Evaluating the Performance of a "Closed-Loop" Swine Waste Treatment System

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Abstract

The Animal and Poultry Waste Management Center at North Carolina State University, in cooperation with Sustainable North Carolina and Frontline Farmers (an organization of swine growers in North Carolina), is evaluating the performance of a "closed-loop" swine waste treatment system developed by Environmental Technologies, LLC, in a project funded by an Environmental Enhancement Grant from the North Carolina Attorney General. The project is located on the farm of Chuck Stokes in Ayden, NC. The evaluation methodology used is the same as that used for the 16 technologies currently being evaluated under the NC Attorney General/Smithfield Foods/Premium Standard Farms/Frontline Farmer Agreements. The evaluation includes overall performance, technical feasibility, emissions (odor, pathogens and emissions of nitrogen), and economic feasibility. The treatment process begins with a solid/liquid separation of the flushed raw waste. Solids are composted; liquids are injected with a flocculant and sanitizing chemical and enter a settling tank. The liquid fraction from the settling tank is returned for use as flush water (with a side stream treated further for use as swine drinking water). Settled solids and floating material will be composted as well.

Introduction

Research efforts to identify and implement "Environmentally Superior Technologies" (ESTs) were initiated in 2000 by the Attorney General of North Carolina by an agreement with Smithfield Foods and its subsidiaries, and a similar agreement with Premium Standard Farms. Performance standards defined in the Agreements mandate that successful ESTs address environmental variables including the discharge of animal waste to surface waters and groundwater; emissions of ammonia; emission of odor; release of disease-transmitting vectors and airborne pathogens; and nutrient and heavy metal contamination of soil and groundwater. Comprehensive determinations of economic feasibility are also mandated by the Agreements. Dr. Mike Williams, Director of the Animal and Poultry Waste Management Center (APWMC) at North Carolina State University, has sole authority for designating a waste treatment system as an EST. The APWMC has led the evaluation of 16 swine waste treatment technologies that were chosen from a pool of respondents to a request for proposals as prescribed in the Agreements.

The Agreements specifically provide for the designation of other technologies as ESTs that were not part of the original 16. The "closed-loop" swine waste treatment technology described herein is not one of the original technologies, but is subject to the same performance criteria and evaluation methodologies as the other technologies. This technology, which is being developed by Environmental Technologies, LLC, in cooperation with Sustainable North Carolina and Frontline Farmers (an organization of swine growers in North Carolina), can therefore be designated an EST provided it meets the technical and economic performance criteria outlined in the Agreements. The project is being funded under an Environmental Enhancement Grant from the North Carolina Attorney General and is located on the farm of Chuck Stokes near Ayden, NC

The primary objective of this "closed-loop" system is to treat the liquid fraction of the swine waste in such a way that it can be reused for flushing the hog barns and can also be used for hog drinking water. Achieving these goals could potentially eliminate the need for the traditional lagoon/sprayfield system. The "closed-loop" system treats the waste from three hog barns, with a steady-state population of 3672 finishing hogs. These barns use a flush system for removing the manure from the barns, which, prior to installation of the treatment system, flushed the waste into a lagoon.

