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Evaluation of Generation 3 Treatment Technology for Swine Waste - A North Carolina's Clean Water Management Trust Fund project

FINAL TECHNICAL ENVIRONMENTAL PERFORMANCE REPORT

Prepared for: Mike Williams, Director,
NCSU Animal and Poultry Waste Management Center

Prepared by:
Matias Vanotti, Patrick Hunt, Mark Rice, Airton Kunz and John Loughrin

Project Title:

Evaluation of Generation 3 Treatment Technology for Swine Waste - A North Carolina's Clean Water Management Trust Fund project.

Project Reference:

The sponsor of this demonstration project is North Carolina's Clean Water Management Trust Fund project (CWMTF), Project 2006A-522: "WW/Alternative Swine Waste System, cape Fear Tributary" – awarded to NC State University, Project PI: Mike Williams, Ph.D., Director, NC State University Animal and Poultry Waste Management Center.

Investigators Contributing to Technical Environmental Performance Report, e-mail and address:

- Matias Vanotti, Ph.D.
  USDA-ARS Coastal Plains Soil, Water and Plant Research Center
  2611 W. Lucas Street, Florence, South Carolina 29501
  Tel. 843-669-5203 ext 108
  Matias.Vanotti@ars.usda.gov

- Patrick Hunt, Ph.D., USDA-ARS, Coastal Plains Soil, Water and Plant Research Center, Florence, South Carolina. Patrick.Hunt@ars.usda.gov

- Mark Rice, North Carolina State University, Dept. Biological And Agricultural Engineering, Raleigh, NC mark_rice@ncsu.edu

- Airton Kunz, Ph.D., Embrapa Swine and Poultry, Brazil (Visiting Scientist at USDA-ARS Florence, SC during evaluation) airton.kunz@embrapa.br

- John Loughrin, Ph.D., USDA-ARS, Animal Waste Management Research Unit, Bowling Green, Kentucky. jloughrin@ars.usda.gov

Field Monitoring: William Brigman and Ray Winans, USDA-ARS, Florence, SC
Laboratory Analyses: Chris Brown, USDA-ARS, Florence, SC

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Revised 8/8/2013 after External Reviewer (3) comments. Data for N removal system during winter weather were added. Production records for a second batch of pigs were also added.

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Executive Summary

This project evaluated and demonstrated the viability of a third generation manure treatment technology. The technology was developed as an alternative to the lagoon/spray field system typically used to treat the wastewater generated by swine farms in North Carolina. The technology does the following: 1) it separates solids and liquids with the aid of settling and polymer flocculants; 2) it biologically removes the ammonia nitrogen with bacteria adapted to high-strength wastewater; 3) it removes phosphorus via alkali precipitation; and 4) it substantially eliminates release into the environment of odors, pathogens, ammonia and heavy metals. The third generation was designed to further reduce cost of manure treatment by economies of scale from installation in larger farms, and through pre-concentration of diluted manure before polymer application. The technology was installed and tested full-scale on a 2,575,444 lbs. steady state live weight (SSLW) Farrow-to-Finish farm that produced approximately 30,450 hogs per year in Wayne County, North Carolina. The system treated the waste stream from two operations: a 1,200-sow Farrow-to-Feeder operation that used flushing system and generated 27,140 gal of manure per day, and a 12,960 Feeder-to-Finish operation that used pit recharge system and generated 48,388 gal of manure per day. The treatment system was contained in tanks and replaced two anaerobic lagoons. Objectives were the evaluation of technical and operational feasibility and environmental performance standards related to the elimination of discharge of animal waste into waters and the reduction of ammonia, phosphorus, odors, pathogens and heavy metals in the treated effluent. Additional objectives were to assess benefits of decanting tank that pre-concentrated the flushed manure from the sow farm. The system was evaluated for 12 weeks under steady-state conditions. Major goals in the demonstration and performance verification of the third generation alternative treatment system for swine manure were achieved. These include highly efficient treatment performance with both high hydraulic loads typical of flushing systems and high strength wastewater typical of the pit-recharge systems. Implementation of the decanting tank in the flushing waste stream reduced the total manure volume processed by the solid separator press by 25,860 gal/day and increased polymer use efficiency 5.4 times. This lower volume is one of the major advances of this project; system efficiency was significantly improved and operating expenses significantly lowered. The treatment system removed 98.6% of the total suspended solids, 98.1% of the COD, 99.3% of the TKN, 100% of ammonia, 91.95% of total phosphorus, 95.4% of copper, and 97.0% of zinc. The treatment system removed 100% of odor compounds in the liquid including skatole and volatile fatty acids. The system can meet 15A NCAC 02T.1307 performance standard for pathogens in effluent (Fecal coliforms < 7,000 MPN/100 mL) when the process pH in phosphorus module is adjusted to 10. The major goals in the demonstration and verification of a third-generation wastewater treatment system for swine manure were achieved. These goals included replacement of anaerobic lagoon treatment, adaptation of the system to receive higher volume of liquid waste typical of flushing systems, and efficient environmental performance when installed in larger swine farms. The confidence in the technical and environmental achievements by this project is high.

