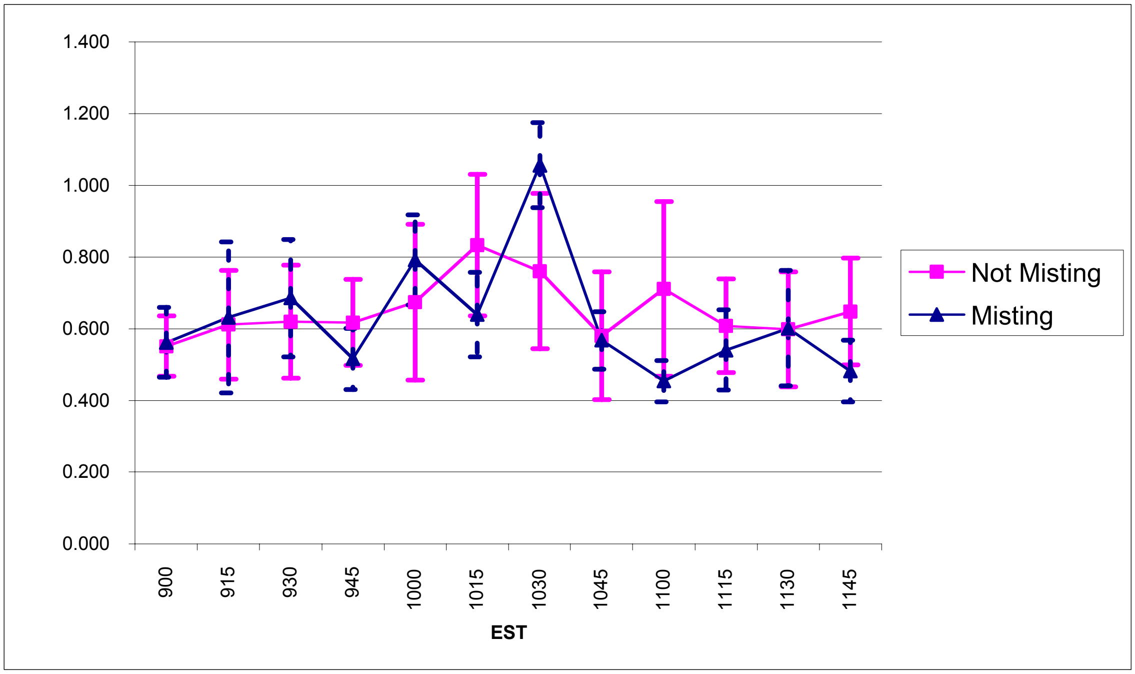


Figure 2.13 June Concentrations of Nitrogen when the Mist was On vs. Mist was Off.



Estimated ammonia emissions from barns

The average nitrogen flux from the hog houses was calculated by multiplying concentrations of nitrogen (measured as ammonia mg/m3) across the midline of the fans by the measured or factory calibrated fan rates (m3/min) for the fans that were on at each time point. The concentrations that were measured were adjusted for the length of the path across the operating fans at each time point. The number for each barn was then normalized by the total live weight of the hogs in the houses at the time of the sampling (1000 Kg LW), see Table 2.9. The operation of the fans (monitoring when they are on or off) was performed during the entire sampling period.

Table 2.9 Flux (KgN/Week/1000Kg weight of pigs)

Date	Location	KgN/Week/1000 kg lw
03/30/04	9 Barns	0.975
06/22/04	5 Barns	1.148

Assessment of Ammonia Emissions from Alternative Technology:

At each alternative technology and conventional site, the estimated ammonia emissions are limited to two two-week long periods, representing warm and cold seasons. But, since measurements at different sites are made at different times of the year, environmental conditions are likely to be different at different sites, even during a representative "warm" or "cold" season. There is a need for accounting for these differences in our relative comparisons of the various alternative and conventional technologies.

The estimated emissions from water-holding structures at an alternative technology for each measurement period are compared with the average estimated emissions from baseline sites, after the later are adjusted to the average environmental parameters (lagoon temperature and air temperature) observed at the former (alternative technology) site. A rational basis for this adjustment for somewhat different environmental conditions is the multiple regression model developed for ammonia emissions and measured environmental parameters at the two baseline sites. The model is described in appendix 2 of the three-year progress report. Such a comparison would not require highly uncertain extrapolations of emissions at alternative technology sites beyond the two measurement periods.

Absolute numbers are not used in assessing ammonia emissions from the proposed alternative technology. A normalized measure of emissions (normalized to calculated N-excreted; $\%E_{EST}$) is compared to a similar normalized measure of emissions ($\%E_{CONV}$) from a baseline site using the conventional lagoon technology for handling swine waste in North Carolina. The %E values are an estimate of rate of loss of N compared to N excreted. Two baseline sites are used to account for differences in housing ventilation across the sites with the proposed EST's. No method exists for adjusting baseline housing emissions to environmental conditions observed at an EST farm. Therefore, actual housing emissions measured at the baseline sites during comparable seasons of the year are used when generating the normalized measures of emissions from houses. It is acknowledged that the housing emissions for the baseline sites were not made under the exact meteorological conditions as the housing measurements for evaluation of an EST. The algorithm followed in deriving an index of performance ($\%\text{reduction} = [(\%E_{CONV} - \%E_{EST})/\%E_{CONV}] * 100$) by the EST in reducing ammonia emissions as compared to the conventional technology currently in use in North Carolina (baseline sites) is presented in Figure 2.14 for water holding structures.

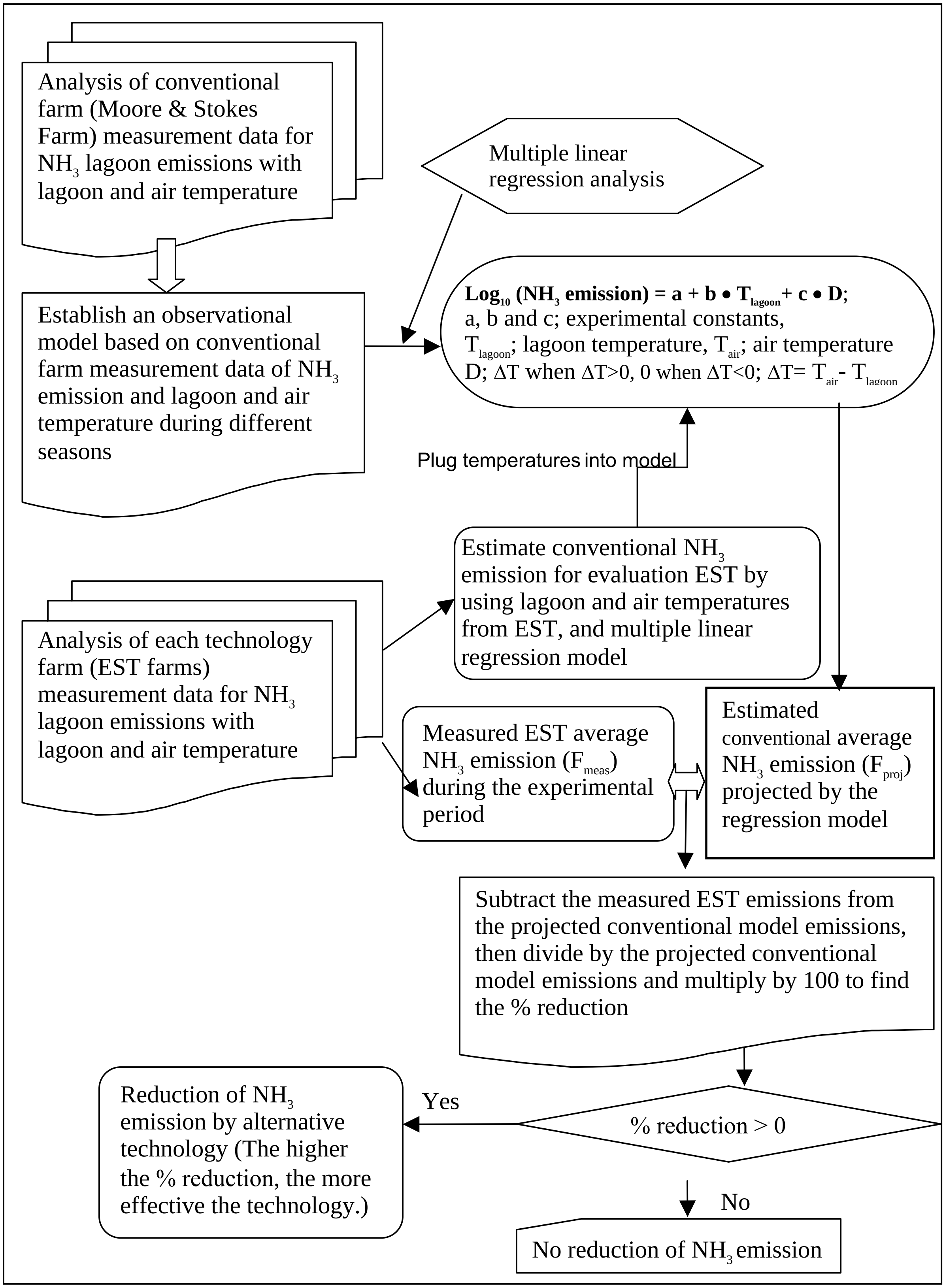


Figure 2.14 Algorithm flow chart for evaluation of alternative technology ammonia emission from water holding structures.

Evaluation of Carroll's farm (ABS)

We compare the lagoon NH_3-N emission from Carroll's farm with the projected average emission from lagoon at the conventional farm, using the observational statistical (multiple linear regression) model.

Table 2.10 gives animal weight, feed consumed, and N-excretion at baseline farms and Carroll's farm. Table 2.11 gives the NH_3-N emissions (kg-N/1000 kg-live weight/wk) data summary for the Carroll's farm and baseline farms for evaluation of EST at the former. The emissions from different components of an EST or baseline farm should be viewed relative to the estimated nitrogen excretion from animal population, weight and feed data.

Table 2.10 Summary of animal weight, feed consumed, and N-excretion at conventional farms (Stokes and Moore) and the EST (Carroll's; ABS) farm.

Farm Information	No. of pigs	average pig weight kg/pig	total pigs weight kg	feed consumed kg/pig/wk	N-excretion, E kg-N/wk/ 1000kg-lw
Stokes (Sep.)	4,392	104.3	458,086	12.84	2.71
Jan.	3,727	88.5	329,840	12.59	2.51
Moore (Oct.)	7,611	52.3	398,055	10.99	4.39
Feb.	5,784	67.0	387,528	12.37	3.90
Carrolls (Mar-Apr.)	6332	59.2	374,854	12.89	3.90
June	6095	59.7	363,872	13.21	4.13

Table 2.11 Estimates of % reduction in NH_3-N emissions from different components and their sum total at the EST (Carroll's: ABS) and conventional farms (kg-N/wk/1000kg-*lw*). (% reduction = [(%E_{CONV}- %E_{EST})/%E_{CONV}]*100

(1) Primary anaerobic lagoon and aerobic digester

Period	Average lagoon temperature (^oC)	Average D (^oC)	Conventional model emissions F_{proj}	% E_{CONV}	ABS measured emission F_{meas}	% E_{EST}	% reduction
Mar 29-Apr 2, 2004	15.0	0.0	0.34	10.6	0.22	5.6	47.2
June 28-July 2, 2004	29.1	0.0	1.50	42.2	0.23	5.6	86.7

(2) Barn Emissions

Period	Moores Farm measured emission	% E_{CONV}	ABS measured emission F_{meas}	% E_{EST}	% reduction
Mar 29-Apr 2, 2004	0.89†	22.8	0.98	25.1	-10.1
June 28-July 2, 2004	1.05‡	23.9	1.15	27.8	-16.3

Total Emissions (1)+(2)

Period	conventional total emission	% E_{CONV}	ABS measured emission	% E_{EST}	% reduction
Mar 29-Apr 2, 2004	1.23	33.4	1.20	30.7	8.1
June 28-July 2, 2004	2.55	66.1	1.29	33.4	49.5

D is ΔT, the difference between the air temperature (T_{air}) and lagoon temperature (T_{lag}), when $T_{air} > T_{lag}$; D = 0 when $T_{air} < T_{lag}$. F_{proj} is baseline lagoon area adjusted NH_3 lagoon emission projected by the baseline multiple linear regression model corresponding to the average lagoon temperature and the average D during Carroll's (ABS) farm measurement periods. % E_{CONV} is the conventional model emissions relative to the N excreted. % E_{EST} is the measured emission from the EST relative to the N excreted.). F_{meas} is sum of the NH_3 emission from water holding structures and NH_3 emission from barn house measured at

Carroll's (ABS system) farm. Soil flux measurements were not taken because there was no lagoon spray and land application during the experimental period. †: overall house emission measured at Moore farm during February 2003, ‡: overall house emission measured at Moore farm during October 2002. % reduction is used to describe how effective a technology is, in reducing NH_3 emissions. A number > 0 indicates a reduction in NH_3.The larger the % reduction, the more effective the technology is in reducing NH_3 emissions. Conversely a number < 0 indicates that there are has been no reduction in NH_3 emissions.

3. Evaluation of Environmentally Superior Technologies for Ammonia Emissions: Harrell's Farm

ISSUES/ Permeable Bio-cover System (PCS)

Alternative Technology: Permeable Cover System (PCS)

Location: Harrell's Farm, Harrells, NC

Period of Operation:
The OPEN team monitored for evaluation during:
1st field experiment: 01/26 – 02/06/2004
2nd field experiment: 05/31 – 06/11/2004
3rd field experiment: 08/23- 09/03/2004

Technology contact: Prince Dugba

Project Investigator: Mike Williams/Len Bull

Statement of Task:

- Measurement of ammonia (NH_3) emissions from Aerobic digester, Storage basin and Permeable covered lagoon by using a flow-through chamber technology during two different campaigns (warm and cool seasons)
- Analysis of water samples from waste storage and treatment areas for Total Ammoniacal Nitrogen (TAN) and Total Kjeldahl Nitrogen (TKN) concentrations (one sample each day during the experimental period)
- On site monitoring of meteorological parameters at 10 meter height
- FTIR technology used to determine ammonia emissions from barns
- Parameters measured: NH_3 flux, wind speed and direction, solar radiation, relative humidity and air temperature

Description of Alternative Technology:

Waste flows first to an anaerobic lagoon covered with a permeable cover. The cover is designed to reduce ammonia emissions and odor. Waste then flows to a nitrification pond (aerobic digester), which is aerated, and then to a denitrification/irrigation storage pond (which was used for land application). For the 1st and 2nd evaluation a portion of the liquid from the aerobic digester was returned to 2 of the 5 houses and used to flush waste to the covered lagoon. For the 3rd evaluation an irrigation/ evaporation system was added. The waste was sprayed onto the permeable cover, with the goal of promoting evaportation.

(Source: Waste management Program, North Carolina State University, http://www.cals.ncsu.edu:8050/waste_mgt/)

- A conceptual flow-diagram of alternative technology;

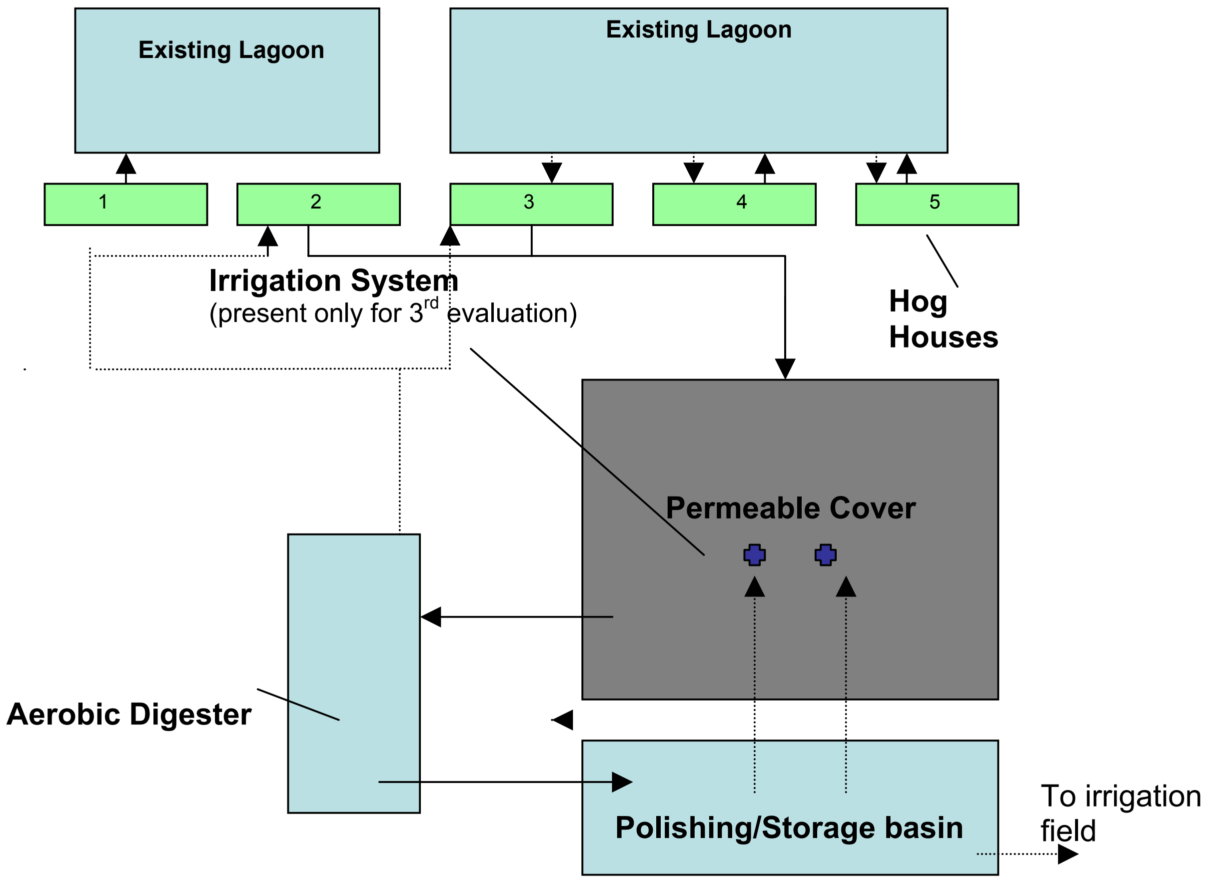


Figure 3.1 Conceptual flow diagram of PCS system (Harrell's Farm).

(Source; http //www.cals.ncsu.edu:8050/waste_mgt)

- Possible points of emissions of ammonia on conceptual flow-diagram and parameters that are important in controlling emissions:
    - Water holding structures: Permeable cover, Aerobic digester, Polishing/Storage basin- water temperature and water chemistry (pH and TAN) are the major controlling factors.

    - Irrigation system.

    - Animal houses: house operational technology flushing sequence and frequency are controlling variables as well as pH and TAN.

An aerial picture of Harrell’s farm with EST is given below:

Aerial photo of PCS site (Harrell’s Farm).

- Table 3.1 Description of Animal Operation (value estimates provided by project investigators and/or animal contract company)

PCS (Harrell's farm) Site---Sampling period: 1st Evaluation (January 26- February 6, 2004)

WEEK 1 1/26-2/1	**House 2**	**House 3**
# of pigs / house	1014	1150
Wks in finishing	17	16
Ave. Wt of pigs (lbs.)	241.6	234.05
Feed consumed (lbs/pig/wk)	40.0	40.6
WEEK 2 2/2-2/6	**House 2**	**House 3**
# of pigs / house	1013	964
Wks in finishing	18	17
Ave. Wt of pigs (lbs.)	252.38	244.83
Feed consumed (lbs/pig/wk)	40.0	40.0

Table 3.2 PCS (Harrell's farm) Site---Sampling period: 2nd Evaluation (May 31 - June11, 2004)

WEEK 1 5/31-6/6	**House 2**	**House 3**
# of pigs / house	1226	1193
Wks in finishing	15	14
Ave. Wt of pigs (lbs.)	198.14	170.36
Feed consumed (lbs/pig/wk)	39.3	32.1
WEEK 2- 5/31/04 6/7-6/11	**House 2**	**House 3**
# of pigs / house	1222	1192
Wks in finishing	16	15
Ave. Wt of pigs (lbs.)	210.81	182.33
Feed consumed (lbs/ pig/wk)	39.3	32.1

Table 3.3 PCS (Harrell's farm) Site---Sampling period: 3rd Evaluation (August 23 – September 3rd, 2004)

WEEK 1- 8/23/04	**House 2**	**House 3**
# of pigs / house	1292	1325
Wks in finishing	7	5
Ave. Wt of pigs (lbs.)	111.16	102.8
Feed consumed (lbs/pig/wk)	29.0	24.3
WEEK 2- 8/30/04	**House 2**	**House 3**
# of pigs / house	1288	1324
Wks in finishing	8	6
Ave. Wt of pigs (lbs.)	121.66	113.36
Feed consumed (lbs/ pig/wk)	29.0	29.0

- Feed Nutrients

Table 3.4 Total elemental analysis of feed samples (6 samples in total for 1st and 2nd sampling period; 1 for 3rd sampling period; each %N measurement is replicated 5 times; %P, Cu (ppm), Zn (ppm) 3 times).

Date	**%N**	**%P**	**Cu(ppm)**	**Zn(ppm)**
Jan 26, 2004	2.26 ± 0.16	0.44± 0.01	12.1 ± 1.4	109 ± 2
May 31, 2004	2.06 ± 0.10	0.49 ± 0.02	14.4 ± 2.4	107 ± 4
Aug 23, 2004	2.98 ± 0.07	0.65 ± 0.03	58.9 ± 2.0	670 ± 11

± indicates 1 standard deviation

Nitrogen Excretion

Computation of Nitrogen Excretion Based on Animal Feed Data (Harrell's Farm: PCS-1st Evaluation period, January 26 –February 6, 2004)

- Animal population / Types:
  - Total number of pigs in 2 finishing houses = 2071
  - Weighted average weight of the pigs =243.14 lb/pig = 110.29 kg/pig

- Nitrogen Intake
  - Average feed consumed = 18.62 kg/pig/wk
  - Average nitrogen content of the feed = 2.26% (from Feed Analysis)
  - Average nitrogen intake per pig = 0.42 kg-N/pig/wk

- Nitrogen Excretion
  - Average gain / feed or feed efficiency rate (ER) for feeder-finish operation, based on the 1999 Pig CHAMP data = 0.3
  - Average N excretion = (1-0.3) x 0.58 = 0.30 kg-N/pig/wk
  - Average N excretion on animal weight (*lw*) basis = *2.67 kg-N/1000kg animal live weight(lw)/wk*

Computation of Nitrogen Excretion Based on Animal Feed (Harrells Farm: PCS-2nd Evaluation period, May 31 - June 11, 2004)

- Animal population / Types:
  - Total number of pigs in 2 finishing houses = 2417
  - Weighted average weight of the pigs =190.59 lb/pig = 86.45 kg/pig

- Nitrogen Intake

  - Average feed consumed = 16.25 kg/pig/wk
  - Average nitrogen content of the feed = 2.06% (from Feed Analysis)
  - Average nitrogen intake per pig = 0.33 kg-N/pig/wk

- Nitrogen Excretion
  - Average gain / feed or feed efficiency rate (ER) for feeder-finish operation, based on the 1999 Pig CHAMP data = 0.3
  - Average N excretion = (1-0.3) x 0.33 = 0.23 kg-N/pig/wk
  - Average N excretion on animal weight (*lw*) basis = *2.71 kg-N/1000kg animal live weight(lw)/wk*

Computation of Nitrogen Excretion Based on Animal Feed (Harrell's Farm: PCS-3^rd Evaluation period, August 23 –September3, 2004)

- Animal population / Types:
  - Total number of pigs in 2 finishing houses = 2615
  - Weighted average weight of the pigs =112.19 lb/pig = 50.89 kg/pig

- Nitrogen Intake
  - Average feed consumed = 12.61 kg/pig/wk
  - Average nitrogen content of the feed = 2.98 % (from Feed Analysis)
  - Average nitrogen intake per pig = 0.37 kg-N/pig/wk

- Nitrogen Excretion
  - Average gain / feed or feed efficiency rate (ER) for feeder-finish operation, based on the 1999 Pig CHAMP data = 0.3
  - Average N excretion = (1-0.3) x 0.37 = 0.26 kg-N/pig/wk
  - Average N excretion on animal weight (*lw*) basis = *5.17 kg-N/1000kg animal live weight(lw)/wk*

Meteorological Measurements

Monthly/Annual Climate Data Results at the nearest weather station
15 km from sampling site
(*Source: State Climatology Office)*
Summary of monthly precipitation (cm) from 1994 to 2004
CLINTON 2 NE, NC (UCAN: 14040,COOP: 311881)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1994	10.46	5.44	14.10	3.20	4.39	18.01	11.30	9.37	9.02	8.74	7.54	5.49	107.06
1995	11.89	13.08	9.53	1.27	7.67	32.69	9.27	3.51	11.02	12.88	8.23	4.85	125.88
1996	9.73	6.55	11.79	6.73	10.34	13.18	21.95	8.05	32.05	13.46	9.75	8.13	151.71
1997	9.83	7.09	8.79	8.33	3.76	4.01	27.66	8.10	16.79	8.69	16.48	12.04	131.57
1998	18.82	17.83	16.92	12.42	14.58	4.67	6.15	18.42	8.20	2.11	3.61	11.33	135.05
1999	20.22	3.91	6.02	10.16	6.88	11.43	10.69	10.77	54.94	17.37	6.40	2.90	161.70
2000	13.87	4.01	10.46	10.90	-	16.15	14.02	12.12	13.08	0.41	7.62	4.39	107.04
2001	1.70	8.13	12.52	1.52	7.77	15.70	12.42	16.10	6.43	3.28	7.49	1.98	95.05
2002	12.62	5.16	15.54	6.10	5.56	15.24	15.19	20.55	6.25	7.24	10.39	8.13	127.97
2003	4.65	12.07	11.51	12.55	17.93	14.38	28.22	11.02	6.38	10.03	5.08	11.73	145.54
2004	2.97	**11.58**	1.42	13.89	18.77	**11.76**	6.38	**23.85**	8.31	3.56	10.24	4.32	117.04
AVG	11.38	8.33	11.72	7.32	8.77	14.55	15.69	11.80	16.42	8.42	8.26	7.10	128.86

Harrell's Precipitation Data Analysis (UCAN: 14040,COOP: 311881)

Compared to the 10-year precipitation average of 8.3 cm for the month of February (1994-2003), Harrell's, conducted for February, 2004, showed a higher precipitation average of 11.6 cm, a difference of 3.3 cm; this is the 3rd highest rainfall in the last 10 years. Compared to the 10-year precipitation average of 14.3 cm for the month of June (1994-2003), Harrell's, conducted for May 31- June 11, 2004, showed a lower precipitation average of 11.8 cm, a difference of 2.5 cm. Compared to the 10-year precipitation average of 14.6 cm for the month of August (1994-2003), Harrell's, conducted for August 23-27, 2004, showed a much higher precipitation average of 23.9 cm, a difference of 9.7 cm, this was the highest rainfall in the last ten years. The 10-year precipitation average total (1994-2003) was 128.9 cm, while the annual precipitation average total for 2004 was 117.0 cm, a difference of 11.9 cm, however this was within the data range for the last ten years.

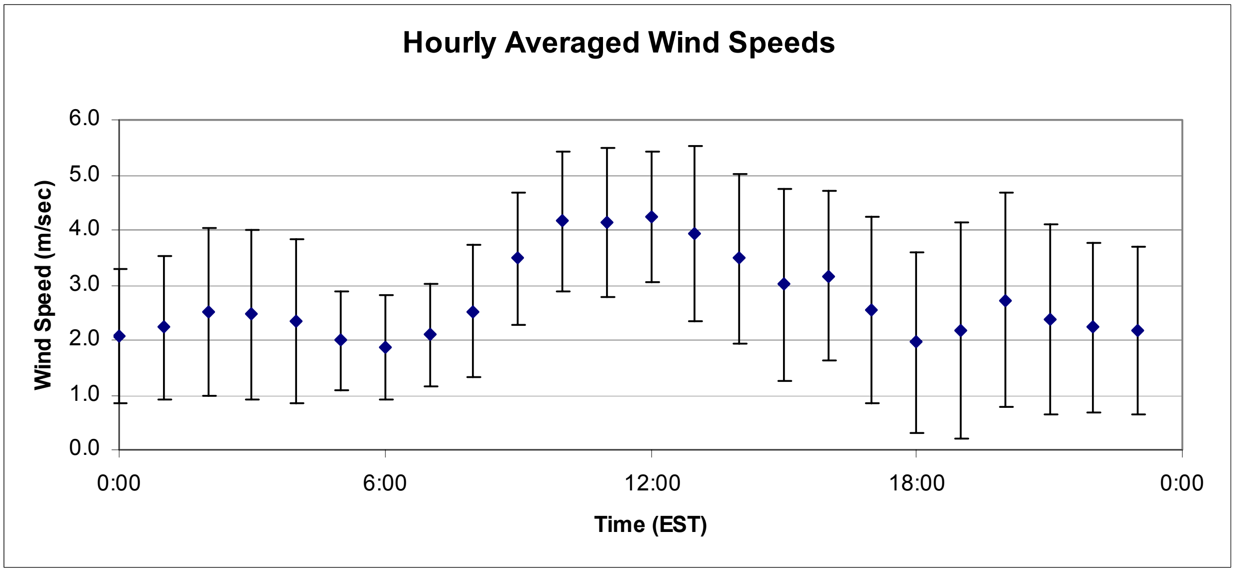
Summary of monthly mean temperature (^{0}C) from 1994 to 2004
Clinton, Sampson county, NC (UCAN: 14040,COOP: 311881)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1994	4.08	7.60	12.44	17.33	18.58	25.41	26.70	24.64	21.18	15.38	14.10	9.23	16.39
1995	6.02	5.06	12.12	17.02	20.85	23.79	27.04	26.49	21.84	18.11	8.73	4.36	15.95
1996	4.87	6.08	8.64	15.58	21.21	24.59	25.92	24.63	22.16	16.46	9.11	8.23	15.62
1997	5.74	8.64	14.17	13.99	18.54	22.99	27.02	24.74	22.46	16.61	9.93	7.08	15.99
1998	8.04	8.49	11.34	16.19	21.40	26.25	27.68	25.98	24.14	17.12	12.09	9.61	17.36
1999	8.44	8.16	9.28	16.93	19.72	23.60	26.86	27.12	22.23	16.21	14.21	7.29	16.67
2000	4.50	8.58	13.21	15.04	-	25.24	25.35	25.22	22.36	16.28	9.75	2.92	15.31
2001	5.31	8.92	9.74	16.40	20.43	25.26	24.82	25.78	21.31	15.67	14.50	10.41	16.55
2002	6.73	8.22	12.01	18.54	20.02	25.04	27.02	26.26	24.15	18.44	9.99	5.56	16.83
2003	3.27	6.21	12.43	14.94	20.23	24.22	26.09	26.31	21.93	15.89	14.46	5.39	15.95
2004	3.95	**5.09**	11.93	16.32	22.95	**24.90**	26.61	**24.30**	22.32	17.32	12.64	6.32	16.22
AVG	5.70	7.60	11.54	16.20	20.11	24.64	26.45	25.72	22.38	16.62	11.69	7.01	16.26

Harrells Mean Temperature Analysis (UCAN: 14040,COOP: 311881)

Compared to the 10-year temperature average of 7.6 °C for the month of February (1994-2003), Harrell's, conducted for January 26- February 6, 2004, showed a much lower mean temperature average of 5.1 °C, a difference of 2.5 °C, this was the 2nd coldest February in the 10 year period. Compared to the 10-year temperature average of 24.6 °C for the month of June (1994-2003), Harrell's , conducted for May 31-June 11, 2004, showed a slightly higher mean temperature average of 24.9 °C, a difference of 0.3 °C. Compared to the 10-year temperature average of 25.7°C for the month of August (1994-2003), Harrell's conducted for August 23-27, 2004, showed a lower mean temperature average of 24.3°C, a difference of 1.4°C, this was the coldest August of the last 10 years.
The 10-year temperature average (1994-2003) was 16.3 °C, while the annual temperature average for 2004 was 16.2 °C, a difference of 0.1 °C.

- Site Meteorological data measured during the measurement periods:



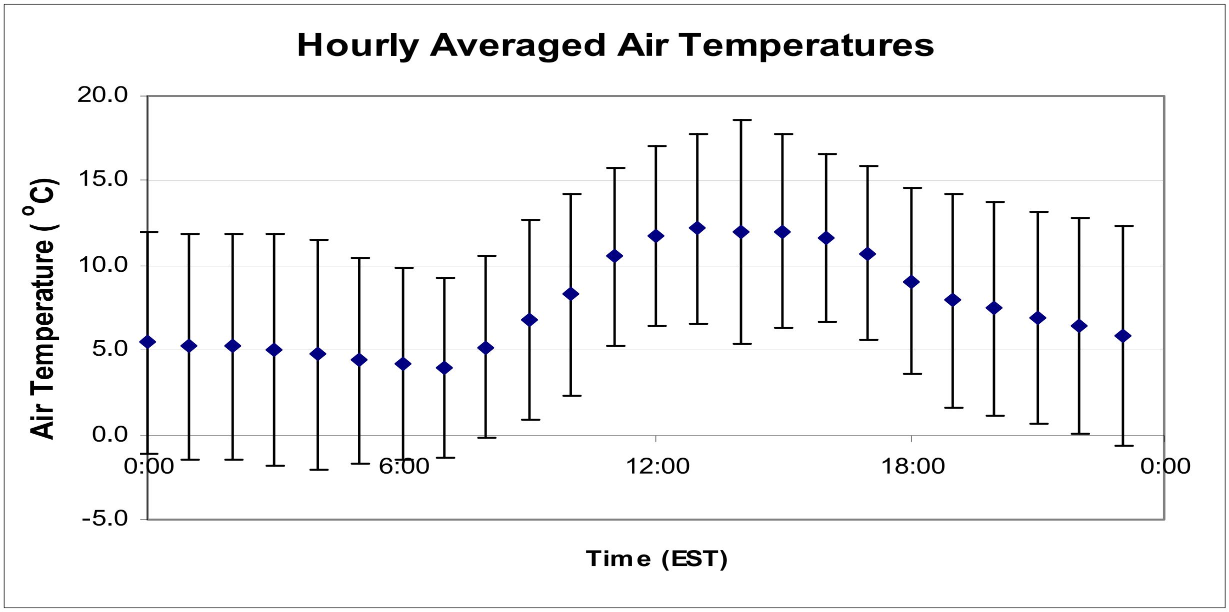


Figure 3.2 Site meteorological data during the 1st measurement period (January 31- February 11, 2004). Error bar indicates ±1 standard deviation of 15 minute averages.

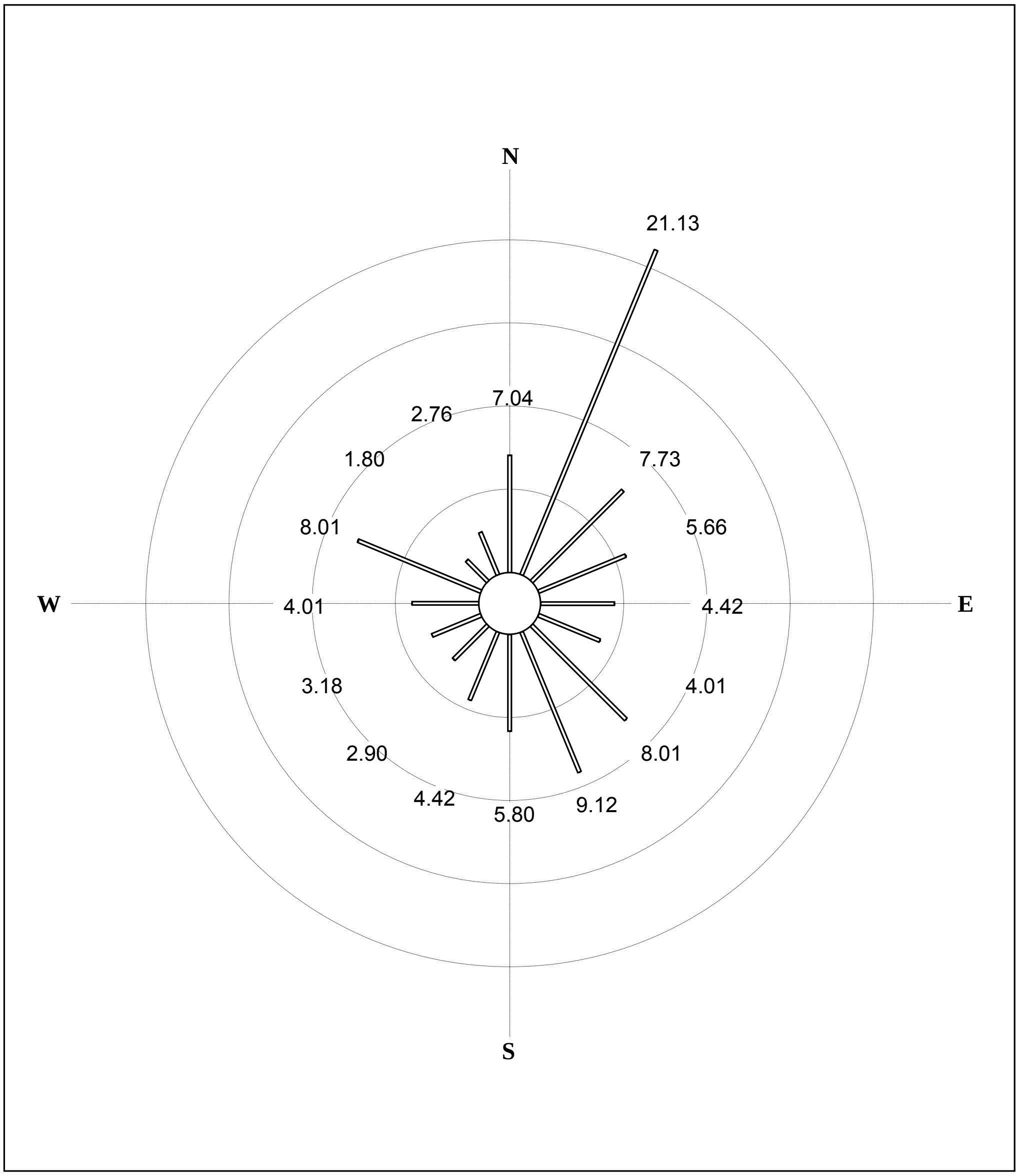
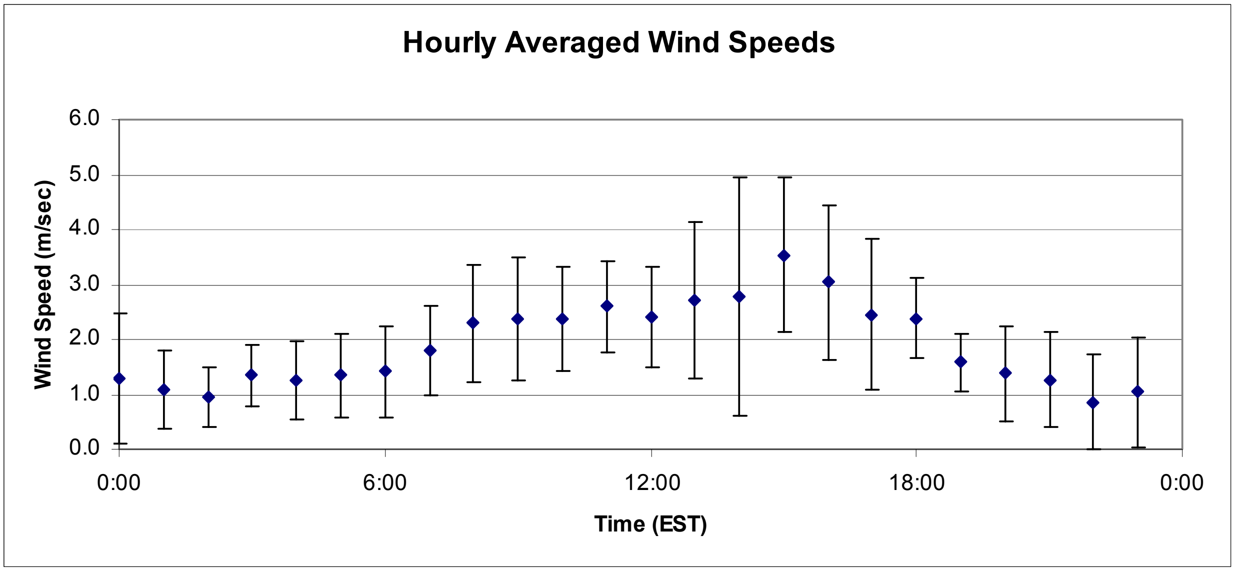


Figure 3.3 Wind rose depicting % wind direction during the 1st measurement period (Jan 31-February 11, 2004).



