NC STATE UNIVERSITY

Modeling Gaseous Emissions From Agricultural Liquid Swine Waste

Sang Ryong Lee[1], Wayne P. Robarge[1], and John T. Walker[2]

[1]Department of Soil Science, North Carolina State University, Raleigh, NC

[2]U.S. Environmental Protection Agency, NRMRL, Research Triangle Park, NC

Introduction

- Swine animal feeding operations in North Carolina are sources of emissions for ammonia (NH_3), hydrogen sulfide (H_2S), methane (CH_4), volatile organic carbons (VOCs), and fine particulate matter.
- Swine operations in the state employ anaerobic lagoons to treat waste (fecal matter and urine) and serve as a source of water to flush manure from the pits under the housing units.
- Anaerobic lagoons are built as a function of treatment volume required for the standing herd at a farm plus a holding capacity to store water between irrigation events to surrounding crop land and after extreme storm events.
- Manure pits within barns also represent a relatively large surface area for emissions, often under different conditions (e.g. temperature, wind speed) then the nearby lagoons.
- Emissions from lagoons are function of pH, temperature, concentration, turbulence, and other dissolved solutes or surface films.

Objective

To quantify emissions from aqueous surfaces in typical swine animal feeding operations in North Carolina (lagoons and housing units) using computer-based models (e.g. WATER9).

Specific Activities:

- Use existing records to build a meteorological database (wind speed, temperature).
- Use existing records to build a lagoon composition database (pH, TKN, salts).
- Assess the ability of WATER9 to predict emissions from lagoons and houses.
- Compare WATER9 predictions to empirical flux models and actual measurements.

Focus on Ammonia – Estimate of Emissions

•Emission factors published for swine operations in NC range from 7 ± 2 kg NH3-N yr^{-1} hog^{-1} (Doorn et al., 2002, *Atmos. Environ.*) to 5.4 kg NH3-N yr^{-1} per finished hog (Aneja, et al., 2003, *JGR*). (Note: NH3-N means the mass of N emitted as ammonia).

•Assuming a steady-state population of ~9.3 million swine (the vast majority of which are finished hogs), the two emission factors cited translates into a range of between 50,220,000 to 65,100,000 kg NH3-N emitted per year from swine operations. (~ 50 to 64% of N excreted by swine – Table 1).

Table 1. Estimate of N excreted from swine production in 1999 for North Carolina (Sources: W. Cherry, NC Pork Council: Dr. T. Van Kempen, formerly An. Sci., NCSU, Raleigh, NC; personal communications).

Swine Production	N Excretion Factor	N Excreted (lbs N)	N Excreted (kg N)
14,358,900 (market hogs)	14.8 lbs N pig^{-1} (6.71 kg N pig^{-1})	212,500,000	96,300,000
3,000,000 (20-50 wt class; sent out of state)	4 lbs N pig^{-1} (1.81 kg N pig^{-1})	12,000,000	5,400,000
TOTAL	18.8 lbs N pig^{-1} (8.53 kg N pig^{-1})	224,500,000	**101,700,000**

Lagoon Analysis for Six Counties In NC

- Land application of swine waste from lagoons in North Carolina requires a chemical analysis of a lagoon sample immediately before or after application (pH, TKN, total dissolved S, P, Ca, Mg, Na, K).
- Results of lagoon analyses are available from Agronomic Division Soil Testing. Laboratory, NC Department of Agriculture and Consumer Services (NCDA&CS).
- Results for analyses were obtained from 1999 to 2007 and segregated by counties with highest density of swine operations (Bladen, Duplin, Lenoir, Sampson, Cumberland, Wayne).

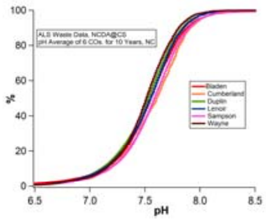

Figure 1. Cumulative frequency of pH.

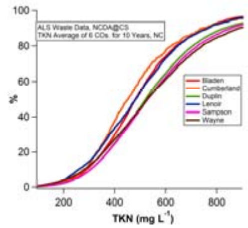

Figure 2. Cumulative frequency of TKN.

- Average lagoon pH and TKN values for period 1999-2007 are 7.51±0.04 (Fig. 1) and 432±29 mg N L^{-1} (Fig. 2).
- Ninety percent of pH values fall between 7.2 and 8.0 (Fig. 1).
- TKN analyses are more skewed to higher concentrations (as high as 1000 mg N L^{-1}).