Technology Name and Description: Generation 3 Terra Blue Technology

The on-farm system used solid-liquid separation, biological nitrogen removal, and disinfection and phosphorus removal unit processes linked together into a practical system for livestock operations (Figure 1). The system used polymer flocculation to increase the efficiency of solid-liquid separation of the suspended solids. In the third generation, the system was adapted to flushing systems that contained much diluted manure. This adaptation used a decanting tank, which concentrated the solids before polymer application, thus reducing separation equipment needs. Nitrogen management to eliminate ammonia emissions was accomplished as before by passing the liquid through a biological module containing high performance nitrification bacteria (HPNS) adapted to high-ammonia wastewater and low-temperature. A phosphorus removal module was also used to precipitate phosphate and disinfect the effluent. The phosphorus precipitate was simultaneously separated with the manure. The system recycled clean water to flush the barns (Figure 2). The phosphorus treated water was stored in the former lagoon and used for crop irrigation. The solids were removed from the farm and used for the manufacture of value-added products.

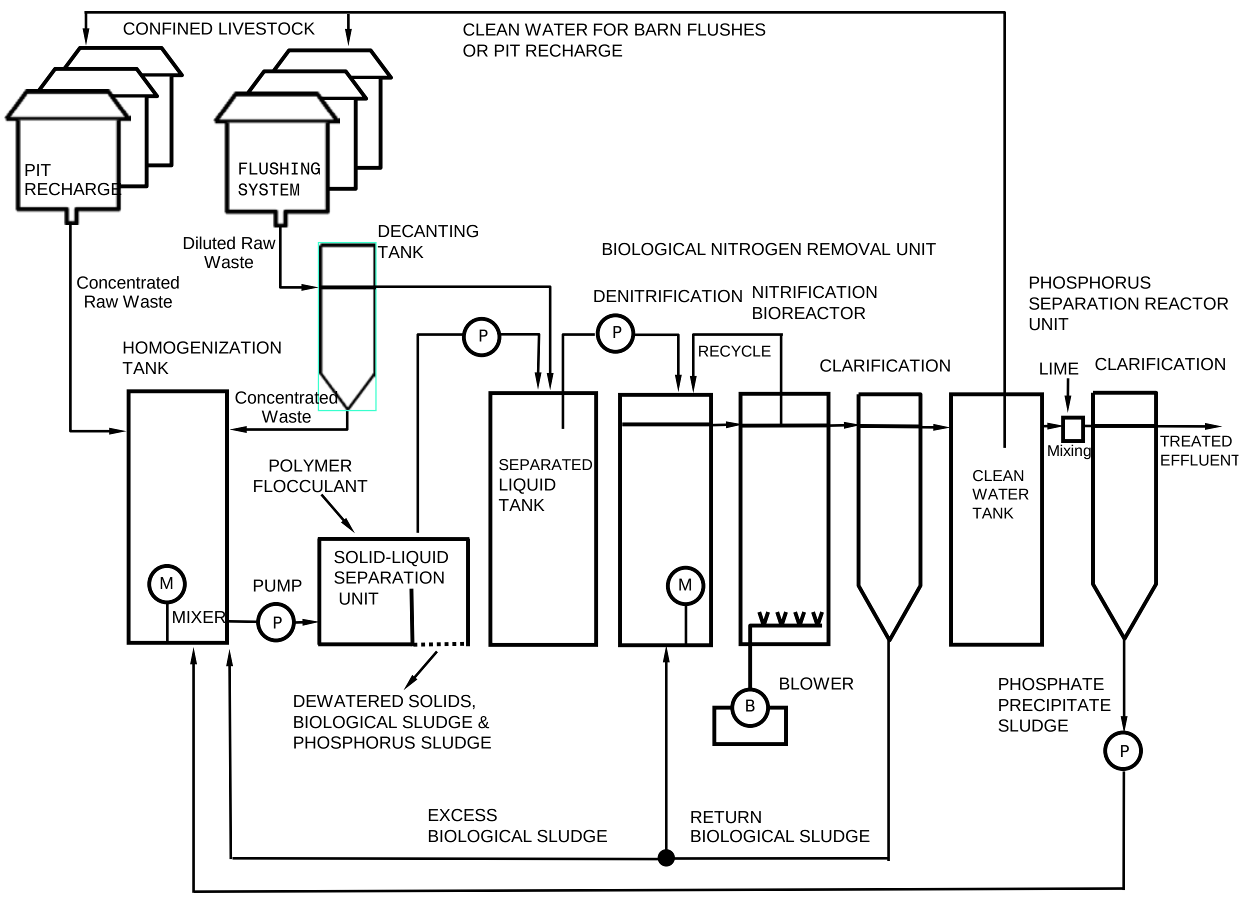


Figure 1. Schematic of the Terra Blue swine waste treatment technology using solids separation, nitrification-denitrification, soluble phosphorus removal/disinfection (Vanotti et al., 2010). Decanting tank was added in this project to the flushing system waste stream.

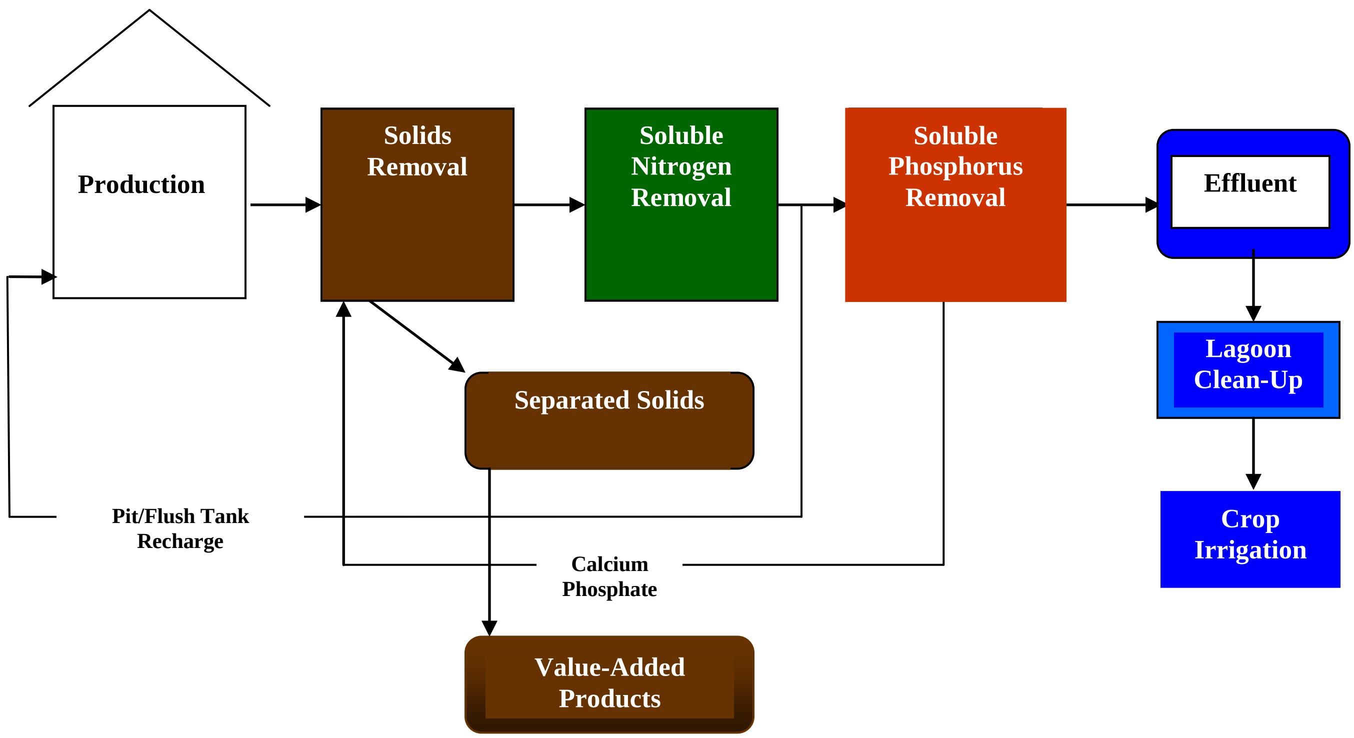


Figure 2. Schematic of the Terra Blue swine waste treatment technology. N treated water is re-used to recharge barn pits or fill the flush tanks.