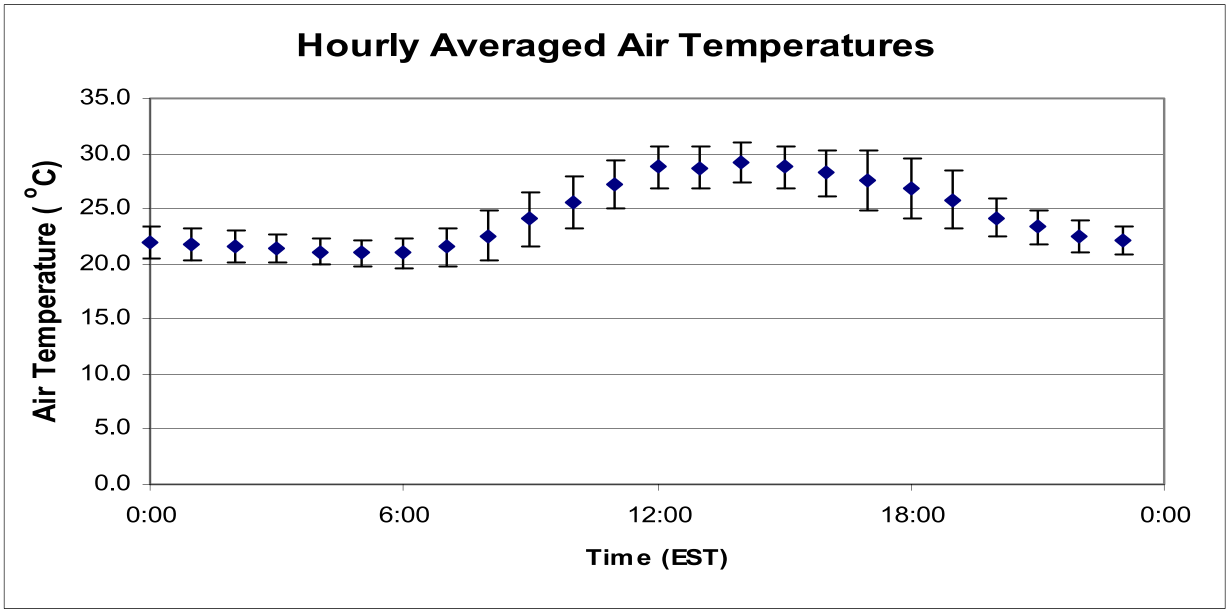


Figure 3.4 Site meteorological data during the 2nd measurement period (June 3- 11, 2004). Error bar indicates ±1 standard deviation of 15 minute averages.

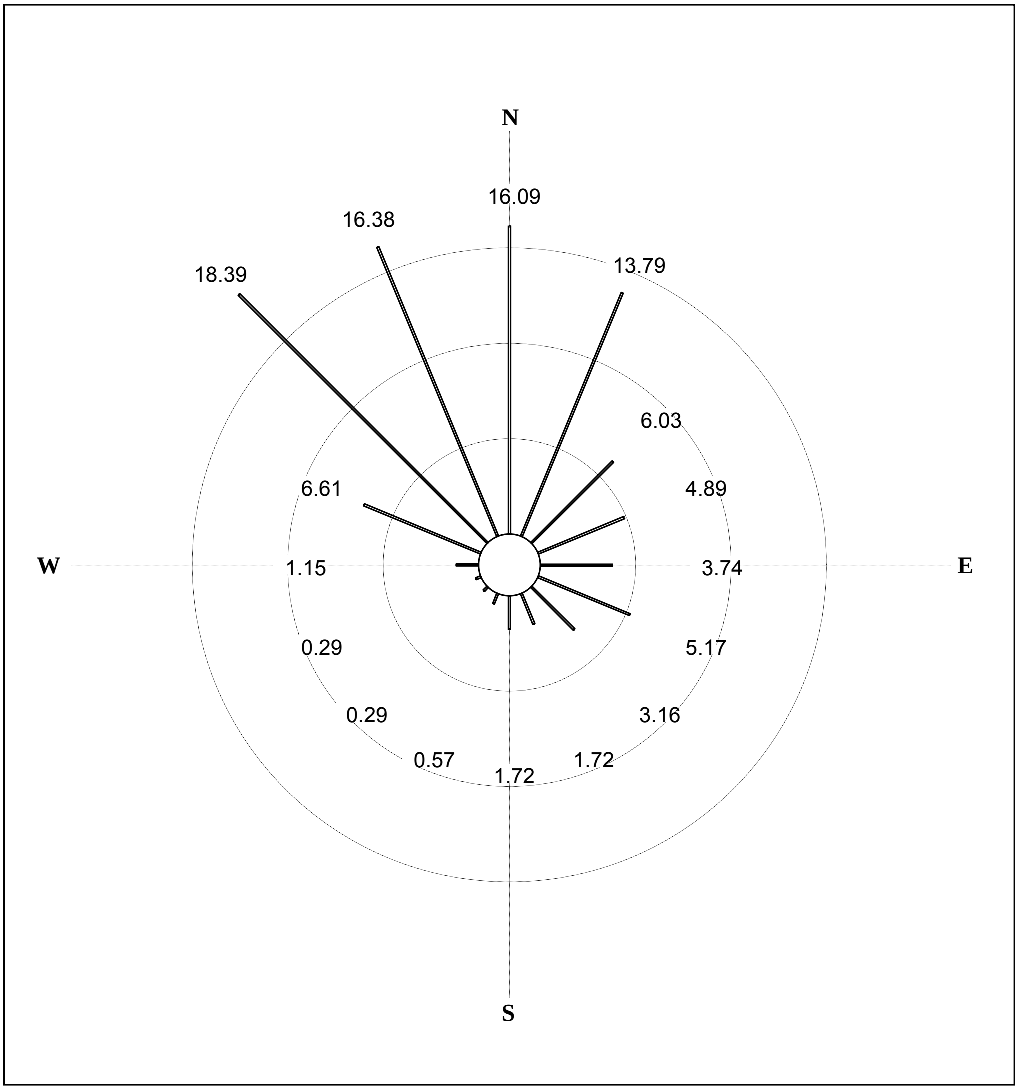
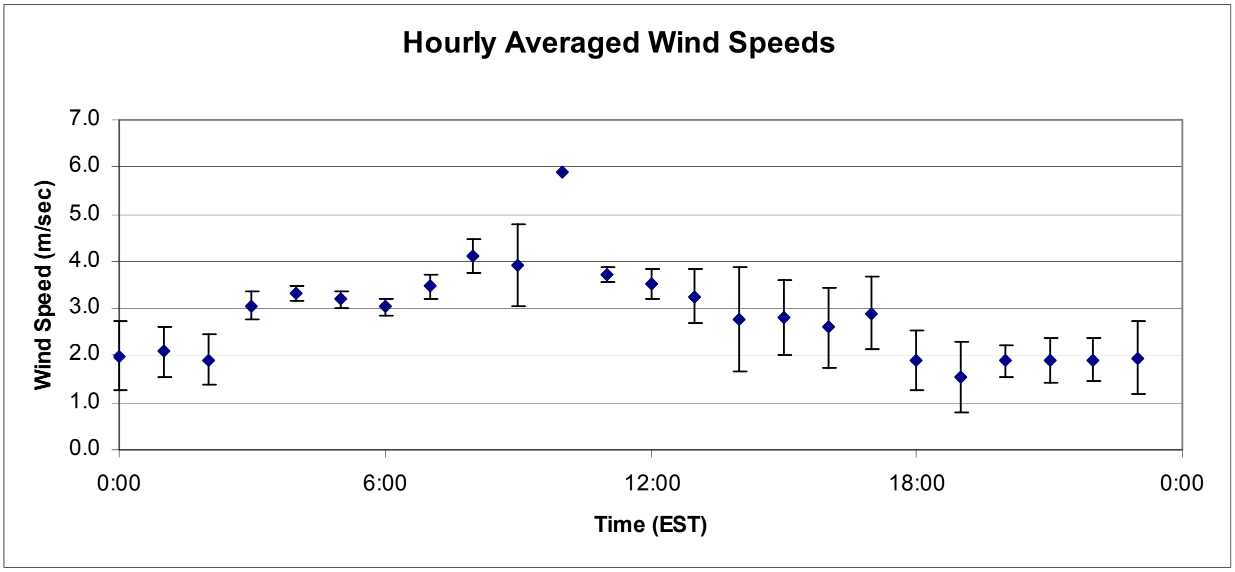


Figure 3.5 Wind rose depicting % wind direction during the 2nd measurement period (June 3-11, 2004).



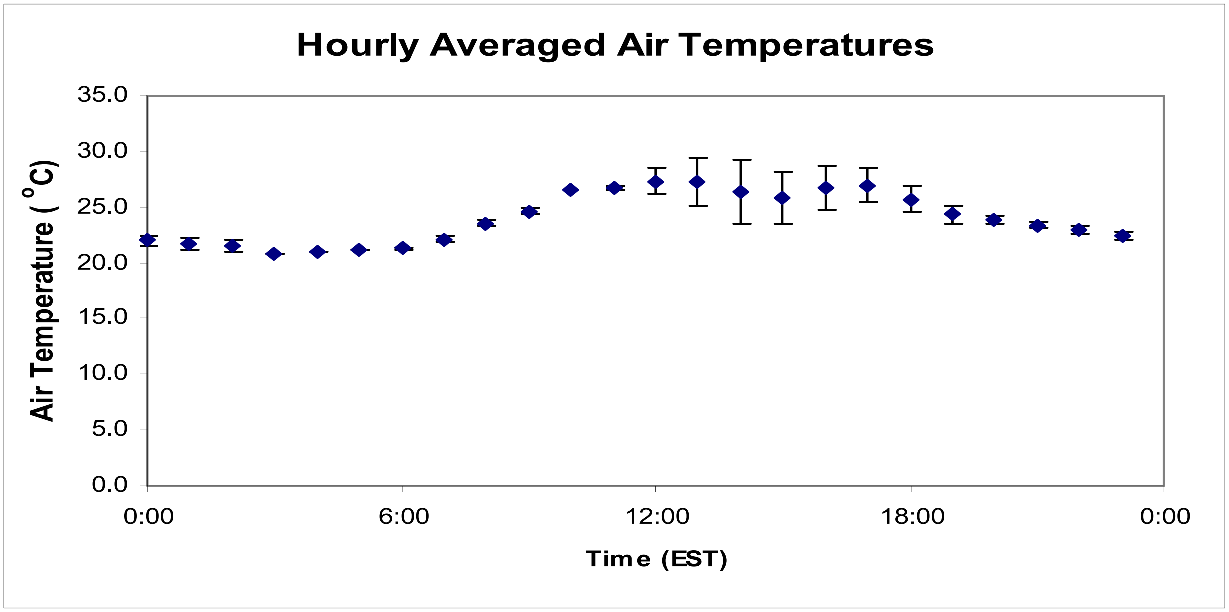


Figure 3.6 Site measurement data during 3rd measurement period (August 25- August 30, 2004). Error bar indicates ±1 standard deviation of 15 minute averages.

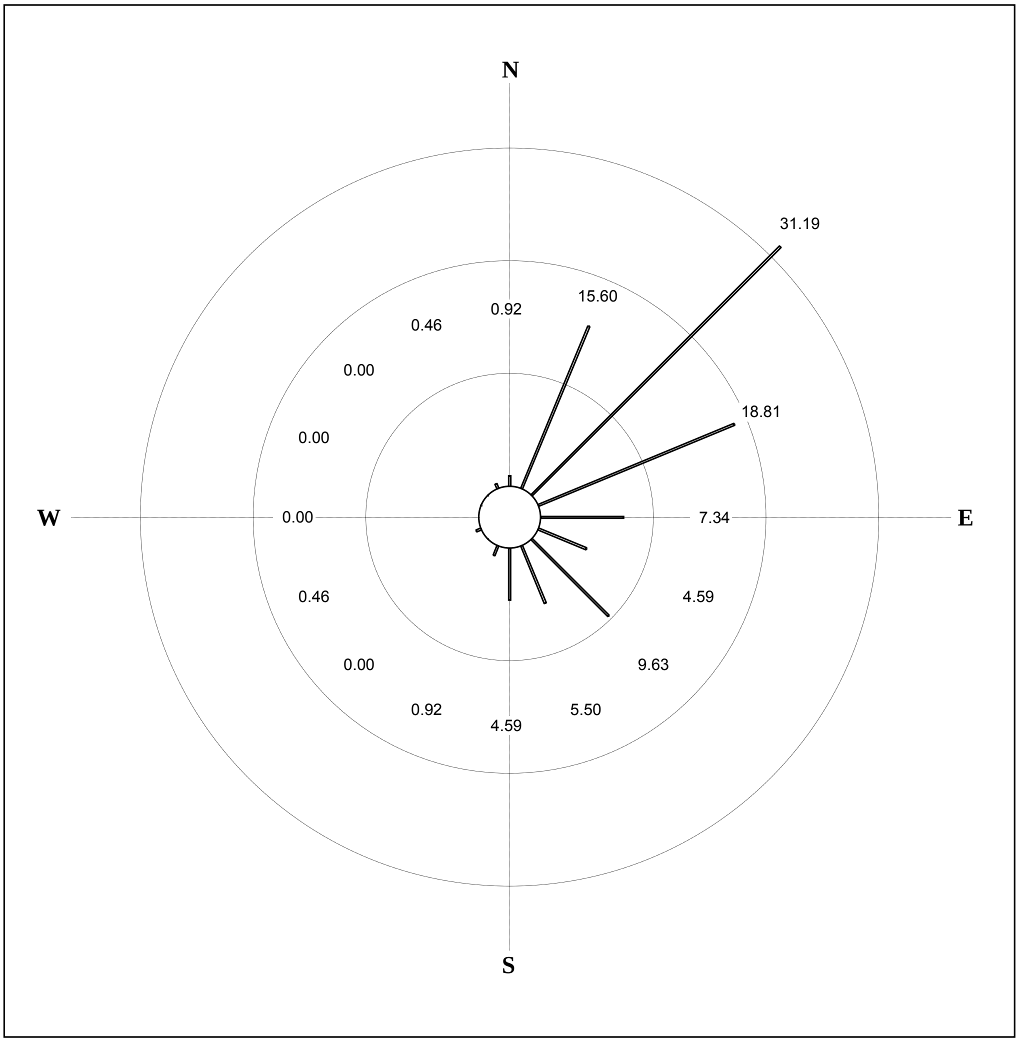


Figure 3.7 Wind rose depicting % wind direction during the 3rd measurement period (August 25-30, 2004).

Measurement of Ammonia Fluxes and Emissions:

Emission Sources -

Major sources of NH_3 are the hog houses and the aerobic digester, polishing/storage basin and permeable cover. In all of the liquid waste environments, the NH_3 flux is expected to depend on ambient air temperature, water temperature, pH, wind speed, and N in waste effluent. A floating flux chamber was deployed on water-holding structures measuring NH_3 flux directly from their surfaces. For the houses, NH_3 emission was determined by using average NH_3 concentration across plumes from one side of hog house and estimated air flow rate from the side during the measurement period by open path FTIR.

Dynamic-Chamber Technique for NH_3 flux measurement

The measurement schedule followed for determining the flux of ammonia from the water-holding structures using the dynamic-chamber technique is described in Table 3.5. Measured flux (presented as hourly averages) as a function of time is presented in Figures 3.9, 3.10 and 3.11. Tabulated hourly average flux values for each water-holding structure are presented in Table 3.6. Table 3.6 also contains the overall average flux values for each water-holding structure for each evaluation period. Table 3.7 contains TAN and TKN concentrations of the effluent samples from the water-holding structures. Table 3.8 presents total emissions of ammonia (kg-N) per week for each water-holding structure calculated for each evaluation period and normalized to 1000 kg live weight of animals present.

Harrell's farm NH_3 emission measurements (PCS site)
- 1st measurement period, January 26 – February 11, 2004
- 2nd measurement period, May 31– June 11, 2004
- 3rd measurement period, August 23-August 27, 2004 (irrigation component)

Table 3.5 NH_3 emissions schedule for 1st, 2nd and 3rd sampling periods at Harrell's farm

Sample dates	Parameters	Instruments	Sample plots	Remarks
Jan 31- Feb 7, 2004	NH_3 flux, lagoon T, lagoon pH, WD, WS, air T, RH, SR	One NH_3 analyzers, Meteorological instrumentations	Polishing/Storage basin	Completed 3 diurnal measurements
Feb 7-9, 2004	NH_3 flux, lagoon T, lagoon pH, WD, WS, SR, RH, air T	One NH_3 analyzers, Meteorological instrumentations	Permeable Cover	Completed 2 diurnal measurements
Feb 9- 11, 2004	NH_3 flux, lagoon T, lagoon pH, WD, WS, air T	Two NH_3 analyzers, Meteorological instrumentations	Aerobic digester	Completed 2 diurnal measurements

T = temperature; WD = wind direction; WS = wind speed; SR = solar radiation; RH = relative humidity. Water samples at each plot were collected every day for analysis of TAN and TKN concentrations at the laboratory.

Sample dates	Parameters	Instruments	Sample plots	Remarks
June 3-5, 2004	NH_3 flux, lagoon T, lagoon pH, WD, WS, SR, RH, air T	One NH_3 analyzer for emissions Meteorological instrumentations	Polishing/storage basin	Completed 2 diurnal measurements
June 7-9, 2004	NH_3 flux, lagoon T, WD, WS, SR, RH, air T	One NH_3 analyzer for emissions Meteorological instrumentations	Permeable cover	Completed 2 diurnal measurements
June 9-11, 2004	NH_3 flux, lagoon T, lagoon pH, WD, WS, SR, RH, air T	One NH_3 analyzer for emissions Meteorological instrumentations	Aerobic digester	Completed 2 diurnal measurements

T = temperature; WD = wind direction; WS = wind speed; SR = solar radiation: RH = relative humidity

Water samples at each plot were collected every day for analysis of TAN and TKN concentrations at the laboratory.

Sample dates	Parameters	Instruments	Sample plots	Remarks
Aug 25-26, 2004	NH_3 flux, lagoon T, lagoon pH, WD, WS, SR, RH, air T	One NH_3 analyzer for emissions Meteorological instrumentations	Permeable cover	Completed 1 diurnal measurements
Aug 26-27, 2004	NH_3 flux, lagoon T, WD, WS, SR, RH, air T	One NH_3 analyzer for emissions Meteorological instrumentations	Polishing/storage basin	Completed 1 diurnal measurements
August 30, 2004	NH_3 flux, lagoon T, lagoon pH, WD, WS, SR, RH, air T	One NH_3 analyzer for emissions Meteorological instrumentations	Aerobic digester	Completed 7 hours of measurements

T = temperature; WD = wind direction; WS = wind speed; SR = solar radiation: RH = relative humidity

Water samples at each plot were collected every day for analysis of TAN and TKN concentrations at the laboratory.

Site photos during the experimental periods

1st Evaluation: measurement at aerobic digester

2nd Evaluation: measurement at permeable cover

3rd Evaluation: Irrigation at the permeable cover

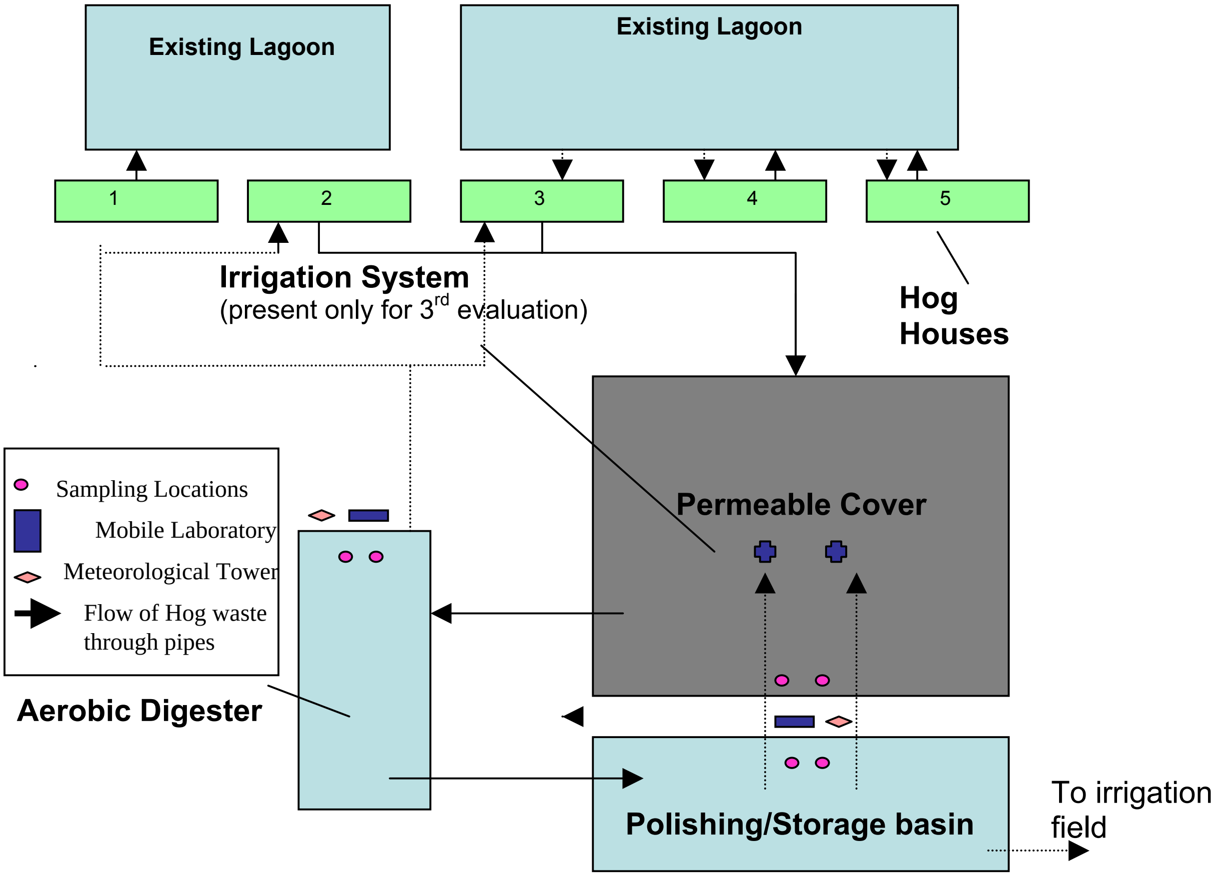
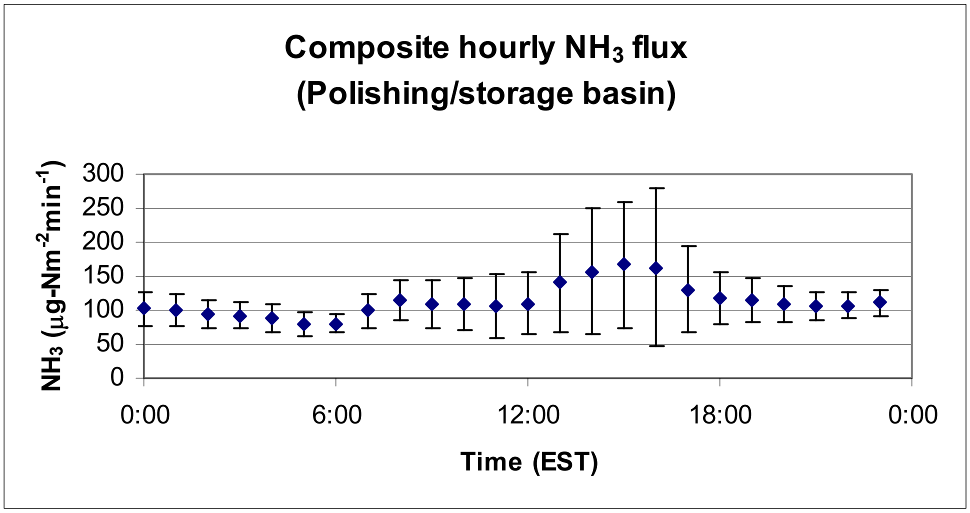
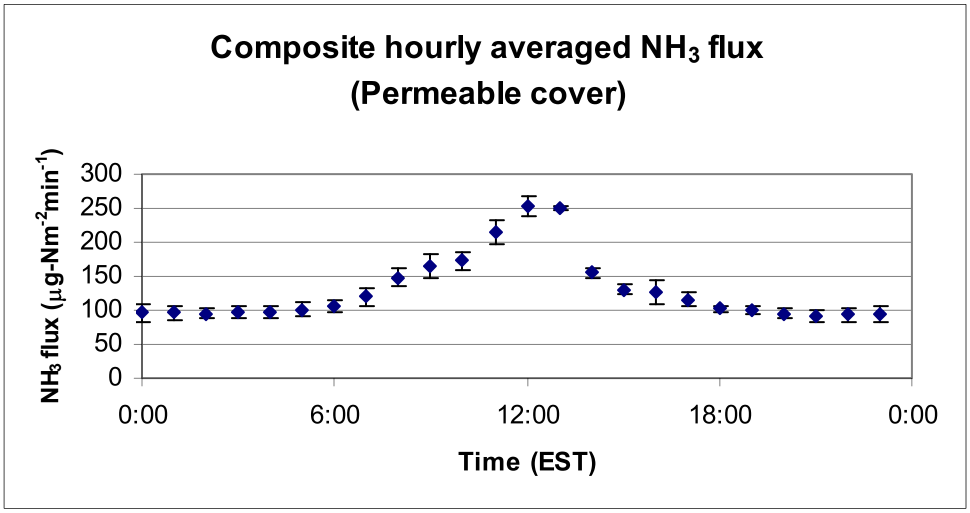


Figure 3.8 PCS experimental site layout and measurement locations.

1st Measurement period (January 31st-February 11, 2004)





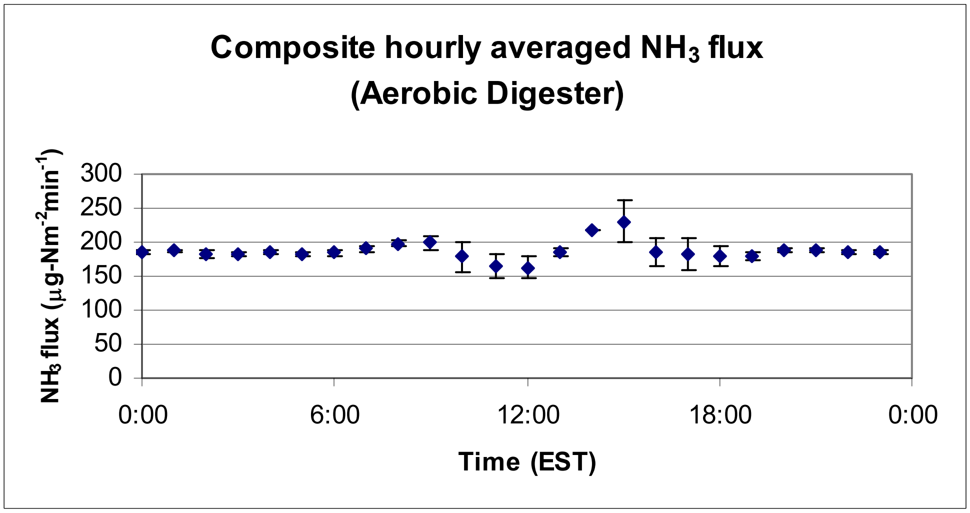
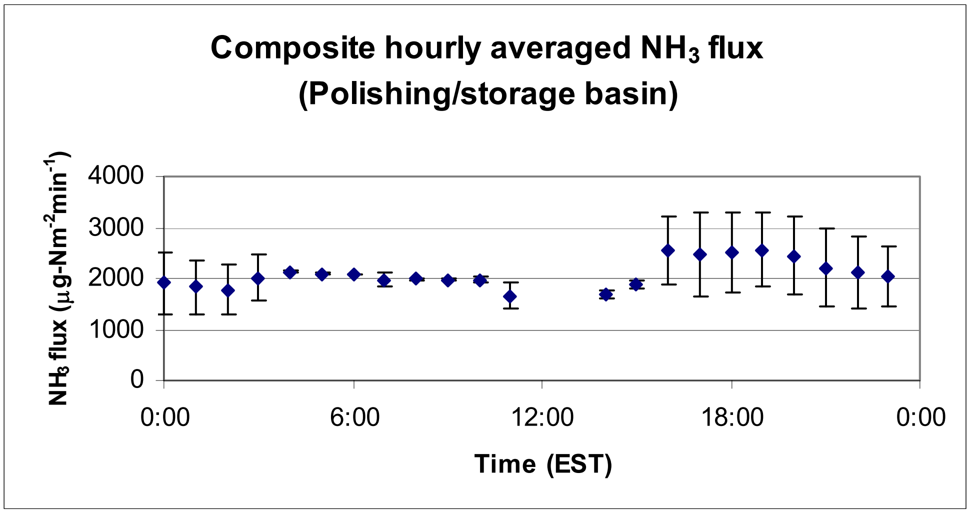
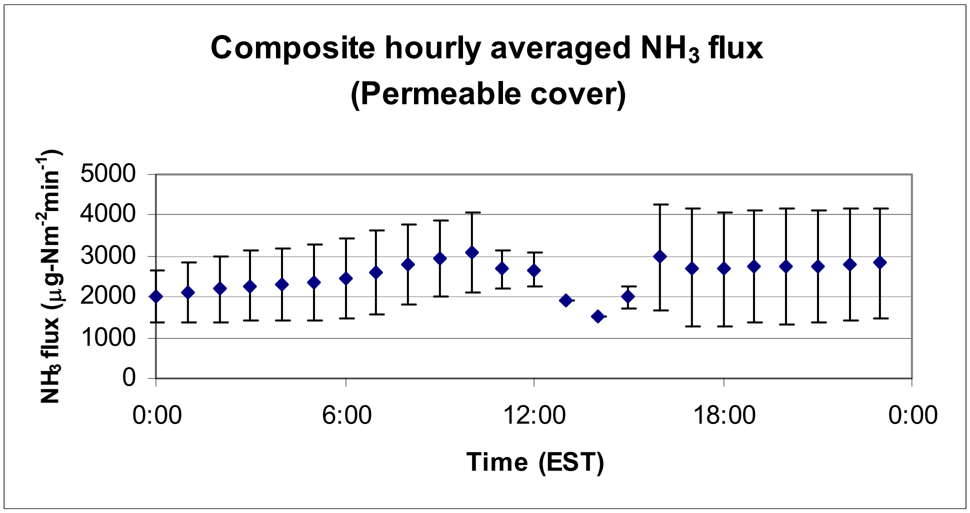


Figure 3.9 Diurnal variation of NH_3 flux from polishing/storage basin, permeable cover and aerobic digester during the 1st measurement period. Error bar indicates ±1 standard deviation.

2^{nd} Measurement period (June 3-11, 2004)





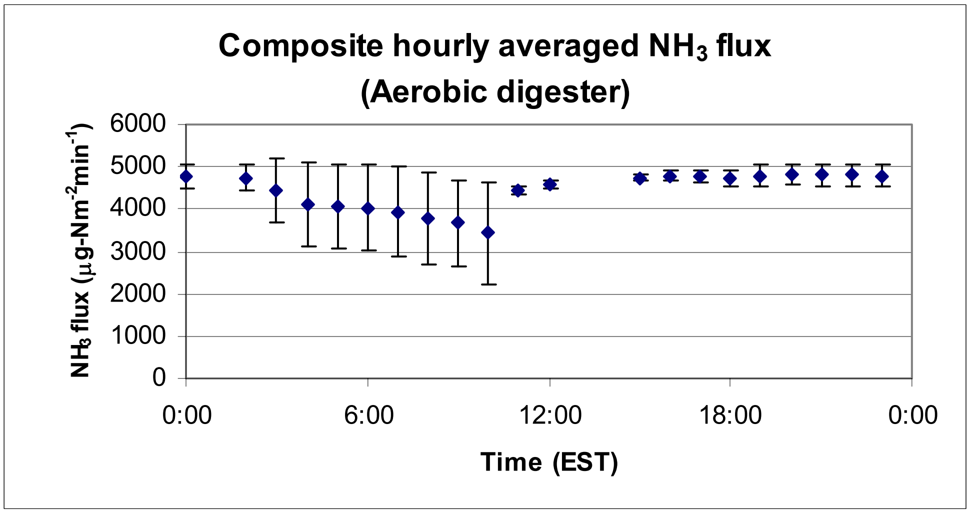
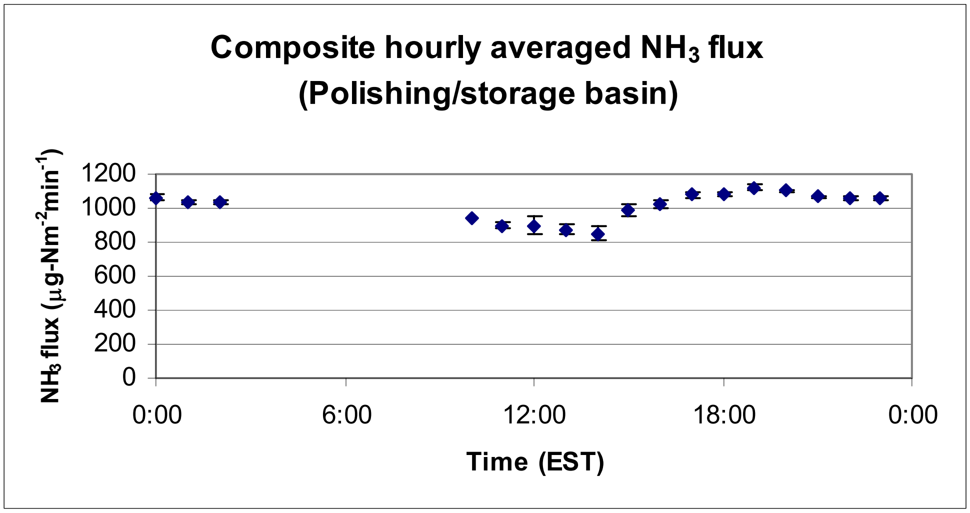
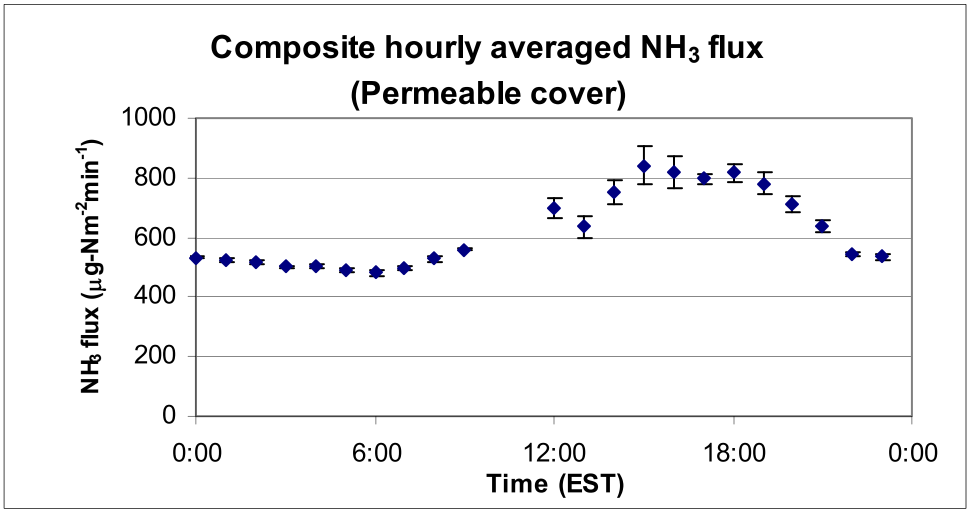


Figure 3.10 Diurnal variation of NH_3 flux from polishing/storage basin, permeable cover and aerobic digester during the 2^{nd} measurement period. Error bar indicates ±1 standard deviation.

3rd Measurement period (August 25-30, 2004)





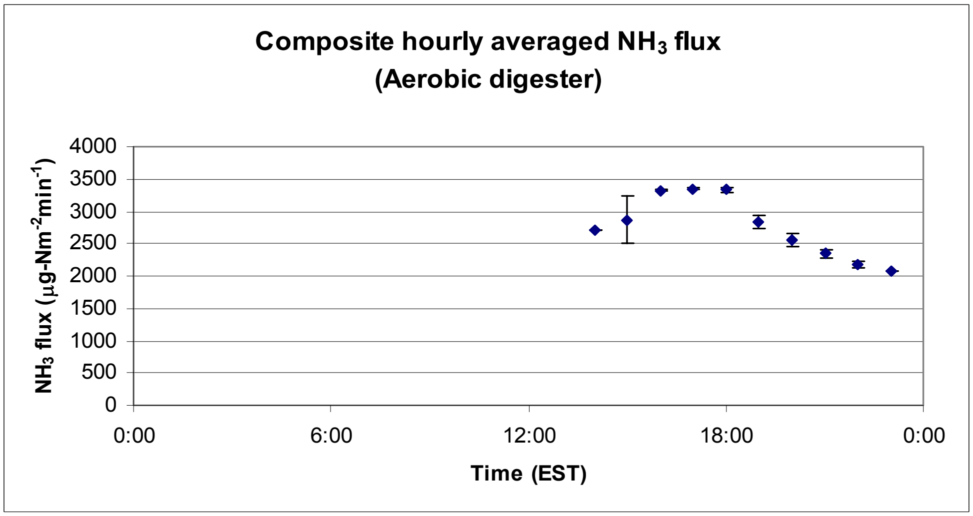


Figure 3.11 Diurnal variation of NH_3 flux from polishing/storage basin, permeable cover and aerobic digester during the 3rd measurement period. Error bar indicates ±1 standard deviation.

Table 3.6 Summary of hourly and overall averaged NH_3 flux from the water-holding structures during the experimental periods at the PCS system.