Estimating Lagoon Surface Area

- Number of registered lagoons per county is known but not actual size of each lagoon.
- Farm design assumes ~1 lb of live-weight hog requires 1 cubic foot of treatment volume in lagoon. Standard treatment design depth is 6 feet, with treatment portion of lagoons more rectangular in dimensions.
- Minimal treatment area per pound of live weight = 0.17 square feet per 6 foot treatment depth.
- Lagoons also have storage capacity so actual depth varies between 8-9 feet. The storage capacity component of lagoons have sloping sides. We assumed this increases actual surface area by factor of ~1.3 for lagoon 8 foot deep.
- Assuming an average depth of 8 feet for most lagoons in use, this translates into a treatment surface area of 0.22 square feet per pound of live-weight of finisher hog.

Example Calculation:

- Assuming standing herd of ~ $9.3x10^6$ hogs = $1.25x10^9$ pounds of live weight (steady state live-weight = 135 pounds per finisher hog).
- Estimated lagoon surface area = 6,328 acres = 2,562 hectares.
- Assume 50% of emissions from lagoons (0.5 x 65,100,000 kg NH3-N yr^{-1}) yields lagoon emissions ~ 12,700 kg NH3-N ha^{-1} yr^{-1}.

Climate Analysis for Six Counties In NC

- Hourly-scaled observations were obtained from the State Climate Office of North Carolina (SCO).

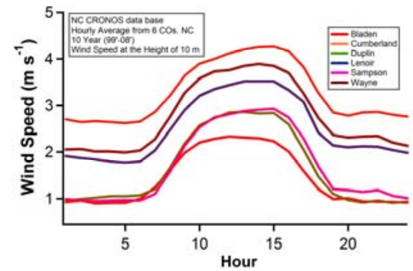

Figure 3. Hourly average wind speed from 1999-2007.

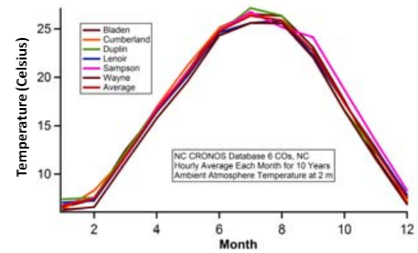

Figure 4. Monthly average temperature from 1999-2007.

Table 2. Grand Average of pH, TKN, temperature, and wind speed for 1999-2007.

County	pH	TKN (mg N L^{-1})	Temperature (ºC)	Wind speed (m s^{-1})
Bladen	7.5	411.58	16.96	1.44
Cumberland	7.55	413.02	17.26	2.87
Duplin	7.48	458.76	16.49	1.66
Lenoir	7.5	403.03	16.93	2.54
Sampson	7.54	461.45	16.87	1.70
Wayne	7.47	437.21	16.51	2.67

WATER9

- WATER9 is a wastewater treatment model for estimating air emissions of individual waste constituents. (http://www.epa.gov/ttn/chief/software/water/).
- WATER9 can be configured to model emission surfaces in both houses and accompanying lagoon.
- Initial model runs have used default parameters for NH_3 provided with the database supplied with the installation software.
- Model outputs will be compared to published measurements of flux from swine lagoons, derived empirical models of flux from lagoons, calculated estimates of flux, as well as field measurements of flux from both houses and lagoons being conducted by the National Air Emissions Monitoring Study (NAEMS).
- Laboratory measurements of flux may be conducted to improve/provide needed parameters for the WATER9 database for emissions of other gases (e.g. H_2S).

Table 3. Initial comparison of ammonia fluxes derived from various approaches.

Researcher	Method	Season/ Condition	Flux (kg NH3-N ha^{-1} yr^{-1})	Housing/ Lagoon
*Aneja	Chamber	Summer	21,290	Lagoon only
Harper (NADP, 2003)	Flux-gradient	Summer	9,745	Lagoon only
McCulloch (Environ. Poll., 102/1998)	Gaussian model	Summer	15,440	Lagoon only
Todd (Atmos. Environ., 35/2001)	Tracers	Summer	35,040	Lagoon only
WATER9	Model Approach	pH 7.6, 16.5 ºC, 459 mg N L^{-1}, 1.6 m s^{-1}	29,960	Houses/ Lagoon

* *Environmental Simulation Chambers: Application to Atmospheric Chemical Processes, 97-109, 2006.*

Summary

•Review of lagoon analyses from 1999-2007 indicates lagoon pH values fall within a narrow range (Fig. 1), but TKN values are more variable (Fig. 2).

•As a first approximation, TKN = total ammoniacal nitrogen (TAN). This assumption probably is unrealistic at higher concentrations of reported TKN.

•Average wind speeds appear to vary greatly across counties in eastern NC with highest density of swine operations (Fig. 3).

•Average monthly air temperatures are nearly identical across these same counties (Fig. 4).

•Initial model outputs from WATER9 are within an order of magnitude of other estimates of NH_3 flux from swine lagoons.