Technology Provider: Terra Blue, Inc

484 Hickory Grove Rd
Clinton, NC 28328
Telephone 910-564-5545

Dr. C. Ray Campbell, Executive Vice President - Research & Development
crcampb@bellsouth.net
Telephone 919- 612-8737

Mr. B. Kyle Held, Interim President
kyle.held@skybounddesigns.com
Telephone 910-990-7776

Swine Producer and Farm

Mr. Doug Jernigan
Jernigan Farms
781 Thunder Swamp Road
Mount Olive, NC 28365

Background:

This project evaluated the viability of a third generation version of a manure treatment technology developed as an alternative to the lagoon/spray field system typically used to treat the wastewater generated by swine farms in North Carolina (Figure 2). It separates solids and liquids with the aid of polymer flocculants; removes the ammonia nitrogen biologically with acclimated bacteria; removes phosphorus; and substantially eliminate release of pathogens, odors, ammonia and heavy metals into the environment. The first generation met the technical and operational feasibility standards of an Environmental Superior Technology (Williams, 2004) (Note: the technology provider, Super Soil Systems USA, was renamed Terra Blue Inc. in 2010). The second generation technology achieved efficient technical (environmental) performance at reduced costs [$132.24/1000 lbs. steady state live weight (SSLW)/year] compared to the first generation system ($399.71/1000 lbs SSLW/year) (Williams, 2007). These cost reductions supported Williams (2007) conclusions that "the optimal method of achieving net cost reductions from alternative technologies is to install targeted technologies on a sufficient number of farms to facilitate engineering improvements, value-added product market development, and other cost reduction methods." The third generation was designed to further reduce costs of treatment by: 1) Economies of scale from installation of the same system in a larger swine farm; and 2) Adaptation to flushing systems by concentrating the diluted manure with rapid settling and applying polymer only to the settled solids. The performance verification of Gen 3 was done in a larger swine operation at full-scale under steady-state operational conditions.

First Generation Technology

The first generation technology was demonstrated by Terra Blue Inc. (previously Super Soil Systems USA) at full-scale at Goshen Ridge farm, a 4,360-head finishing farm in Duplin County, NC, that used pit-recharge (Vanotti et al., 2007). The system, which combined solids separation, nitrification/denitrification and phosphorus removal, received US Patent (6,893,567 B1, 2005). The on-farm technology met the environmental performance criteria of an EST (Williams, 2004).

Second Generation Technology

The second generation was demonstrated by Terra Blue Inc. (previously Super Soil Systems USA) at full-scale in B&B Tyndall farm, a 5,145-head finishing farm located in Sampson County, NC, that used pit-recharge (Williams, 2007; Vanotti et al., 2009). The second generation incorporated two new inventions that significantly lowered capital, maintenance and operating costs of the Terra Blue system: 1) US Patent 7,674,379 B2 (2010) "Wastewater treatment system with simultaneous separation of phosphorus and manure solids", and 2) US Patent 8,445,253 B2 (2013) "High performance nitrifying sludge (HPNS) for high ammonium concentration and low temperature wastewater treatment". The system met unconditional EST status when implemented in new farms (combined with an unconditional EST for solids treatment), but at that time it did not meet economic feasibility conditions as required for unconditional EST to be implemented onto existing farm categories in North Carolina (Williams, 2007).

Gen 3 System Description

Swine farm characteristics: The waste treatment system was designed and constructed by Terra Blue Inc. and installed at Jernigan farm near Mount Olive in Wayne County, NC. The system evaluated provided treatment to all the manure generated by both a farrow-to-feeder operation (Sow farm B) with 1,200 sows, and a finishing operation (feeder-to-finish) with 12,960 heads (Figure 3). This was a complete farrow-to-finish operation: all the feeders produced in Sow farm B were moved into the finishing operation and finished in 21 weeks. Once the treatment plant was fully operational, it replaced the lagoon treatment. The system used three process units (Figure 2) and incorporated the three US Patents referenced above.