Harrells 1st Period

	NH_3 flux (1st period: 1/26-2/6/2004) (μg-N m^{-2} min^{-1})					
	Storage basin		Permeable cover		Aerobic digester	
EST	hrly avg	stdev	hrly avg	stdev	hrly avg	stdev
0:00	102.6	24.8	96.0	12.8	186.4	3.1
1:00	98.8	23.3	96.4	10.9	187.5	1.9
2:00	94.6	20.0	95.5	8.5	181.9	5.7
3:00	92.0	18.8	96.9	9.1	181.8	3.1
4:00	88.3	19.2	98.0	9.0	184.3	2.9
5:00	78.8	18.0	101.3	10.0	182.2	2.0
6:00	79.8	12.8	106.1	10.1	183.8	4.9
7:00	98.7	23.8	119.6	13.1	190.3	4.2
8:00	114.5	29.5	148.3	14.3	197.8	3.7
9:00	110.0	35.0	165.0	16.5	199.1	11.1
10:00	109.5	38.7	172.5	12.4	178.2	21.6
11:00	107.1	47.2	214.5	16.4	164.7	18.0
12:00	109.5	45.3	252.8	14.1	162.8	16.4
13:00	140.1	72.1	249.4	3.1	184.5	6.3
14:00	156.2	92.3	154.5	8.6	217.8	
15:00	167.4	92.6	130.8	7.7	230.3	31.6
16:00	163.2	116.8	125.9	18.3	186.3	21.0
17:00	130.4	63.4	116.0	9.4	182.4	24.5
18:00	118.5	38.6	101.8	4.6	179.4	14.4
19:00	114.6	31.4	99.0	5.9	178.5	6.4
20:00	108.7	25.5	95.2	7.0	189.4	3.1
21:00	105.2	20.4	92.1	8.5	187.8	2.7
22:00	106.1	19.2	93.2	10.5	184.6	2.4
23:00	110.4	18.6	93.8	11.3	185.3	2.5
average†	112.7		129.8		187.0	
stdev	23.6		48.8		14.0	
# of data	24.0		24		24	
average‡	110.4		123.7		185.7	
stdev	57.7		43.7		16.3	
# of data	196.0		175		175	
(15 min)			T_{lag}=8.9± 3.4(n=441)			

† Statistics for hourly averages

‡ Statistics for 15 minute averages for the experimental period

Harrells 2nd Period

	NH$_3$ flux (2nd period: 5/31-6/11/2004) (µg-N m^{-2} min^{-1})					
	Storage basin		Permeable cover		Aerobic digester	
EST	hrly avg	stdev	hrly avg	stdev	hrly avg	stdev
0:00	1902.1	604.0	2021.9	644.0	4772.2	264.2
1:00	1840.5	527.7	2101.6	717.7	4754.7	283.0
2:00	1781.1	498.0	2201.6	809.2	4727.7	306.3
3:00	2003.0	448.1	2270.3	862.3	4440.0	760.7
4:00	2132.0	21.8	2305.8	878.3	4098.7	989.4
5:00	2096.3	2.7	2369.7	926.9	4073.7	990.8
6:00	2078.7	4.7	2440.0	972.1	4034.5	1021.5
7:00	1978.5	133.6	2615.9	1031.8	3936.8	1057.8
8:00	1981.3	18.1	2771.1	979.5	3765.3	1080.0
9:00	1967.8	20.1	2957.7	930.8	3672.6	1020.5
10:00	1972.0	48.6	3078.7	993.8	3427.0	1200.7
11:00	1663.6	269.5	2675.4	476.1	4437.9	114.8
12:00	1412.5	41.6	2662.8	425.4	4573.1	88.5
13:00			1933.9			
14:00	1687.1	83.2	1519.8			
15:00	1894.2	80.2	1992.8	270.7	4746.5	71.2
16:00	2550.3	661.5	2967.7	1278.7	4788.5	114.9
17:00	2469.4	808.5	2712.0	1445.0	4773.6	124.4
18:00	2513.4	790.3	2681.5	1390.6	4726.0	198.4
19:00	2565.8	735.1	2726.7	1377.5	4790.8	251.9
20:00	2446.7	764.2	2737.7	1405.7	4805.9	237.0
21:00	2209.6	774.1	2747.4	1387.1	4800.2	268.4
22:00	2108.0	696.9	2788.0	1370.7	4802.5	275.6
23:00	2042.6	575.6	2831.1	1350.6	4780.9	262.6
average[†]	2085.6		2504.6		4427.3	
stdev	271.1		388.5		446.5	
# of data	22.0		24		21	
average[‡]	2113.9		2244.6		4415.9	
stdev	602.7		763.7		779.0	
# of data	136.0		175		156	
			T$_{lag}$=27.0			
(15 min)			± 1.6(n=628)			

[†] Statistics for hourly averages

[‡] Statistics for 15 minute averages for the experimental period

Harrells 3rd Period

	NH_3 flux (2nd period: 5/31-6/11/2004) (μg-N m^{-2} min^{-1})					
	Storage basin		Permeable cover		Aerobic digester	
EST	hrly avg	stdev	hrly avg	stdev	hrly avg	stdev
0:00	1064.0	13.1	531.5	4.2		
1:00	1031.9	14.0	520.7	6.2		
2:00	1034.5	13.6	517.0	7.4		
3:00			501.2	3.3		
4:00			505.2	6.2		
5:00			490.8	5.1		
6:00			482.1	11.2		
7:00			495.7	5.3		
8:00			526.9	9.9		
9:00			560.2	1.7		
10:00	938.2					
11:00	894.4	17.9				
12:00	897.4	51.6	698.5	33.4		
13:00	874.5	28.3	636.2	37.9		
14:00	850.6	42.6	750.4	40.7	2704.5	
15:00	987.0	37.4	840.0	62.7	2865.6	368.7
16:00	1021.9	20.9	818.1	56.3	3326.0	10.2
17:00	1078.1	21.2	796.0	16.7	3354.1	5.2
18:00	1083.4	12.7	816.2	30.1	3337.5	34.8
19:00	1120.7	16.9	779.5	37.3	2839.6	101.0
20:00	1102.5	3.9	711.5	26.0	2552.0	99.4
21:00	1065.6	3.9	636.1	21.6	2345.2	66.6
22:00	1063.9	12.0	544.2	5.9	2185.0	54.9
23:00	1058.9	12.3	533.7	8.1	2082.6	
average†	1009.9		622.4		2759.2	
stdev	86.2		128.5		475.2	
# of data	17.0		22		10	
average‡	1013.2		622.0		2823.7	
stdev	87.2		130.4		463.8	
# of data	65.0		84		34	
(15 min)			T_{lag}=26.2±1.0(n=184)			

† Statistics for hourly averages

‡ Statistics for 15 minute averages for the experimental period

Table 3.7 Total Ammoniacal Nitrogen (TAN) and Total Kjeldahl Nitrogen (TKN) averages and their standard deviation from water-holding structures at Harrell's farm.

	Storage basin		**Permeable Cover**		**Aerobic Digester**	
	TKN (mg-N l^{-1})	TAN (mg-N l^{-1})	TKN (mg-N l^{-1})	TAN (mg-N l^{-1})	TKN (mg-N l^{-1})	TAN (mg-N l^{-1})
1st Period (Jan 31-Feb 11)	115.5 ±2.1 n=2	83.7±8.7 n=2	190.7±46.5 n=3	87.8±14.6 n=3	582.3±14.6 n=2	575.3±15.3 n=2
2nd Period (Jun 3-11)	230.0±17.3 n=3	160.7±16.6 n=3	174.5±0.7 n=2	46.8±6.3 n=2	726.0±14.1 n=2	648.0±2.8 n=2
3rd Period (Aug 25-30)	136.5±0.7 n=2	53.3±9.9 n=2	153.0 n=1	80.8 n=1	540.0 n=1	453.0 n=1

n represents the total number of effluent samples collected at each water-holding structure.

Table 3.8 Summary of total emissions from water-holding structures at PCS during the experimental periods.

1st Period

Water holding structure	Storage basin	Permeable cover	Aerobic digester
Area (m^2)	2874.3	6318.0	2138.6
Weekly NH_3 emission (kg-N/wk)	3.2	7.9	4.0
Total emission from water-holding structures (kg-N/wk)	15.1		
Total emission/pig (kg-N/pig/wk)	0.007		
Total emission/1000 kg-lw (kg-N/1000kg-lw/wk)	0.066		

2nd Period

Water holding structure	Storage basin	Permeable cover	Aerobic digester
Area (m^2)	2874.3	6318.0	2138.6
Weekly NH_3 emission (kg-N/wk)	176.7	142.9	127.9
Total emission from water-holding structures (kg-N/wk)	447.6		
Total emission/pig (kg-N/pig/wk)	0.185		
Total emission/1000 kg-lw (kg-N/1000kg-lw/wk)	2.142		

3rd Period

Water holding structure	Storage basin	Permeable cover	Aerobic digester
Area (m^2)	2874.3	6318	2138.6
Weekly NH_3 emission (kg-N/wk)	84.7	39.6	81.8
Total emission from water-holding structures (kg-N/wk)	206.1		
Total emission/pig (kg-N/pig/wk)	0.079		
Total emission/1000 kg-lw (kg-N/1000kg-lw/wk)	1.549		

Average Ammonia Concentrations Using Open-Path Fourier Transform Infrared (OP-FTIR) Spectrometers

OP-FTIR spectrometer concentration measurements were obtained during February 3-4, 2004, June 1-2, 2004, and on August 24, 2004. For the February and June measurement periods, data was collected over the permeable covered lagoon and along the long side of one of the barns across the curtain opening, see Figure 3.12. OP-FTIR spectrometer concentration measurements were obtained on August 24, 2004 for the irrigation system. See Figures 3.13, 3.14, 3.15 for average concentrations and standard deviations in mg--N/m3 for all locations in February, June, and August, 2004, respectively. Table 3.9 lists the average daily concentrations of nitrogen in mg/m3. For the irrigation evaluation, the irrigation system would typically run continuously. To compare nitrogen concentrations when the irrigation system was on and off, in August, the system was turned off from 1130 until 1300 EST see Figure 3.15.

Figure 3.12 Locations of Measurements taken with the OP-FTIR Spectrometers.

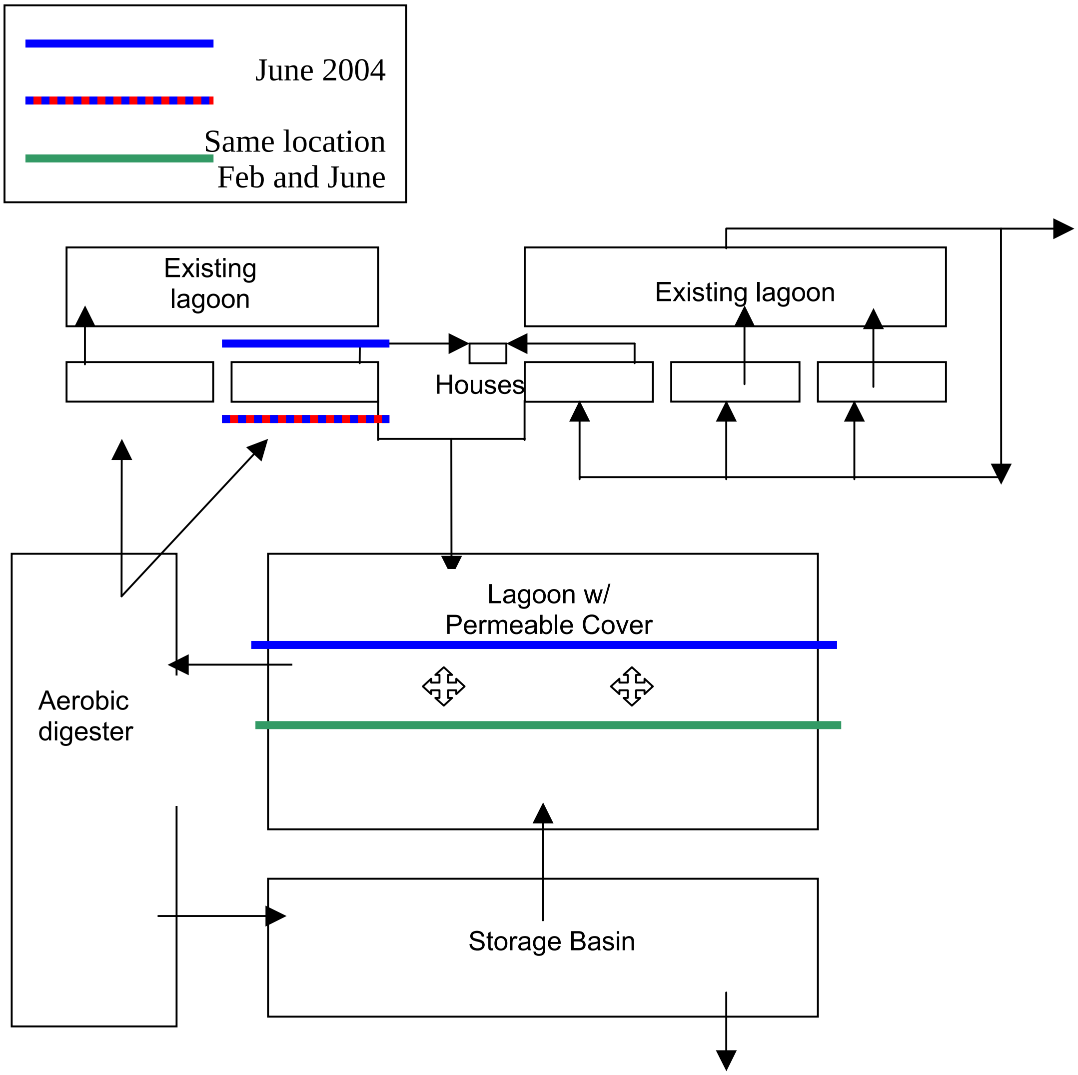


Figure 3.13 Fifteen-minute Average Concentrations and Standard Deviations measured in February, 2004.

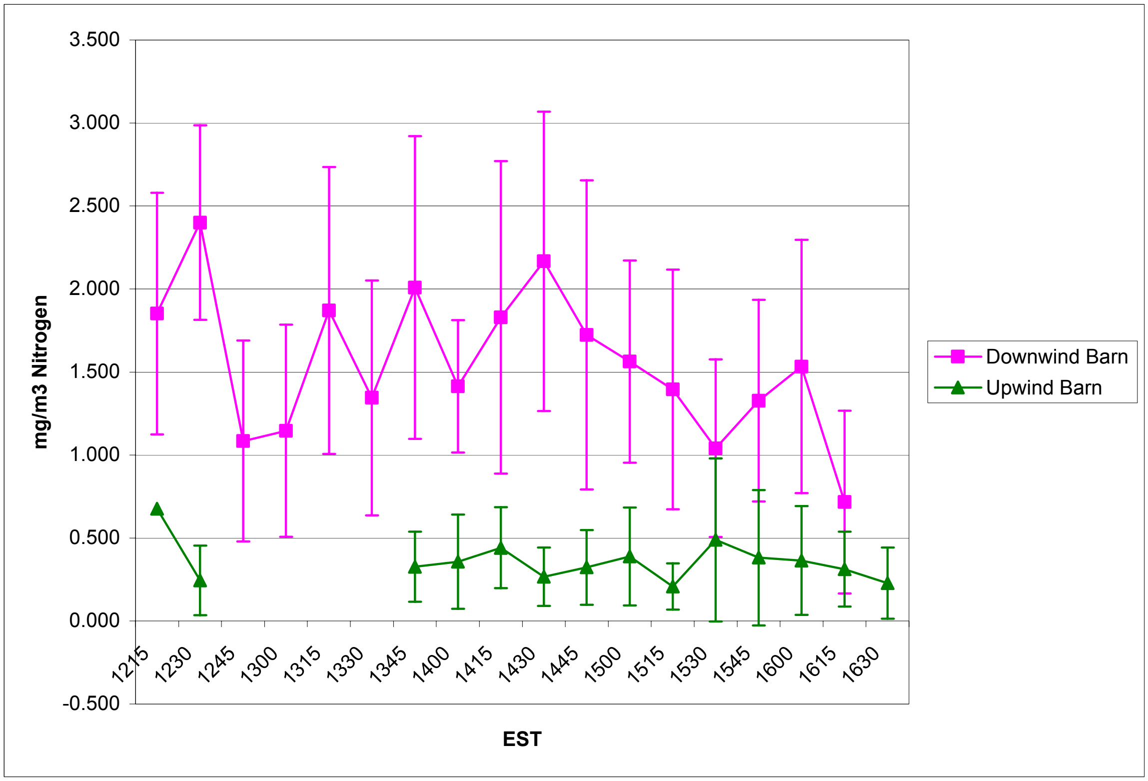


Figure 3.14 Fifteen-minute minute Average Concentration with Standard Deviation measured in June, 2004.

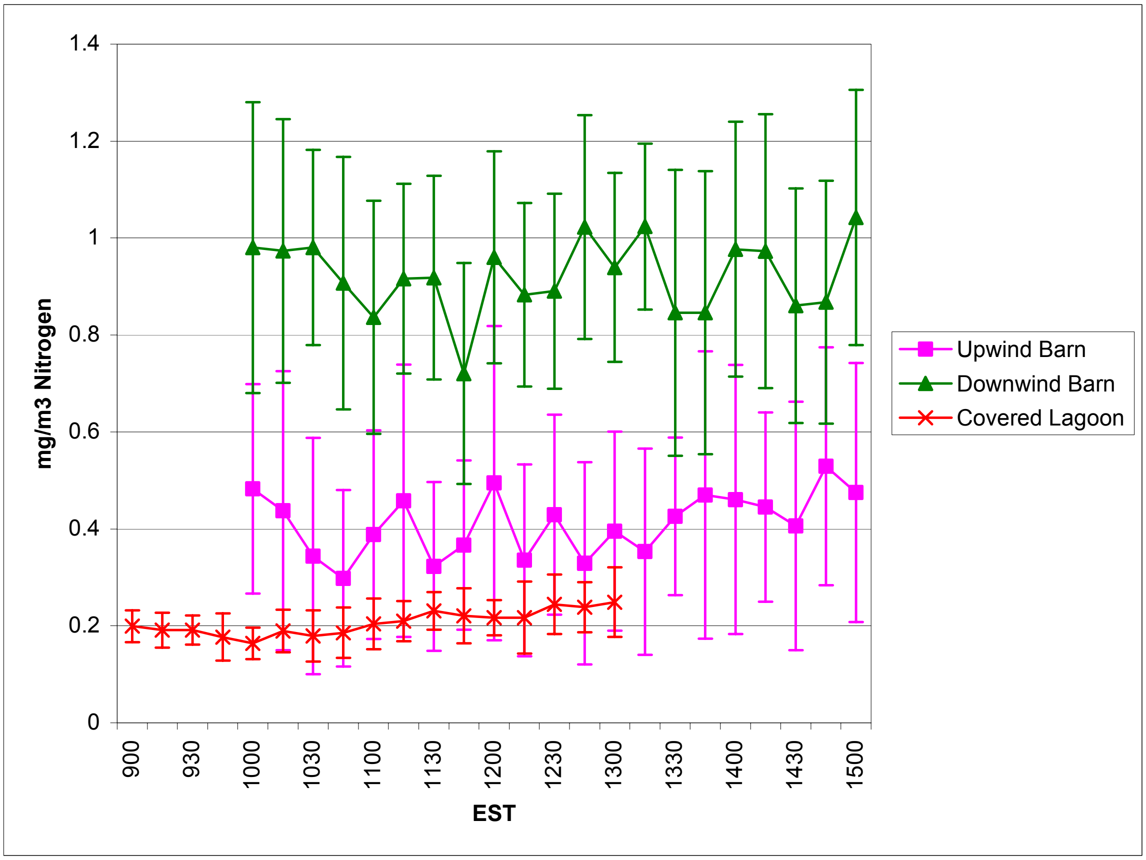


Figure 3.15 Fifteen-minute Average Concentrations and Standard Deviations Measured in August, 2004.

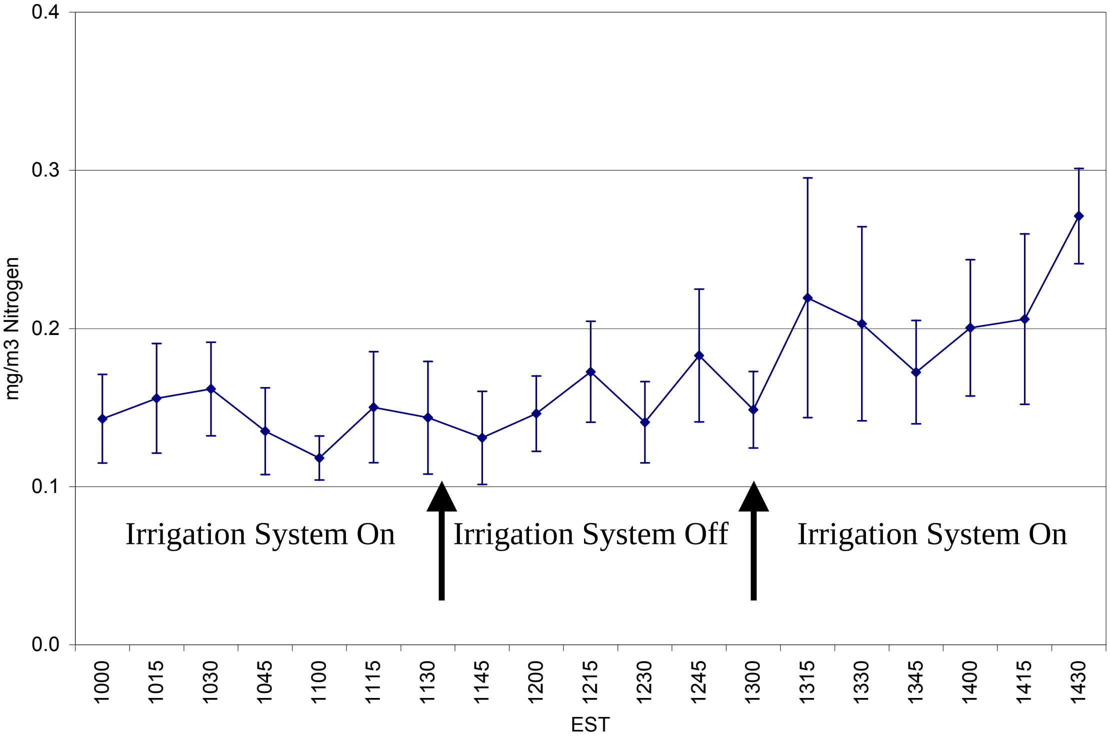


Table 3.9 Average Daily Concentrations of Nitrogen in mgN/m3.

Date	**Component**	
	Barn (mg N/ m3)	
2004	**Upwind Barn**	**Downwind Barn**
February 3	**0.358**	**1.554**
June 1	**0.412**	**0.922**
	Covered Lagoon	
June 1	**0.206**	
August 24	**0.169**	

Estimated Ammonia Emissions from Barns

To calculate the average nitrogen flux from the naturally ventilated houses, air-flow measurements were made by sampling at one location along each of the four sections of the building on the upwind side while the OP-FTIR was deployed. Each location was sampled for 30-60 seconds and the high and low readings recorded for all four locations over a 5-7 minute period of time. The high and low wind velocity readings were used to calculate the average wind velocity. The curtain opening for each section was measured and the volume of air per second (ventilation rate) flowing through the upwind side of the barn was calculated as the sum of curtain openings times the average wind velocities for the four sections of the building. The net ammonia concentrations associated with emissions from the building were obtained by subtracting the upwind readings from the downwind readings using the OP-FTIR and then converting the difference to concentrations of ammonia. A moving average was then applied to the concentration data to reduce the effect of wind variations (times when the wind deviated from the predominate direction). Flux from the building was obtained by multiplying net ammonia concentration times the corresponding ventilation rate. The flux calculations were then normalized by the total live weight of swine in the house (1000 Kg LW) (Table 3.10).

Table 3.10 Flux (KgN/Week/1000Kg weight of pigs)

Date	Location	KgN/Week/ 1000 KG
02/03/04	1 Barn	0.050
06/01/04	1 Barn	0.265

Assessment of Ammonia Emissions from Alternative Technology:

At each alternative technology and conventional site, the estimated ammonia emissions are limited to two two-week long periods, representing warm and cold seasons. But, since measurements at different sites are made at different times of the year, environmental conditions are likely to be different at different sites, even during a representative "warm" or "cold" season. There is a need for accounting for these differences in our relative comparisons of the various alternative and conventional technologies.

The estimated emissions from water-holding structures at an alternative technology for each measurement period are compared with the average estimated emissions from baseline sites, after the later are adjusted for the average environmental parameters (lagoon temperature and air temperature) observed at the former (alternative technology) site. A rational basis for this adjustment for somewhat different environmental conditions is the multiple regression model developed for ammonia emissions and measured environmental parameters at the two baseline sites. The model is described in appendix 2 of the three-year report. Such a comparison would not require highly uncertain extrapolations of emissions at alternative technology sites beyond the two measurement periods. Absolute numbers are not used in assessing ammonia emissions from the proposed alternative technology. A normalized measure of emissions (normalized to calculated N-excreted; $\%E_{EST}$) is compared to a similar normalized measure of emissions ($\%E_{CONV}$) from a baseline site using the conventional lagoon technology for handling swine waste in North Carolina. The %E values are an estimate of rate of loss of N compared to N excreted. Two baseline sites are used to account for differences in housing ventilation across the sites with the proposed EST's. No method exists for adjusting baseline housing emissions to environmental conditions observed at an EST farm. Therefore, actual housing emissions measured at the baseline sites during comparable seasons of the year are used when generating the normalized measures of emissions from houses. It is acknowledged that the housing emissions for the baseline sites were not made under the exact meteorological conditions as the housing measurements for evaluation of an EST.

The algorithm followed in deriving an index of performance (%reduction = $[(\%E_{CONV} - \%E_{EST})/\%E_{CONV}] * 100$) by the EST in reducing ammonia emissions as compared to the conventional technology currently in use in North Carolina (baseline sites) is presented in Figure 3.16 for water holding structures.

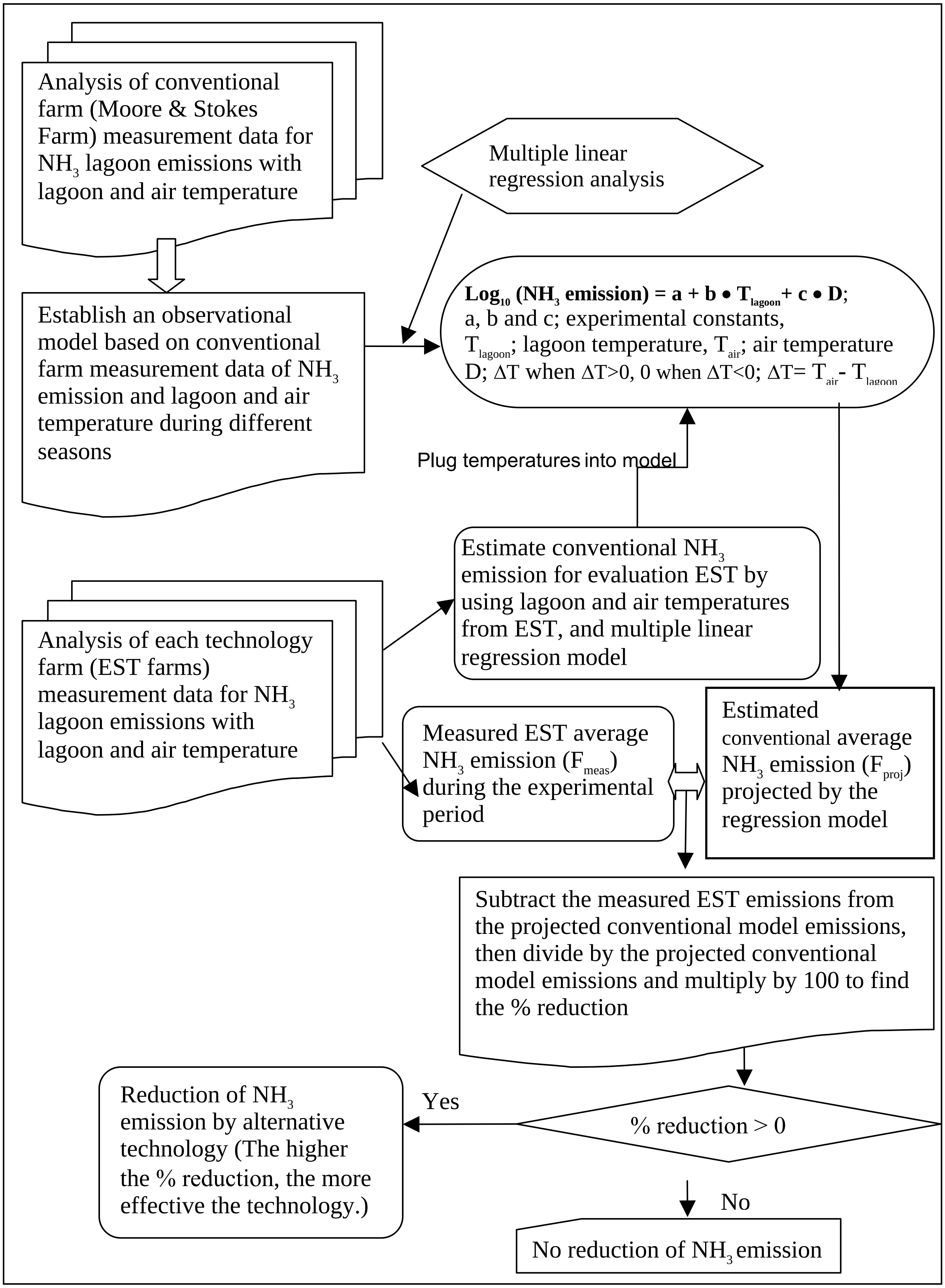


Figure 3.16 Algorithm flow chart for evaluation of alternative technology ammonia emission from water holding structures.

Evaluation of Harrell's farm (PCS)

We compare NH_3-N emission from water-holding structures at Harrell's farm with the projected average emission from lagoon at the conventional farm, using the observational statistical (multiple linear regression) model.

Table 3.11 gives animal weight, feed consumed, and N-excretion at two conventional farms and Harrell's farm. Table 3.12 gives the NH_3-N emissions (kg-N/1000 kg-live weight/wk) data summary for the Harrell's farm and baseline farms for evaluation of EST at the former. The emissions from different components of an EST or baseline farm should be viewed relative to the estimated nitrogen excretion from animal population, weight and feed data.

Table 3.11 Summary of animal weight, feed consumed, and N-excretion at conventional farms (Stokes and Moore) and the EST (Harrell's farm; PCS) farm.

Farm Information	No. of pigs	average pig weight kg/pig	total pigs weight kg	feed consumed kg/pig/wk	N-excretion, E kg-N/wk /1000kg-lw
Stokes (Sep.)	4,392	104.3	458,086	12.84	2.71
Jan.	3,727	88.5	329,840	12.59	2.51
Moore (Oct.)	7,611	52.3	398,055	10.99	4.39
Feb.	5,784	67.0	387,528	12.37	3.90
Harrell's (Feb)	2,071	110.3	228,431	18.62	2.67
June	2,417	86.5	209,071	16.25	2.71
Aug	2615	50.9	133,103	12.61	5.17

Table 3.12 Estimates of % reduction in NH_3-N emissions from different components and their sum total at the EST (Harrell's: PCS) and conventional farms (kg-N/wk/1000kg-*lw*). (% reduction = [($\%E_{CONV}$- $\%E_{EST}$)/$\%E_{CONV}$]*100

(1)Permeable cover, Aerobic digester and Storage basin emissions

Period	Average lagoon temperature (°C)	Average D (°C)	Conventional model emissions F_{proj}	% E_{CONV}	PBS measured emission F_{meas}	% E_{EST}	% reduction
Jan 31-Feb 11, 2004	8.5	1.4	0.15	4.7	0.07	2.6	44.7
Jun 3-11, 2004	27.0	0.3	1.15	32.4	2.14	79.0	-143.8
Aug 25-30, 2004	26.2	0.4	1.05	29.6	1.55	30.0	-1.4

(2) Barn Emissions

Period	Stokes Farm measured emission	% E_{CONV}	PBS measured emission F_{meas}	% E_{EST}	% reduction
Jan 31-Feb 11, 2004	0.25‡	10.0	0.05	1.9	81.0
Jun 3-11, 2004	0.25‡	10.0	0.27	10.0	0
Aug 25-30, 2004	N/A	N/A	N/A	N/A	N/A

Total Emissions (1)+(2)

Period	conventional total emission	% E_{CONV}	PBS measured emission	% E_{EST}	% reduction
Jan 31-Feb 11, 2004	0.40	14.7	0.12	4.5	69.4
Jun 3-11, 2004	1.40	42.4	3.56	89.0	-109.9

D is ΔT, the difference between the air temperature (T_{air}) and lagoon temperature (T_{lag}), when $T_{air} > T_{lag}$; D = 0 when $T_{air} < T_{lag}$. F_{proj} is baseline lagoon area adjusted NH_3 lagoon emission projected by the baseline multiple linear regression model corresponding to the average lagoon temperature and the average D during Harrell's (PCS) farm measurement periods. % E_{CONV}

is the conventional model emissions relative to the N excreted. % E_{EST} is the measured emission from the EST relative to the N excreted. F_{meas} is sum of the NH_3 emission from water holding structures and NH_3 emission from barn house measured at Harrell's (PCS system) farm. Soil flux measurements were not taken because there was no lagoon spray and land application during the experimental period. Hog houses at Harrell's (PCS) farm are naturally ventilated, like Stokes farm. ‡: Overall house emission measured at Stokes farm during January 2003. % reduction is used to describe how effective a technology is, in reducing NH_3 emissions. A number > 0 indicates a reduction in NH_3.The larger the % reduction, the more effective the technology is in reducing NH_3 emissions. Conversely a number < 0 indicates that there are has been no reduction in NH_3 emissions.

4. Evaluation of Environmentally Superior Technologies for Ammonia Emissions: Super Soil Demonstration Project

Composting Unit

Alternative Technology: Composting of Separated Solids

Location: Hickory Grove, NC

Evaluation Periods:
1st evaluation: July 19 – 30, 2004
2nd evaluation: November 9 -19, 2004

Technology contact: Lew Fetterman and Ray Campbell, Super Soils Systems, USA (919-851-5751)

Principal Investigators: Drs. Matias Vanotti, Patricia Millner, Ariel Szogi, Patrick Hunt, USDA ARS, Florence, SC (843-669-5203)

Statement of Task:

- Measurement of ammonia (NH_3) emissions from active composting bins and a curing pile using a dynamic flow-through chamber system and a simple flow-through chamber system during two different campaigns (warm and cool seasons)
- On site monitoring of meteorological parameters at 10 or 3 meter height
- FTIR technology to assess atmospheric ammonia concentrations above composting bins
- Parameters measured: NH_3 flux, compost and curing pile temperature, wind speed and direction, solar radiation, relative humidity and air temperature

Description of Alternative Technology:

The following was provided by Dr. Matias Vanotti, Project PI for Composting Unit – Super Soil Demonstration Project:

The process is divided into three physical areas:

> 1) A concrete pad at the front of the process that receives the manure solids arriving in trailers from Goshen Ridge farm. The same area is used to put the bulking materials (cotton gin trash and wood chips) that are used in the compost mixes. A front-end loader is used to carry manure and bulking material loads to the composting bins.
>
> 2) Composting bins (or rows) that are 192-ft (58.5 m) long, where the mixtures of manure and bulking materials go through aerobic composting treatment. There were 5 bins

> installed in the composting facility, all under one common roof; only bins 1 and 2 were used for this evaluation (using swine solids produced in Goshen Ridge Unit 1). A mechanical mixer that served all bins moved about once per day though each of the bins, turning the compost, and at the same time advancing the material from one end to the other. It takes 30 passes of the machinery for the material to travel full-length from one end of the bin to the other.
>
> 3) Curing piles that complete the process. Two curing piles were assessed; they received compost material exiting bins 1 and 2. "

(Source: Waste management Programs, North Carolina State University, http://www.cals.ncsu.edu:8050/waste_mgt/)

- A conceptual flow-diagram of alternative technology

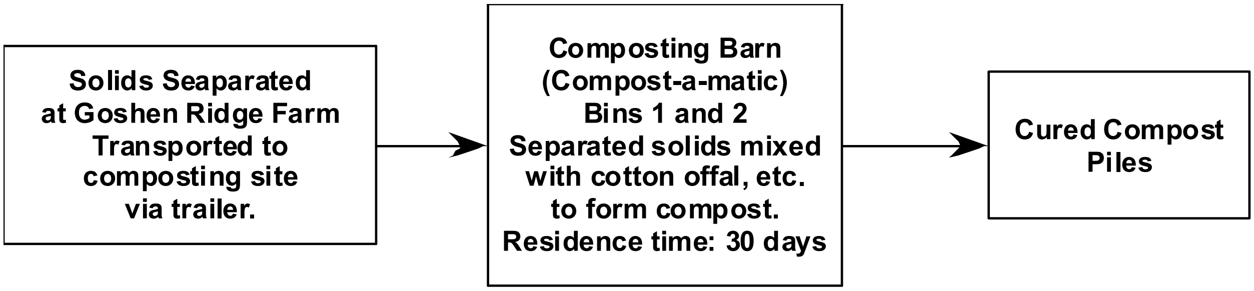


Figure 4.1 Conceptual flow diagram of Super Soil Demonstration Project composting unit.

- Possible points of emissions of ammonia on conceptual flow-diagram and parameters that are important in controlling emissions:
  - **Transportation to composting site**: this potential source was not evaluated.
  - **Composting Barn** – compost located within each bin (TAN content, pH, internal temperature during composting process, moisture content)
  - **Curing Pile** - compost located within each bin (TAN content, pH, internal temperature during composting process, moisture content).

Descriptive Information for Farm with EST:

Figure 4.2. Aerial photograph of Super Soils Demonstration Project Composting Unit.

Figure 4.3 Cross-sectional view of composting barn showing 5 bins for holding composting material. Mechanical mixer is mounted on railing above Bin 2.

Figure 4.4 Close-up view of mechanical mixer used to mix compost.

- **Composting Bins and Curing Pile**

The following was derived from information provided by Dr. Matias Vanotti, Project PI for Composting Unit – Super Soil Demonstration Project.

First evaluation period (July 19-July 30, 2004):
Composting material associated with the Super Soil Demonstration Project was only present in Bins 1 and 2 (Fig. 4.3). Bin 2 was started February 17, 2004 and was at steady-state during the first evaluation period. It used a mixture comprised of 1SS:2CGT (SS=manure solids; CGT=Cotton Gin Trash; mixture done on a volume basis). The full length of Bin 2 was occupied with compost material during the two-week OPEN visit. The corresponding curing pile was 8.1-m long on July 29,2004. Bin 1 was started July 16, 2004 (the week before the first evaluation period). It used a mixture 1SS:2CGT:4WC (SS=manure solids; CGT=Cotton Gin Trash; WC=Wood Chips; mixture on volume basis). On July 19, 2004, only the initial 8% the Bin 1 length was occupied with compost material and the remainder of the bin was empty. By July 30,

2004, 43% of Bin 1 was occupied with composting material and the remainder of the bin was empty. No curing pile was yet present for material derived from Bin 1. During the month of July 2004 (July 1-July30), Bins 1 and 2 received a total of 45.02 m^3 of manure solids; 84.9% of the solids were processed in Bin 2 (1SS:2CGT mixture) and 15.1% were processed in Bin 1.

Table 4.1 Composition of manure and bulking agents (N,C,P,Cu,Zn are % on dry basis). Manure analysis is the average of 7 composite samples obtained during one-month period (July, 2004).

Ingredient	Moisture (%)	Density (kg/L)	Total N (%)	C (%)	P (%)	Cu (%)	Zn (%)
Manure solids (SS)	83.2	0.834	4.76	36.82	4.65	0.38	0.33
Cotton Gin Trash (CGT)	12.7	0.092	1.02	42.88	0.23	0.004	0.007
Wood Chips (WC)	66.1	0.455	0.67	42.13	0.30	0.009	0.015

Table 4.2 Retention times and loadings rates into the bins during OPEN evaluation. Volume load takes into account manure solids and bulking materials added into the mix. Nutrient loads are mass calculations and combine inputs from both manure solids and bulking materials.

Bin #	Retention time in Bin (days)	Material travel speed (m/day)	Volume Load (m3/day)	Dry Matter load (kg/day)	N Load (kg/day)	P Load (kg/day)
Bin 1	30.0	1.95	1.59	401	5.48	3.92
Bin 2	32.7	1.79	3.82	383	10.58	8.77
Bins 1 + 2			5.41	784	16.06	12.69

Table 4.3 Flow of material exiting Bins (into Curing piles):

Bin #	Volume Flow (m3/day)	Dry Matter Flow (kg/day)	N Flow (kg/day)	P Flow (kg/day)
Bin 1	0	0	0	0
Bin 2	0.591	226	8.23	7.05

Table 4.4 Characteristics of curing pile material corresponding to Bin 2 (1SS:2CGT), sampled July 29, 2004 (N,C,P,Cu and Zn are % composition on a dry basis).

Age of material	Moisture (%)	Density (kg/L)	Total N (%)	C (%)	P (%)	Cu (%)	Zn (%)
1 day old (new)	55.23	0.773	3.55	31.29	3.270	0.184	0.190
52 day old (aged)	45.00	0.676	3.55	29.76	3.040	0.171	0.179

Second Evaluation Period (November 9 – 19, 2004):
The full length of Bin 2 was occupied with compost material (1SS:2CGT; SS=manure solids; CGT=Cotton Gin Trash; mixture on volume basis) during the two-week OPEN visit. The corresponding curing pile was 36.0-m long on November 1, 2004. The full length of Bin 1 (1SS:2CGT:4WC; SS=manure solids; CGT=Cotton Gin Trash; WC=Wood Chips; mixture on volume basis) was occupied with compost material during the two-week OPEN visit. The corresponding curing pile was 35.9-m long on November 1, 2004. During the period of October 19-November 19, Bins 1 and 2 received a total of 51.06 m^3 of manure solids; 51.1% of the solids were processed in Bin 1 and 48.9% were processed in Bin 2.

Table 4.5 Composition of manure and bulking agents (N,C,P,Cu,Zn are % on dry basis). Manure analysis is the average of 9 composite samples during a one month period October 19-November 19, 2004.

Ingredient	Moisture (%)	Density (kg/L)	Total N (%)	C (%)	P (%)	Cu (%)	Zn (%)
Manure solids (SS)	83.4	0.836	5.33	40.64	3.75	0.330	0.277
Cotton Gin Trash (CGT)	12.7	0.092	1.02	42.88	0.23	0.004	0.007
Wood Chips (WC)	66.1	0.455	0.67	42.13	0.30	0.009	0.015

Table 4.6 Retention times and loadings rates into the bins during OPEN evaluation. Volume load takes into account manure solids and bulking materials added into the mix. Nutrient loads are mass calculations and combine inputs from both manure solids and bulking materials.