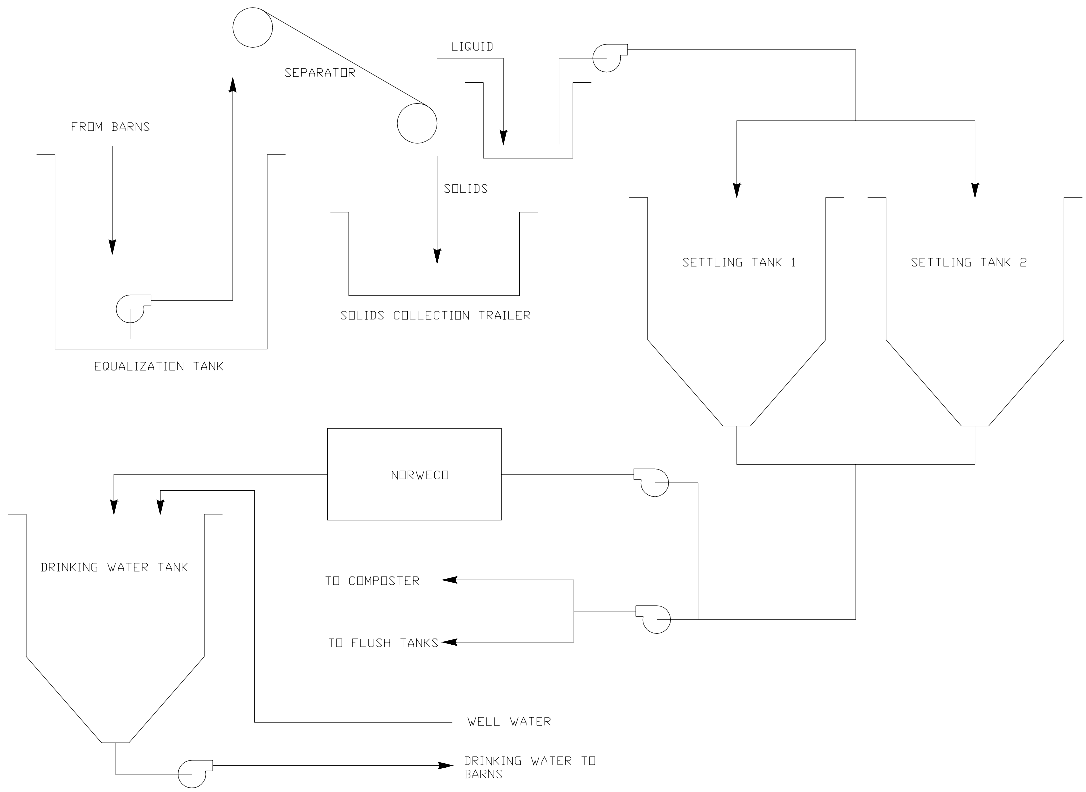

Figure 1. System Schematic for "Closed-Loop" Swine Waste Treatment System

A schematic of the system is shown in Figure 1. The first step in the "closed-loop" process is collection of the flushed waste in an "equalization" or buffering tank. The waste in the tank is pumped to an inclined-screen separator (see Figure 2) where the solids are collected and composted prior to field application on-farm or being sold. The liquid collected from the separator is injected with a polymer flocculant and sanitizer/disinfectant and pumped into a settling tank (see Figure 3), where flocculated solids collect at the bottom over a period of approximately four hours. The flocculant used is a proprietary polymer formulation developed by Environmental Technologies, LLC. The active ingredient in the sanitizer/disinfectant is trichloromelamine made by H&S Chemical Company in Covington, Kentucky. Among other uses, this compound has been used by the U.S. Army as a disinfecting fruit and vegetable wash.

Figure 2. Inclined Separator for Separating Raw Waste

Most of the liquid fraction from the settling tank is returned to the hog barns for re-use as flush water. But when the flush tanks are full, excess water is pumped to a tertiary treatment system. This system provides filtration and aeration and is housed in a septic tank. The treated water is blended with well water to achieve a solids content consistent with human drinking water standards for use as hog drinking water. Settled solids (and floating debris) in the settling tank will be composted along with the solids from the inclined-screen separator.

Figure 3. Settling Tank for Flocculated Solids

Evaluation Methodology

The evaluation methodology being used is the same as that used for the 16 technologies currently being evaluated under the Smithfield Foods/Premium Standard Farms/Frontline Farmer Agreements. The evaluation includes overall performance, technical feasibility, pathogen reduction, odor emissions, nitrogen emissions, and economic feasibility. By using this evaluation methodology, this technology can be designated an Environmentally Superior Technology (EST), as defined in the agreements, as long as it meets the performance and economic criteria defined in those agreements.

While the primary purpose of the evaluation is to determine whether it can be designated as an EST, a second objective of the evaluation of the "closed-loop" swine waste treatment system is to provide an independent assessment of the system's performance and to provide verification that the system meets stated claims concerning its performance. Thus, to the extent possible, independent measurements of system flows, weights, solids and nutrients were made.

In the first separation process -- the inclined-screen separator -- the separated solids drop into a manure spreader and are transported with one of the farm's tractors to a nearby composting site on a daily basis. During the week of July 18, 2005, a pair of wheel scales made by Cas Corporation (model RW-15P) were used to weigh the tractor front wheels, the tractor rear wheels and the manure spreader wheels when the manure spreader was full and then again when empty. The weight of the manure in the spreader was calculated as the difference between the sum of the three sets of wheel weights under full and empty conditions. Measurement of the total solids content of the separated manure allowed calculation of the weight of the manure on a dry basis, which was critical to the overall mass balance calculations.

The effluent flow from the swine houses and the flow from the equalization tanks into the settling tanks were not measured directly. Instead, batch volumes exiting the settling tanks were measured by the height of the liquid in the tanks and tank geometry. It was assumed that the volume of material leaving the hog barns and entering the settling tanks equaled the volume of material leaving the settling tanks. As the settling tank begins to empty, the settled solids at the bottom of the tank exit first and are directed to the lagoon (the settled solids will eventually be directed to the composter instead) by the programmable logic controller (PLC) that operates the system. When the depth in the tank drops to a preset level, the PLC redirects the flow from the settling tank to the flush tanks for the hog barn. When these flush tanks are full, remaining liquid in the settling tank is directed to the Norweco, the tertiary treatment system used to produce drinking water for the hogs. When the settling tank is nearly empty, flow is again directed to the lagoon to dispose of any floating debris. The volume of liquid in the tank at the beginning of each stage was calculated so that the quantity of liquid directed to each subsequent process could be computed.

Two samples (one for each of the analytical labs mentioned below) were taken at all key points in the system including the solids collected from the inclined-screen separator. The method for capturing samples was to draw from the appropriate sample valve in the piping leading from one process to another during periods of active flow. Due to time constraints, a complete set of samples may consist of samples from the end of one batch and the beginning of another batch. These samples were analyzed by the North Carolina Department of Agriculture & Consumer Services' Agronomic Division (total nitrogen, total phosphorous, copper, zinc, K, Ca, Mg, S, Fe Mn, Zn, B, Mo, and Cl) and the Analytical Laboratory in the Biological and Agricultural Engineering Department at NC State University (total solids, volatile solids, chemical oxygen demand). A third private laboratory (Chemical & Environmental Technology, Inc., in Research Triangle Park, North Carolina) was used for verification.

Mass flows have been conducted on total solids, nitrogen, and phosphorous, copper and zinc. For a given species (solids, nutrients or metals) leaving the settling tanks, the volume of liquid leaving the settling tanks and proceeding to a subsequent processing step was known, as described above. A sample of each of these streams was taken so that the mass of a given species could be calculated by multiplying its measured concentration by the volume of that stream. The system is operated in a batch mode, so that the total mass of a given species per batch is multiplied by the number of batches per day (currently eight batches per day) to arrive at a total daily mass of the species entering or leaving a given process.