The finishing operation used pit-recharge system (Barker, 1996a) that evacuates manure from the barn once per week; it was also used at Goshen Ridge and Tyndall farms during testing of the first- and second-generation. The Sow farm B used flushing system (Barker, 1996b) that used flush tanks to evacuate manure form the barn several times per day producing much diluted manure. This configuration was not tested with the Terra Blue system before.

Before conversion, lagoon liquid (with 433 ± 146 mg NH_4-N/L) was used to recharge the pits (finishers) and fill the flush tanks (sow farm). After conversion, the N treated water (with 14 ± 26 mg NH_4-N/L) replaced lagoon water to recharge the pits and fill the flush tanks; it was stored in the clean water storage tank (Figure 4).

Figure 3. Terra Blue Gen 3 wastewater treatment system (tanks in center) that replaced the lagoon treatment at Jernigan farm. The system provided treatment to all the manure from a 1200-sow (farrow to feeder) farm (three barns shown at right) with flushing system, and a 12,960-head feeder to finish farm (four and a half "quad" barns shown at left) with pit-recharge system. Photo source: Flashearth.com.

Solids separation: The liquid manure from the finishing operation was diverted weekly Monday to Friday (one barn per day) into a 204,000 gal, 14.9-ft height homogenization tank (Figure 4). The main lift station serving the finish farm was 8-ft diam. x 16-ft depth tank with two 7.5-HP pumps with capacity of 300 gpm each. The manure collected in the homogenization tank was kept well mixed using two submersible mixers (6.2-HP ABS).

The manure from the Sow farm (B) operation was flushed about twice per day from three barns. Barn 1 (breeding) and barn 2 (gestation) had one flush tank each of 1500 gal capacity; barn 3 (farrow/nursery) had five flush tanks of 1000 gal capacity each. The lift station serving the sow farm was an 8 x 16-ft tank, 8-ft deep powered by a 2-HP pump with a 150-gpm capacity. The flushed manure was lifted into a decant tank (11-ft dia. x 19.9-ft height) with an effective volume of 10,000 gal. The settled manure solids in the decant tank were transferred into the homogenization tank about once every two days (bottom 2,500 gal per transfer). The decant tank supernatant flowed by gravity into the separated water tank.

The manure contained in the homogenization tank (all manure received from the finishing farm plus manure from the sow farm that was pre-concentrated in the decanting tank) received solid-liquid separation with flocculants. The separation process used polymer flocculants as described in previous reports to enhance separation of fine suspended particles typical of swine manure. Solids were separated using a four-channel Fournier rotary press separator (Model 4 900/4000 CV) with dewatering area of 43.1 ft^2 and 5-HP motor. The separator module was enclosed in a metal building and included a polymer preparation tank (120 gal), a 1,200 gal polymer activation tank, a polymer metering pump, a sludge feed pump, in-line flocculator, and cake chutes and sensors for the solids. The installed capacity of the four channel rotary press was 100-150 gal/min. The polymer solution was prepared using 2 g polymer/L (0.2%) and mixed with the manure at a 7% rate (9 gal/min of polymer solution mixed with 132 gal/min of manure). This results in a final polymer dosage of about 141 mg/L. The separated manure solids were transported off-site to a centralized solids processing facility and converted to organic-based plant fertilizer, soil amendments, and plant growth media as described in the EST evaluation report of the solids processing Vanotti (2005).

Nitrogen module: Separated liquid from both the rotary press and the decanting tank were temporarily stored in the "separated water tank" that had the same size as the homogenization tank, and further treated continuously in the second process unit using nitrification – denitrification (NDN) to remove the ammonia. A pump with a capacity of 130 gal/min was used to feed the NDN process. The nitrification and denitrification tanks in the N removal module had an effective volume of 256,000 gal each (56-ft diam. x 14.9-ft height). To start the process, the nitrification tank was inoculated with 1-L of the high-performance nitrifying sludge bacteria (HPNS) developed by USDA-ARS for high ammonium concentration and low temperature wastewater treatment. The HPNS provides very-high nitrification rates at low temperatures: 0.45 and 0.81 kg N/m^3-tank/day at water temperatures of 5^{o}C and 10^{o}C, respectively (US Patent 8,445,253 B2, May 11, 2013). In wastewater industry, sludge settling and compaction characteristics are rated as "excellent" when sludge volume index (SVI) is < 80 ml/g and "moderate" for SVI of 80-150. The HPNS has a sludge volume index (SVI) of 62 ml/g. Air was provided continuously to the nitrification tank with two blowers