Bin #	Retention time in Bin (days)	Material travel speed (m/day)	Volume load (m3/day)	Dry Matter load (kg/day)	N Load (kg/day)	C Load (kg/day)	P Load (kg/day)
Bin 1	30.0	1.95	5.71	748	10.74	314.3	6.06
Bin 2	36.0	1.63	2.34	233	7.05	97.7	4.35
Bins 1 + 2			8.05	981	17.79	412.0	10.41

Table 4.7 Flow of material exiting Bins (into curing piles).

Bin #	Volume Flow (m3/day)	Dry Matter Flow (kg/day)	N Flow (kg/day)	C Flow (kg/day)	P Flow (kg/day)
Bin 1	1.969	450	6.14	155.4	4.05
Bin 2	1.117	349	9.18	90.07	5.41
Bin 1 + 2	3.086	799	15.32	245.47	9.46

Table 4.8 Characteristics of curing pile material corresponding to Bin 1 and 2 (1SS:2CGT), sampled Nov. 1, 2004 (N,C,P,Cu and Zn are % composition on a dry basis).

Curing pile	Age of material	Moisture (%)	Density (kg/L)	Total N (%)	C (%)	P (%)	Cu (%)	Zn (%)
Mix 1SS:2CGT:4WC (From Bin 1)	1 day old (new)	55.19	0.496	1.580	28.33	0.630	0.034	0.042
	12 days old	48.83	0.464	1.760	27.80	0.788	0.052	0.061
	35 days old (aged)	50.29	0.478	2.185	28.46	0.941	0.062	0.078
Mix 1SS:2CGT (From Bin 2)	1 day old (new)	59.13	0.707	2.630	26.44	1.600	0.116	0.121
	17 days old	41.81	0.739	2.280	24.6	1.742	0.150	0.142
	33 days old (aged)	52.23	0.704	3.395	27.02	2.878	0.198	0.180

Field Measurements:

- **Air Temperature**

Average air temperature recorded near the composting barn was 25 +/- ˚C for the later part of the first evaluation period (July 28, 2004 to August 12, 2004. There was a pronounced drop in temperature on August 6th, followed by a gradual warming, but the differences between daily maximum and minimum temperatures were more evident after the sixth. Average air temperature was 9.6 +/- ˚C for the second evaluation period (November 9 – 19, 2004). In general this period was characterized by cold nights (near freezing) followed by 15 degree changes during the day.

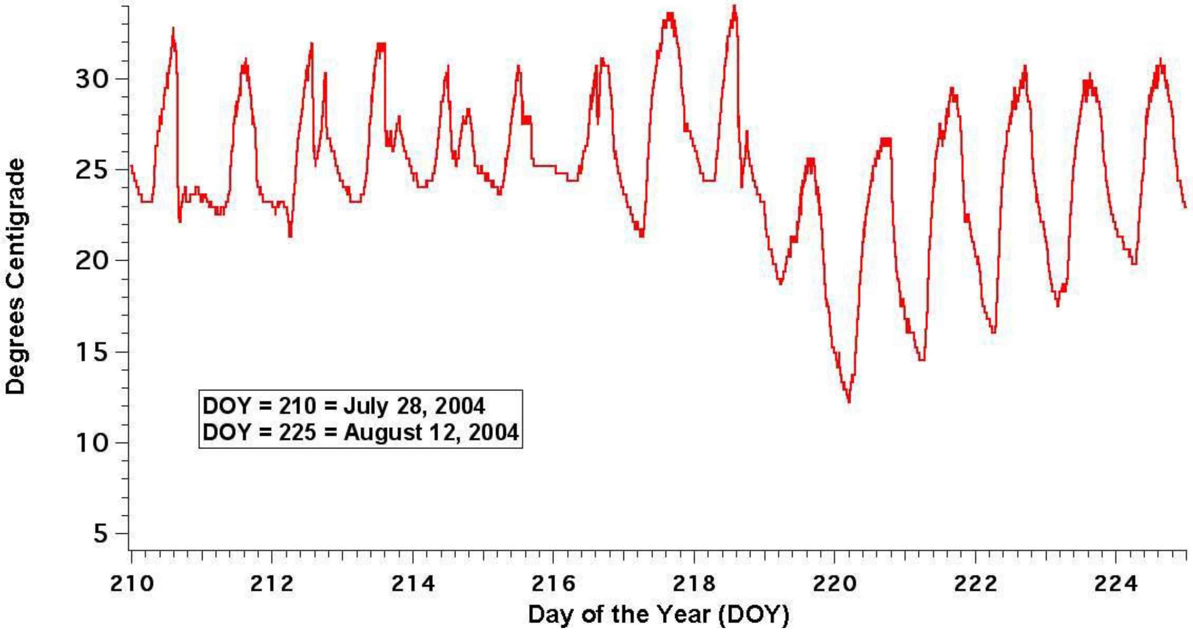


Figure 4.5. Air temperature (h = 3m) recorded during the period July 28, 2004 to August 12, 2004.

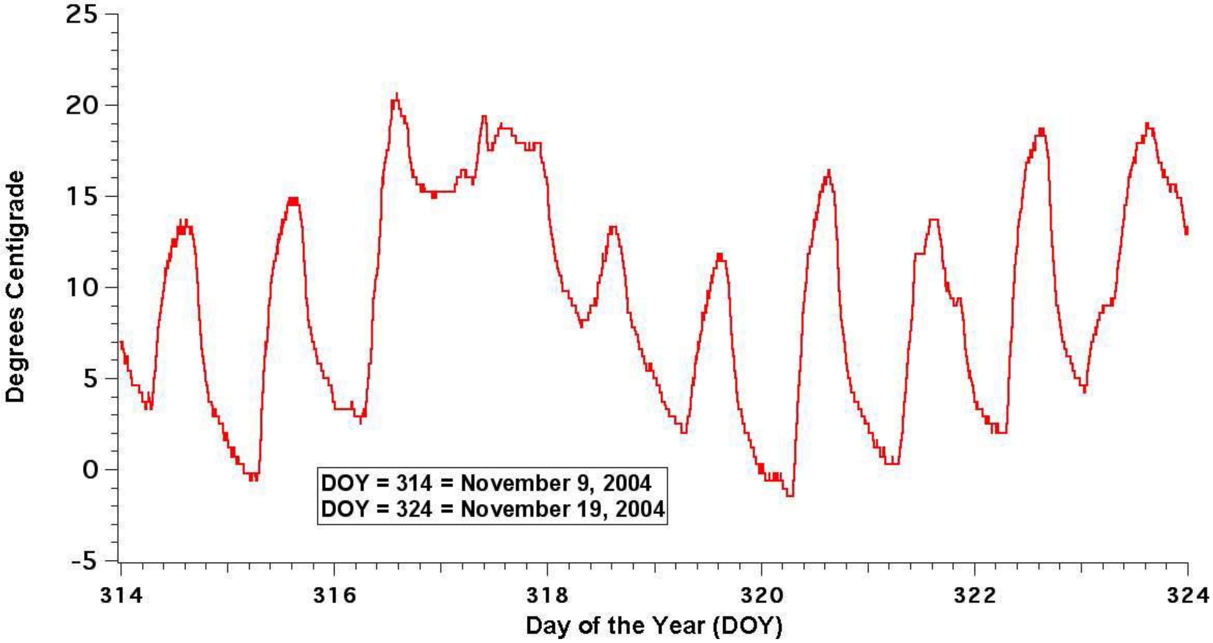


Figure 4.6. Air temperature (h = 3m) recorded during the period November 9, 2004 to November 19, 2004.

- **Recorded Temperatures in Compost Bins and Curing Pile**

As expected, recorded temperatures in Bins 1 and 2 were higher than ambient for both evaluation periods (Figs. 4.7 and 4.8). Both Bins followed the same general trend in temperature, with highest temperatures being recorded approximately a third the way down the Bins from the input end. Temperature then declined gradually till beyond the 50 m mark, where the decrease in temperature became more pronounced. The observed pattern is consistent with anticipated level of microbial activity within the composting bins. In general, higher temperatures were observed during the second evaluation period (cold season) than the first (Fig. 4.7), even though ambient temperatures were much colder. The data in Figs. 4.7 and 4.8 support the assumption that the temperature within the composting bins is essentially independent of ambient atmospheric temperature.

Elevated temperatures substantially above ambient were also noted in the curing pile for Bin 2 during the second evaluation period (Fig. 4.9). (No observations were recorded for the Bin 2 curing pile during the first evaluation period.) The top 7 cm of the pile appeared to respond to daily variations in ambient sir temperature, but this variation appeared to disappear at the 15 cm depth. These measurements were taken midway along the curing pile at the top of the pile.

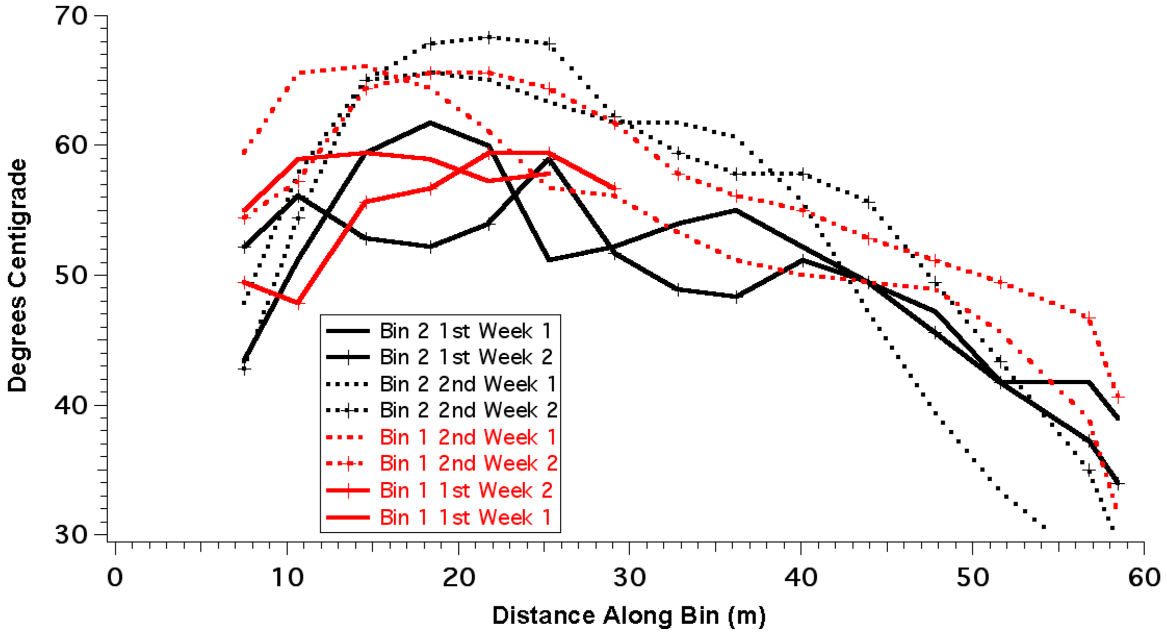


Figure 4.7 Mean temperatures of composted material in Bins 1 and 2 for both evaluation periods as a function of distance down bins from input end. Data provided by Dr. Matias Vanotti, Project PI for Composting Unit – Super Soil Demonstration Project.

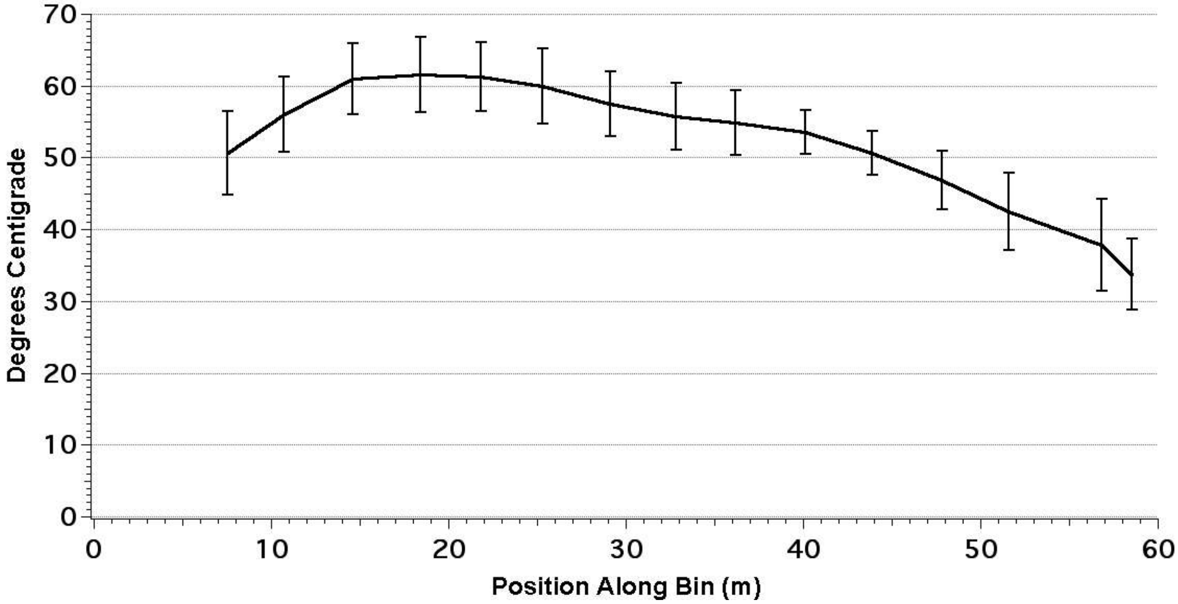


Figure 4.8. Overall mean (+/- standard deviation) temperature of composting material in Bins 1 and 2 for both evaluation periods as a function of distance down bins from input end. Mean and standard deviation values generated from data provided by Dr. Matias Vanotti, Project PI for Composting Unit – Super Soil Demonstration Project.

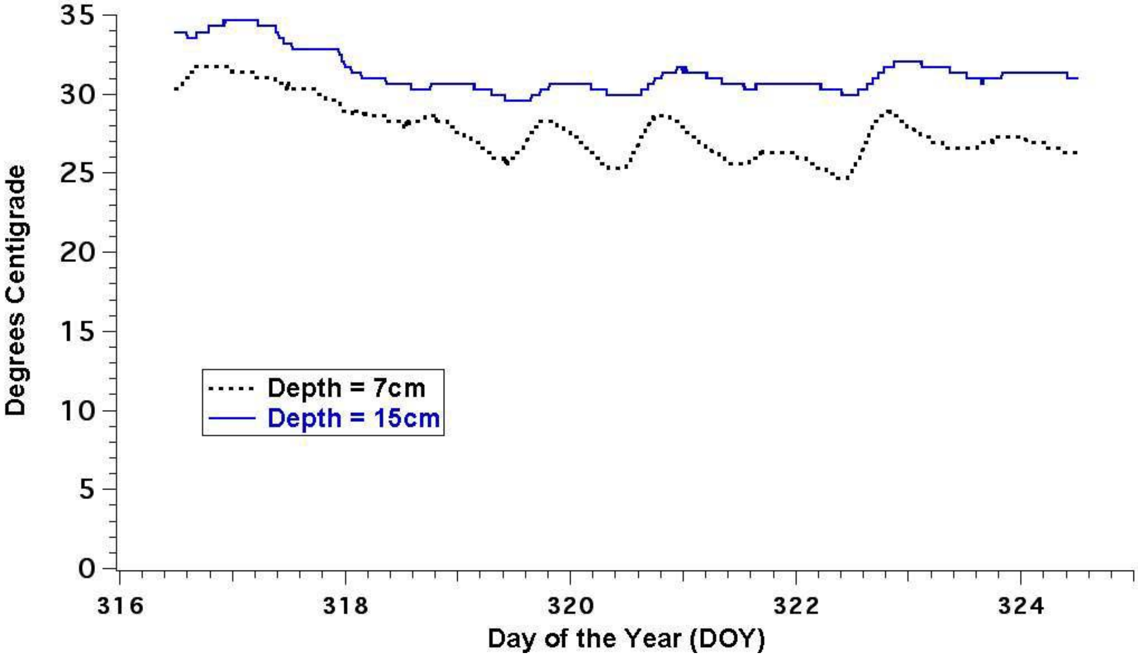


Figure 4.9. Temperature of Bin 2 curing pile as a function of time recorded during the second evaluation period (November 9 – 19, 2004) at two depths (7 and 15 cm). Temperature probes were inserted near top of the mid-point of the curing pile.

- **Ammonia Flux Measurements**

Composting Bins:
The dynamic flow-through chamber system was used to make flux measurements from the material in Bins 1 and 2. Attempts to insert the dynamic flow-through chamber-mounting frame directly into the composting material proved unsuccessful. The dynamic flow-through system requires the flow of air into the chamber to operate, and an air-tight seal between the mounting frame and the composting material is a necessity to obtain accurate results. Because of the porous, heterogeneous nature of the composting material, attempting to obtain an air-tight seal with the mounting frame proved impossible.

This difficulty was overcome by excavation of composting material out of the respective bin and placing the material into a 5 gallon plastic bucket to which the mounting frame for the dynamic flow-through chamber system could be firmly attached (Fig. 4.10). Typically composting material was excavated from a bin using a shovel, the material placed into the bucket, dynamic flow-through chamber attached, and then the system allowed to equilibrate for 30 minutes before commencing recording readings. Total elapsed time for one sampling position within a bin was typically 2 hours. Calculated ammonia flux for both evaluation periods as a function of bin and position along a bin is listed in Table 4.9.

Attempts to use the simple flow-through chamber system to measure ammonia flux from the composting material proved impossible given the high rates of flux obviously emitted from the bins. In certain instances, even the upper working limit of the dynamic flow-through chamber system was approached or exceeded. In these cases, the highest calculated fluxes were recorded, with the understanding that actual ammonia flux may have been somewhat higher.

Table 4.9. Ammonia flux from composting bins as determined using the dynamic flow-through chamber system. Each calculated flux represents the average flux observed during an approximately 2-hour observation period. Fluxes denoted by an * indicate that the dynamic flow-through system at or near the upper limit of its operating range.

First Evaluation Period		
Bin Number (Fig. 4.3)	**Distance Along Bin (meters)**	**Average Ammonia Flux (ug-N m^{-2} min^{-1})**
1	7	5513
1	27	3615
2	6	3801
2	38	11354*
2	56	287
Second Evaluation Period		
2	4	9150*
2	28	9150*
2	54	87

Figure 4.10. Dynamic flow-through chamber system mounted on 5 gallon plastic bucket. Modification in measurement protocol was necessary to successfully measure ammonia flux from the porous, heterogeneous material in the composting bins.

Curing Pile:

Measurements of ammonia flux from the Bin 2 curing pile were made using a simple flow-through chamber system (Fig. 4.11). This system allowed replication per measurement location and allowed direct measurement of flux from the surface of the curing pile. Basically the system works by directly measuring mass of ammonia released instead of calculating mass via a separate measurement of ammonia concentration within the chamber multiplied by the flow of air through the chamber. Input air to the chamber was not scrubbed of ambient ammonia. Rather, the chamber inlets were directed away from the curing pile and set at the same height as the intake of an annular denuder system which was used to measure the average ambient ammonia concentration while the chambers were in operation. This measurement allowed for correction for the mass of ammonia pulled into the chamber from the ambient air. In practice, this correction is minimal, typically accounting for <3.5% of mass of ammonia collected from the chamber. The dynamic flow-through chamber system was used to measure ammonia flux from the curing pile at one location on one day. All measurements were made during the second evaluation period.

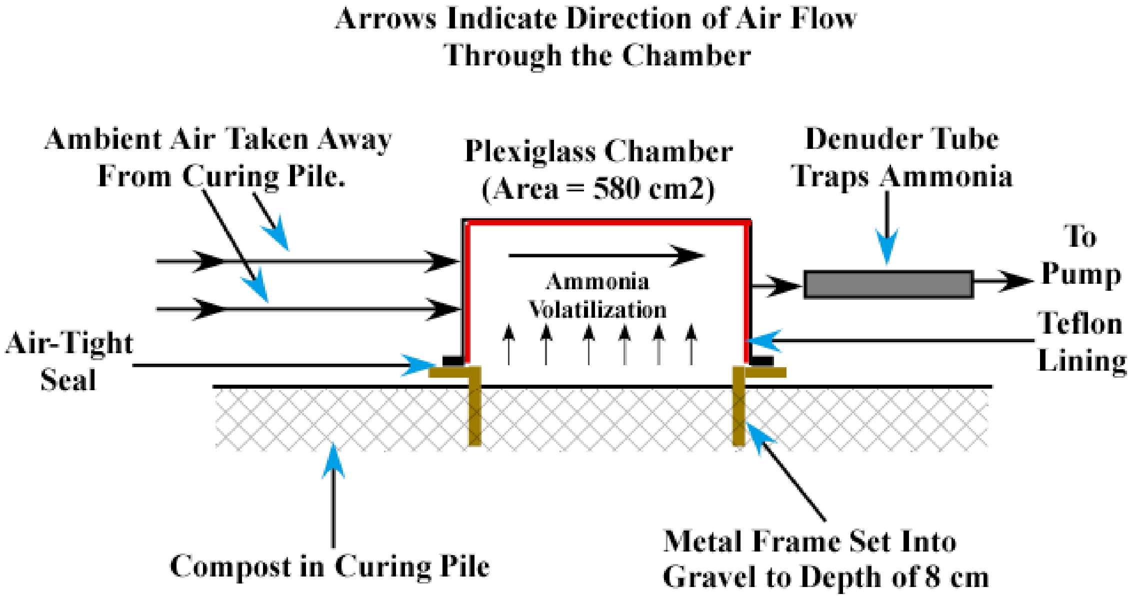


Figure 4.11. Schematic of simple flow-through chamber system used to measure ammonia flux from Bin 2 curing pile during the second evaluation period. Concentration of ammonia in ambient air is measured by separate annular denuder system during the operation of the chamber system.

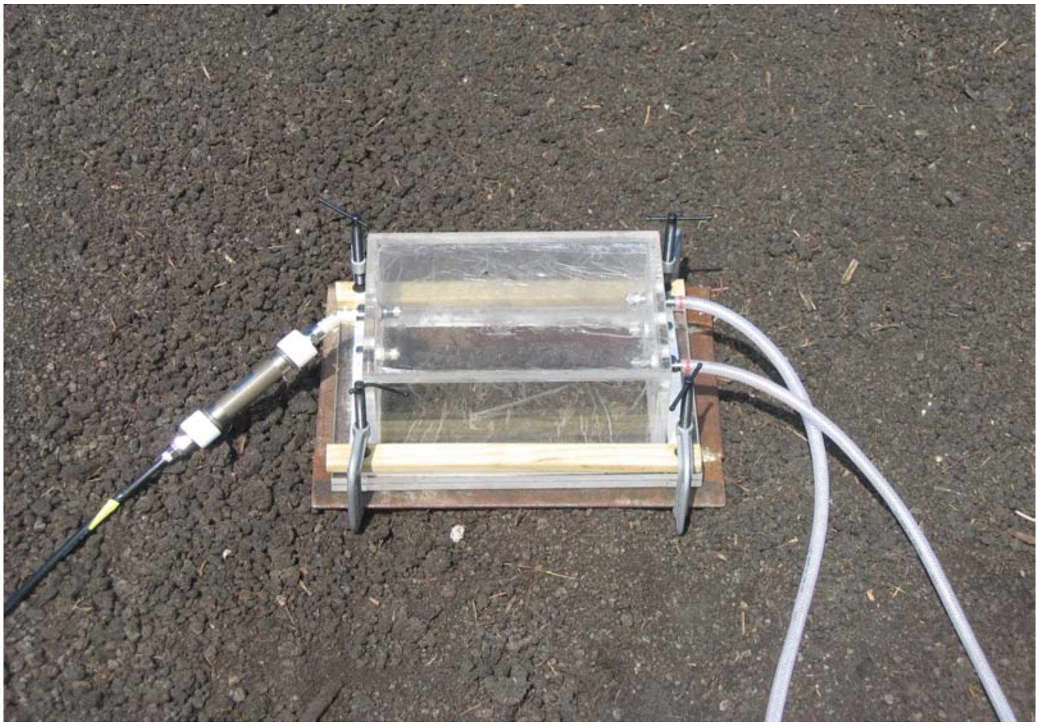


Figure 4.12. Picture of simple flow-through chamber system deployed on surface of Bin 2 curing pile during second evaluation period. A pump is located to the left of the chamber pulling air out of the chamber and through the acid-coated denuder tube. The intake for the air input tubes on the right are located several meters away from the pile at a height of 2.6 m.

Table 4.10. Ammonia flux from Bin 2 curing pile as measured using the simple flow-through chamber system, and the dynamic flow-through chamber system during the second evaluation period. Position value indicates distance from newest end of pile (> value = older segments of pile). On November 1, 2004, the Bin 2 curing pile was 36 meters long.

Date (2004)	**Time Start**	**Time End**	**Position (m)**	**Ammonia Flux (ug-N m^{-2} min^{-1})**			
				Rep 1	**Rep 2**	**Rep 3**	**Mean**
Simple Flow-Through Chamber System							
Nov. 10	12:30	13:26	27-36	8.8	15.9	17.7	14.1
Nov. 10	13:35	14:26	27-36	10.3	18.2	20.2	16.2
Nov. 11	11:59	12:56	18-27	26.3	27.8	25.5	26.6
Nov. 11	12:56	13:56	18-27	39.6	29.4	43.9	37.3
Nov. 17	11:39	12:36	9-18	25.7	25.7	9.2	20.2
Nov. 17	12:36	13:36	9-18	30.7	31.9	11.4	24.7
Nov. 18	11:58	12:48	4-9	7.5	7.0	8.2	7.6
Nov. 18	12:48	13:39	4-9	11.3	7.9	8.2	9.1
Dynamic Flow-Through Chamber System							
Nov. 17	11:00	13:00	9-18	22	-	-	22

- **Ammonia Concentration Measurements**

Open-Path Fourier Transform Infrared (OP-FTIR) Spectrometry was used to measure atmospheric concentrations of ammonia above the composting bins and within the composting shelter during both evaluation periods. Measurements were carried out during July 20-22 and November 9-10, 2004. For both evaluation periods, data was collected over the Bins 1 and 2 (Fig. 4.3).

For measurements made in July, a retroreflector was placed in Bin 3 at three positions: at the loading end, 20 meters from the loading end, 40 meters from the loading end, and at the finishing end of the row (Figure 4.13). Bin 3 is purposefully left empty by the technology provider to allow access to the entire length of Bins 2 and 4, which contain composting material. These four positions within Bin 3 allowed measurements of ammonia concentrations across the first third and two-thirds of the composting material in Bin 2, as well as the ammonia concentration entering the composting shelter and the ammonia concentration exiting the shelter. The fifteen-minute average ammonia concentrations measured for each of these four positions is presented in Fig. 4.14.

Ammonia concentrations at the loading end of Bins 1 and 2 were relatively low, which is consistent with the predominant wind direction during the measurement period (Fig. 4.14). Ammonia concentrations increase substantially, however, above the first third, and two-thirds of the composting material in Bins 1 and 2. The magnitude of these concentrations is indicative of a strong immediate source of ammonia and corresponds to similar measurements for exhaust fans on swine ventilated housing units and/or above the surface of swine lagoons. Relatively high ammonia concentrations were observed at the finishing end of the composting shelter, but the degree of variation in the signals was substantially greater than within the composting shelter. The wider greater variance associated with these measurements is probably due to turbulence within composting shelter as well as a lessening of the ammonia source term near the finishing end of Bins 1 and 2.

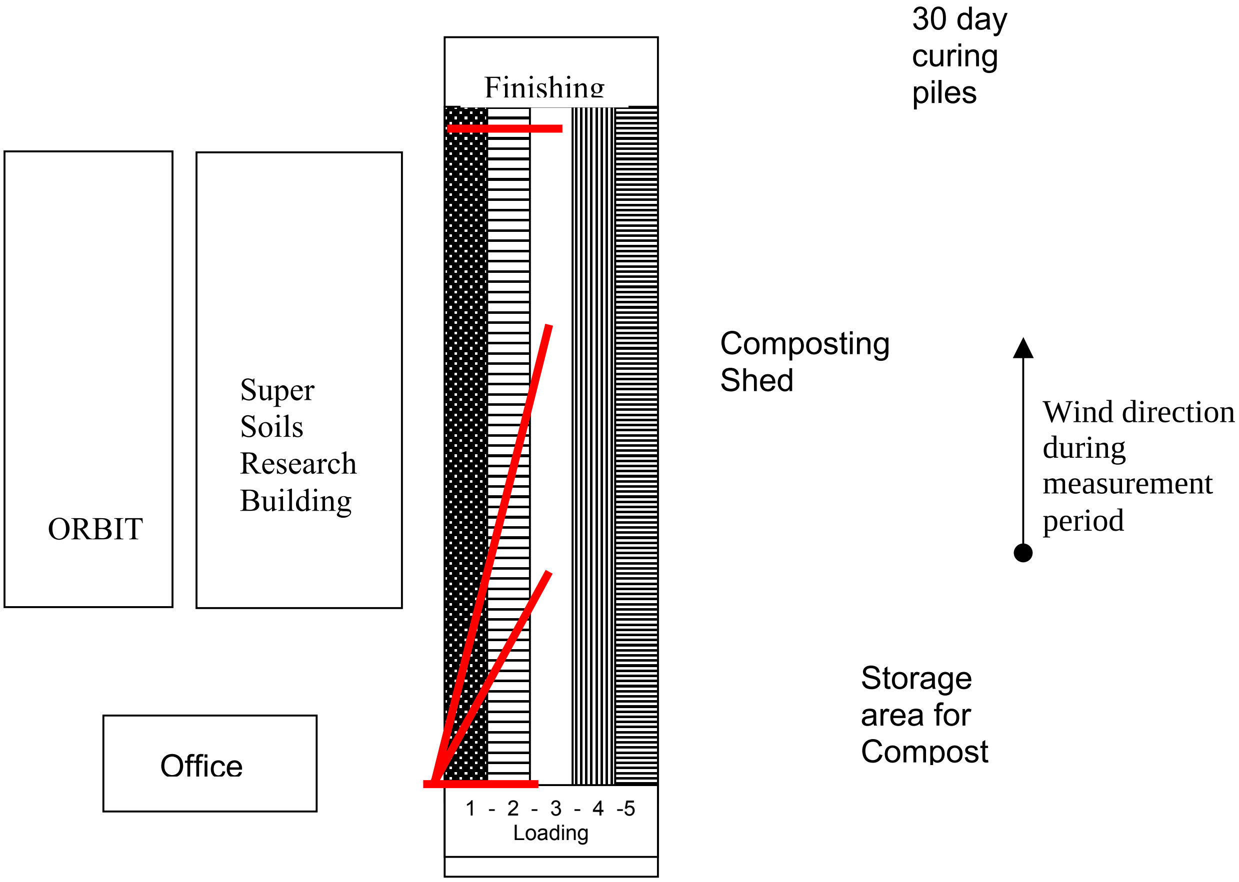


Figure 4.13. Measurement transects used for OP FTIR during July, 2004 evaluation period.

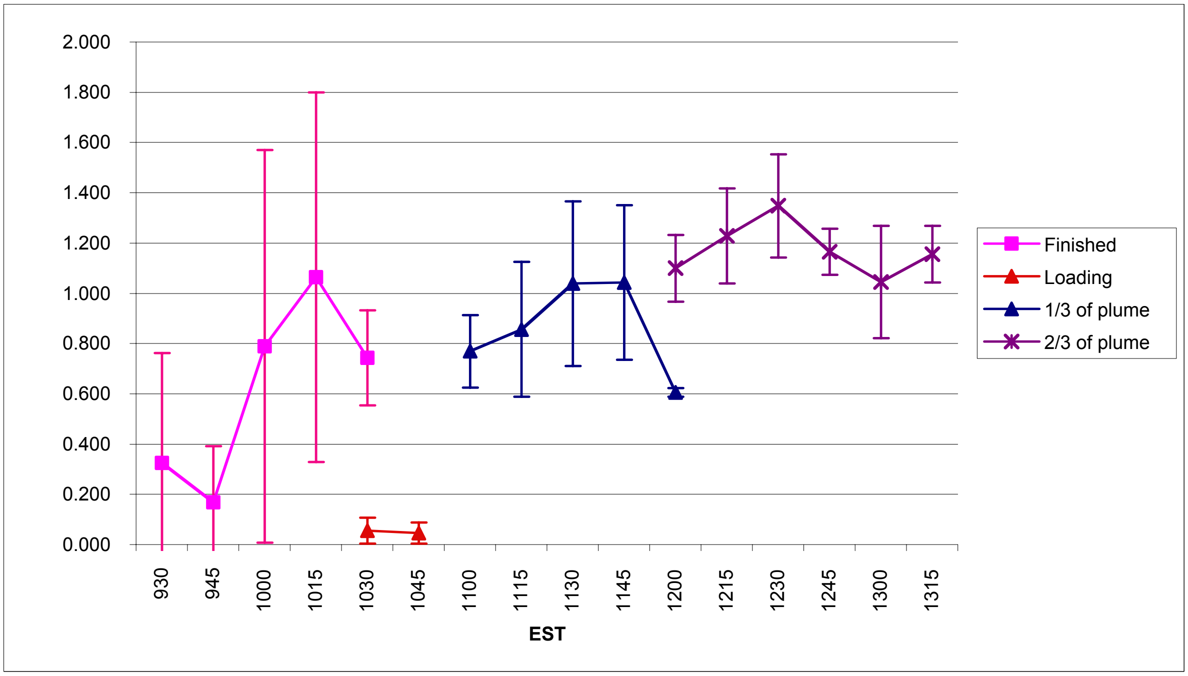


Figure 4.14. Fifteen-minute average (+/- standard deviation) ammonia concentrations measured along transects designated in Fig. 4.13. Plume refers to ammonia being released above Bins 1 and 2 (Fig. 4.3).

On the first day of the second measurement period in November 2004, the retroreflector was again placed at certain distances within Bin 3 to capture ammonia emissions from Bin 2. The retroreflector was also placed on the outside of the building at the same distances to capture ammonia emissions from Bin 1. Measurements were initiated from the finishing end because the predominant wind direction was 180˚ degrees from that observed during the first evaluation period (Fig. 4.15).

As observed in the first evaluation period, measurement transects which included the first two-thirds of either Bin 1 or Bin 2 resulted in recording of high ammonia concentrations (Fig. 4.16). Significant ammonia concentrations were recorded for the last third of Bins 1 and 2, but the variance associated with these measurements was again relatively large as was the range in 15-minute averaged ammonia concentrations observed. These observations are consistence with the hypothesis that the last third of the composting material in Bins 1 and 2 releases significantly less ammonia than the first two-thirds of the bins.

For the second day of the second evaluation period, measurement transects were oriented down the entire length of Bins 1 and 3, and off the finishing end of the composting shelter (upwind) (Fig. 4.17). As expected, the upwind transect yielded relatively low ammonia concentrations, as did the transect down the length of Bin 3 (which is empty of composting material). The transect down the length of Bin 1 yielded relatively constant, substantial readings of ammonia, consistent with the conclusion that the compositing material in Bin 1 (and Bin 2) was releasing substantial amounts of ammonia.

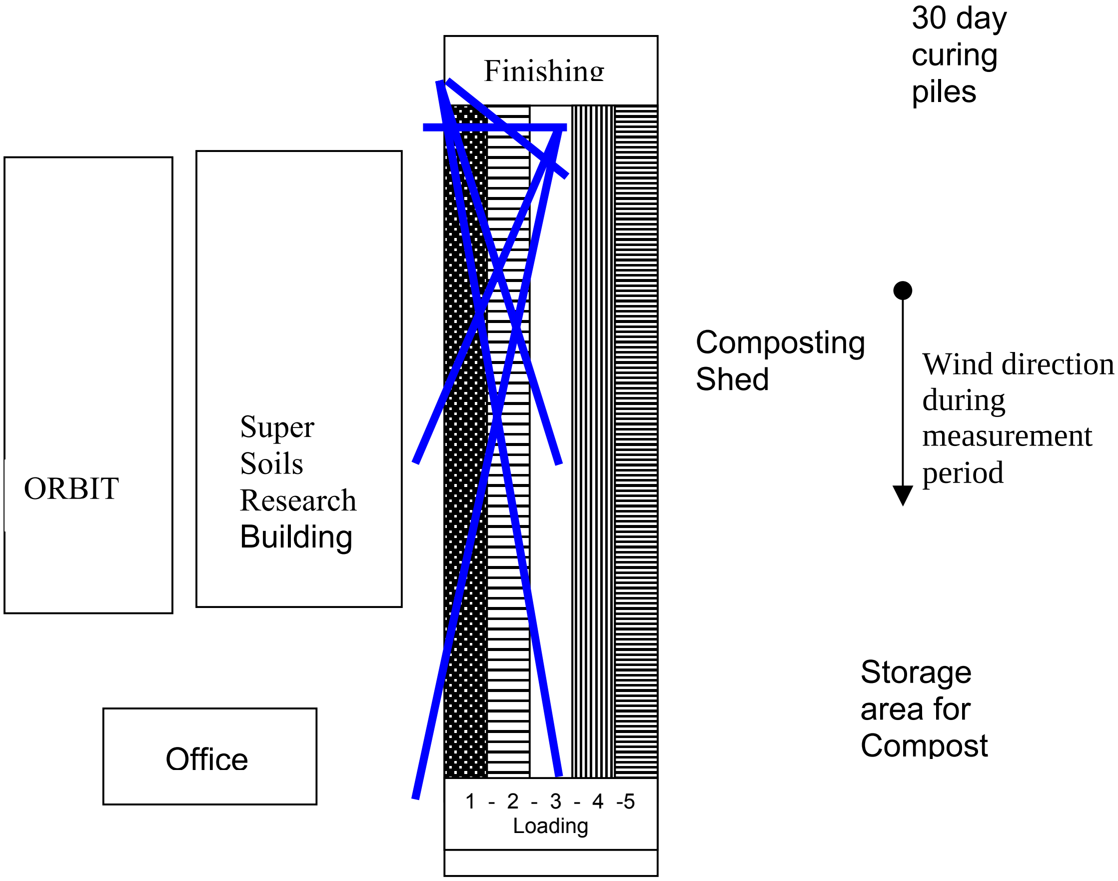


Figure. 4.15. Measurement transects used for OP FTIR during Novmber, 2004 evaluation period.

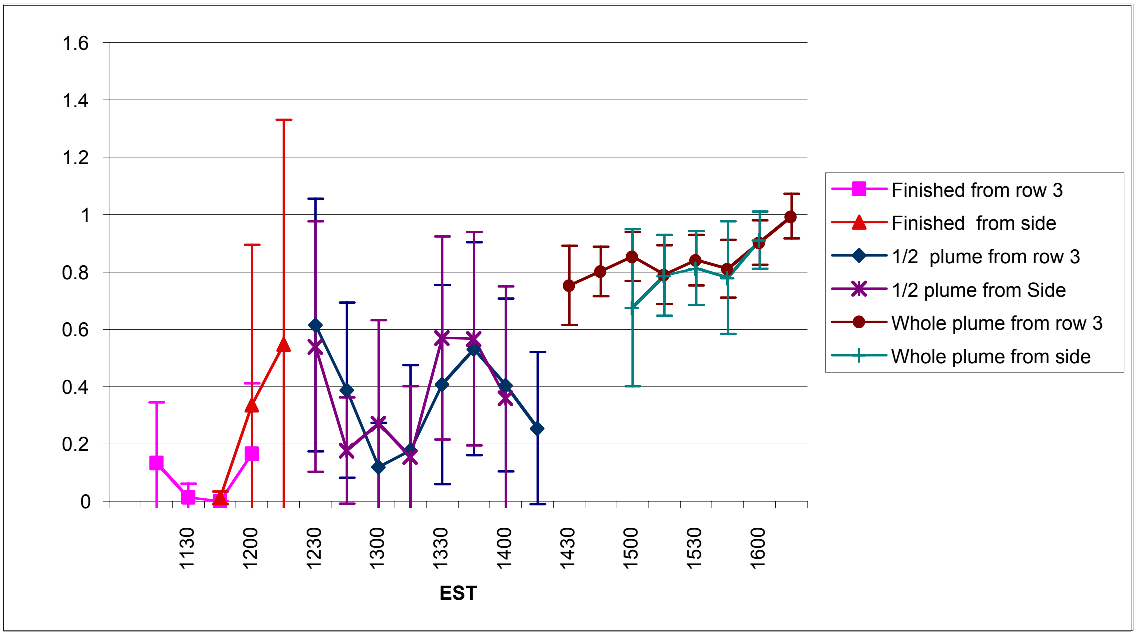


Figure 4.16. Fifteen-minute average (+/- standard deviation) ammonia concentrations measured along transects designated in Fig. 4.15. Plume refers to ammonia being released above Bins 1 and 2 (Fig. 4.3).