Separated Solids = 418 gallons/day	
Solids, %	22.8%
N, ppm	10,300
P, ppm	6,000
Cu, ppm	64.1
Zn, ppm	248.0

Settled Solids = 2,924 gallons/day	
Solids, %	2.6%
N, g/L	2.3
P, g/L	0.8
Cu, mg/L	8.6
Zn, mg/L	39.0

House Effluent = 14,865 gallons/day	
Solids, %	unknown
N, g/L	3.1
P, g/L	1.6
Cu, mg/L	11.4
Zn, mg/L	64.6

Separated Liquid = 14,447 gallons/day	
Solids, %	2.2%
N, g/L	2.8
P, g/L	1.4
Cu, mg/L	16.0
Zn, mg/L	65.8

Supernatant = 11,523 gallons/day	
Solids, %	1.4%
N, g/L	2.4
P, g/L	0.9
Cu, mg/L	9.4
Zn, mg/L	41.7

To Flush Tanks = 9,600 gallons/day

To Norweco = 1,923 gallons/day

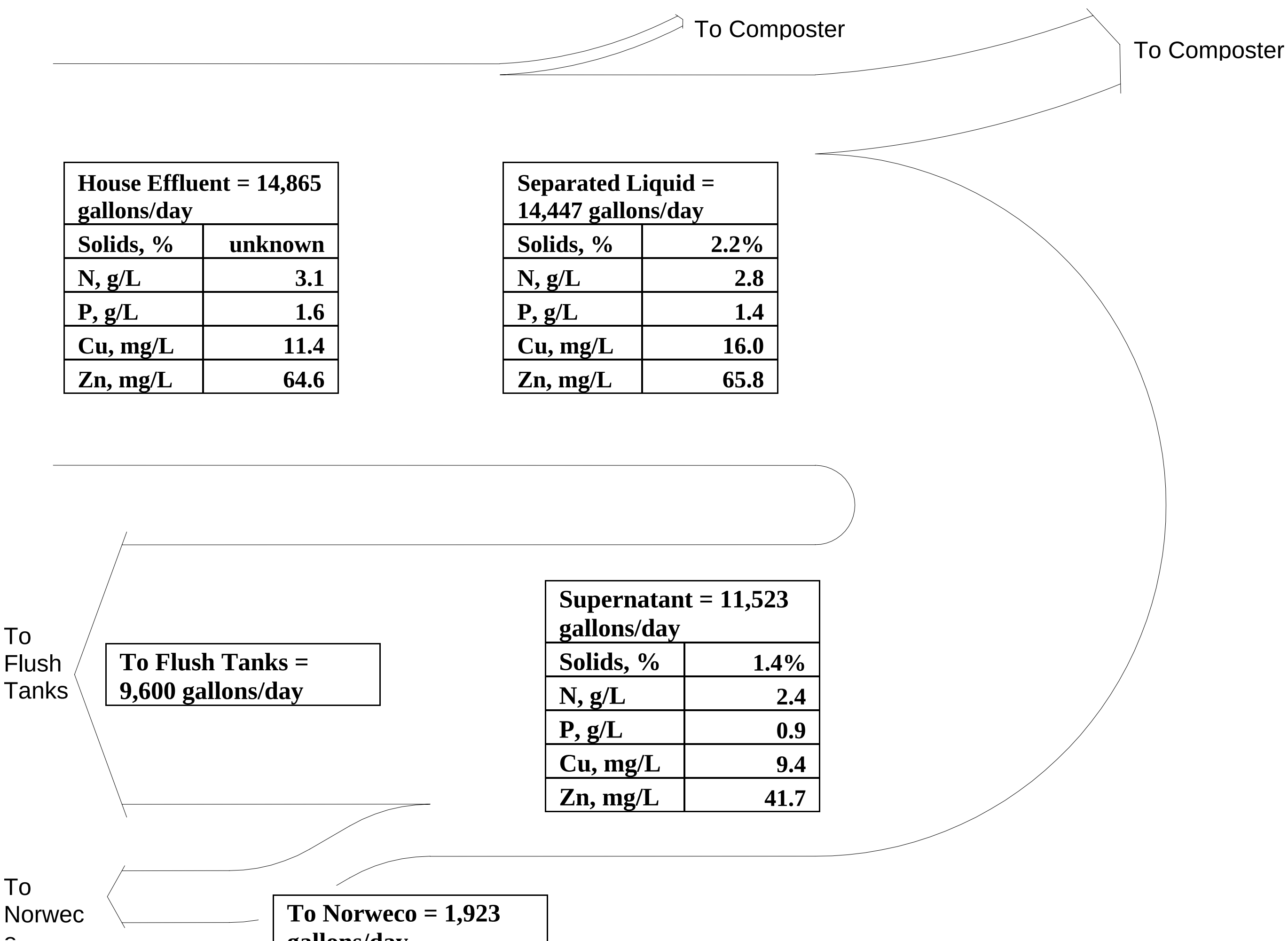

Figure 4. Volume of Treatment Streams for the Closed-Loop Swine Waste Treatement System Along with Measured Values for Key Species from Samples Collected on 7/21/05.

Results and Discussion

The fate of solids, nutrients and metals is critical to the performance evaluation of this "closed-loop" swine waste treatment system. An effort was made to determine all system flows and concentrations during the course of the testing but the expense and effort associated with measuring the weight of the solids collected from the inclined-screen separator dictated that these solids were measured only for four days out of a two-week window beginning July 18, 2005. For other sampling dates, it was assumed that the quantity of solids collected in the manure spreader was comparable to the quantity collected during the two-weeks beginning July 18, 2005. This assumption is less than ideal because the quantity of solids collected will vary considerably with the age of the pigs.

The volume (on a daily basis) of liquid associated with each treatment step is shown in Figure 4. Note that the width of each stream is directly proportional to the volume. Also shown in this Figure are the concentrations of the various species as measured on 7/21/2005, except for the effluent from the Norweco system which was not measured reliably for reasons mentioned later in the report. The concentrations of solids and nitrogen in the supernatant being used to fill flush tanks on this date are 3-4 times higher than concentrations in typical lagoon liquid, and concentrations could increase before reaching steady-state (lagoon liquid is typically about 0.3-0.4 % solids and about 500-600 mg/L nitrogen).