(25-HP each with 832 cfm), and 416 fine-air disc (12”) diffusers. Nitrification transformed NH_4-N into NO_3-N and NO_2-N. A pre-denitrification configuration transformed NO_3-N into N_2 gas where nitrified wastewater was continually recycled to anoxic denitrification tank. In this tank, suspended denitrifying bacteria used soluble manure carbon contained in the separated liquid to remove the NO_3^-. The microbial sludge was suspended with two submersible mixers (6.2-HP ABS). A settling tank with cone bottom (22-ft diam. x 15.25-ft height) and 36,000 gal capacity as used to clarify the N effluent and to return the suspended bacteria into the N tanks. The rates of nitrified liquid recycle and sludge recycle into the DN tank were about 3 and 0.5 times the inflow rate, respectively. The clarified effluent was stored in a clean water storage tank (203,000 gal, 50-ft diam.) and used to refill the barn pits and flush tanks in the production barns.

Phosphorus module: The third process unit was used to recover soluble phosphorus as calcium phosphate solid and reduce pathogens by the alkaline environment (Vanotti et al., 2012). The effluent from the biological N treatment was treated with hydrated lime in an 80 gal reaction chamber. The pH of the process was controlled using a pH probe and GLI 52 controller linked to the lime injection pump. The reaction produced calcium phosphate precipitate, which was separated in a settling tank of equal size than the N settling tank. The P precipitate was further dewatered using the solid-liquid separation unit in the front of the plant and combined with the manure solids that left the farm (Figure 1).

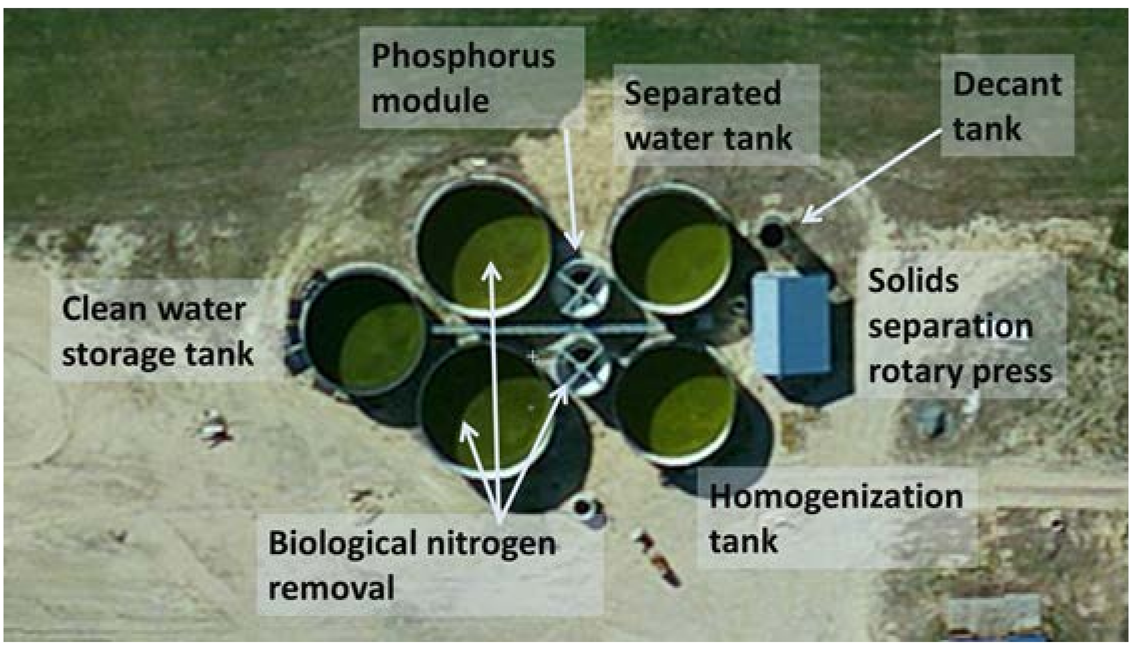


Figure 4. Detail of Terra Blue Gen 3 wastewater treatment system installed at Jernigan farm.