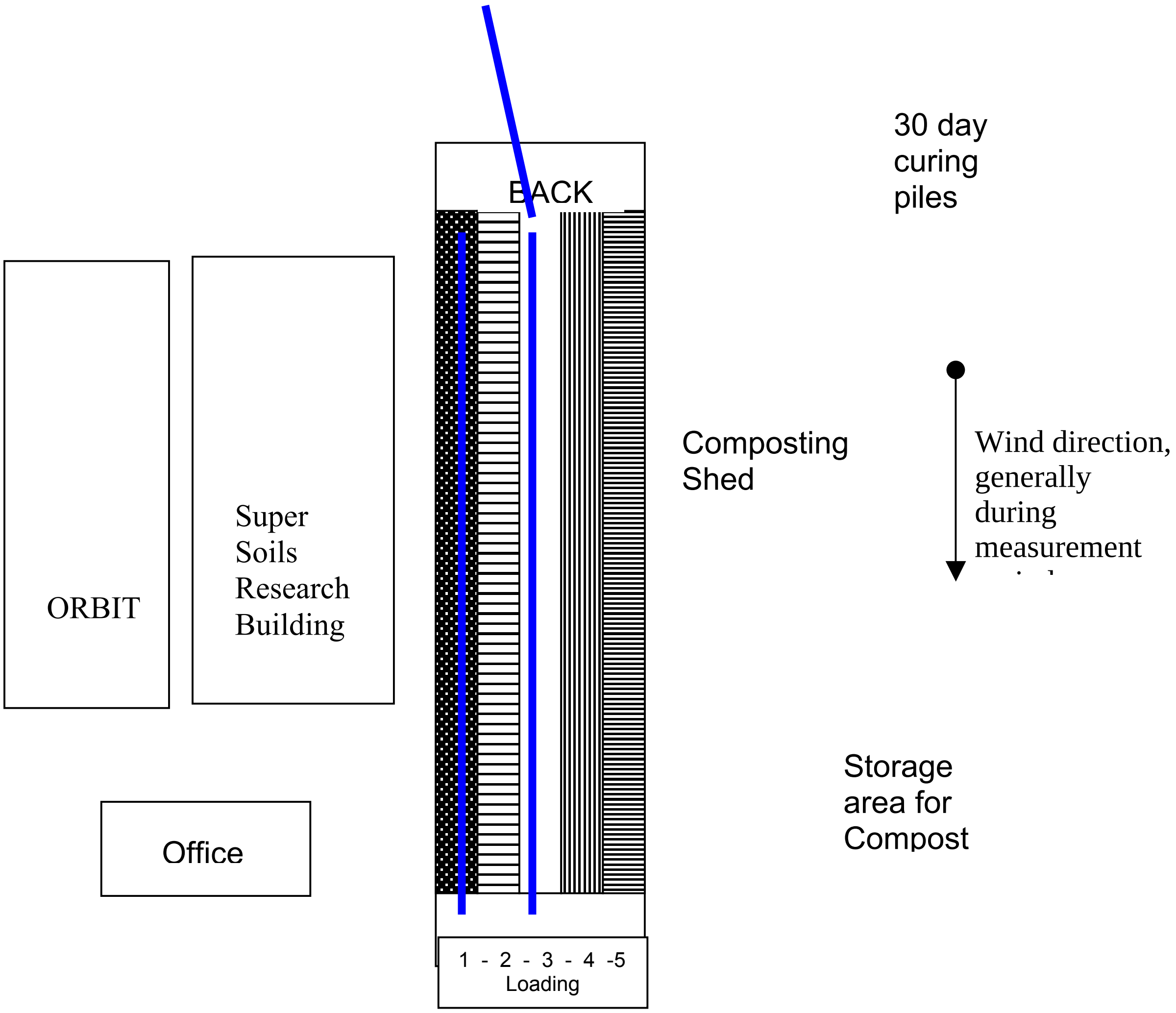


Figure. 4.17. Measurement transects used for OP FTIR during November, 2004 evaluation period.

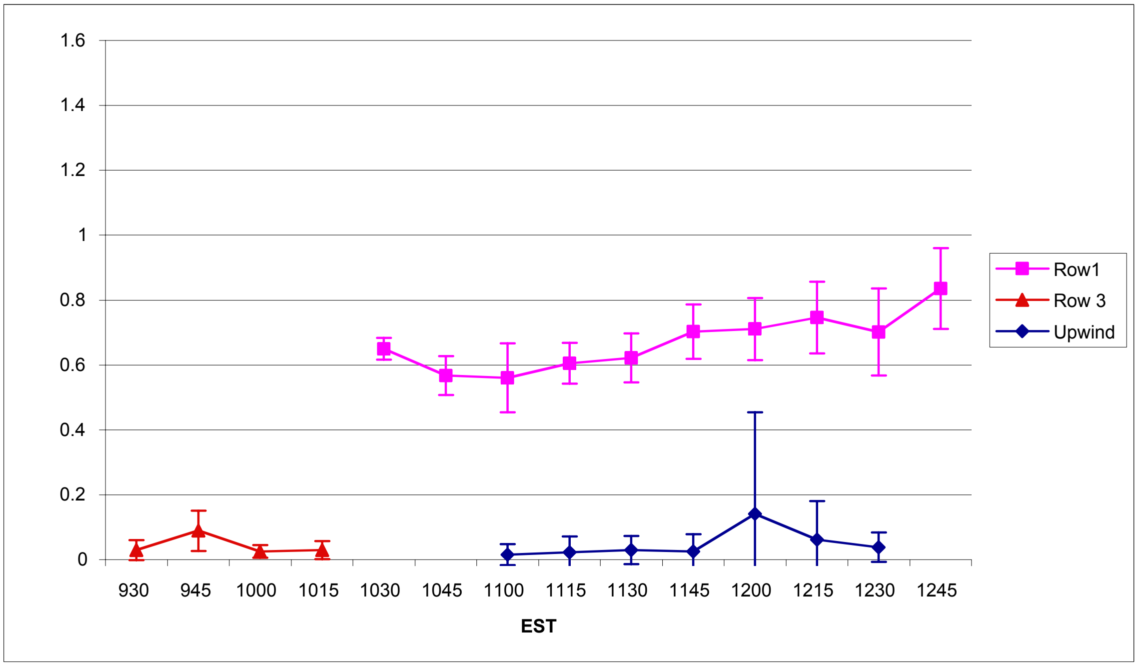


Figure 4.18. Fifteen-minute average (+/- standard deviation) ammonia concentrations measured along transects designated in Fig. 4.17. Row refers to Bin. Upwind is the finishing end of the composting shelter for this evaluation period.

Evaluation of Ammonia Emissions from Alternative Technology:

- **Composting Bins**

Calculation of the total ammonia emissions from Bin 2 for only the first evaluation period and Bins 1 & 2 from the second evaluation period is shown in Table 4.11. Bin 1 was excluded from the calculations for the first evaluation period because Bin 1 was only operating for two-weeks prior to arrival of the Project OPEN Ammonia science team. For the second evaluation period, no ammonia flux measurements were made using the Bin 1 composting material. Therefore, the average ammonia flux derived using Bin 2 composting material was applied to Bin 1 for the second evaluation period.

Ammonia emissions are strongly influenced by temperature. As evident in Fig. 4.8, the internal temperature of the composting material in Bins 1 and 2 is substantially above ambient atmospheric temperature, such that it can be assumed that there is no seasonal influence of temperature on emissions. Therefore, combining results for the two evaluation periods yields a total of 6 observations for ammonia flux from Bin 2 (Table 4.9) as determined by the dynamic flow-through chamber technology. These observations range from 11354 to 87 ug-N m^{-2} min^{-1}.

The observations using OP FTIR strongly suggest that while the first two-thirds of the composting materials in the bins are a strong source term for ammonia, there is most likely a decline in ammonia emissions in the later third of the bins (Figs. 4.14 and 4.16). This is consistent with the observation that the lowest calculated ammonia flux values for Bin 2 derived using the dynamic flow-through chamber technique are associated with the last third of Bin 2 (Distance Along Bin of 54 and 56; Table 4.9). From Figs. 4.7 and 4.8 it is also apparent that there is a rate of change in the decline of temperature within the composting material for the last third of the bin as well. It was therefore concluded that a simple average ammonia flux applied to the entire area represented by the bins would be in error, and that the bins should be divided into two sections of approximately a two-thirds and one-third. The first two-thirds represents the portion of the bins with relatively high ammonia flux. The remaining one-third represents the portion of the bins with relatively low ammonia flux. The six ammonia flux observations associated with Bin 2 where partitioned accordingly.

Table 4.11 Calculation of Ammonia Emissions from Composting Material in Bins 1 & 2.
Total area of Bin 2 assumed to be 2 m x 58.5 m = 117 m^2.
Total area of Bins 1 and 2 assumed to be 234 m^2.

Area (m^2)	**Ammonia Flux (ug-N m^{-2} min^{-1})**	**Ammonia Emissions (kg-N/day)**
Bin 2 only – First Evaluation Period		
78	8363	0.93
39	187	0.01
	Total =	0.94
Bins 1 and 2 – Second Evaluation Period		
156	8363	1.87
78	187	0.02
	Total=	1.89

In Table 4.12 is a summary of information provided by Dr. Matias Vanotti, Project PI for Composting Unit – Super Soil Demonstration Project regarding the loading and exiting of N from the bins via mass balance. The differences are 2.4 and 2.5 kg-N day^{-1} for the first and second evaluations periods respectively. These numbers correspond to a N loss of from 22.6 to 14% of input N. Using the estimated total loss of ammonia-N from Table 4.11 yields a loss of approximately 9.7% of loaded N. Or, if the estimate derived in Table 4.11 is accurate, approximately 39 to 76% of the N loss calculated by mass balance is as ammonia-N.

Table 4.12 Comparison of Measured Ammonia Emissions to Calculated N Mass Balance (N – Loading – N Exiting) Provided by Project PI.

N Loading (kg-N/day)	**N Exiting (kg-N/day)**	**Difference (kg-N/day)**	**Ammonia Emission (kg-N/day)**
Bin 2 only – First Evaluation Period			
10.6	8.2	2.4	0.94
Bins 1 and 2 – Second Evaluation Period			
17.8	15.3	2.5	1.89

It is most likely that the calculated estimate of ammonia-N loss in Table 4.11 is biased low, as three of the six observations for ammonia flux calculated from the dynamic flow-through chamber system were at the upper limit of the systems operating range. It is also possible that the division of area in Bin 2 associated with substantially reduced flux was too liberal and should be reduced.

- **Curing Pile**

As with Bin 2, the relatively high temperatures recorded near the surface for the curing pile (Fig. 4.9) suggest that the loss of ammonia will be somewhat independent of ambient atmospheric temperature. Visual inspection of the 36 m long curing pile derived from the finished product from Bin 2 showed it to be on average 1.16 m high and 3.4 m wide. These dimensions yield a length of slope of 2.05 m or a total surface area of 148 m^2, ignoring the ends of the pile. From Table 4.10, the average ammonia flux combining all observations across the pile is 19.7 +/- 9 ug-N m^{-2} min^{-1}. The combination of this flux and the calculated surface area of the pile yields an ammonia emissions value of 0.004 kg-N day^{-1}. This is less than 1% of the N flowing into the curing pile form the finished product from the composting bins and does not represent any appreciable loss of N. Indeed, chemical analysis of the curing pile material as a function of age indicates no measurable change in content of N (e.g., Table 4.4), however, Table 4.8 does record differences in composting material over time. These measurements suggest that any such chances in N content with time are not the result of substantial losses of ammonia-N.

The results from the two evaluations conducted at the Super Soil Demonstration Project Composting facility support the conclusion that significant ammonia loss will occur during the composting process. The extent of this loss appears to be as high as 20% of input N, however, direct measurements reveal a loss closer to 10% of input N. On the other hand, these results indicate that from 80 to 90% of the N in the original manure will be stabilized by the composting process with little to no additional loss when stored in a curing pile for further conditioning.

5. Evaluation of Environmentally Superior Technology for Ammonia Emissions: Howard Farm

Solids Separation/Constructed Wetlands System

Alternative Technology: Solids Separation/Constructed Wetlands System

Location: Brandon Howard Farm (Richlands, Duplin, NC)

Period of Operation:
The evaluation dates are:
1st field experiment: 06/03 – 06/14/2002
2nd field experiment: 12/02 – 12/13/2002

Technology Provider: Brandon Howard (farm owner), Frank Humenik (919-515-6767) and Mark Rice (919-515-6794)

NCSU Representative PI: Frank Humenik (Site PI, 919-515-6767)
Other contacts for alternative technology from NCSU: Co-PI, Mark Rice (919-515-6794, Main contact), other contact: Craig Baird (919-513-2515)

Statement of Task:

- Measurement of ammonia (NH_3) emissions from wetland cells and holding pond by using a flow-through chamber system interfaced with mobile laboratory during two different sampling campaigns (e.g. warm and cold seasons)
- Ambient ammonia concentrations upwind and downwind from the sources of ammonia emissions
- Water samples from wetland cells and storage pond for chemical analysis
- On site monitoring of meteorological parameters at 10 meter height
- Parameters measured: NH_3 flux, ambient NH_3 concentrations, wetland cell and storage pond temperature, pH, water chemistry (TKN, TAN), soil temperature, wind speed and direction, solar radiation, and air temperature
- Exhaust fan flow rate from hog houses

Description of Alternative Technology:

This project involves the utilization of constructed wetlands for effluent treatment following primary screening and solids separation. Waste from the hog houses moves first to a solids separator, a screen that removes the solid portion of the waste stream. The solids are available for off-farm use and land application. The remaining liquid waste flows through an 8-acre constructed wetlands filled with wetland plants. The waste is treated biologically by microbes within the root zone of the plants. The microbial action converts nitrogen in the waste from ammonia and/or organic nitrogen to nitrogen gas via nitrification-denitrification. After moving through the wetland, the liquid flows to a storage pond. The basic research for this technology was conducted on another swine production facility located in Duplin County. This project is located on the Brandon Howard farm near Richlands, North Carolina. The Brandon Howard Farm is a 3,200 head finishing operation, on contract with Murphy-Brown of Warsaw, North Carolina. The farm owner is serving as the Technology Provider for this project, with North Carolina State University Faculty providing the design parameters and technical support for the process.

- A conceptual flow-diagram of alternative technology;
  (Process flow diagram)

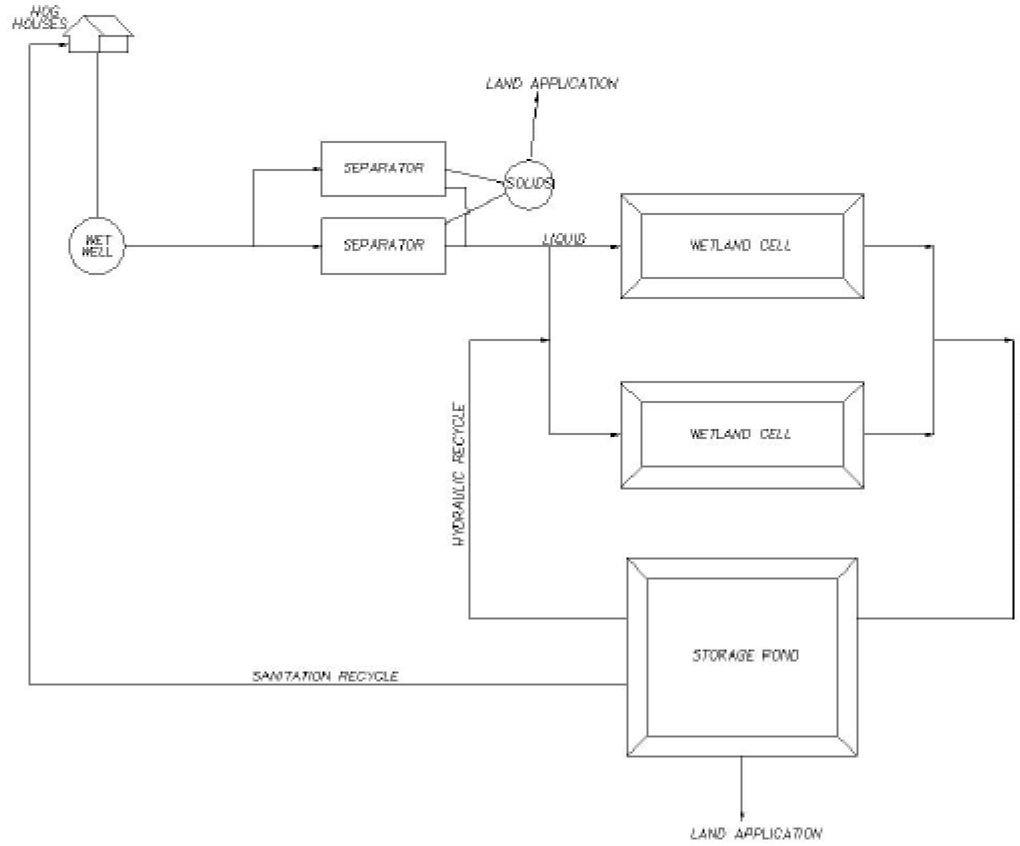


Figure 5.1 Process flow diagram of Howard farm (constructed wetland). (*Source; Development Environmentally Superior Technologies; Two-year Progress Report, A&PWMC, NCSU, 2002)*

- Possible points of emissions of ammonia and parameters that are important in controlling emissions:
    - Water holding structures: Water temperature and water chemistry (pH and TAN) are the major controlling factors.
    - Animal houses: house operational technology flushing sequence and frequency are controlling variables as well as pH and TAN.
    - Solid separation equipment.
    - Land: biogenic emission from soils during liquid land application.

Deployment of Alternative Technology:

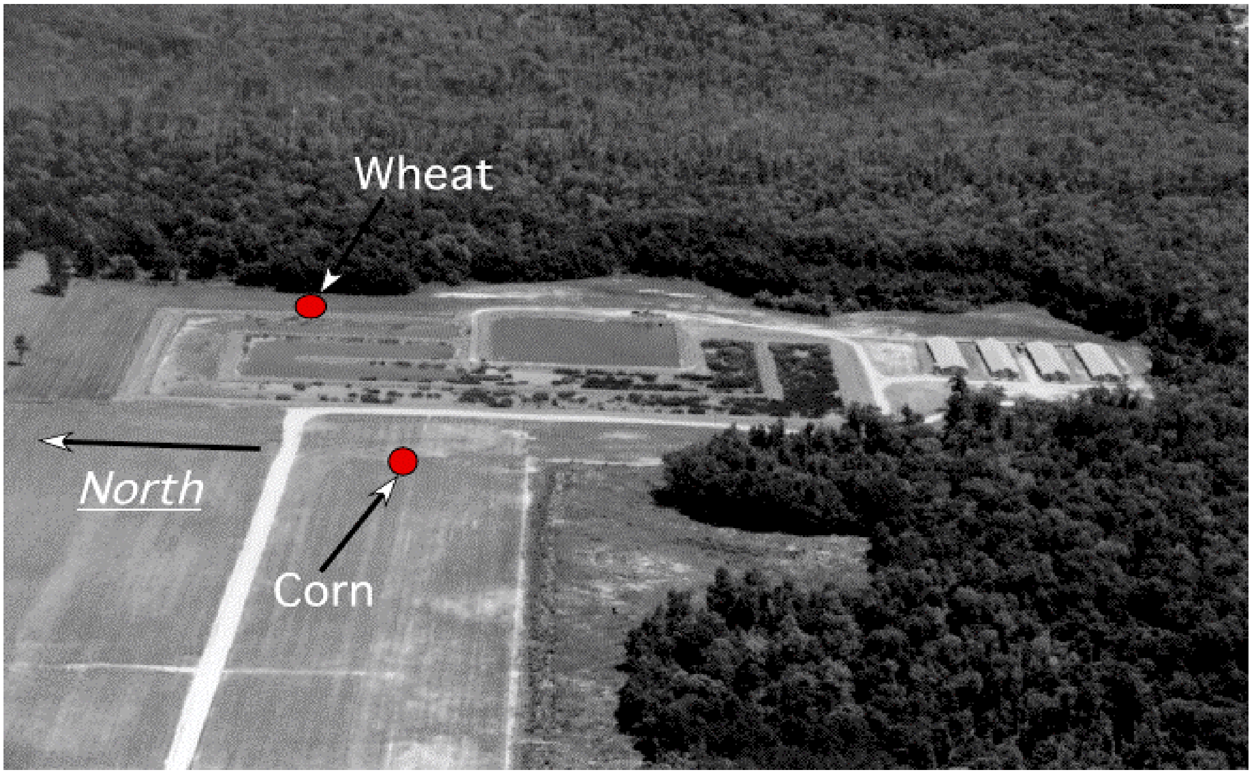


Figure 5.2 Aerial photo of the operational system (Howard Farm). The Wheat and Corn designations refer to the placement of annular denuder technology to assess ambient ammonia concentrations upwind and downwind of the alternative technology. Wheat and Corn refer to crop residue in these areas.

- Description of Animal Operation (value estimates provided by project investigators and/or animal contract company).

Constructed Wetlands (Howard Farm) 1st Evaluation, Sampling period: 6/3/02-6/14/02

WEEK 1 **6/3-6/10**	**House 1**	**House 2**	**House 3**	**House 4**
# of pigs / house	840	1054	863	865
Wks in finishing	11	10	8	6
Ave. Wt of pigs (lbs.)	155	150	130	110
Feed consumed (lb/pig/wk)	31	30	27.7	25.5
Liquid flow (gals/hse/wk)	40000	40000	40000	40000
Solids removed (lb/wk)	1800	1800	1800	1800
WEEK 2 **6/10-6/14**	**House 1**	**House 2**	**House 3**	**House 4**
# of pigs / house	840	1049	861	864
Wks in finishing	12	11	9	7
Ave. Wt of pigs (lbs.)	165	160	140	120
Feed consumed (lb/pig/wk)	32.1	31.1	28.9	26.6
Liquid flow (gals/hse/wk)	40000	40000	40000	40000
Solids removed (lb/wk)	1800	1800	1800	1800

Table 5.2 Description of Animal Operation for Howard Farm (value estimates provided by project investigators and/or animal contract company).
2nd Evaluation, Sampling period: 12/2/02-12/13/02

WEEK 1 **12/2-12/9**	**House 1**	**House 2**	**House 3**	**House 4**
# of pigs / house	801	1015	1098	973
Wks in finishing	18	16	14	12
Ave. Wt of pigs (lbs.)	240	220	200	180
Feed consumed (lb/pig/wk)	37	35	33	31
Liquid flow (gals/hse/wk)	40000	40000	40000	40000
Solids removed (lb/wk)	1800	1800	1800	1800
WEEK 2 **12/9-12/13**	**House 1**	**House 2**	**House 3**	**House 4**
# of pigs / house	800	1011	1091	973
Wks in finishing	19	17	15	13
Ave. Wt of pigs (lbs.)	250	230	210	190
Feed consumed (lb/pig/wk)	38	36	34	32
Liquid flow (gals/hse/wk)	40000	40000	40000	40000
Solids removed (lb/wk)	1800	1800	1800	1800

- Feed Nutrients

Table 5.3 Feed analysis data (N - analyses replicated 5 times.)

Site	Date	% N	%P	ppm Cu	ppm Zn
Howard					
	June 2002	2.59	0.49	15	133
	December 2002	2.25	0.43	15.3	89.5

Nitrogen Excretion

Computation of Nitrogen Excretion Based on Animal Feed (Howard Farm): Constructed Wetlands- 1st Evaluation period, June 3 – 14, 2002

- Animal population / Types:
  - Total number of pigs in 4 finishing houses = 3,618
  - Weighted average weight of the pigs=141.83 lb/pig=64.34 kg/pig
- Nitrogen Intake
  - Average feed consumed = 13.24 kg/pig/wk
  - Nitrogen content of the feed = 2.59 % (from Feed Analysis)
  - Nitrogen intake per pig = 0.34 kg N/pig/wk
- Nitrogen Excretion
  - Average gain / feed ratio or feed efficiency rate (ER) = 0.30
  - Average N excretion = (1-0.30) x 0.34 = 0.24 kg N/pig/wk
  - Average N excretion on animal live weight (*lw*) basis = 3.73 kg N/1000kg animal live weight/wk

Computation of Nitrogen Excretion Based on Animal Feed (Howard Farm): Constructed Wetlans)-2nd Evaluation period, December 2 – 13, 2002

- Animal population / Types:
  - Total number of pigs in 4 finishing houses = 3,881
  - Weighted average weight of the pigs = 213.45 lb/pig = 96.82 kg/pig
- Nitrogen Intake
  - Average feed consumed = 15.58 kg/pig/wk
  - Nitrogen content of the feed = 2.25 % (from Feed Analysis)
  - Nitrogen intake per pig = 0.35 kg N/pig/wk
- Nitrogen Excretion
  - Average gain / feed ratio or feed efficiency rate (ER) = 0.30
  - Average N excretion = (1-0.30) x 0.35 = 0.25 kg N/pig/wk
  - Average N excretion on animal live weight (*lw*) basis = 2.53 kg N/1000kg animal live weight/wk

Meteorological Measurements-

Monthly/Annual Climate Data Results at the nearest weather station

(Source: State Climatology Office)

Summary of monthly precipitation (inch) from 2002 to 2003

HOFMANN FOREST, NC (UCAN: 14151,COOP: 314144)

Year	Jan	Feb	Mar	Apr	May	**Jun**	Jul	Aug	Sep	Oct	Nov	**Dec**	Ann
2002	4.72	2.73	5.44	2.39	3.06	**3.69**	8.46	5.8	4.82	2.55	3.7	**2.99**	**50.35**
2003	--	--	--	--	--	**--**	--	--	--	--	--	**--**	
AVG	4.72	2.73	5.44	2.39	3.06	**3.69**	8.46	5.8	4.82	2.55	3.7	**2.99**	

Summary of monthly precipitation (inch) from 1992 to 2001

HOFMANN FOREST (nearest to Jacksonville), NC (UCAN: 14151,COOP: 314144)

Year	Jan	Feb	Mar	Apr	May	**Jun**	Jul	Aug	Sep	Oct	Nov	**Dec**	Ann
1992	7.19	2	3.98	2.29	5.49	**6.18**	3.79	16.41	3.26	1.96	5.7	**3.62**	61.87
1993	6.73	3.76	9.77	3.62	2.03	**3.09**	3.92	2.64	5.05	6.59	2.87	**3.06**	53.13
1994	7.02	2.95	7.57	1.15	2.86	**2.21**	10.47	5.61	6.06	5.2	2.92	**5.47**	59.49
1995	6.12	4.54	3.81	0.31	3.83	**16.96**	2.82	4.03	2.87	5.38	3.77	**2.08**	56.52
1996	4.32	1.72	5.33	2.49	2.66	**5.49**	20.23	4.52	17.58	7.9	3.01	**1.92**	77.17
1997	4.05	5.49	2.43	2.6	1.76	**5.1**	4.84	2.72	5.6	3.25	6.69	**4.36**	48.89
1998	5.87	11.3	2.74	4.07	4.79	**2.19**	9.22	13.66	6.71	--	1.23	**2.7**	64.48
1999	0.95	2.15	2.95	3.86	3.22	**5.53**	4.16	4.32	19.58	5.49	2.41	**1.34**	55.96
2000	5.84	1.39	3.12	7.45	1.77	**5.48**	10.38	7.62	10.8	0.26	5.64	**4.03**	63.78
2001	2.01	3.01	5.56	1.98	4.9	**7.77**	6.96	5.5	2.81	0.73	1.29	**2.4**	44.92
AVG	5.01	3.83	4.73	2.98	3.33	**6**	7.68	6.7	8.03	4.08	3.55	**3.1**	**58.62**

Average precipitation in the month of June from 1992-2001= 6.0" = 15.2 cm (largely affected by amount in 1995)

Average precipitation in the month of June 2002= 3.69" = 9.4 cm

Average of precipitation in the month of December from 1992-2001= 3.1" = 7.9 cm

Average of precipitation in the month of December 2002= 2.99" = 7.6 cm

Average of precipitation from 1992-2001= 58.62" = 148.9 cm

Average of precipitation in the year 2002= 50.35" = 127.9 cm

Howard Precipitation Data Analysis (Hofmann Forest, NC ECONET site)

Compared to the 10-year precipitation average of 15.2 cm for the month of June (1992-2001), Howard Farm, conducted for June 3-14, 2002, showed a lower precipitation average of 9.4 cm, a difference of 5.8 cm.

Compared to the 10-year precipitation average of 7.9 cm for the month of December (1992-2001), Howard, conducted for December 2-13, 2002, showed a near-equivalent precipitation average of 7.6 cm, a difference of 0.3 cm.

The 10-year precipitation average (1992-2001) was 148.9 cm, while the annual precipitation average for 2002 was lower at 127.9 cm, a difference of 21 cm.

Monthly mean temperature (°F) from 2002 to 2003

HOFMANN FOREST (nearest to Jacksonville), NC (UCAN: 14151,COOP: 314144)

Year	Jan	Feb	Mar	Apr	May	**Jun**	Jul	Aug	Sep	Oct	Nov	**Dec**	Ann
2002	48.89	47.38	57.53	69.74	68.23	**76.27**	80.9	79.27	76.27	66.74	52.38	**45.02**	64.05
2003	--	--	--	--	--	**--**	--	--	--	--	--	**--**	
AVG	48.89	47.38	57.53	69.74	68.23	**76.27**	80.9	79.27	76.27	66.74	52.38	**45.02**	

Monthly mean temperature (°F) from 1992 to 2001

HOFMANN FOREST (nearest to Jacksonville), NC (UCAN: 14151,COOP: 314144)

Year	Jan	Feb	Mar	Apr	May	**Jun**	Jul	Aug	Sep	Oct	Nov	**Dec**	Ann
1992	46	49.71	52.26	58.8	66.31	**75.27**	83.87	79.19	75.57	62.24	59.8	**49.95**	63.25
1993	50.82	46.7	54.94	61.6	69.66	**76.75**	82.08	77.39	73.98	63.35	52.83	**42.84**	62.75
1994	42.69	46.88	54.31	62.67	64.37	**76.47**	78.82	75.05	69.02	61.1	57.22	**52.11**	61.72
1995	46	44.64	54	63.22	68.79	**74.63**	79.98	78.11	71.98	65.55	50.22	**41.02**	61.51
1996	47.26	54.52	49.9	59.58	69.77	**74.95**	78.37	75.67	71.67	62.1	48.77	**48.73**	61.77
1997	44.55	49.38	57.23	57.58	65.06	**72.42**	78.05	76.89	73.38	63.02	51.57	**46.82**	61.33
1998	50.26	50.61	54.16	62.02	71.16	**79.38**	81.11	79.08	75.78	--	59.25	**56.03**	65.35
1999	55.41	47.88	49.47	62.72	67.84	**74.37**	81.61	79.98	72.1	62.84	57.68	**47.16**	63.25
2000	42.79	49.17	55.81	60.87	72.15	**77.42**	77.53	77.47	73.21	62.29	51.07	**40.74**	61.71
2001	43.9	51.43	51.55	61.85	68.39	**77.7**	77.32	79.39	71.17	63.15	59.07	**53.48**	63.2
AVG	46.97	49.09	53.36	61.09	68.35	**75.94**	79.88	77.82	72.79	62.85	54.75	**47.89**	**62.58**

Average temperature in the month of June from 1992-2001= 75.94°F= 24.4°C
Average temperature in the month of June 2002= 76.27°F= 24.6°C
Average temperature in the month of December from 1992-2001= 47.89°F= 8.8°C
Average temperature in the month of December 2002= 45.02°F = 9.3°C
Average temperature from 1992-2001= 62.58°F= 17.0°C
Average temperature in the year 2002= 64.05°F = 17.8°C

Howard Temperature Data Analysis (Hofmann Forest, NC ECONET site)

Compared to the 10-year temperature average of 24.4 °C for the month of June (1992-2001), Howard, conducted for June 3-14, 2002, showed an equivalent temperature average of 24.6 °C, a difference of 0.2 °C.

Compared to the 10-year temperature average of 8.8 °C for the month of December (1992-2001), Howard, conducted for December 2-13, 2002, also showed a near- equivalent mean temperature average of 9.3 °C, a difference of 0.5 °C.

The 10-year temperature average (1992-2001) was 17.0 °C, while the annual temperature average for 2002 was 17.8 °C, a difference of 0.8 °C.

- Site Meteorological data measured during the experimental periods:

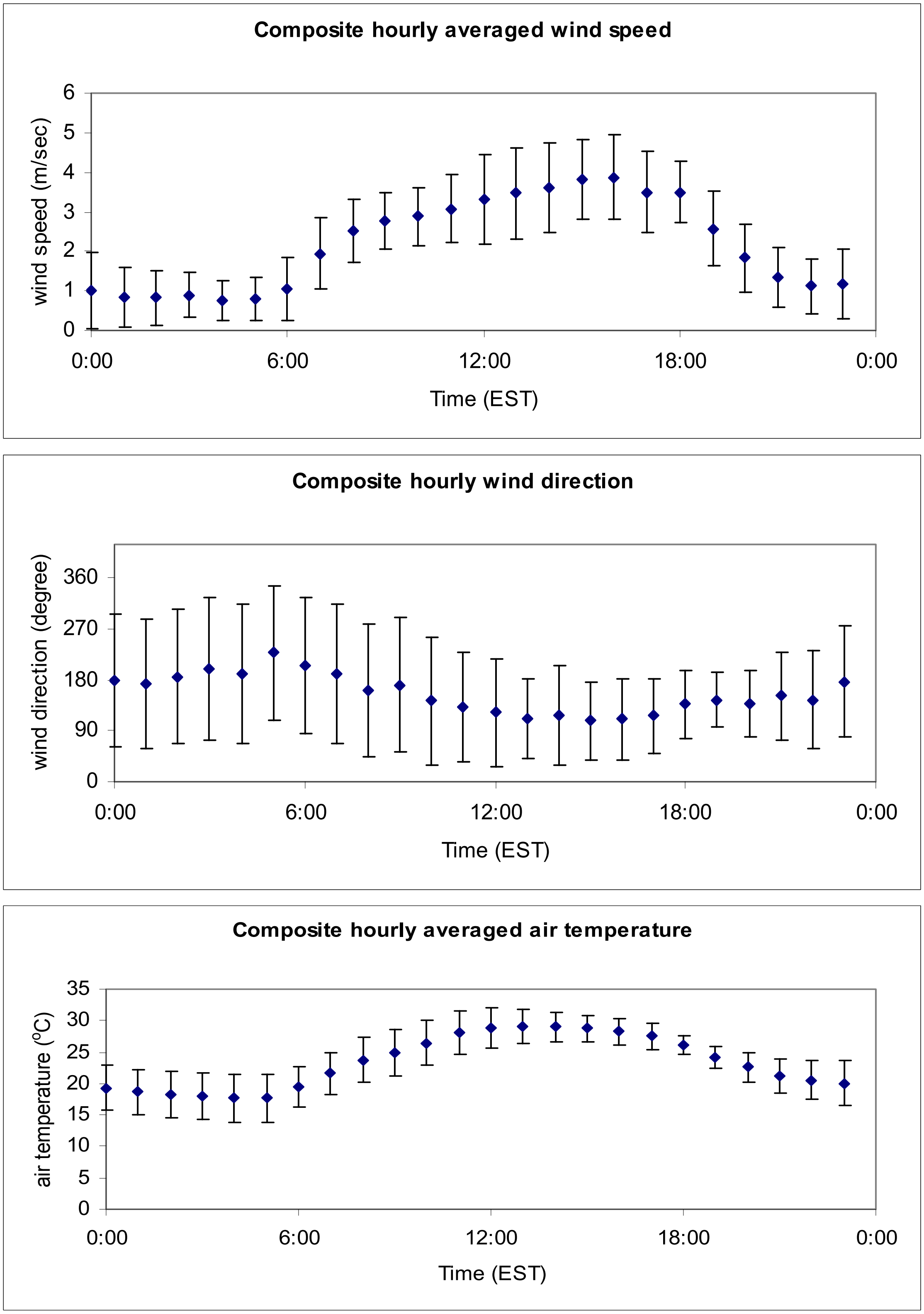


Figure 5.3 Site meteorological data during the 1st measurement period (June 3 – 14, 2002). Error bar indicates ±1 standard deviation of 15 minute averages.

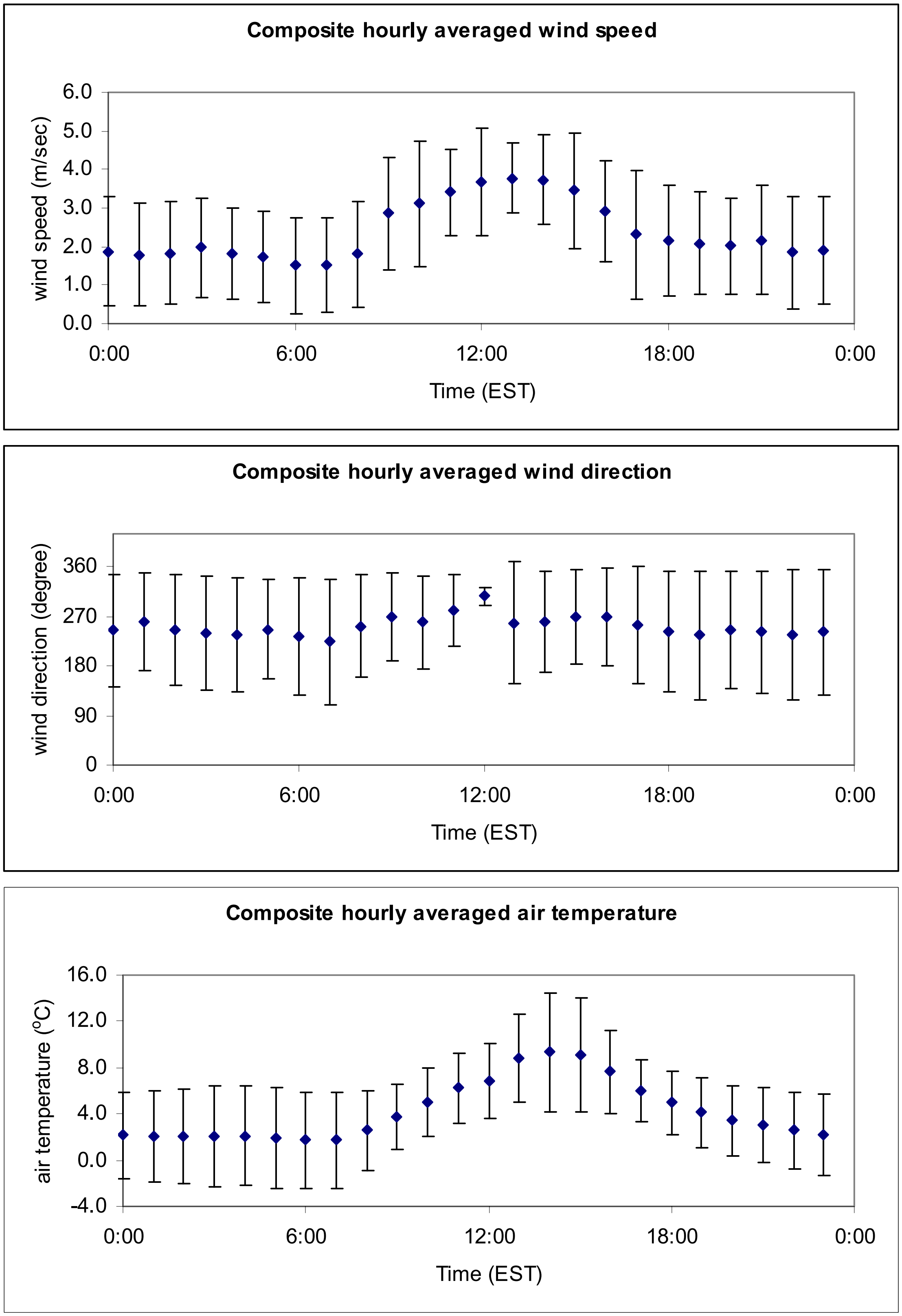


Figure 5.4 Site measurement data during 2nd measurement period (December 2-13, 2002). Error bar indicates ±1 standard deviation of 15 minute averages.

Measurement of Ammonia Fluxes and Emissions:

Emission Sources -

Major sources of NH_3 emission are hog houses, wetland cells, storage pond, and biogenic emissions from soils during land applications. NH_3 emission from spray-soils after land application were found to be insignificant (near zero values during most of sampling hours- more than 95 % of sampling hours). NH_3 fluxes from wetland cell and storage pond depends on ambient air temperature, water temperature, pH, and N in waste effluent. The flux chamber was deployed on wetland cell, storage pond, and spray-soil to measure NH_3 fluxes directly from source surfaces. For the houses, NH_3 emission was determined by using average NH_3 concentration across plumes from exhaust fans and estimated air flow rate from fans.