The solids are collected from the inclined-screen separator in a manure spreader over a period of approximately 24 hours and then transported to the nearby composting site. All results that follow are based on data collected during the same period of time that the solids from the inclined-screen separator were measured, so that a complete mass balance on the system could be conducted. The average weight of the pigs during this period was approximately 230 lbs.

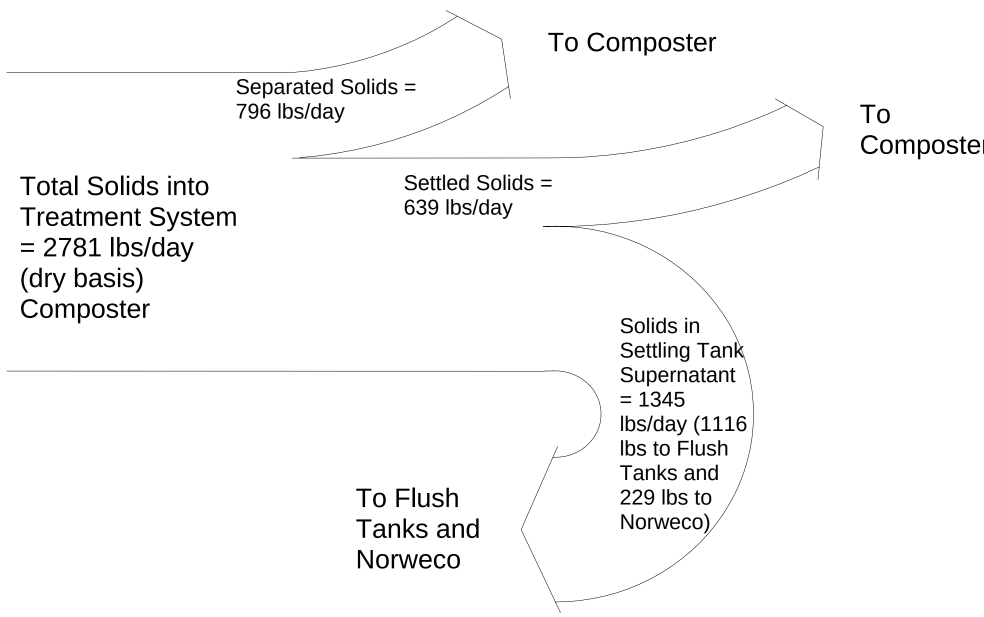

Figure 5. Fate of Solids Entering the Closed-Loop Swine Waste Treatment System

Figure 5 shows a representation of the fate of solids that enter the treatment system as measured during the intense two-week sampling period beginning July 18, 2005. After being collected in the equalization tank, wastewater flushed from the barns is processed in the inclined-screen separator. The total mass of solids entering the treatment system per day during the testing period was 2781 lbs on a dry basis (note: all subsequent solids measurements are given on a per day, dry basis). Of this amount, the solids collected in the manure spreader from the inclined-screen separator weighed 796 lbs. As discussed earlier, the liquid fraction from the inclined-screen separator is injected with a flocculant and disinfectant/sanitizer and allowed to settle for approximately four hours. The settled solids in the bottom of the settling tank that currently flow to the lagoon but will eventually be composted weighed 639 lbs. Note that this amount also includes a small amount of solids consisting of floating debris on the surface of the liquid in the settling tank. The supernatant from the settling tank, while having a lower solids content on a percentage basis, still contains substantial solids (1345 lbs) because of the large volume of liquid. As discussed earlier, the supernatant flows back to the flush tanks until the flush tanks are full. The remaining supernatant is then redirected to the tertiary treatment system (the Norweco system). Table 1 shows the fate of solids in the treatment system as a percentage of the total amount of solids entering the treatment system for different sampling dates throughout the project period. The solids directed to the flush tanks do not leave the system and may tend to accumulate in the flush water before reaching a steady-state condition in which the amount of solids excreted by the pigs equals the amount of solids leaving the system. In Table 1, the high percentage of solids captured by the inclined-screen separator on June 10 may be an artifact of the assumption that the amount of solids is constant for all sampling dates and comparable to the amount captured during the two week sampling window beginning July 18, 2005. On June 10, according to samples taken at various points throughout the system, there was an explicably low quantity of solids being processed by the system. Thus the assumption of a constant mass of solids captured by the inclined screen separator makes the reported percent solids captured artificially high for this date.

Table 1. Fate of Solids as a Percentage of Solids Entering the Treatment System

Sample Description	3/14/05	4/28/05	5/12/05	6/10/05	7/18/05	7/21/05	Average
Separated Solids (from inclined-screen separator)	26%	13%	15%	53%	18%	29%	**26%**
Settled Solids to Composter	26%	17%	15%	27%	15%	21%	**20%**
Supernatant to Flush Tanks	38%	57%	56%	16%	54%	40%	**44%**
Supernatant to Norweco	8%	11%	11%	3%	11%	8%	**9%**
Supernatant to Composter (floating debris)	1%	2%	2%	1%	2%	2%	**2%**
Solids to Composter	54%	32%	33%	81%	35%	52%	**48%**
Solids to Flush Tanks and Norweco	46%	68%	67%	19%	65%	48%	**52%**

Figure 6 shows the flow and fate of nitrogen through the treatment system. Because of the presence of soluble nitrogen in the ammonia/ammonium form, nitrogen is present in the liquid phase of the wastewater as well as in the suspended organic solids. It is estimated that during the week of July 18, 2005, approximately 321 lbs of nitrogen entered the treatment system on a daily basis. Of this amount, 36 pounds were captured in the solids fraction collected in the manure spreader from the inclined-screen separator. Another 57 lbs was present in the settled and floating solids in the settling tank. Thus a total of 93 pounds of nitrogen were removed from the system destined ultimately for the composting process. Another 228 lbs of nitrogen were contained in the supernatant from the settling tank. This nitrogen is returned to the flush tanks or is directed to the tertiary treatment system. As with the solids, nitrogen returned to the flush tanks may tend to accumulate in the system before reaching a steady-state condition in which the amount of nitrogen excreted by the pigs equals the amount of nitrogen leaving the system. Table 2 shows the fate of nitrogen as a percentage of the total amount of nitrogen entering the treatment system for different sampling dates throughout the sampling period.

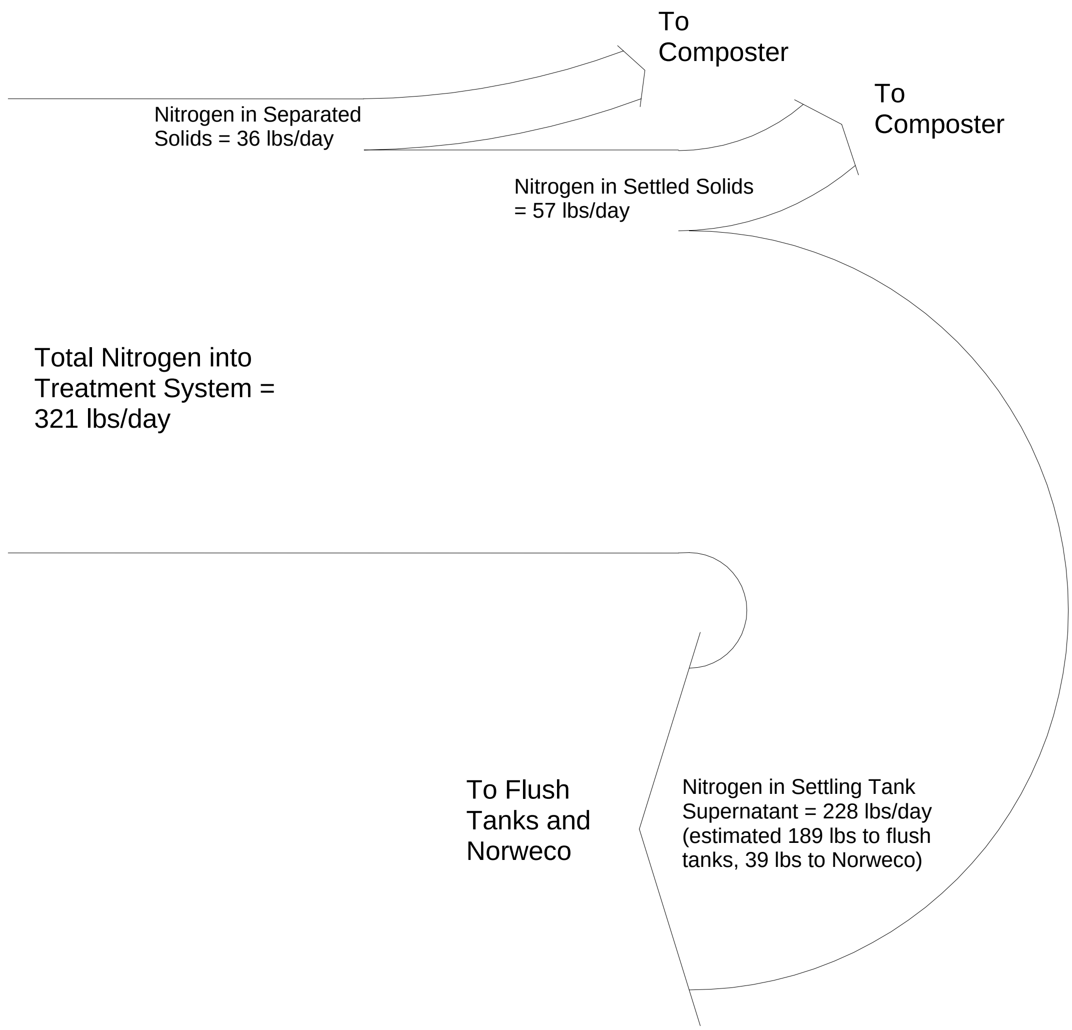

Figure 6. Fate of Nitrogen Entering the Closed-Loop Swine Waste Treatment System

Table 2 Fate of Nitrogen as a Percentage of Total Nitrogen Entering the Treatment System

Sample Description	4/28/05	5/12/05	6/10/05	7/18/05	Average
Nitrogen in Separated Solids (from inclined-screen separator)	7%	18%	54%	11%	**23%**
Nitrogen in Settled Solids to Composter	17%	15%	13%	16%	**15%**
Nitrogen in Supernatant to Flush Tanks	62%	54%	26%	59%	**50%**
Nitrogen in Supernatant to Norweco	12%	11%	5%	12%	**10%**
Nitrogen in Supernatant to Composter (floating debris)	2%	2%	1%	2%	**2%**
Nitrogen to Composter	26%	35%	69%	29%	**40%**
Nitrogen to Flush Tanks and Norweco	74%	65%	31%	71%	**60%**

The specific nitrogen compounds being returned to the hog barn are important in evaluating the impact of recycled flush water on hog barn air quality. For the settling tank supernatant, which is returned to the hog barn to be recycled as flush water, Table 3 lists the ammonia/ammonium nitrogen in ppm and as a percentage of total nitrogen (TKN) for different sampling dates.