Dynamic-Chamber Technique for NH_3 flux measurement

The measurement schedule followed for determining the flux of ammonia from the water-holding structures using the dynamic-chamber technique is described in Table 5.4. Measured flux (presented as hourly averages) as a function of time is presented in Figure 5.6. Tabulated hourly average flux values for each water-holding structure are presented in Table 5.5. Table 5.6 contains TAN and TKN concentrations of the effluent samples from the water-holding structures. Table 5.7 presents total emissions of ammonia (kg-N) per week for each water holding structure calculated for each evaluation period and normalized to 1000 kg live weight of animals present.

- Howard Farm (1st and 2nd Measurement Periods: June 3-14, 2002; December 2-13, 2002)

Table 5.4 NH_3 emission measurement schedule at Howard Farm (1st and 2nd measurement period)

Sample dates	Parameters	Instruments	Sample plots	Remarks
June 3-5, 2002	NH_3 flux, ambient NH_3, cell T, cell pH, WD, WS, SR, air T	Two NH_3 analyzers (1 for emission and 1 for ambient), Meteorological instruments	Outlet of inner constructed wetland cell	Completed two diurnal measurements
June 6-8, 2002	NH_3 flux, ambient NH_3, cell T, cell pH, WD, WS, SR, air T	Two NH_3 analyzers (1 for emission and 1 for ambient), Meteorological instruments	Middle of inner and outer constructed wetland cell	Completed two diurnal measurements
June 9-11, 2002	NH_3 flux, ambient NH_3, cell T, cell pH, WD, WS, SR, air T	Two NH_3 analyzers (1 for emission and 1 for ambient), Meteorological instruments	Inlet of inner constructed wetland cell	Completed two diurnal measurements
June 12-13, 2002	NH_3 flux, ambient NH_3, HP T, HP pH, WD, WS, SR, air T	Two NH_3 analyzers (1 for emission and 1 for ambient), Meteorological instruments	Storage pond	Completed two diurnal measurements
June 14, 2002	NH_3 flux, ambient NH_3, soil T, WD, WS, SR, air T	Two NH_3 analyzers (1 for emission and 1 for ambient), Meteorological instruments	Spray field planted with wheat field	Partly one diurnal measurements

T = temperature; WD = wind direction; WS = wind speed; SR = solar radiation
Water samples at each plot were collected every day for analysis of TAN and TKN concentrations at the laboratory.

Sample dates	Parameters	Instruments	Sample plots	Remarks
December 2-4, 2002	NH_3 flux, ambient NH_3, cell T, cell pH, WD, WS, SR, air T	Two NH_3 analyzers (1 for emission and 1 for ambient), Meteorological instruments	Outlet of inner constructed wetland cell	Completed 2 diurnal measurements
December 4-7, 2002	NH_3 flux, ambient NH_3, cell T, cell pH, WD, WS, SR, air T	Two NH_3 analyzers (1 for emission and 1 for ambient), Meteorological instruments	Storage Pond	Completed 3 diurnal measurements
December 7-10, 2002	NH_3 flux, ambient NH_3, cell T, cell pH, WD, WS, SR, air T	Two NH_3 analyzers (1 for emission and 1 for ambient), Meteorological instruments	Middle of inner and outer constructed wetland cell	Completed 2 diurnal measurements
December 11-12, 2002	NH_3 flux, ambient NH_3, HP T, HP pH, WD, WS, SR, air T	Two NH_3 analyzers (1 for emission and 1 for ambient), Meteorological instruments	Inlet of inner constructed wetland cell	Completed 1 diurnal measurements
December 12 - 13, 2002	NH_3 flux, ambient NH_3, soil T, WD, WS, SR, air T	Two NH_3 analyzers (1 for emission and 1 for ambient), Meteorological instruments	Spray field planted with wheat field	Partly one diurnal measurements

T = temperature; WD = wind direction; WS = wind speed; SR = solar radiation
Water samples at each plot were collected every day for analysis of TAN and TKN concentrations at the laboratory.

- Site photos during experimental period

1st Campaign

2nd Campaign

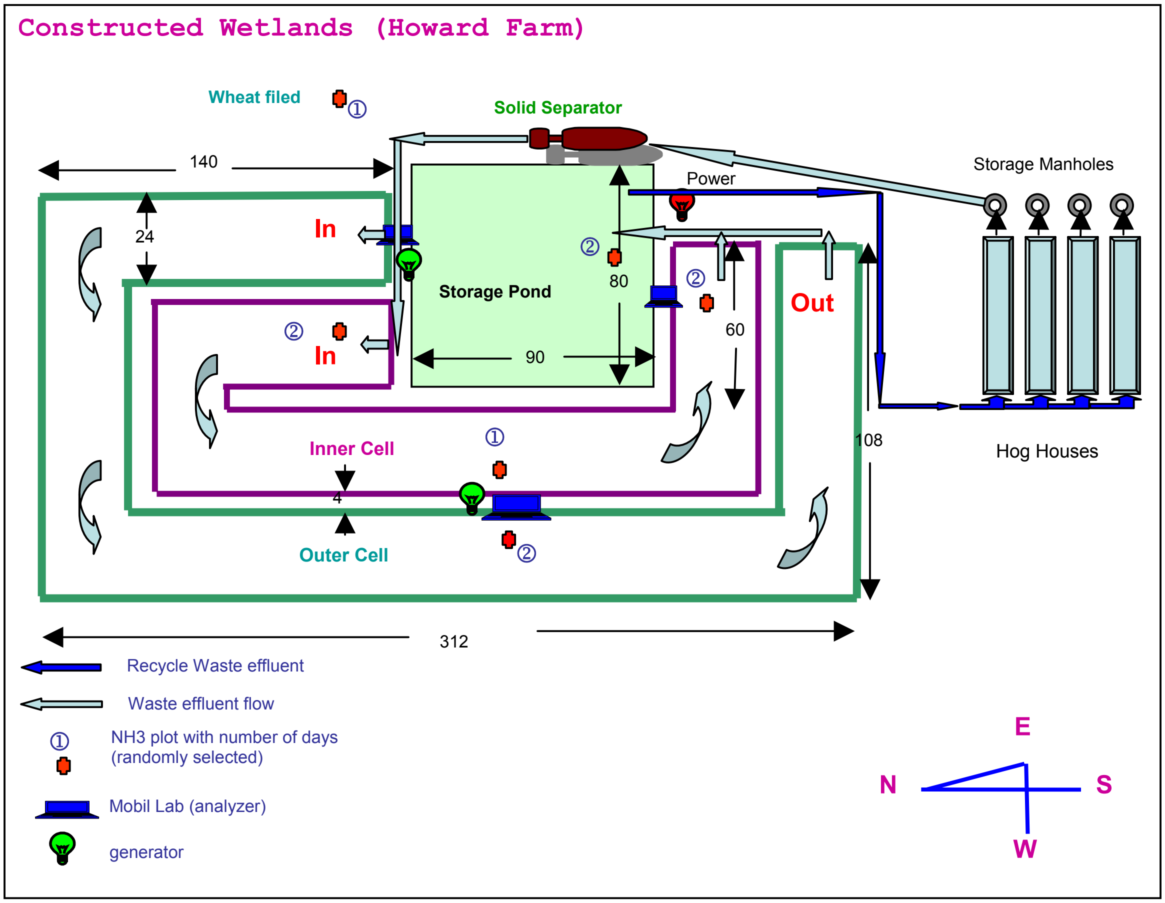
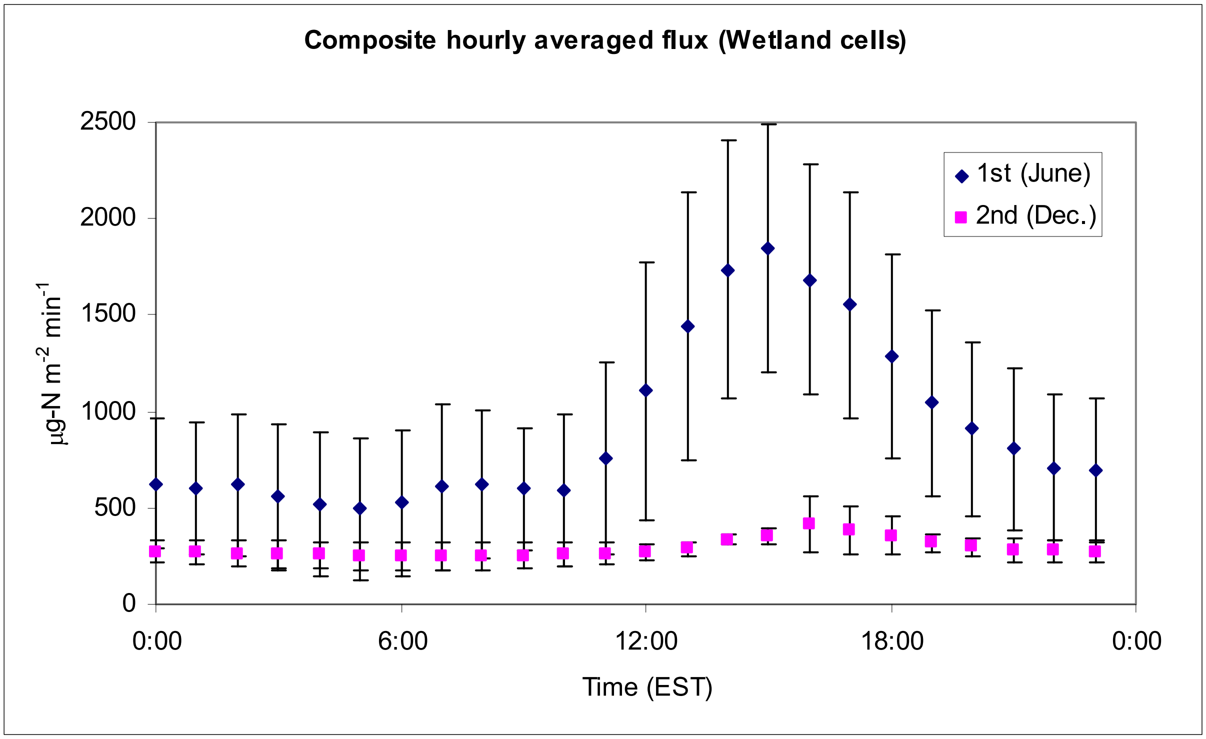


Figure 5.5 Experimental site layout and measurement locations at Howard farm

NH_3 emission measurement results by using flow-through flux chamber system during 1st and 2nd Measurement periods

Diurnal variation of NH_3 flux from wetland cell and storage pond



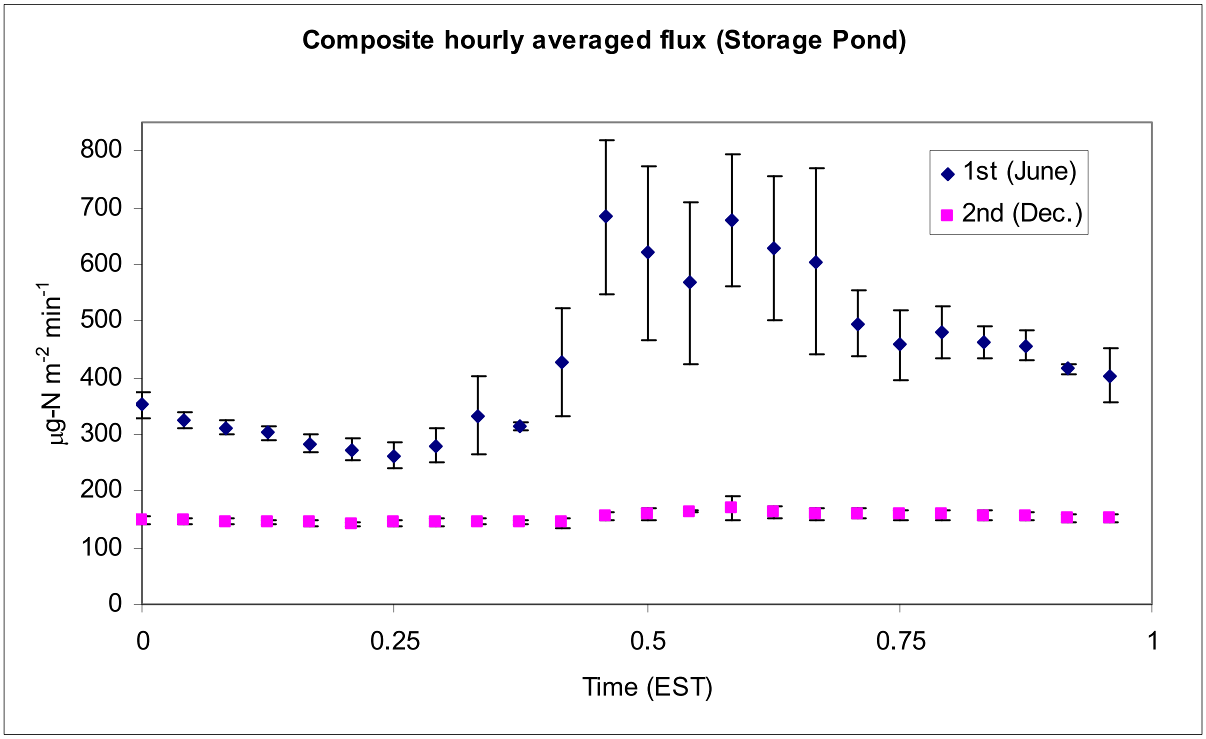


Figure 5.6 Diurnal variation of NH_3 flux from wetland cell and storage pond during the 1st and 2nd measurement period at Howard farm. Error bar indicates ±1 standard deviation of 15 minute averages

Table 5.5 Summary of hourly average NH_3 flux from the water holding structures during the experimental periods.

***Howard Farm-1st;* NH$_3$ flux (μg-N m^{-2} min^{-1})**					***Howard Farm-2nd;* NH$_3$ flux (μg-N m^{-2} min^{-1})**			
	Date (6/3-6/11)		Date (6/11-6/13)		Date cells (12/2-4; 12/7-12/12		Date (12/4-12/7)	
	wetland cells		Storage pond		Wetland cells		Storage pond	
Time	hourly average	standard deviation	hourly average	standard deviation	hourly average	standard deviation	hourly average	standard deviation
0	627.2	340.1	351.3	22.1	272.3	59.2	148.2	5.4
1	605.4	342.0	324.3	13.1	267.8	62.0	146.9	4.3
2	618.6	366.4	311.2	12.2	264.0	65.5	145.3	5.1
3	556.2	379.5	301.8	13.6	258.9	68.9	143.9	4.2
4	520.3	372.9	283.8	15.6	254.3	71.6	144.0	5.0
5	493.3	365.5	273.2	20.2	251.9	71.2	142.3	3.0
6	526.0	381.1	261.7	22.3	248.8	70.0	143.1	4.9
7	609.4	432.2	279.6	30.8	248.1	69.4	144.8	5.7
8	619.9	381.6	331.7	68.7	246.6	69.8	145.0	5.0
9	597.2	313.1	312.7	7.2	251.4	65.6	144.4	4.5
10	589.6	395.8	428.1	94.9	262.4	64.3	142.9	9.2
11	756.4	502.1	682.7	135.9	263.5	54.7	154.3	7.4
12	1107.6	668.7	619.0	151.9	270.5	41.1	159.3	10.2
13	1441.6	691.6	567.1	142.2	286.6	36.4	162.9	1.4
14	1732.9	669.6	675.8	116.5	335.5	27.7	168.8	21.0
15	1846.1	639.7	627.9	125.7	353.9	37.7	161.7	9.9
16	1685.2	598.9	604.4	163.8	415.8	141.0	157.5	10.6
17	1554.3	585.7	495.4	56.9	387.5	125.8	159.9	9.2
18	1284.1	527.3	458.1	61.8	355.3	99.6	157.5	7.7
19	1044.8	482.6	478.6	45.5	319.1	47.1	157.9	9.3
20	911.6	451.3	461.6	28.9	296.9	45.6	156.1	8.5
21	804.8	419.8	455.9	25.6	277.7	62.5	154.7	7.7
22	709.6	380.0	414.7	8.4	275.6	55.6	153.1	7.3
23	698.7	373.9	403.8	48.4	273.6	60.5	151.2	6.0
average	914.2		433.5		289.1		151.9	
stdev	437.4		136.1		47.1		7.7	
No. of data (15min.)		616		181		584		277
average lagoon temperature (°C)				24.6 ± 1.0	average lagoon temperature (°C)			6.2 ± 2.1

Table 5.6 Total Ammoniacal Nitrogen (TAN) and Total Kjeldahl Nitrogen (TKN) averages and their standard deviation from water-holding structures at Howard farm.

	Wetland cell		**Storage lagoon**	
	TKN (mg-N l^{-1})	TAN (mg-N l^{-1})	TKN (mg-N l^{-1})	TAN (mg-N l^{-1})
1st Period	153.3±60.5 n=4	85.9±44.5 n=4	63.4 n=1	34.8 n=1
2nd Period	$^{\Delta}$	235.7±86.0 n=7	86.0±5.7 n=2	52.5±1.5 n=2

n represents the total number of effluent samples collected at each water-holding structure.

$^{\Delta}$ No TKN values for this period due to problems with sample analysis

Table 5.7 Summary of total emissions from water-holding structures at Howard Farm during the experimental periods.

1st Period

Water holding structure	Storage Pond	Wetland Cells
Area (m^2)	7427.7	26,623.0
Weekly NH_3 emission (kg-N/wk)	32.5	245.3
Total emission from cells and lagoon (kg-N/wk)	277.8	
Total emission/pig (kg-N/pig/wk)	0.08	
Total emission/1000 kg-lw (kg-N/1000kg-lw/wk)	1.19	

2nd Period

Water holding structure	Storage Pond	Wetland Cells
Area (m^2)	7427.7	26,623.0
Weekly NH_3 emission (kg-N/wk)	11.4	77.6
Total emission from cells and lagoon (kg-N/wk)	89.0	
Total emission/pig (kg-N/pig/wk)	0.02	
Total emission/1000 kg-lw (kg-N/1000kg-lw/wk)	0.24	

Average Ammonia Concentrations Using Open-Path Fourier Transform Infrared (OP-FTIR)

OP-FTIR concentration measurements were obtained during the week of June 10, 2002 and December 9, 2002. Measurements were made over the storage pond, wetland cells, two locations over the solid separator, and across the fans of the swine barn. The OP-FTIR spectrometers were placed as close to the surface of the lagoon and wetland cell as possible while being positioned. For the houses, the OP-FTIR spectrometers were placed adjacent to the fans of the houses and the open-path beam was placed at the centerline of the fan opening. Figure 5.7 shows the locations of the OP_FTIR measurements. Figure 5.8 shows the 15-minute average concentrations and the standard deviations in mg-N/m^3 for all locations in June 2002. Figure 5.9 shows the 15-minute average concentrations and the standard deviations in mg-N/m^3 for all locations in December 2002. Table 5.8 lists the average daily concentrations of nitrogen in mg/m^3.

Figure 5.7 Locations of FTIR Measurements taken with the OP-FTIR Spectrometer

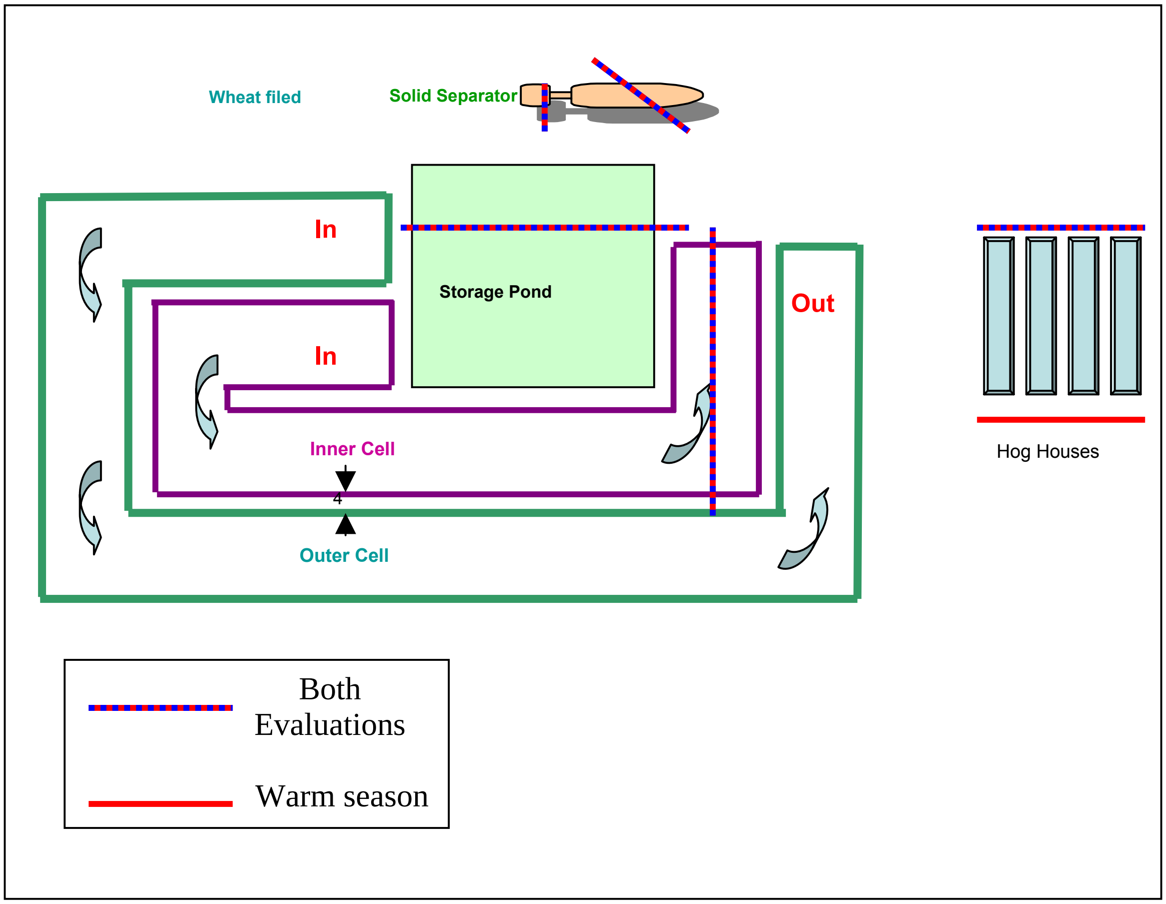


Figure 5.8 Fifteen- minute average concentrations of nitrogen in mg/m^3 in June 2002.

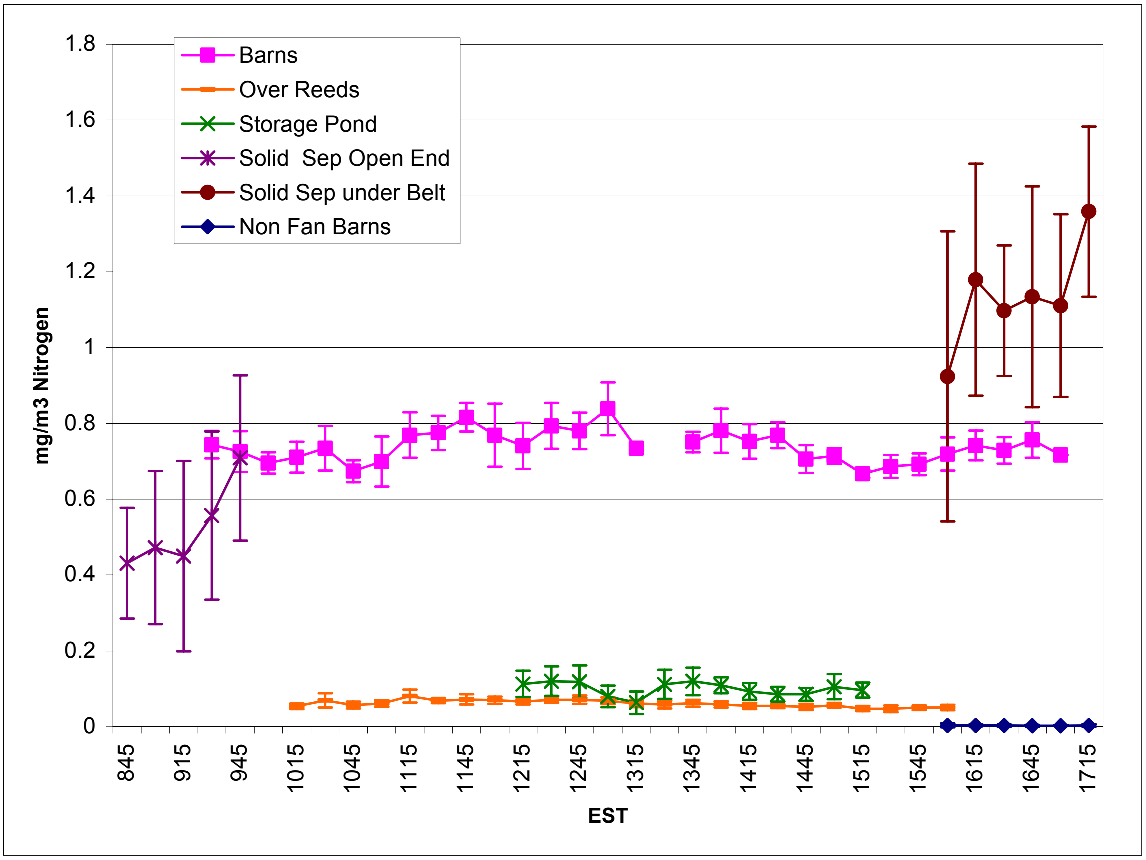


Figure 5.9 Fifteen- minute average concentrations of nitrogen in mg/m^3 in December 2002.

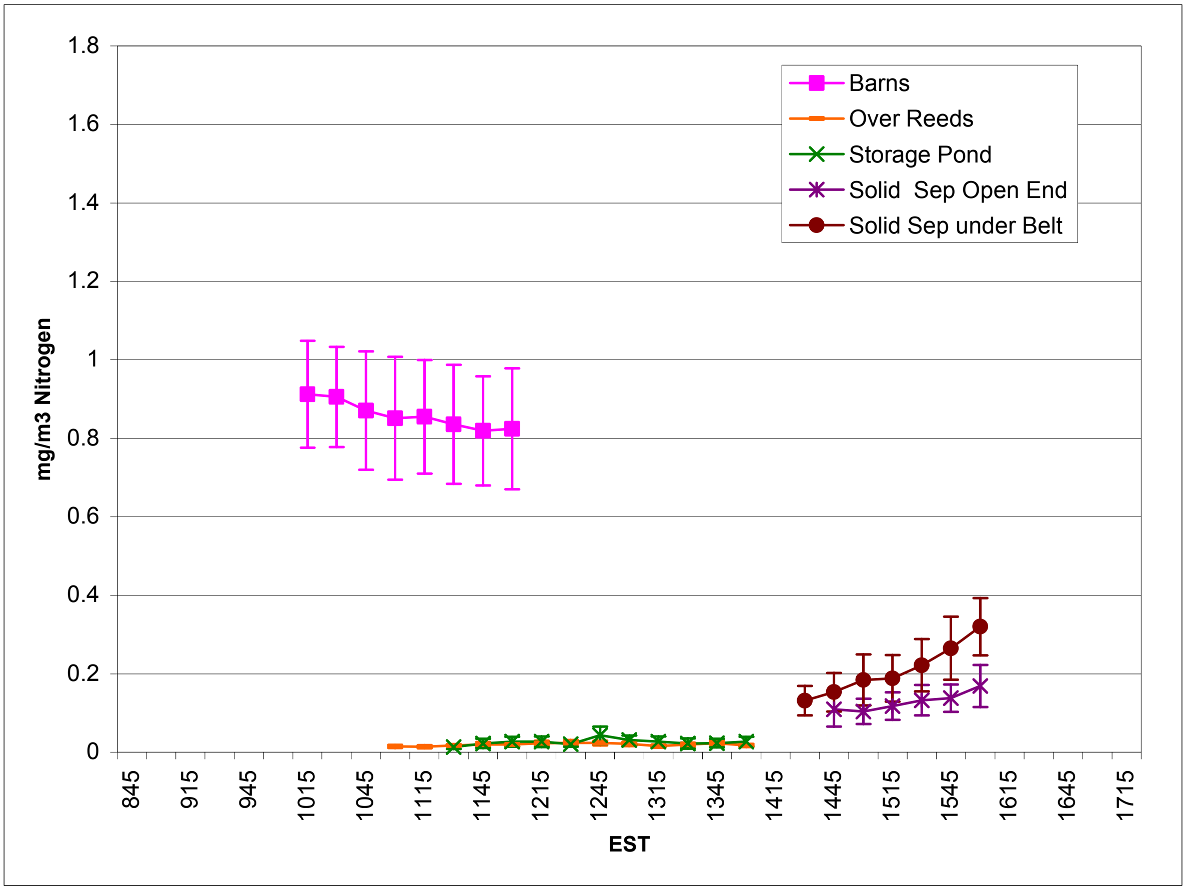


Table 5.8 Average Daily Concentrations of Nitrogen in mgN/m^3.

Date	**Component**	
	Barn (mg N/ m3)	
2002	**Fan Side Barn**	**Non-Fan Side Barn**
June 10	**0.739**	**0.003**
December 11	**0.859**	**---**
	Over Reeds	
June 11	**0.061**	
December 9	**0.019**	
	Solid Separator	
	Solid Separator	**Solid Separator Open End**
June 11	**1.134**	**0.524**
December 9	**0.209**	**0.128**
	Storage Pond	
June 11	**0.100**	
December 9	**0.026**	

Estimated Ammonia Emissions from Barns

The average nitrogen flux from the hog houses was calculated by multiplying the 15 minute path-averaged concentrations of Nitrogen (measured as ammonia mg/m^3) across the midline of the fans exhausting the houses by the measured or factory calibrated fan rates (m^3/min). This number for each barn was then normalized by the total live weight of the hogs in the houses at the time of the sampling (1000 Kg LW), see Table 5.9. The operation of the fans (monitoring when they are on or off) was performed during the entire sampling period.

Table 5.9 Flux (Kg-N/Week/1000 Kg-lw)

Date	Location	NH_3 Flux
6/11/2002	Barns	1.418
12/6/2002	Barns	0.847

- Annular Denuder Technology

Annular denuder technology was used to provide an integrated measure of ambient ammonia concentrations approximately upwind and downwind of a portion of the EST, specifically one end of the constructed wetland (see figure 5.2) . Samples were collected during midday to promote collection of data during periods of relatively stable wind speed and direction. Differences between concentrations were always significant when one of the sampling sites became downwind of the monitored portion of the constructed wetland. During June 2002, the Wheat site was in the downwind position for all three days of data collection, with ambient ammonia concentrations ranging from 36 to 123 μg NH_3-N m^{-3}. The relatively high ammonia concentrations of >100 μg NH_3-N m^{-3} were probably a result of the warm temperatures (which favor NH_3 emissions from aqueous surfaces), and the fact that the winds shifted to the south (S) or southwest (SW) during the measurement period maintaining the Wheat site in the downwind position across the constructed wetland. In November, the temperatures were much colder (typically near freezing at night, data not shown), and the winds were from the northeast (NE), which limited the exposure of the denuder at the Corn position, although the measured ammonia concentrations are higher than at the Wheat position. Note however that when the winds shifted back to the northwest (NW) on Dec. 11 and 12, the Wheat position again experienced relatively high ammonia concentrations, even under relatively cold temperatures. Overall the data support the conclusion that the constructed wetland (at least that portion directly impacting the annular denuders) is a significant source of ammonia emissions, even during periods of relatively cold temperatures.

Table 5.9 Ambient ammonia (NH_3) concentrations at the ends of an approximate southwest to northeast transect across a portion of the proposed environmentally superior technology as determined by annular denuder technology.

Date	Time		Air Temp.	Wind Speed	Wind Direction	NH_3 Concentration	
	Start	End				Wheat	Corn
2002			- °C -	- m/sec -		-μgN/m^3-	-μgN/m^3-
June 12	10:45	16:15	30.5	2.4	NW > S	36	12
June 13	10:12	15:45	33.0	2.2	NW > S	123	6.8
June 14	11:14	15:20	32.5	2.9	W > SW	103	4.3
Dec. 3	11:17	15:30	11.4	4.1	NE	2.3	4.0
Dec. 9	12:14	15:30	7.0	3.6	NE	1.6	4.7
Dec. 10	12:14	15:15	6.1	3.0	NE	1.4	2.7
Dec. 11	12:30	15:40	7.0	3.4	NW	35	2.4
Dec. 12	11:45	15:10	11.9	0.7	NE >NW	34	3.2

Site labeled Wheat represents the northeast (NE) end of the transect; the site labeled Corn represents the southwest (SW) end.

Assessment of Ammonia Emissions from Alternative Technology:

At each alternative technology and conventional site, the estimated ammonia emissions are limited to two two-weeks long periods, representing warm and cold seasons. But, since measurements at different sites are made at different times of the year, environmental conditions are likely to be different at different sites, even during a representative "warm" or "cold" season. There is a need for accounting for these differences in our relative comparisons of the various alternative and conventional technologies.

The estimated emissions from water-holding structures at an alternative technology for each measurement period are compared with the average estimated emissions from baseline sites, after the later are adjusted to the average environmental parameters (lagoon temperature and air temperature) observed at the former (alternative technology) site. A rational basis for this adjustment for somewhat different environmental conditions is the multiple regression model developed for ammonia emissions and measured environmental parameters at the two baseline sites. The model is described in appendix 2 of the three-year report. Such a comparison would not require highly uncertain extrapolations of emissions at alternative technology sites beyond the two measurement periods. Absolute numbers are not used in assessing ammonia emissions from the proposed alternative technology. A normalized measure of emissions (normalized to calculated N-excreted; $\%E_{EST}$) is compared to a similar normalized measure of emissions ($\%E_{CONV}$) from a baseline site using the conventional lagoon technology for handling swine waste in North Carolina. The %E values are an estimate of rate of loss of N compared to N excreted. Two baseline sites are used to account for differences in housing ventilation across the sites with the proposed EST's. No method exists for adjusting baseline housing emissions to environmental conditions observed at an EST farm. Therefore, actual housing emissions measured at the baseline sites during comparable seasons of the year are used when generating the normalized measures of emissions from houses. It is acknowledged that the housing emissions for the baseline sites were not made under the exact meteorological conditions as the housing measurements for evaluation of an EST.

The algorithm followed in deriving an index of performance ($\%\text{reduction} = [(\%E_{CONV} - \%E_{EST})/\%E_{CONV}] * 100$) by the EST in reducing ammonia emissions as compared to the conventional technology currently in use in North Carolina (baseline sites) is presented in Fig. 5.9 for water holding structures.

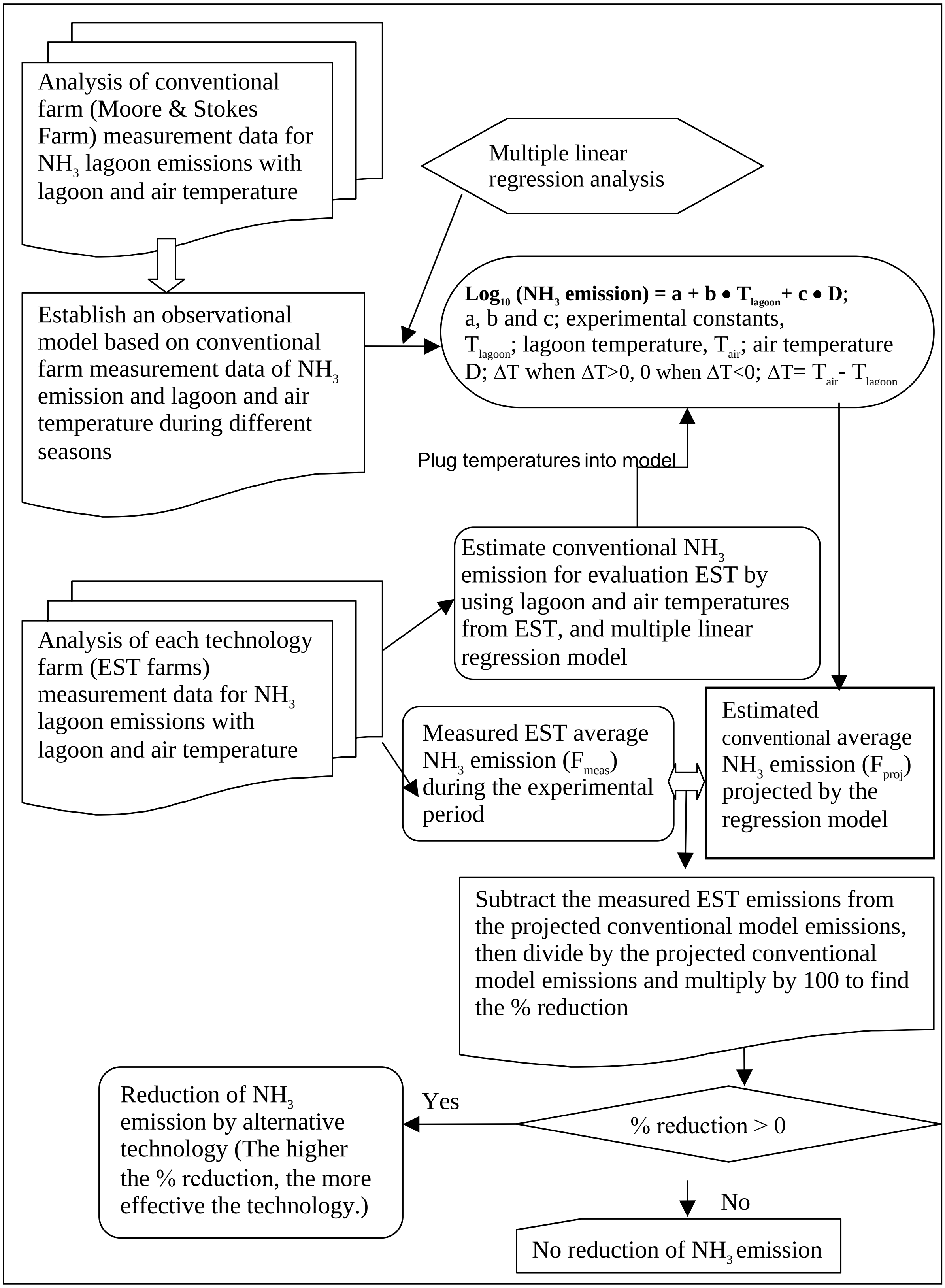


Figure 5.9 Algorithm flow chart for evaluation of alternative technology ammonia emission from lagoons and storage ponds.

Evaluation of Howard farm

We compare the lagoon NH_3-N emission from Howard farm with the projected average emission from lagoon at the conventional farm, using the observational statistical (multiple linear regression) model.

Table 5.10 gives animal weight, feed consumed, and N-excretion at baseline farms and Howard farm. Table 5.11 gives the NH_3-N emissions (kg-N/1000 kg-live weight/wk) data summary for the Howard farm and conventional farms for evaluation of EST at the former. The emissions from different components of an EST or baseline farm should be viewed relative to the estimated nitrogen excretion from animal population, weight and feed data.

Table 5.10 Summary of animal weight, feed consumed, and N-excretion at conventional farms (Stokes and Moore) and the EST (Howard) farm.

Farm Information	No. of pigs	average pig weight kg/pig	total pigs weight kg	feed consumed kg/pig/wk	N-excretion, E kg-N/wk /1000kg-lw
Stokes (Sep.)	4,392	104.3	458,086	12.84	2.71
Jan.	3,727	88.5	329,840	12.59	2.51
Moore (Sep.)	7,611	52.3	398,055	10.99	4.39
Jan.	5,784	67.0	387,528	12.37	3.90
Howard (Jun.)	3,618	64.3	232,777	13.24	3.73
Dec.	3,881	96.8	375,762	15.58	2.53

Table 5.11 Estimates of % reduction in NH_3-N emissions from different components and their sum total at the EST (Howard: Constructed Wetlands) and conventional farms (kg-N/wk/1000kg-*lw*). (% reduction = [(%E_{CONV}- %E_{EST})/%E_{CONV}]*100

(1) Wetland Cells and Storage Pond Emissions

Period	Average lagoon temperature (°C)	Average D (°C)	Conventional model emissions F_{proj}	% E_{CONV}	Howard measured emission F_{meas}	% E_{EST}	% reduction
Jun. 3-14, 2002	24.6	1.2	0.80	22.5	1.19	31.9	-41.8
Dec. 2-13, 2002	6.2	0.9	0.12	3.7	0.24	9.5	-156.8

(2) Barn Emissions

Period	Moore Farm measured emission	% E_{CONV}	Howard Farm measured emission	% E_{EST}	% reduction
June, 2002	1.05†	23.9	1.42	38.1	-59.4
December, 2002	0.89‡	22.8	0.85	33.6	-47.4

Total Emissions (1)+(2)

Period	Conventional total emission	% E_{CONV}	Howard Farm total emission	% E_{EST}	% reduction
June, 2002	1.85	46.4	2.61	70.0	-50.9
December, 2002	1.01	26.5	1.09	43.1	-62.6

D is ΔT, the difference between the air temperature (T_{air}) and lagoon temperature (T_{lag}), when $T_{air} > T_{lag}$; D = 0 when $T_{air} < T_{lag}$. F_{proj} is baseline lagoon area adjusted NH_3 lagoon emission projected by the baseline multiple linear regression model corresponding to the average lagoon temperature and the average D during Howard farm measurement periods. % E_{CONV} is the conventional model emissions relative to the N excreted. % E_{EST} is the measured emission from the EST relative to the N excreted. F_{meas} is sum of the NH_3 emission from water holding structures and NH_3 emission from barn house measured at Howard farm. †: overall house emission measured at Moore farm during October 2002, ‡: overall house emission measured at Moore farm during February 2003. % reduction is used to describe how effective a technology is, in reducing NH_3 emissions. A number > 0 indicates a reduction in NH_3.The larger the % reduction, the more effective the technology is in reducing NH_3 emissions. Conversely a number < 0 indicates that there are has been no reduction in NH_3 emissions.

6. Evaluation of Environmentally Superior Technologies for Ammonia Emissions: Vestal Farm

ISSUES/ Recycling of Nutrient, Energy and Water System (RENEW)

Alternative Technology: Recycling of Nutrient, Energy and Water System (RENEW)

Location: Vestal Farm, Kenansville, NC

Period of Operation:
The OPEN team monitored for evaluation during:
1st field experiment: 03/08 – 03/19/2004
2nd field experiment: 08/02 – 08/13/2004

Technology contact: Prince Dugba

Project Investigator: Mike Williams/Len Bull

Statement of Task:

- Measurement of ammonia (NH_3) emissions from Aerobic digester, and Polishing storage basin by using a flow-through chamber technology during two different campaigns (warm and cold seasons)
- Analysis of water samples from waste storage and treatment areas for Total Ammoniacal Nitrogen (TAN) and Total Kjeldahl Nitrogen (TKN) concentrations (one sample each day during the experimental period)
- On site monitoring of meteorological parameters at 10 meter height
- FTIR technology used to determine ammonia emissions from barns
- Parameters measured: NH_3 flux, wind speed and direction, solar radiation, and air temperature

Description of Alternative Technology:
The RENEW System employs a mesophilic digester as well as aeration and a wastewater filtering and disinfection systems. This project also incorporates the microturbine generator. Waste flows from pig barns to an equalization tank and then to a concentrator/ thickener tank, which serve to produce a thickened liquid. This liquid then flows to a mesophilic digester (solids with the liquid fraction being delivered to the storage basin). The digester, which operates at a temperature of 95 degrees F, produces biogas, which is used to fuel the microturbine generator. The generator produces electricity, which is sold and used on the electric power grid. The waste stream then flows to a polishing storage basin, then to an aerobic digester, also called a nitrification pond. A portion of the waste stream from the aerobic digester, is used to flush the pig barns. The remaining portion of the waste stream flows through a filtration system. The filtration system consists of sand carbon filters and reverse osmosis. The water is then

disinfected using ozonation and ultraviolet light. Filtered and disinfected water is returned to the pig barns, with the goal of being used as drinking water for the pigs.

(Source: Waste management Programs, North Carolina State University, http://www.cals.ncsu.edu:8050/waste_mgt/)

- A conceptual flow-diagram of alternative technology;

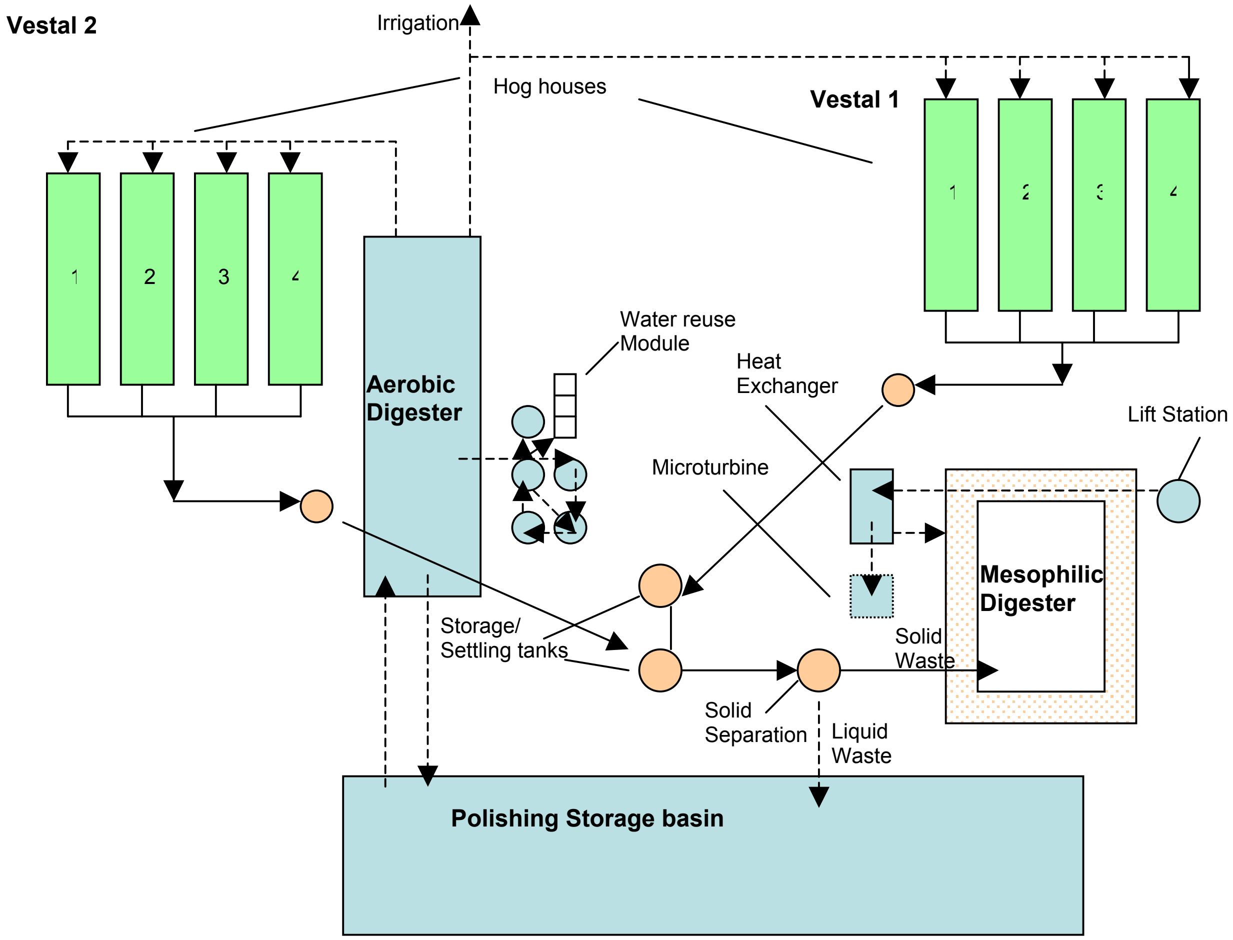


Figure 6.1 Conceptual flow diagram of RENEW system (Vestal Farm).

(Source; http //www.cals.ncsu.edu:8050/waste_mgt)

- Possible points of emissions of ammonia on conceptual flow-diagram and parameters that are important in controlling emissions:
  - Water holding structures: Aerobic digester, Polishing Storage basin- water temperature and water chemistry (pH and TAN) are the major controlling factors.
  - Mesophilic digester.

- Animal houses: house operational technology flushing sequence and frequency are controlling variables as well as pH and TAN.

An aerial photo of Vestal farm with EST is given below:

Aerial photo of RENEW site (Vestal Farm).

- Table 6.1 Description of Animal Operation (value estimates provided by project investigators and/or animal contract company)

RENEW (Vestal farm) Site---Sampling period: 1st Evaluation (March 8- March 19, 2004)

WEEK 1 3/8- 3/14	**Vestal 1 House 1**	**Vestal 1 House 2**	**Vestal 1 House 3**	**Vestal 1 House 4**	**Vestal 2 House 1**	**Vestal 2 House 2**	**Vestal 2 House 3**	**Vestal 2 House 4**
# of pigs / house	1201	1160	1252	1214	1208	1190	1193	1111
Wks in finishing	5	4	2	2	3	3	5	5
Ave. Wt of pigs (lbs.)	85.9	83.0	68.1	52.4	82.4	74.3	100.5	91.0
Feed consumed (lbs/pig/wk)	21.0	21.0	21.0	16.4	21.0	21.0	24.3	24.3
WEEK 2 3/5- 3/19	**Vestal 1 House 1**	**Vestal 1 House 2**	**Vestal 1 House 3**	**Vestal 1 House 4**	**Vestal 2 House 1**	**Vestal 2 House 2**	**Vestal 2 House 3**	**Vestal 2 House 4**
# of pigs / house	1196	1152	1250	1212	1202	1178	1191	1103
Wks in finishing	6	5	3	3	4	4	6	6
Ave. Wt of pigs (lbs.)	95.8	93.1	78.3	62.3	92.5	84.5	110.7	101.2
Feed consumed (lbs/ pig/wk)	24.3	24.3	21.0	16.4	24.3	21.0	29.0	24.3

Table 6.2 RENEW (Vestal farm) Site---Sampling period: 2nd Evaluation (August 2 - 13, 2004)

WEEK 1 8/2-8/8	**Vestal 1 House 1**	**Vestal 1 House 2**	**Vestal 1 House 3**	**Vestal 1 House 4**	**Vestal 2 House 1**	**Vestal 2 House 2**	**Vestal 2 House 3**	**Vestal 2 House 4**
# of pigs / house	1257	1248	1301	1268	1310	1351	1226	1311
Wks in finishing	5	5	3	3	6	6	7	7
Ave. Wt of pigs (lbs.)	97.8	92.9	79.6	76.6	97.4	96.6	102.0	104.8
Feed consumed (lbs/pig/wk)	24.3	24.3	21.0	21.0	24.3	24.3	24.3	24.3
WEEK 2 8/9-8/14	**Vestal 1 House 1**	**Vestal 1 House 2**	**Vestal 1 House 3**	**Vestal 1 House 4**	**Vestal 2 House 1**	**Vestal 2 House 2**	**Vestal 2 House 3**	**Vestal 2 House 4**
# of pigs / house	1248	1243	1298	1258	1309	1345	1223	1299
Wks in finishing	6	6	5	5	7	7	8	8
Ave. Wt of pigs (lbs.)	107.9	103.1	89.7	86.8	107.3	106.5	112.0	114.8
Feed consumed (lbs/pig/wk)	24.3	24.3	24.3	21.0	24.3	24.3	29.0	29.0

- Feed Nutrients

Table 6.3 Total elemental analysis of feed samples (8 samples in total for 1st and 2nd sampling period; each %N measurement is replicated 5 times; %P, Cu (ppm), Zn (ppm) 3 times).

Date	%N	%P	Cu(ppm)	Zn(ppm)
March 8, 2004	2.79 ± 0.11	0.54± 0.01	19.2 ± 3.1	136.1 ± 3.3
August 2, 2004	3.17 ± 0.10	0.59± 0.01	17.7 ± 2.4	130.5 ± 2.0

± indicates 1 standard deviation

Nitrogen Excretion

Computation of Nitrogen Excretion Based on Animal Feed Data (Vestal Farm: RENEW Technology-1st Evaluation period, March 8 – March 19, 2004) Note: Sampling was only conducted the week of March 15, therefore only that week's production data was used to calculate nitrogen excretion.

- Animal population / Types:
  - Total number of pigs in 8 finishing houses = 9484
  - Weighted average weight of the pigs =89.56 lb/pig = 40.62 kg/pig

- Nitrogen Intake
  - Average feed consumed = 10.45 kg/pig/wk
  - Average nitrogen content of the feed = 2.79% (from Feed Analysis)
  - Average nitrogen intake per pig = 0.29 kg-N/pig/wk

- Nitrogen Excretion
  - Average gain / feed or feed efficiency rate (ER) for feeder-finish operation, based on the 1999 Pig CHAMP data = 0.3
  - Average N excretion = (1-0.3) x 0.29 = 0.20 kg-N/pig/wk
  - Average N excretion on animal weight (*lw*) basis = *5.03 kg-N/1000kg animal live weight(lw)/wk*

Computation of Nitrogen Excretion Based on Animal Feed (Vestal Farm: RENEW Technology-2nd Evaluation period, August 2 - 13, 2004)

- Animal population / Types:
  - Total number of pigs in 8 finishing houses = 10248
  - Weighted average weight of the pigs =98.49 lb/pig = 44.68 kg/pig

- Nitrogen Intake
  - Average feed consumed = 11.02 kg/pig/wk

  - Average nitrogen content of the feed = 3.17% (from Feed Analysis)
  - Average nitrogen intake per pig = 0.35 kg-N/pig/wk

- Nitrogen Excretion
  - Average gain / feed or feed efficiency rate (ER) for feeder-finish operation, based on the 1999 Pig CHAMP data = 0.3
  - Average N excretion = (1-0.3) x 0.35 = 0.25 kg-N/pig/wk
  - Average N excretion on animal weight (*lw*) basis = <u>*5.47 kg-N/1000kg animal live weight(lw)/wk*</u>

Meteorological Measurements

Monthly/Annual Climate Data Results at the nearest weather station
15 km from sampling site
(*Source: State Climatology Office)*
Summary of monthly precipitation (cm) from 1994 to 2004
WARSAW 5 E, NC (UCAN: 14389,COOP: 319081)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1994	11.66	4.57	-	1.96	6.27	24.92	23.32	13.74	12.57	8.26	11.18	3.76	122.20
1995	8.94	11.13	10.72	1.35	8.41	40.26	12.09	3.40	4.90	11.56	10.39	4.19	127.33
1996	7.52	-	12.62	6.05	4.70	7.34	26.52	-	-	18.29	5.74	8.41	97.18
1997	8.10	7.34	8.03	8.00	6.63	7.14	16.94	8.36	19.13	5.21	13.06	11.33	119.25
1998	16.38	19.33	11.73	13.26	9.98	5.66	12.93	27.43	6.73	0.81	3.76	13.03	141.05
1999	18.36	5.56	6.96	11.66	8.20	13.21	13.74	28.45	62.31	7.16	5.72	4.06	185.39
2000	14.35	4.57	16.31	11.63	4.06	11.86	14.86	9.91	20.45	0.00	6.86	3.30	118.16
2001	2.08	9.42	18.44	1.45	11.89	16.59	7.21	14.00	-	2.92	3.30	2.59	89.89
2002	15.14	4.80	17.78	5.59	6.07	12.12	8.74	13.97	3.91	7.90	10.97	6.88	113.87
2003	4.09	12.42	16.00	14.10	15.19	13.61	45.87	9.09	10.36	13.00	5.21	12.27	171.22
2004	2.92	13.23	**2.44**	14.86	15.95	11.81	8.51	**24.13**	14.40	5.89	12.70	4.19	131.04
AVG	10.66	8.79	13.18	7.50	8.14	15.27	18.22	14.26	17.55	7.51	7.62	6.98	128.55

Vestal Precipitation Data Analysis (UCAN: 14040,COOP: 311881)

Compared to the 10-year precipitation average of 13.2 cm for the month of March (1994-2003), Vestal, conducted for March 16-March 19, 2004, showed a much lower precipitation average of 2.4 cm, a difference of 10.8 cm. This is the lowest average precipitation in the last ten years. Compared to the 10-year precipitation average of 14.3 cm for the month of August (1994-2003), Vestal, conducted for August 4-12 , 2004, showed a much higher precipitation average of 24.1 cm, a difference of 9.8 cm. However, it is within the range for the last ten years. The 10-year precipitation total average (1994-2003) was 128.6 cm, while the annual precipitation average for 2004 was 131.0 cm, a difference of 2.4 cm.

Summary of monthly mean temperature (^{0}C) from 1994 to 2004
WARSAW 5 E, NC (UCAN: 14389,COOP: 319081)

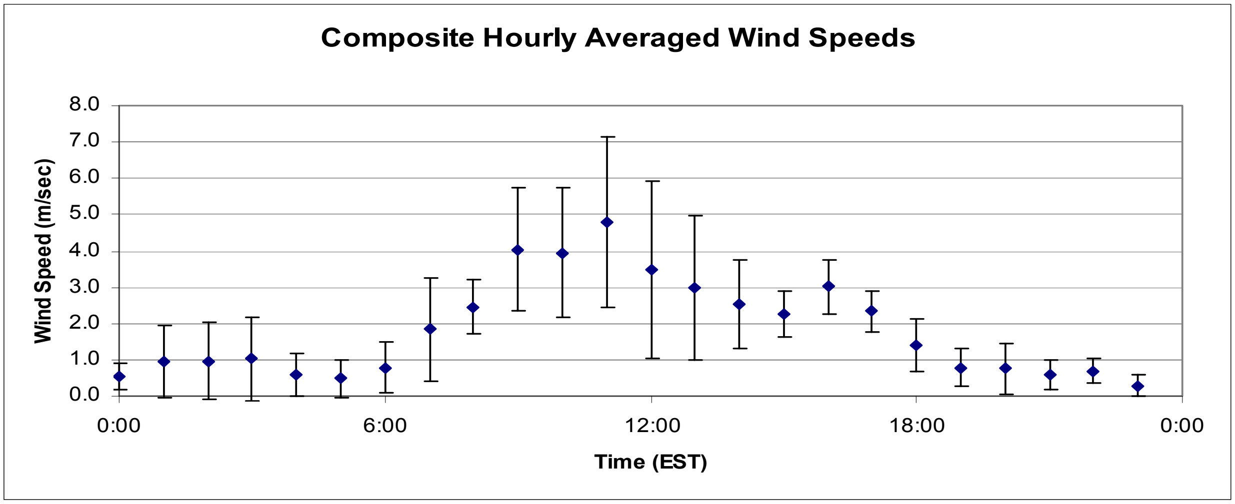
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1994	5.91	8.69	-	18.35	19.72	26.38	27.92	25.43	21.88	15.78	14.13	9.81	17.63
1995	6.80	5.97	12.28	17.14	20.77	23.75	27.31	26.38	22.31	18.64	9.32	4.86	16.29
1996	5.68	-	8.74	16.18	21.36	24.74	26.33	-	-	17.56	9.87	9.44	15.55
1997	6.45	9.53	14.97	14.38	18.48	22.51	27.08	24.73	22.21	16.42	10.71	7.89	16.28
1998	8.88	9.18	11.55	15.87	21.08	26.29	27.41	25.79	24.22	16.65	12.76	10.31	17.50
1999	9.24	8.78	9.82	17.24	19.43	23.38	26.72	26.66	22.57	16.55	14.73	7.84	16.91
2000	5.06	9.21	13.23	15.51	-	25.04	25.03	25.23	22.52	16.18	10.17	3.64	15.53
2001	6.03	9.81	10.23	16.60	20.38	24.77	24.57	25.67		15.73	14.84	10.82	16.31
2002	7.84	8.69	12.75	18.82	19.66	24.91	26.87	26.26	24.12	18.95	10.29	5.95	17.09
2003	3.47	7.11	12.91	15.25	20.56	24.40	26.07	26.49	22.12	16.52	14.72	6.14	16.31
2004	4.54	5.94	**12.50**	16.40	22.91	24.96	26.45	**24.39**	22.81	17.33	13.07	6.94	16.52
AVG	6.53	8.55	11.83	16.53	20.16	24.62	26.53	25.85	22.74	16.90	12.16	7.67	16.54

Vestal Mean Temperature Analysis (UCAN: 14040,COOP: 311881)

Compared to the 10-year temperature average of 11.8 °C for the month of March (1994-2003) , Vestal conducted for, March 8-19 2004, showed a slightly higher mean temperature average of 12.5 °C, a difference of 0.7 °C.

Compared to the 10-year temperature average of 25.9 °C for the month of August (1994-2003), Vestal conducted for August 4-12, 2004, showed a lower mean temperature average of 24.4 °C, a difference of 1.5 °C. This was the coldest August in the last ten years.

- Site Meteorological data measured during the measurement periods:



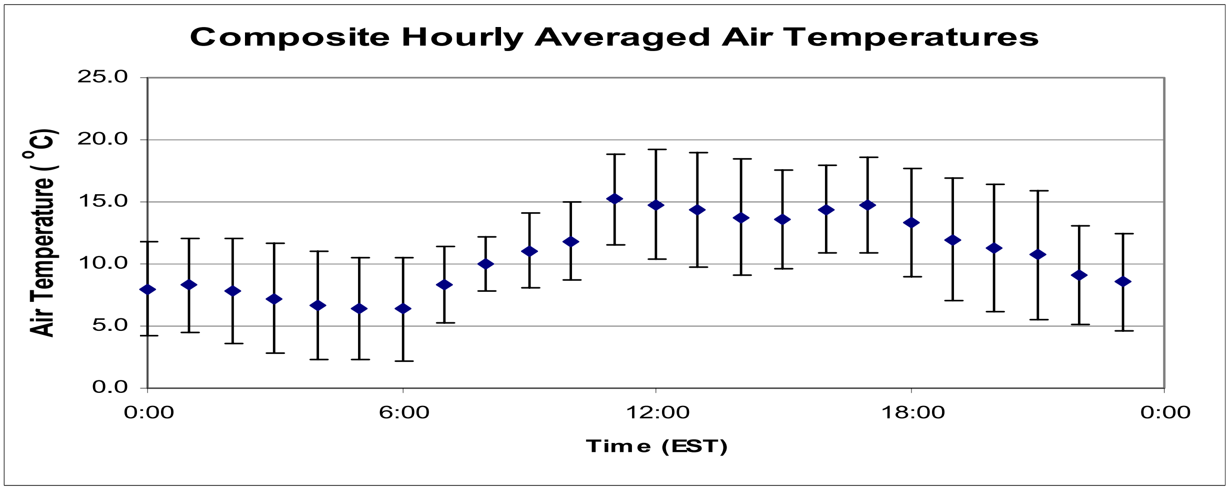


Figure 6.2 Site meteorological data during the 1st measurement period (March 16- March 19, 2004). Error bar indicates ±1 standard deviation of 15 minute averages.

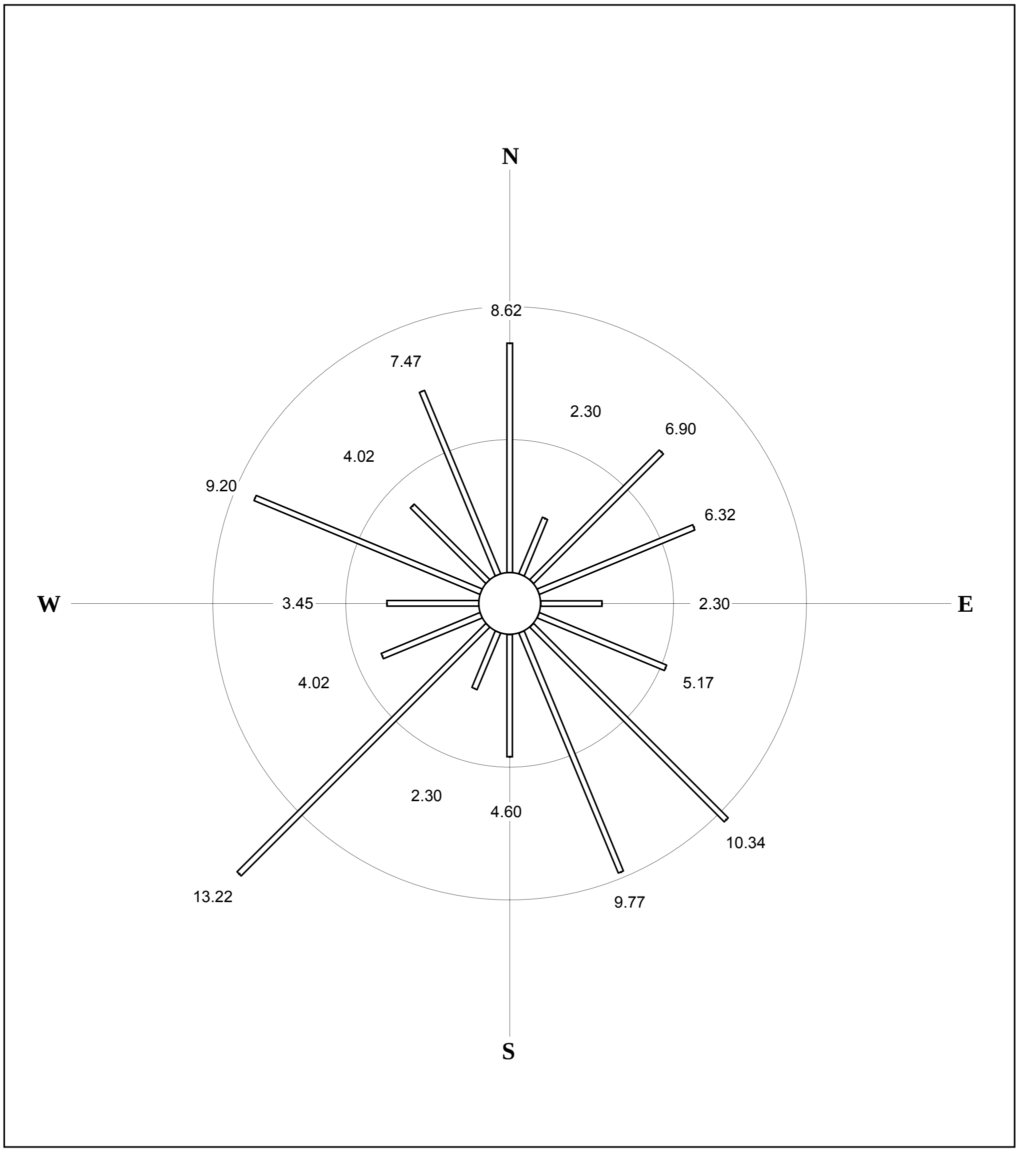
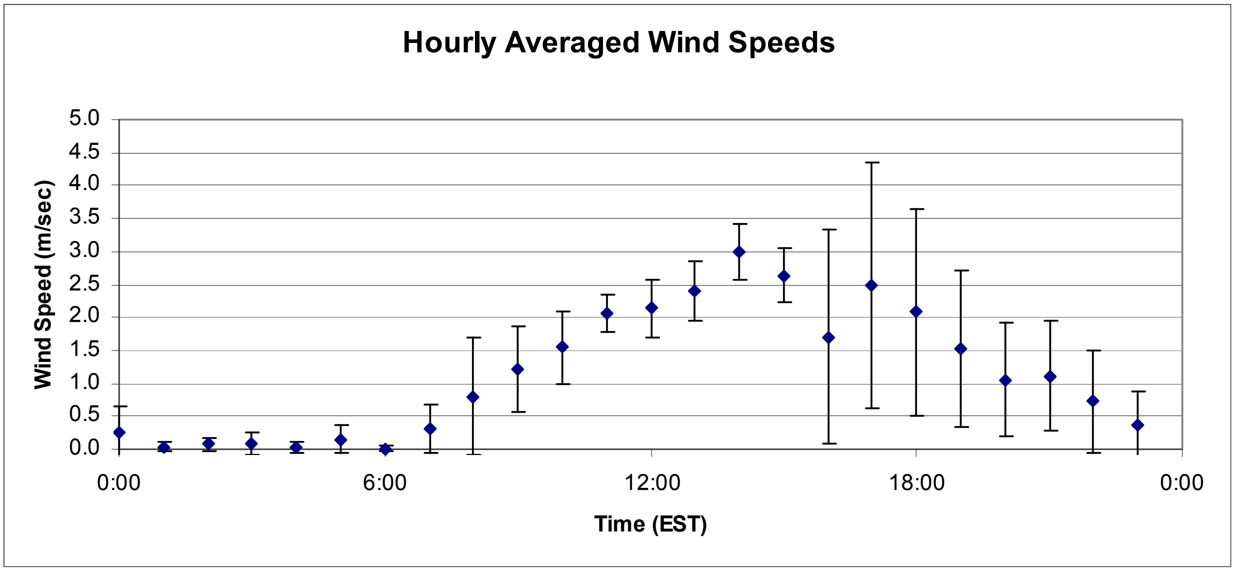


Figure 6.3 Wind rose depicting % wind direction during 1st measurement period (March 16-March 19).



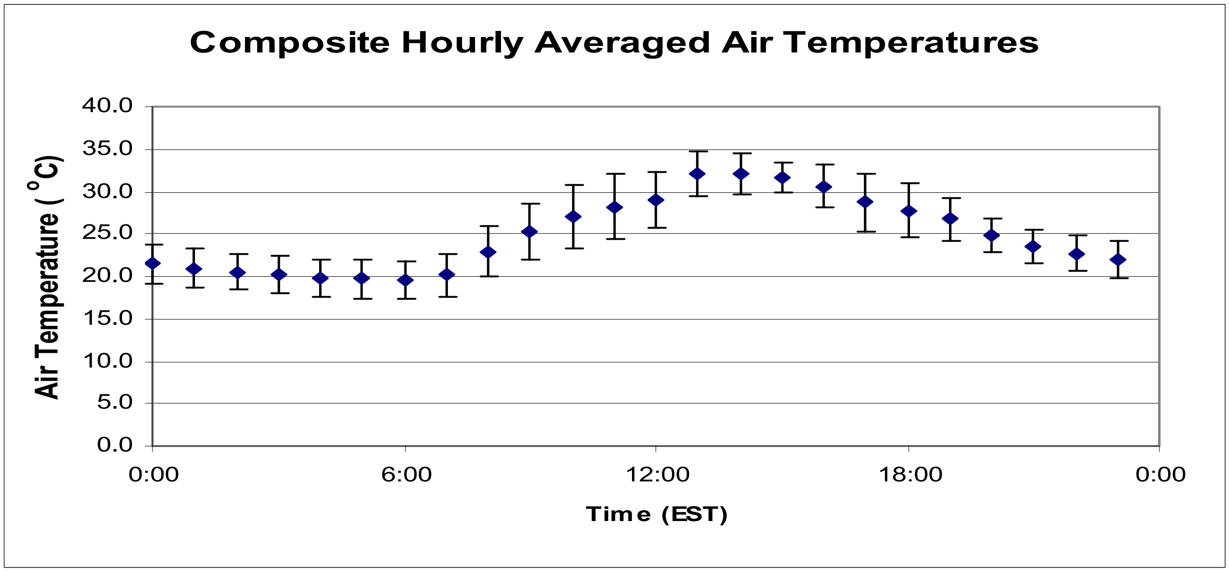


Figure 6.4 Site measurement data during 2nd measurement period (August 4-12, 2004). Error bar indicates ±1 standard deviation of 15 minute averages.

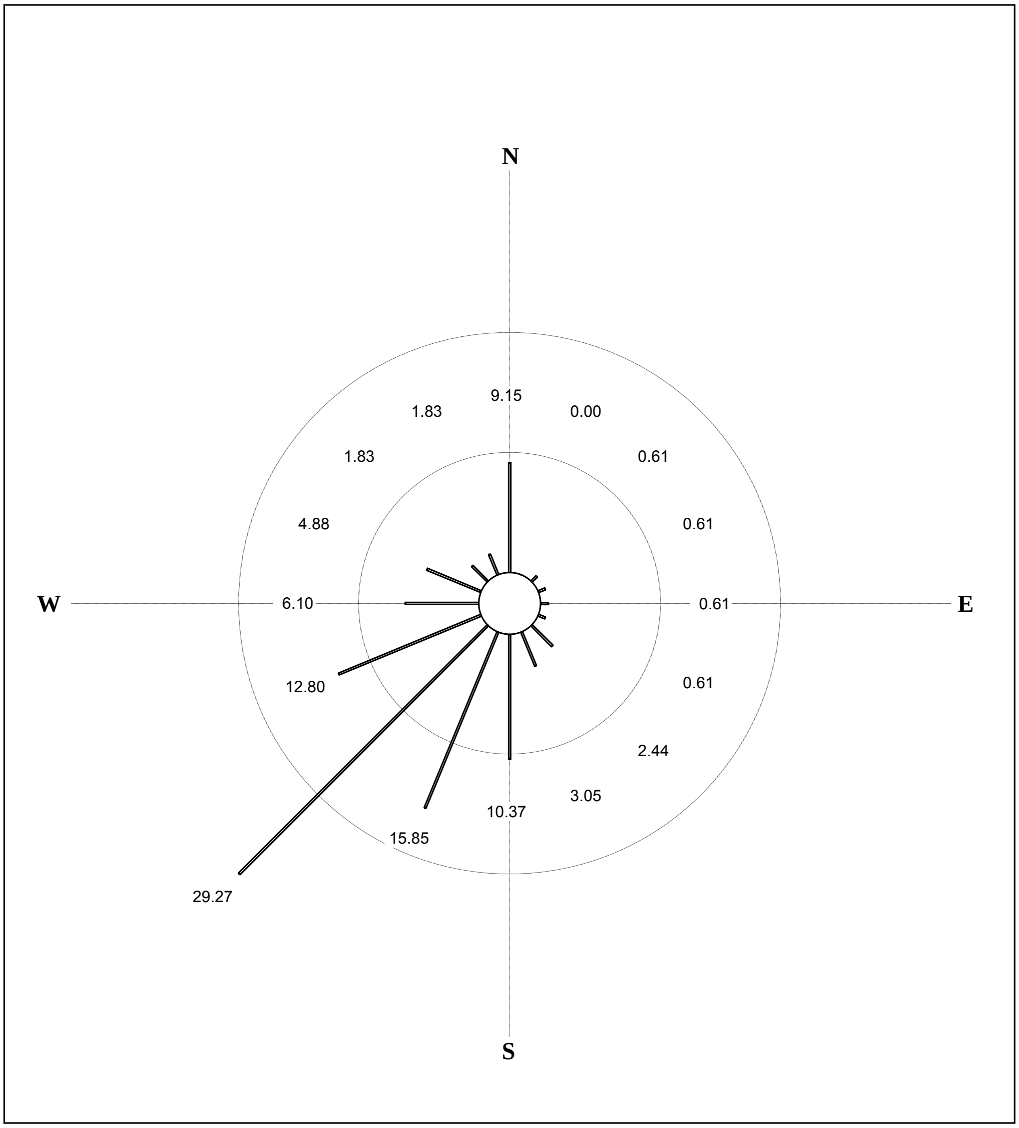


Figure 6.5 Wind rose depicting % wind direction during 2nd measurement period (August 4-12, 2004)

Measurement of Ammonia Emissions:

Emission Sources -

Major sources of NH_3 are the hog houses and the aerobic digester and the polishing storage basin. Other possible sources include the mesophilic digester. In all of the liquid waste environments, the NH_3 flux is expected to depend on ambient air temperature, water temperature, pH, wind speed, and N in waste effluent. A floating flux chamber was deployed on water-holding structures measuring NH_3 emissions directly from their surfaces. For the houses, NH_3 emission was determined by using average NH_3 concentration across plumes from one side of hog house and estimated air flow rate from the side during the measurement period by open path FTIR. For the mesophilic digester the emissions could not be determined. Using the open path FTIR the concentration of ammonia was measured to see if the mesophilic digester was a significant source.

Dynamic-Chamber Technique for NH_3 flux measurement

The measurement schedule followed for determining the flux of ammonia from the water-holding structures using the dynamic-chamber technique is described in Table 6.4. Measured flux (presented as hourly averages) as a function of time is presented in Figures 6.7 and 6.8. Tabulated hourly average flux values for each water-holding structure are presented in Table 6.5. Table 6.5 also contains the overall average flux values for each water-holding structure for each evaluation period. Table 6.6 contains TAN and TKN concentrations of the effluent samples from the water-holding structures. Table 6.7 presents total emissions of ammonia (kg-N) per week for each water-holding structure calculated for each evaluation period and normalized to 1000 kg live weight of animals present.

- Vestal farm NH_3 emission measurements (RENEW site)
  - 1st measurement period, March 16 – March 19, 2004
  - 2nd measurement period, August 4-12, 2004

Table 6.4 NH_3 emissions schedule for 1st and 2nd sampling periods at Vestal farm

Sample dates	Parameters	Instruments	Sample plots	Remarks
March 16 -18, 2004	NH_3 flux, lagoon T, WD, WS, air T, RH, SR	One NH_3 analyzer, Meteorological instruments	Aerobic digester	Completed 2 diurnal measurements
March 18-19, 2004	NH_3 flux, lagoon T, WD, WS, S air T, RH, SR	One NH_3 analyzer, Meteorological instruments	Polishing storage basin	Completed 1 diurnal measurements

T = temperature; WD = wind direction; WS = wind speed; SR = solar radiation, RH = relative humidity

Water samples at each plot were collected every day for analysis of TAN and TKN concentrations at the laboratory.

Sample dates	Parameters	Instruments	Sample plots	Remarks
Aug 4 -6, 2004	NH_3 flux, lagoon T, air T, RH, SR	One NH_3 analyzer, Meteorological instruments	Aerobic digester	Completed 2 diurnal measurements
Aug 9-12, 2004	NH_3 flux, lagoon T, WD, WS, S air T, RH, SR	One NH_3 analyzer, Meteorological instruments	Polishing storage basin	Completed 3 diurnal measurements

T = temperature; WD = wind direction; WS = wind speed; SR = solar radiation, RH = relative humidity

Water samples at each plot were collected every day for analysis of TAN and TKN concentrations at the laboratory.