Table 3. Ammonia/Ammonium Concentrations in Settling Tank Supernatant (recycled for use as flush water in hog barns)

Sampling Date	Ammonia/Ammonium Nitrogen, ppm	Ammonia/Ammonium Nitrogen, as a percentage of total nitrogen
4/28/05	3867	72%
5/12/05	1000	57%
6/10/05	286	80%
7/18/05	1147	48%

Figure 7 shows a flow representation through the system for phosphorous. On a daily basis, 124 lbs of phosphorous enter the treatment system. The inclined separator removes 21 lbs of phosphorous in the form of separated solids. Another 20 lbs of phosphorous is removed in the form of settled solids and floating debris. The balance of phosphorous, 83 lbs, is returned in the supernatant to the flush tanks, except for a small portion directed to the tertiary treatment system. Table 4 shows the fate of phosphorous as a percentage of the total amount of phosphorous entering the treatment system for different sampling dates throughout the sampling period.

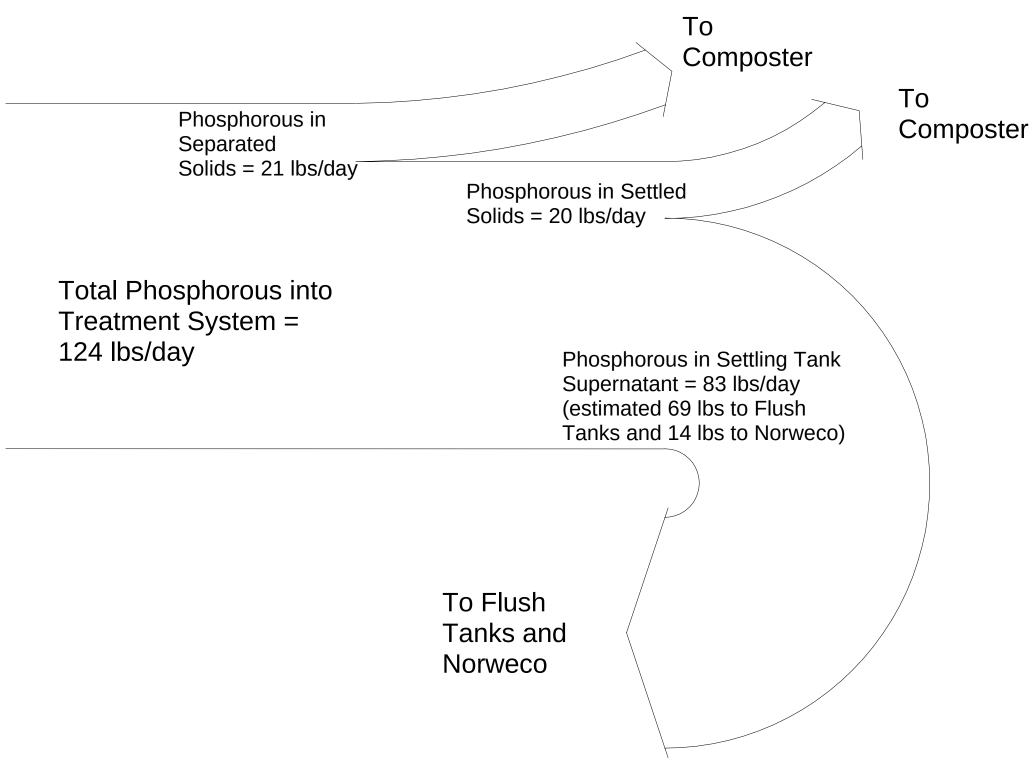

Figure 7. Fate of Phosphorous Entering the Closed-Loop Swine Waste Treatment System

Table 4. Fate of Phosphorous as a Percentage of Total Phosphorous Entering the Treatment System

Sample Description	4/28/05	5/12/05	6/10/05	7/18/05	Average
Phosphorous in Separated Solids (from inclined-screen separator)	19%	24%	77%	17%	**34%**
Phosphorous in Settled Solids to Composter	15%	14%	13%	14%	**14%**
Phosphorous in Supernatant to Flush Tanks	53%	50%	8%	56%	**42%**
Phosphorous in Supernatant to Norweco	11%	10%	2%	11%	**8%**
Phosphorous in Supernatant to Composter (floating debris)	2%	2%	0%	2%	**2%**
Phosphorous to Composter	36%	40%	90%	33%	**50%**
Phosphorous to Flush Tanks and Norweco	64%	60%	10%	67%	**50%**

Figure 8 is a flow diagram of copper through the treatment system during the intensive sampling period beginning on July 18, 2005. As can be seen from the diagram, only about one-third of the copper is captured by the treatment system. The remaining copper is returned to the system in the flush water or in the Norweco-treated water. Table 5 shows the fate of copper as a percentage of the total copper entering the treatment system for different sampling dates throughout the sampling period.