Site photos during experimental period

1st Evaluation: view of aerobic digester

2nd Evalaution: view of mesophilic digester

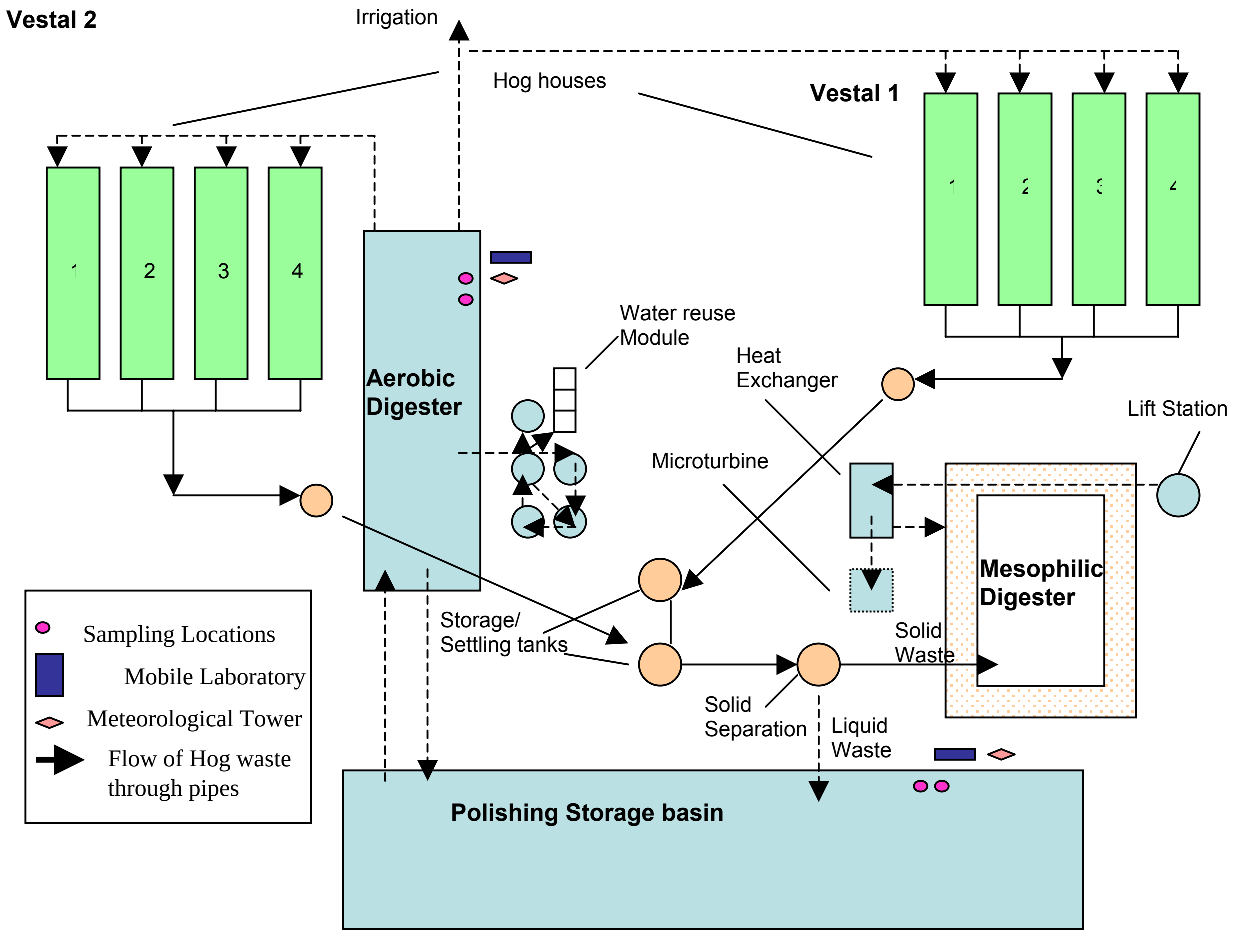
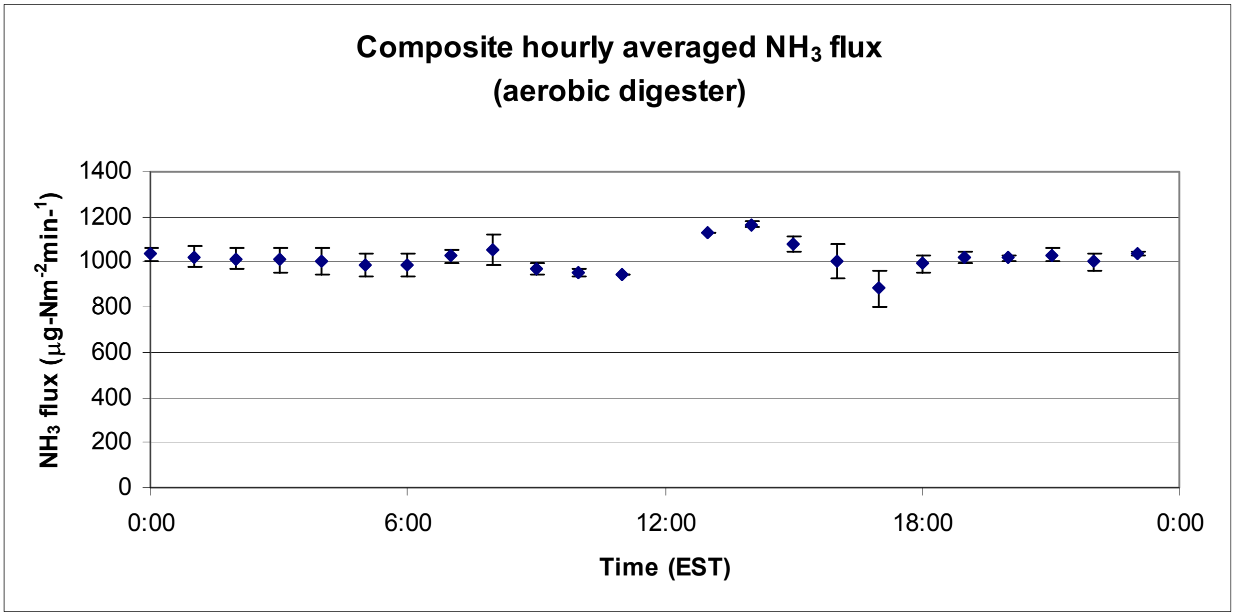


Figure 6.6 Experiment site layout and measurement locations.

1st Measurement period (March 16-19, 2004)



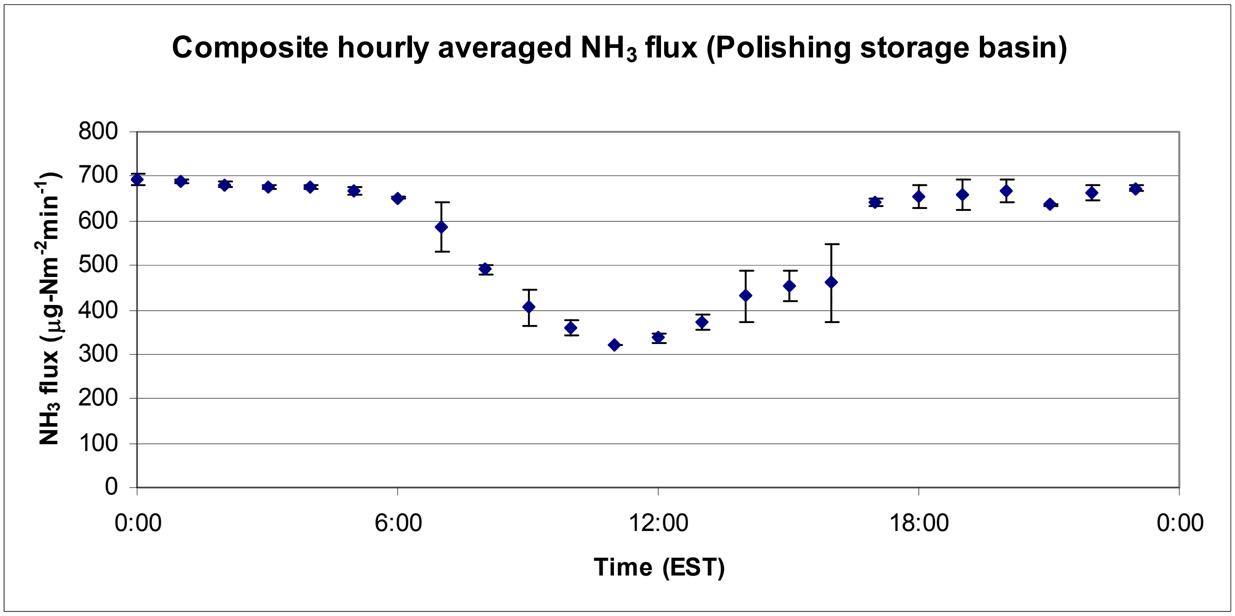
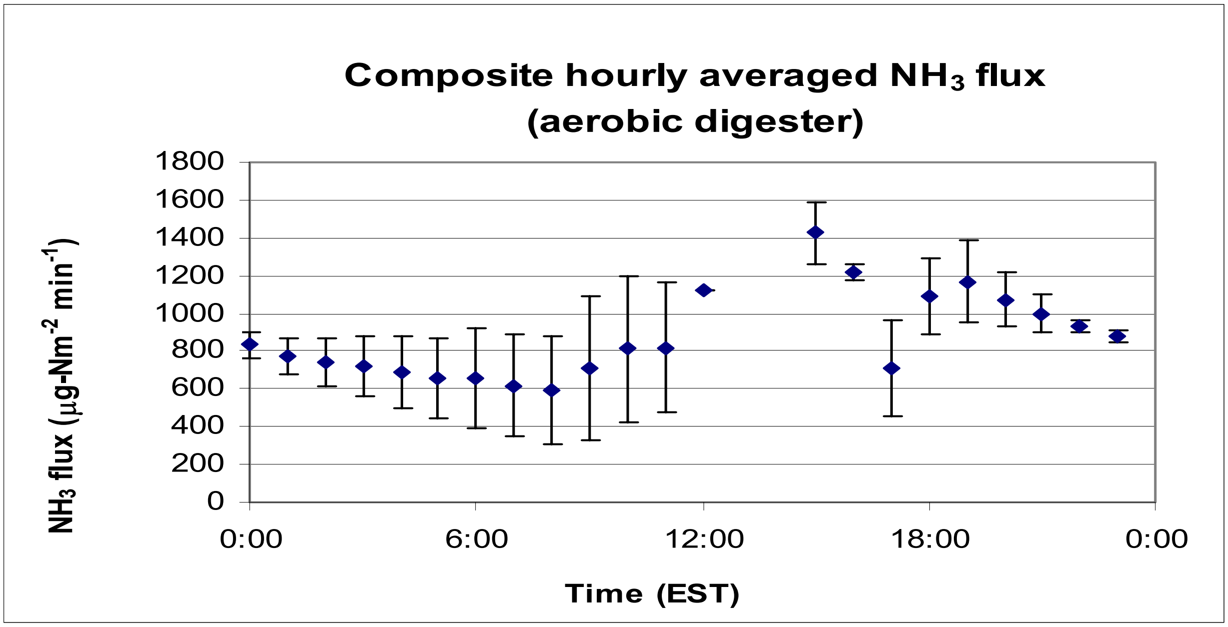


Figure 6.7 Diurnal variation of NH_3 flux from aerobic digester and polishing storage basin during the 1st measurement period. Error bar indicates ±1 standard deviation.

2nd Measurement period (August 4-12, 2004)



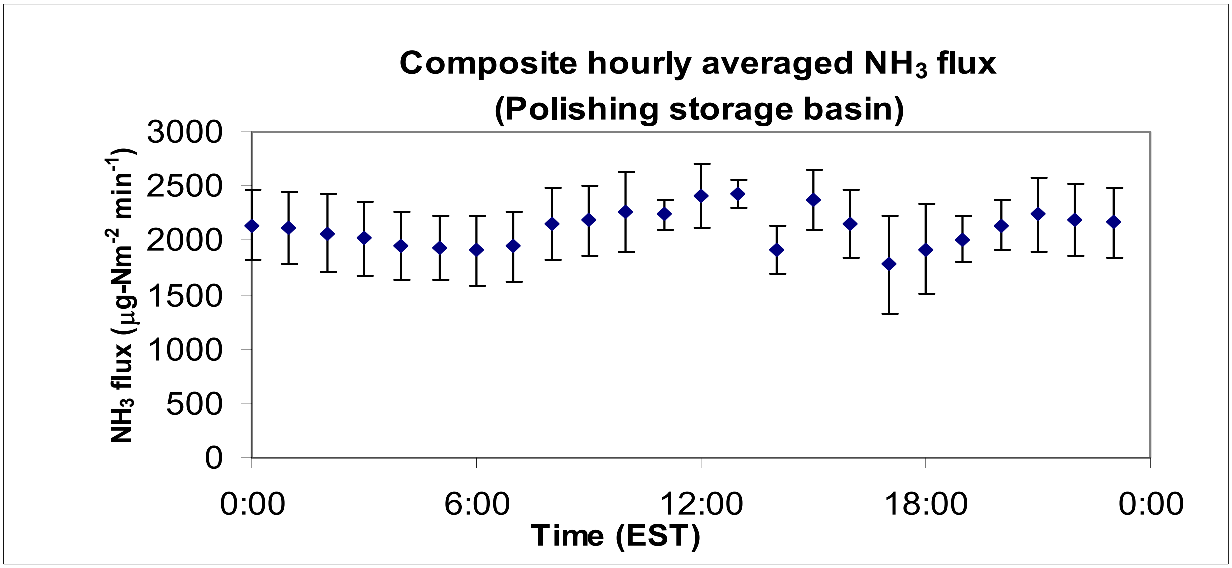


Figure 6.8 Diurnal variation of NH_3 flux from aerobic digester and polishing storage basin during the 2nd measurement period. Error bar indicates ±1 standard deviation.

Table 6.4 Summary of hourly and overall averaged NH_3 flux from water-holding structures during the experimental periods at Vestal farm.

Vestal 1st Period

	NH_3 flux (µg-N m^{-2} min^{-1}) (1st period: 3/16-3/19/2003)			
	aerobic digester		Polishing storage basin	
EST	hrly avg	stdev	hrly avg	stdev
0:00	1035.9	29.3	693.8	13.0
1:00	1024.0	46.3	689.8	5.0
2:00	1016.1	49.9	681.6	5.6
3:00	1009.6	53.7	675.0	3.7
4:00	1001.4	57.9	675.7	5.2
5:00	985.2	48.4	666.4	7.5
6:00	985.6	51.5	651.9	2.3
7:00	1026.4	28.4	587.9	55.8
8:00	1053.5	69.6	489.9	10.8
9:00	971.5	27.7	405.0	41.1
10:00	952.3	20.2	358.0	16.6
11:00	948.3		321.1	1.7
12:00			337.1	11.1
13:00	1130.1		371.9	227.4
14:00	1167.5	15.4	431.6	100.1
15:00	1080.8	31.6	454.5	33.9
16:00	1003.1	79.0	460.7	88.0
17:00	883.3	79.3	642.0	9.0
18:00	991.6	38.6	655.0	25.7
19:00	1019.6	22.7	657.6	34.2
20:00	1018.3	11.6	668.9	26.2
21:00	1032.9	28.2	635.6	3.4
22:00	1001.0	38.4	663.2	17.0
23:00	1036.4	11.0	672.4	7.0
average[†]	1016.3		574.6	
stdev	58.1		125.0	
# of data	23.0		24	
average[‡]	1010.7		573.1	
stdev	60.7		136.7	
# of data	156.0		100	
(15 min)			T_{lag}=14.8 ± 2.2(n=265)	

[†] Statistics for hourly averages

[‡] Statistics for 15 minute averages for the experimental period

Vestal 2nd Period

	NH_3 flux (μg-N m^{-2} min^{-1}) (2nd period: 8/2-8/13/2004)			
	aerobic digester		Polishing storage basin	
EST	hrly avg	stdev	hrly avg	stdev
0:00	833.6	70.3	2140.6	318.8
1:00	773.1	93.6	2116.1	323.4
2:00	746.2	127.3	2070.1	350.8
3:00	718.3	160.3	2016.8	346.3
4:00	689.4	193.8	1950.2	308.7
5:00	654.2	212.1	1932.9	303.0
6:00	657.2	262.7	1912.3	321.8
7:00	618.3	270.3	1947.2	322.7
8:00	595.0	287.1	2160.0	329.5
9:00	710.4	380.6	2181.6	313.8
10:00	810.6	390.2	2267.8	371.0
11:00	818.4	341.1	2243.0	135.6
12:00	1127.5		2411.3	298.4
13:00			2425.2	126.5
14:00			1918.2	225.9
15:00	1424.8	164.0	2368.9	272.4
16:00	1218.8	42.9	2159.6	314.6
17:00	710.8	252.1	1781.1	448.5
18:00	1094.9	200.8	1921.0	418.5
19:00	1167.9	219.1	2013.8	216.4
20:00	1074.0	145.0	2142.4	229.4
21:00	996.7	101.6	2238.7	334.8
22:00	934.5	31.1	2191.9	330.2
23:00	880.3	35.0	2165.8	327.9
average†	875.2		2111.5	
stdev	225.3		169.5	
# of data	22.0		24	
average‡	840.6		2080.7	
stdev	284.8		340.8	
# of data	154.0		234	
(15 min)			T_{lag}=28.5 ± 1.6 (n=406)	

† Statistics for hourly averages

‡ Statistics for 15 minute averages for the experimental period

Table 6.5 Total Ammoniacal Nitrogen (TAN) and Total Kjeldahl Nitrogen (TKN) averages and their standard deviation from water-holding structures at Vestal farm.

	Aerobic digester		**Polishing storage basin**	
	TKN (mg-N l^{-1})	TAN (mg-N l^{-1})	TKN (mg-N l^{-1})	TAN (mg-N l^{-1})
1st Period (Mar 16-18)	567.0±23.1 n=3	469.0±21.8 n=3	541.0 n=1	454.0 n=1
2nd Period (Aug 4-12)	1810.0±1094.6 n=2	304.0±67.9 n=2	457.3±42.5 n=3	391.3±3.2 n=3

n represents the total number of effluent samples collected at each water-holding structure.

Table 6.6 Summary of total emissions from water-holding structures at RENEW during the experimental periods

1st Period

Water holding structure	Aerobic digester	Polishing storage basin
Area (m^2)	1880.6	22,636.0
Weekly NH_3 emission (kg-N/wk)	19.2	130.8
Total emission from lagoon (kg-N/wk)	149.9	
Total emission/pig (kg-N/pig/wk)	0.016	
Total emission/1000 kg-lw (kg-N/1000kg-lw/wk)	0.39	

2nd Period

Water holding structure	Aerobic digester	Polishing storage basin
Area (m^2)	1880.6	22,636.0
Weekly NH_3 emission (kg-N/wk)	15.9	474.8
Total emission from tanks and lagoon (kg-N/wk)	490.7	
Total emission/pig (kg-N/pig/wk)	0.048	
Total emission/1000 kg-lw (kg-N/1000kg-lw/wk)	1.07	

Average Ammonia Concentrations Using Open-Path Fourier Transform Infrared (OP-FTIR) Spectrometers

OP-FTIR spectrometer concentration measurements were obtained during March 9-10 and August 11-12, 2004. For both measurement periods, data was collected over the aerobic digester and at the long sides of one of the barns in the curtain opening. In March, measurements were also made over the mesophilic digester, see Figure 6.9. Figure 6.10 shows the 15 minute concentrations in mg--N/m3 for all locations in March, 2004. Figure 6.11shows the 15-minute concentrations in mg--N/m3 for all locations in August, 2004. Table 6.7 lists the average daily concentrations of nitrogen in mgN/m3.

Figure 6.9 Locations of Measurements Taken with the OP-FTIR Spectrometers

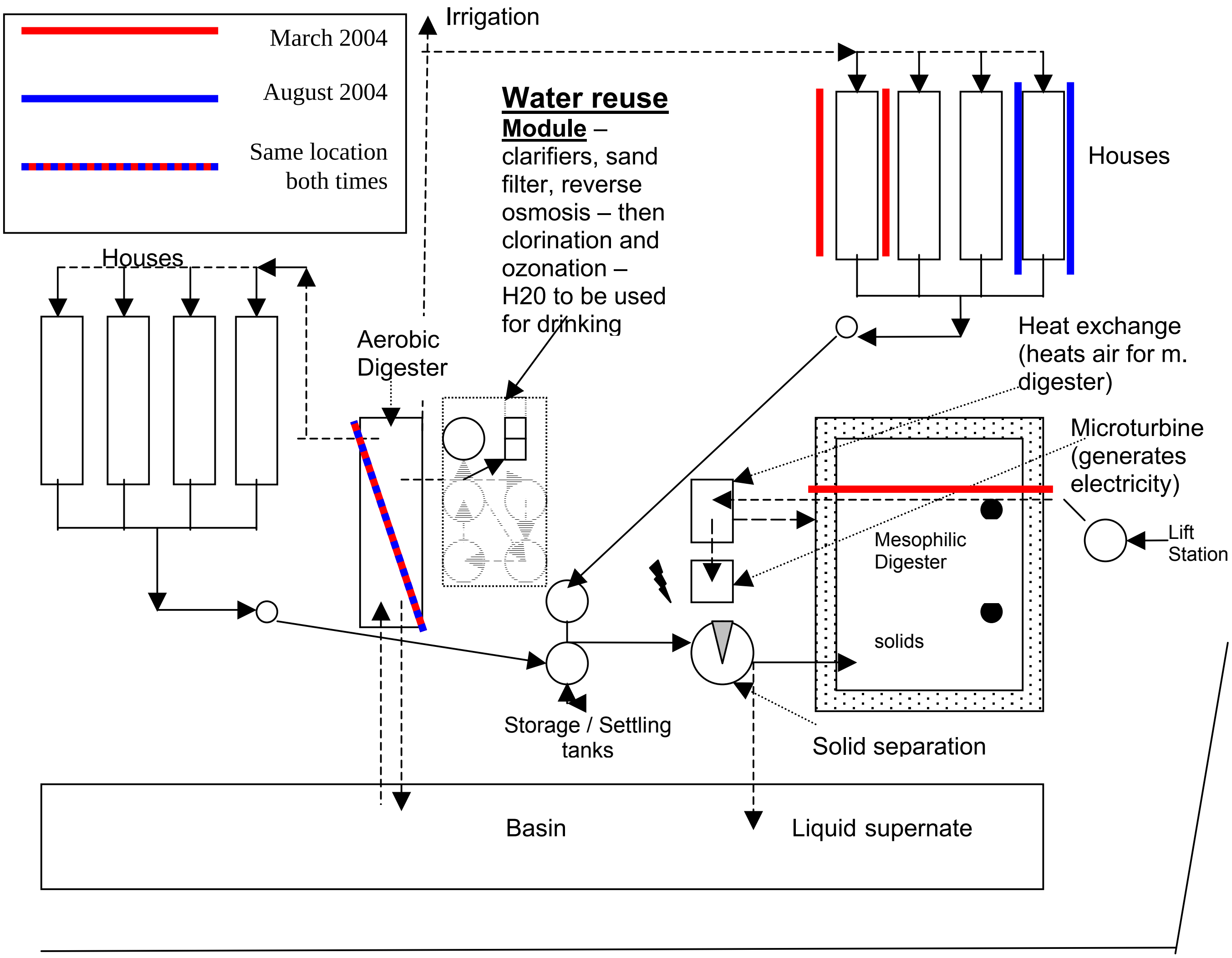


Figure 6.10 Fifteen-minute Average Concentrations and Standard Deviations Measured in March, 2004.

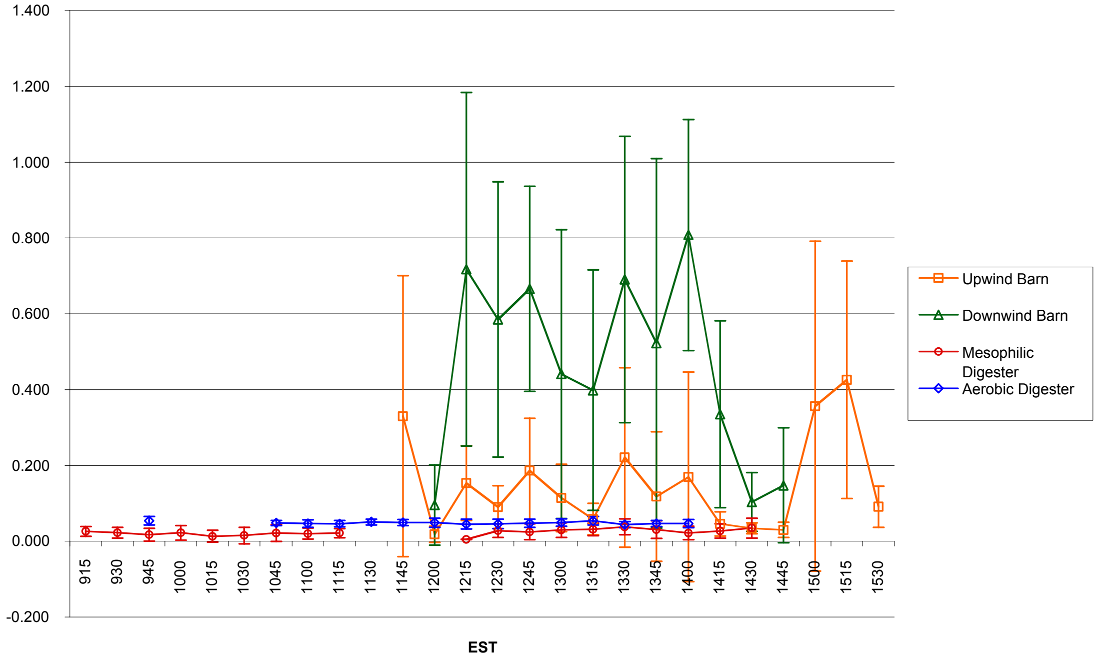


Figure 6.11 Fifteen-minute Average Concentrations and Standard Deviations Measured in August 2004.

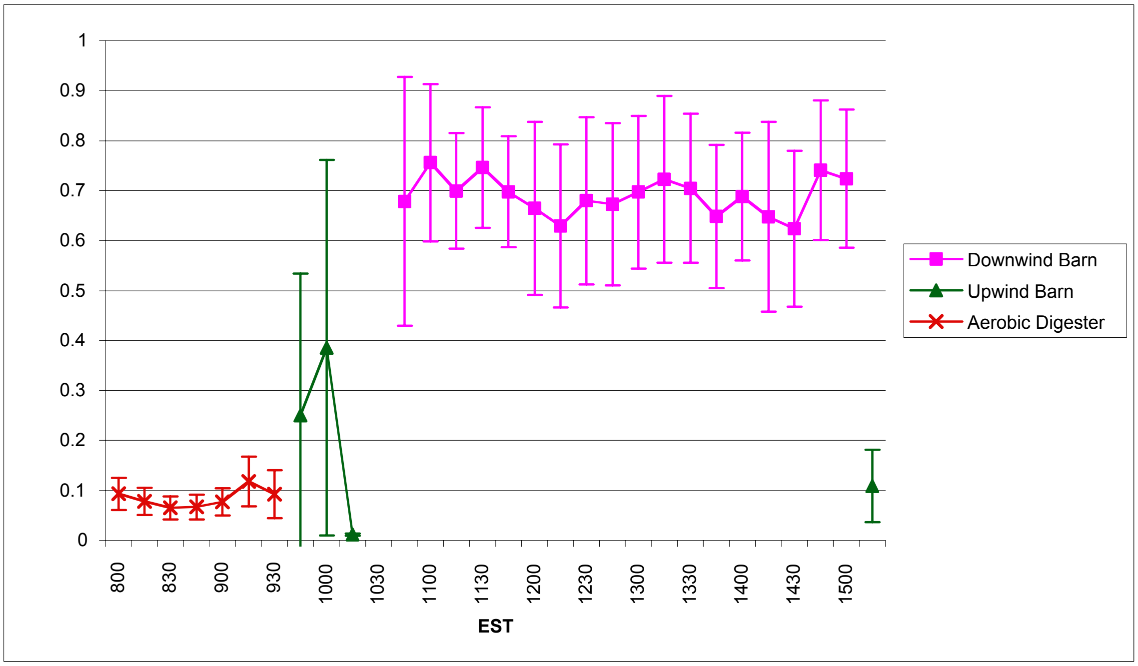


Table 6.7 Average daily concentrations of Nitrogen in mg/m3.

Date	**Component** **Barn (mg N /m3)**	
2004	**Upwind Barn**	**Downwind Barn**
March 9	**0.152**	**0.459**
August 11	**0.216**	**0.690**
	Mesophilic Digester	
March 10	**0.024**	
	Aerobic Digester	
March 10	**0.048**	
August 12	**0.084**	

Estimated Ammonia Emissions from Barns

To calculate the average nitrogen flux from the naturally ventilated houses, air-flow measurements were made by sampling at one location along each of the four sections of the building on the upwind side while the OP-FTIR was deployed. Each location was sampled for 30-60 seconds and the high and low readings recorded for all four locations over a 5-7 minute period of time. The high and low wind velocity readings were used to calculate the average wind velocity. The curtain opening for each section was measured and the volume of air per second (ventilation rate) flowing through the upwind side of the barn was calculated as the sum of curtain openings times the average wind velocities for the four sections of the building. The net ammonia concentrations associated with emissions from the building were obtained by subtracting the upwind readings from the downwind readings using the OP-FTIR and then converting the difference to concentrations of ammonia. A moving average was then applied to the concentration data to reduce the effect of wind variations (times when the wind deviated from the predominate direction). Flux from the building was obtained by multiplying net ammonia concentration times the corresponding ventilation rate. The flux calculations were then normalized by the total live weight of swine in the house (1000 Kg LW) (Table 6.8).

Table 6.8 Flux (KgN/Week/1000Kg weight of pigs)

Date	Location	KgN/Week/1000 KG
03/09/04	1 Barn	0.068
08/11/04	1 Barn	0.746

Assessment of Ammonia Emissions from Alternative Technology:

At each alternative technology and conventional site, the estimated ammonia emissions are limited to two two-week long periods, representing warm and cold seasons. But, since measurements at different sites are made at different times of the year, environmental conditions are likely to be different at different sites, even during a representative "warm" or "cold" season. There is a need for accounting for these differences in our relative comparisons of the various alternative and conventional technologies.

The estimated emissions from water-holding structures at an alternative technology for each measurement period are compared with the average estimated emissions from baseline sites, after the later are adjusted to+ the average environmental parameters (lagoon temperature and air temperature) observed at the former (alternative technology) site. A rational basis for this adjustment for somewhat different environmental conditions is the multiple regression model developed for ammonia emissions and measured environmental parameters at the two baseline sites. The model is described in appendix 2 of the three-year report. Such a comparison would not require highly uncertain extrapolations of emissions at alternative technology sites beyond the two measurement periods.

Absolute numbers are not used in assessing ammonia emissions from the proposed alternative technology. A normalized measure of emissions (normalized to calculated N-excreted; $\%E_{EST}$) is compared to a similar normalized measure of emissions ($\%E_{CONV}$) from a baseline site using the conventional lagoon technology for handling swine waste in North Carolina. The %E values are an estimate of rate of loss of N compared to N excreted. Two baseline sites are used to account for differences in housing ventilation across the sites with the proposed EST's. No method exists for adjusting baseline housing emissions to environmental conditions observed at an EST farm. Therefore, actual housing emissions measured at the baseline sites during comparable seasons of the year are used when generating the normalized measures of emissions from houses. It is acknowledged that the housing emissions for the baseline sites were not made under the exact meteorological conditions as the housing measurements for evaluation of an EST. The algorithm followed in deriving an index of performance ($\%reduction = [(\%E_{CONV} - \%E_{EST})/\%E_{CONV}] * 100$) by the EST in reducing ammonia emissions as compared to the conventional technology currently in use in North Carolina (baseline sites) is presented in Fig. 6.12 for water holding structures.

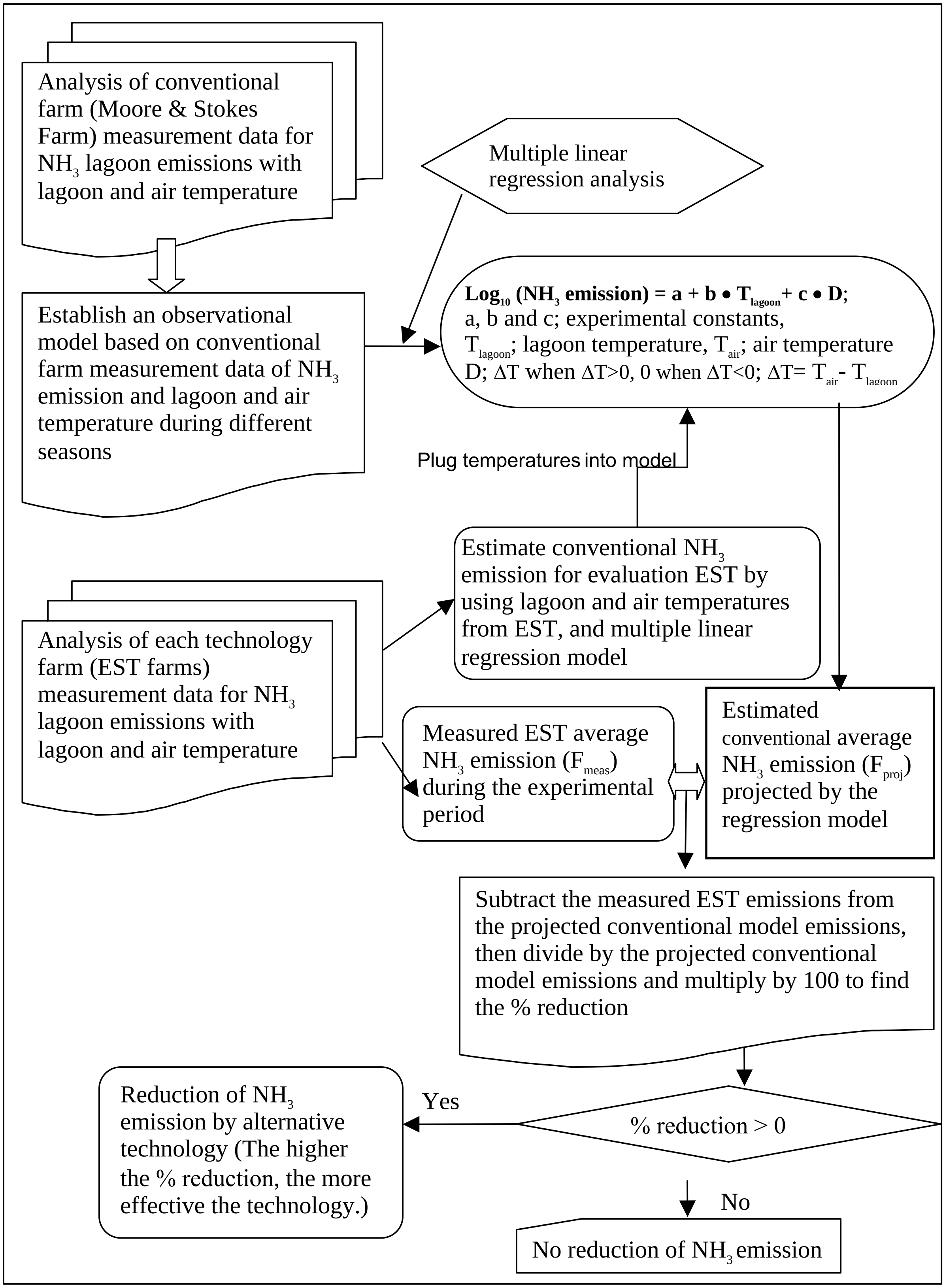


Figure 6.12 Algorithm flow chart for evaluation of alternative technology ammonia emission from water holding structures.

Evaluation of Vestal farm (RENEW System)

We compare NH_3-N emission from waste effluent treated RENEW system at Vestal farm with the projected average emission from lagoon at the conventional farm, using the observational statistical (multiple linear regression) model.

Table 6.9 gives animal weight, feed consumed, and N-excretion at two conventional farms and Vestal farm. Table 6.10 gives the NH_3-N emissions (kg-N/1000 kg-live weight/wk) data summary for the Vestal farm and baseline farms for evaluation of EST at the former. The emissions from different components of an EST or baseline farm should be viewed relative to the estimated nitrogen excretion from animal population, weight and feed data.

Table 6.9 Summary of animal weight, feed consumed, and N-excretion at conventional farms (Stokes and Moore) and the EST (Vestal farm; RENEW) farm.

Farm	No. of pigs	average pig weight	total pigs weight	feed consumed	N-excretion, E
Information		kg/pig	kg	kg/pig/wk	kg-N/wk /1000kg-lw
Stokes (Sep.)	4,392	104.3	458,086	12.84	2.71
Jan.	3,727	88.5	329,840	12.59	2.51
Moore (Oct.)	7,611	52.3	398,055	10.99	4.39
Feb.	5,784	67.0	387,528	12.37	3.90
Vestal (Mar)	9507	38.3	364,118	10.03	5.03
Aug	10248	44.7	458,086	11.02	5.47

Table 6.10 Estimates of % reduction in NH_3-N emissions from different components and their sum total at the EST (Vestal: RENEW) and conventional farms (kg-N/wk/1000kg-*lw*). (% reduction = $[(\%E_{CONV} - \%E_{EST})/\%E_{CONV}]*100$

(1)Aerobic digester and Polishing storage basin emissions

Period	Average lagoon temperature (°C)	Average D (°C)	Conventional model emissions F_{proj}	% E_{CONV}	RENEW measured emission F_{meas}	% E_{EST}	% reduction
Mar 16-18 ,2004	14.8	0.6	0.32	10.0	0.39	7.8	22.0
Aug 4-12, 2004	28.5	0.3	1.36	38.3	1.07	19.6	48.8

(2) Barn Emissions

Period	Stokes Farm measured emission	% E_{CONV}	RENEW measured emission F_{meas}	% E_{EST}	% reduction
Mar 16-18 ,2004	0.25‡	10.0	0.07	1.4	86.0
Aug 4-12, 2004	0.25‡	10.0	0.75	13.7	-37.0

Total Emissions (1)+(2)

Period	conventional total emission	% E_{CONV}	RENEW measured emission	% E_{EST}	% reduction
Mar 16-18 ,2004	0.57	20.0	0.48	9.2	54.0
Aug 4-12, 2004	1.61	48.3	1.82	33.3	31.1

D is ΔT, the difference between the air temperature (T_{air}) and lagoon temperature (T_{lag}), when $T_{air} > T_{lag}$; D = 0 when $T_{air} < T_{lag}$. F_{proj} is baseline lagoon area adjusted NH_3 lagoon emission projected by the baseline multiple linear regression model corresponding to the average lagoon temperature and the average D during Vestal (RENEW) farm measurement periods. % E_{CONV} is the conventional model emissions relative to the N excreted. % E_{EST} is the measured emission from the EST relative to the N excreted. F_{meas} is sum of the NH_3 emission from water holding structures and NH_3 emission from barn house measured at Vestal (RENEW system) farm. Soil flux measurements were not taken because there was no lagoon spray and land application during the experimental period. Hog houses at Vestal (RENEW) farm is naturally ventilated, like Stokes farm. ‡: Overall house emission measured at Stokes farm during January 2003. % reduction is used to describe how effective a technology is, in reducing NH_3 emissions. A number > 0 indicates a reduction in NH_3.The larger the % reduction, the more effective the technology is in reducing NH_3 emissions. Conversely a number < 0 indicates that there are has been no reduction in NH_3 emissions.

Summary of Ammonia Emissions

The Ammonia science team of Project OPEN has successfully completed its assessment for potential reduction of ammonia emissions as part of the Phase 2 Technology Determinations. These assessments have been accomplished through a combination of field measurements conducted during approximately two-week intensives at each technology (both warm and cool season measurements), and the application of an algorithm for evaluation of alternative technologies whereby ammonia emissions from alternative technologies and baseline (conventional) sites are compared under the same environmental conditions.

Use of a dynamic flow-through chamber is the primary means by which the Ammonia science team directly measures flux from different components (aqueous/soil surfaces) of the alternative technologies. The Ammonia science team constantly strives to improve upon and validate use of the dynamic flow-through chamber system to measure flux. In regards to the overall goals of Project OPEN, the Ammonia science team has completed a comparison of data recorded by use of the dynamic flow-through chamber system to projected ammonia flux as predicted by the U.S. EPA WATER9 Model for the same environmental conditions. The chamber flux measurements of ammonia showed excellent agreement with the U.S. EPA WATER9 Model predictions. For more information on this model the reader is referred to http://www.epa.gov/ttn/chief/software/water/index.html

Environmentally Superior Technology performance for ammonia reduction (Phase 2 Technology Determinations). Values shown are % reductions as compared to ammonia emissions from comparable conventional technology sites (positive values indicate reductions in emissions, negative values indicate enhancement of emissions).[1]

<table>
<tr><th>Technology</th><th colspan="3">% Reduction in Emissions from Water Holding Structures[2]</th><th colspan="2">% Reduction in Barn Emissions</th><th colspan="2">Total % Emission Reduction at Technology site[3,4]</th></tr>
<tr><td></td><td colspan="7">--- Season ---</td></tr>
<tr><td></td><td colspan="2">Warm</td><td>Cool</td><td>Warm</td><td>Cool</td><td>Warm</td><td>Cool</td></tr>
<tr><td>“SBR-AHA Hunt”</td><td colspan="2">31.5</td><td>-23.5</td><td>-95.0</td><td>98.0</td><td>-4.9</td><td>67.2</td></tr>
<tr><td>“ABS- Carroll’s”</td><td colspan="2">86.7</td><td>47.2</td><td>-16.3</td><td>-10.1</td><td>49.5</td><td>8.1</td></tr>
<tr><td>“PCS- Harrell’s[5]”</td><td>-143.8</td><td>-1.4</td><td>44.7</td><td>0</td><td>81.0</td><td>-109.9</td><td>69.4</td></tr>
<tr><td>“Wetlands- Howard”</td><td colspan="2">-41.8</td><td>-156.8</td><td>-59.4</td><td>-47.4</td><td>-50.9</td><td>-62.6</td></tr>
<tr><td>“RENEW- Vestal”</td><td colspan="2">48.8</td><td>22.0</td><td>-37.0</td><td>86.0</td><td>31.1</td><td>54.0</td></tr>
<tr><td>“Super Soils Composting[6]”</td><td colspan="2">-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
</table>

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[1] Conventional technology sites included a primary anaerobic lagoon and either tunnel (Moore Brothers farm) or naturally (Stokes farm) ventilated houses.

[2] Percent reductions in water holding structures are based against average lagoon ammonia emissions measured at both conventional farm sites for the respective season. Percent reductions in barn emissions are based against the conventional technology using the corresponding housing ventilation technique.

[3] Percent emission reduction figures are calculated using a precise algorithm that is documented in the respective reports for each technology. The summary numbers provided in this table should not be averaged or combined in any fashion across components of the technologies or across season.

[4] Unless otherwise noted, % reduction in emissions from water holding structures means emissions from all measured structures at a technology were combined together for a single season to arrive at the single % reduction figure.

[5] Right hand box represents the warm season evaluation of Harrell’s with the irrigation system. The total emissions were not calculated for this evaluation as no barn measurements were taken at this time.

[6] This technology had no accompanying water holding structures, nor animal barns. This was due to the configuration and location of the technology.