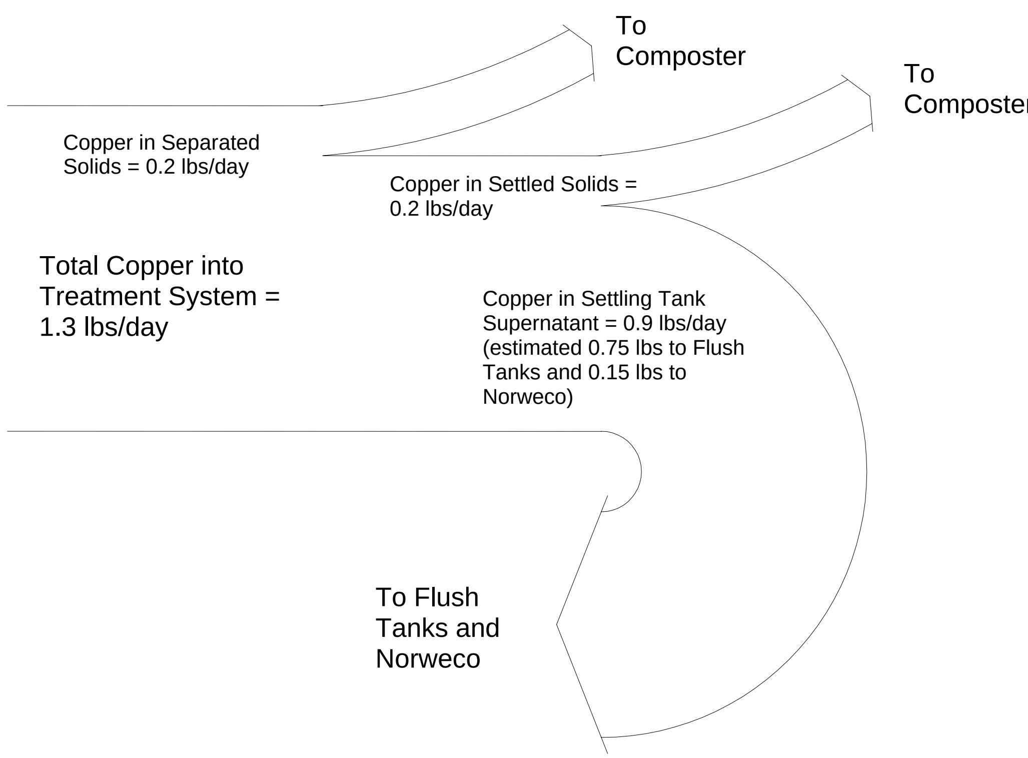

Figure 8. Fate of Copper Entering the Closed-Loop Swine Waste Treatment System

Table 5 Fate of Copper as a Percentage of Total Copper Entering the Treatment System

Sample Description	4/28/05	5/12/05	6/10/05	7/18/05	Average
Copper in Separated Solids (from inclined-screen separator)	21%	39%	77%	17%	**39%**
Copper in Settled Solids to Composter	16%	10%	15%	13%	**14%**
Copper in Supernatant to Flush Tanks	51%	41%	6%	56%	**38%**
Copper in Supernatant to Norweco	10%	8%	1%	11%	**8%**
Copper in Supernatant to Composter (floating debris)	2%	2%	0%	2%	**1%**
Copper to Composter	39%	51%	93%	32%	**54%**
Copper to Flush Tanks and Norweco	61%	49%	7%	68%	**46%**

Figure 9 is a flow diagram of zinc through the treatment system during the intensive sampling period beginning on July 18, 2005. As with copper, only about one-third of the zinc is captured by the treatment system. The remaining zinc is returned to the system in the flush water or in the Norweco-treated water. Table 6 shows the fate of zinc as a percentage of the total zinc entering the treatment system for different sampling dates throughout the sampling period.

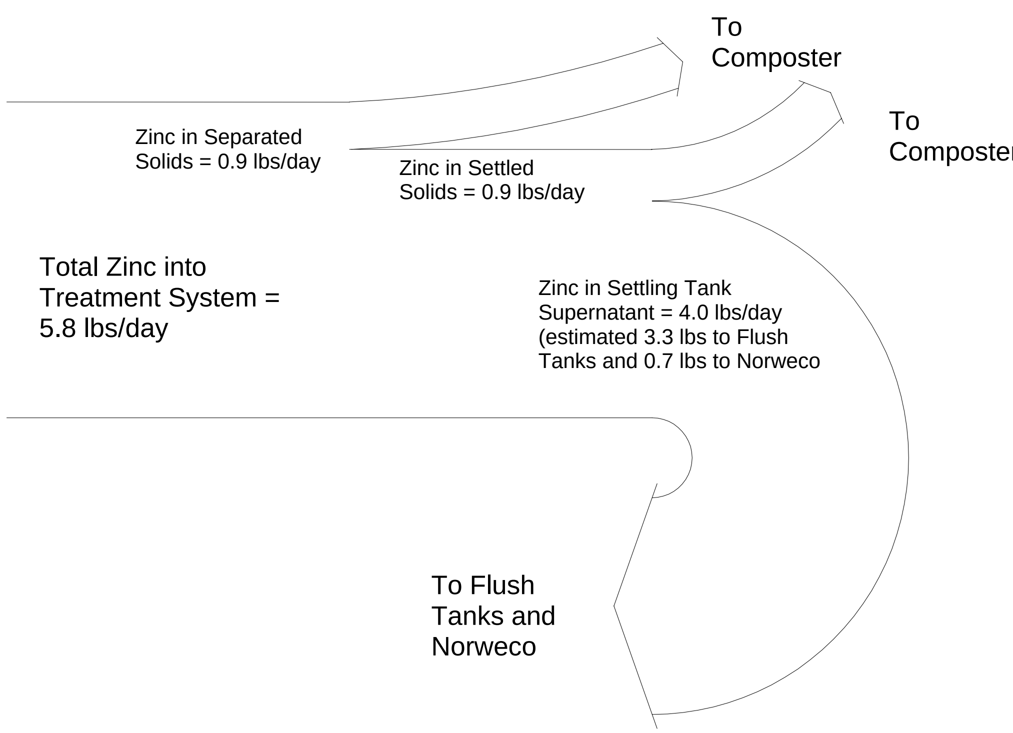

Figure 9. Fate of Zinc Entering the Closed-Loop Swine Waste Treatment System

Table 6. Fate of Zinc as a Percentage of Total Zinc Entering the Treatment System

Sample Description	4/28/05	5/12/05	6/10/05	7/18/05	Average
Zinc in Separated Solids (from inclined-screen separator)	18%	24%	78%	15%	**34%**
Zinc in Settled Solids to Composter	16%	15%	14%	14%	**15%**
Zinc in Supernatant to Flush Tanks	53%	50%	7%	57%	**42%**
Zinc in Supernatant to Norweco	11%	10%	1%	11%	**8%**
Zinc in Supernatant to Composter (floating debris)	2%	2%	0%	2%	**2%**
Zinc to Composter	37%	40%	92%	31%	**50%**
Zinc to Flush Tanks and Norweco	63%	60%	8%	69%	**50%**

An important component of the "closed-loop" swine waste treatment system is the tertiary treatment system (the Norweco) that allows re-use of the wastewater for hog drinking water. This system, housed in a concrete tank, consists of an aeration and filtering system. The supernatant from the settling tanks is directed to the Norweco once the flush tanks are full. As such, the amount of wastewater directed to the Norweco varies from cycle to cycle and depends to some extent on leakage from the flush tank seals and other factors. Therefore, the Norweco does not operate at steady-state, making its performance evaluation difficult. Another problem with evaluating the performance of the Norweco is that a mass balance could not be performed on this unit process. The levels of chlorine (and other highly soluble ions) in the supernatant from the settling tanks (the supernatant from the settling tanks is the wastewater stream that enters the Norweco), were much greater than the levels of chlorine in the treated water leaving the Norweco for all sampling dates. The aeration and filtration processes incorporated into the Norweco should not have any impact on chlorine levels. The chlorine is very soluble and is not subject to chelation, precipitation, adsorption or uptake by microbes that would impact its concentration. Thus the chlorine in the influent to the Norweco should be comparable to the chlorine in the treated effluent. The differences between the influent and effluent chlorine levels make it impossible to confidently calculate a mass balance on the Norweco system. Therefore, no conclusions can be drawn with regard to the fate of solids, nitrogen, phosphorous, zinc and copper in the Norweco system.

The composter was added to the overall system towards the end of the intense two-week sampling period beginning July 18, 2005. The composter, therefore, did not reach steady-state operation prior to the end of the sampling period. The composting operation is a completely separate operation that in Environmental Technology's business model would be a central facility taking waste from separate farms. It is expected that the fate of solids, nitrogen, phosphorous, copper and zinc in this composter would be similar to that in other composting operations. Thus information on the fate of these compounds in other composting operations could be used in making the determination of "Environmentally Superior Technology" for this unit process separately from the rest of the system.

An "Environmentally Superior Technology" should not create new environmental concerns, so a preliminary evaluation of chemicals used in this waste treatment technology was conducted to determine if they could become a threat to the environment. Two key chemicals are used in the treatment process, a proprietary flocculating agent consisting of a cationic polymer, and a sanitizing/disinfecting chemical, trichloromelamine. A Material Safety Data Sheet was obtained for the cationic polymer solution, and a preliminary evaluation indicates that this is a relatively safe chemical from the standpoint of flammability, toxicity, carcinogenicity, and corrosivity. The sanitizer/disinfectant, trichloromelamine, is apparently used widely by the U.S. army as a fruit/vegetable wash. It is also used as a sanitizer in "third-sink" applications in bars and restaurants. An exhaustive evaluation of the use of these two chemicals is beyond the scope of this study, but this cursory examination of the chemicals used in the process indicates no obvious environmental concerns.

Observations and Recommendations

With regard to the performance evaluation, as it relates to the fate of solids, nitrogen, phosphorous, copper and zinc, the following observations and recommendations are offered:

- As discussed above, an evaluation of the tertiary treatment unit process (the Norweco) could not be conducted because of inexplicable differences in the concentration of highly soluble ions in the effluent from the Norweco as compared to the inffluent. The plan for determining the ratio of Norweco effluent to well water to make hog drinking water was to use the concentrations of highly soluble ions in the treated wastewater, well water, and hog drinking water. The concentration of highly soluble ions in the hog drinking water is directly related to the ratio of Norweco effluent to well water. Unfortunately, because of the lack of confidence in the treated Norweco effluent concentrations, this ratio could not be calculated. The inability to calculate this ratio has ramifications for evaluating whether the overall system can be operated in a closed-loop fashion. If the amount of well water used to dilute the Norweco effluent exceeds the amount of water removed from the system in the form of separated solids, settled solids and evaporation, then the system will not be able to operate in a closed-loop fashion. This "excess water" would appear as supernatant from the settling tanks that exceeds the amount of supernatant required for use as flush water and for use as a component of hog drinking water. It would need to be stored and/or treated in an environmentally sound manner. Guidelines for drinking water for pigs have not been well established. The water quality target for pig drinking water will impact the necessary degree of dilution with well water, which in turn will affect the amount of excess water entering the system, as discussed above.

- While significant quantities of solids, nutrients and metals are removed from the system in the separated solids and settled solids fractions, substantial amounts of these materials remain in the supernatant from the settling tanks and are returned to the hog barns in the form of flush water. If the return of these materials interferes with long-term operation of the flushing or treatment systems, occasional diversion of the contents of the treatment system and introduction of fresh water into the flushing system may be required. As with the issue of "excess water" described above, the diverted contents from the treatment system would have to be stored and/or treated in an environmentally acceptable manner.

- No obvious environmental concerns arise from the utilization of the two key chemicals in this waste treatment technology, the proprietary cationic polymer and the sanitizer/disinfectant (trichloromelamine)

- A complete evaluation of the impacts on hog health of utilizing treated wastewater for drinking water is beyond the scope of this study.

References

1. Agreements between Attorney General of North Carolina and, Smithfield Foods, Premium Standard Farms, and Frontline Farmers (North Carolina Department of Justice, on file with Ryke Longest, 2000 & 2002). Also available: www.cals.ncsu.edu/waste_mgt/T