How the treatment tanks are named by Terra Blue:

- Homogenization Tank: contained manure from pit-recharge barns and settled solids from decant tank, before solids-liquid separation with polymer and rotary press.
- Decant Tank: provided rapid settling to flushed manure from sow farm (flushing system)
- Separated Water Tank: contained separated liquid (both rotary press and decanting)
- Nitrification and Denitrification tanks: performed the biological N removal process

- Clean Water Tank: stored liquid after N treatment for recycle (flushing the barns and recharging the pits under the barns).
- Plant effluent: is the final effluent after treatment in the phosphorus module. This effluent was stored in the former lagoon and land applied.

Design Considerations

The installed system was designed to treat the manure from three units in the same farm: the finishing operation (12,960 head feeder to finish), Sow farm A (across Thunder Swamp road) with 1085 sows (farrow-to-feeder), and Sow farm B with 1200 sows (farrow-to-feeder) that is also shown in Figure 3. This is the system that was permitted by NC Department of Environment and Natural Resources, NCDENR (Innovative Animal Waste Treatment System Permit No. AWI960127, Jernigan Farms, issued Nov. 25, 2009). Although Sow farm A (considered for Phase II of Permit implementation) was not connected into the system during this evaluation, its manure was considered in the design of the system installed.

Design of the new system considered expected manure generation volumes and nutrient loads. For the finishing operation, the expected loads were based on maximum generation volume and nutrient loads previously obtained in the 2nd Generation Terra Blue system tested at Tyndall farm (finishing operation with pit-recharge system). After 15 months testing at full-scale in that project (5145 pig feeder-to-finish operation with 694,575 lbs. SSLW), the maximum monthly manure generation obtained was 14,870 gal/day (2.88 gal/hog/day or 21.4 gal/1000 lbs. SSLW/d (Fig. 2 of Vanotti et al., 2009). Thus, the wastewater volume used for design was 2.88 gal/hog and 20% refill (Table 1). For the Sow farms, a value of 4.84 gal/sow/day was used to predict new manure generated, and existing flush tanks at the farm and flushing practices were used to estimate total volume into the new plant. The farrow/nursery barn in Sow farm B was going to be transformed into pit-recharge but it did not happen during evaluation.

Separators, homogenization tanks and storage tanks in the plant were sized by the company to process at least 85,000 gal/day of liquid manure with the rotary press with a predicted flow rate of 80 gal/min and to provide more than 44,000 gal/day of clean water to flush/refill the production barns (Table 1). Accordingly, the separator selected (4 heads, 20 gal/min/head) was going to be operated 17.7 hours/day, 7 days/week. <u>This sizing and operational schedule did not consider the lower volumes resulting from decanting tank.</u>

Table 1. Wastewater volumes projected for Jernigan farm used to design solid separator equipment and clean water tank

	Production units	New manure generated (gal/day)	Clean water required for pit refill or flushing (gal/day)	Wastewater volume to be processed by new plant (gal/day)
Finishing operation	12,960 hogs	29,860	7,465	37,325
Sow farm A	1,085 sows	5,251	24,000	29,251
Sow farm B	1,200 sows	5,808	12,938	18,746
Total		**40,919**	**44,403**	**85,322**

For sizing the nitrification tank, it was projected that Sow farms A and B (2,285 sows) would be equivalent to 8,830 finishing pigs (by animal weight (SSLW), 522 lbs./sow vs. 135 lbs./finishing pig). Therefore, the biological N removal system in this project was designed to treat polymer separated wastewater equivalent from about 21,790 finishing pigs (12,960 + 8,830). This number was 4.2 times greater than the 2nd Generation project that had a capacity to treat peak monthly loads of about 159 lbs. of ammonia-N/day (72 kg N/day) in winter from 5,145 finishing pigs using HPNS in a 60,000 gal nitrification tank. Thus, the nitrification tank size installed in the new project was 4.2 times larger (254,000 gal tank), and other design components like air supply and diffusers were adjusted proportionally. The exception was the size of the denitrification tank that was reduced 20% in relative size from previous project.

The incorporation of an experimental small decanting tank (11,000 gal) was proposed by Vanotti for this project to improve system efficiency by reducing liquid volume load into the rotary press separator from the sow farms that used flushing systems and large amounts of water (Figure 1). The decanting tank size was designed to handle the flushes from Sow farm B during Phase One of the project, based on results of previous research using rapid (60 min) gravity settling of flushed swine manure (Chastain and Vanotti, 2003).

Objectives:

Our objectives were to: 1) assist company with the start-up of the new system in this large operation to achieve steady state conditions; 2) to assess in more detail the benefits of using a decanting tank before polymer separation in operations with flushing systems; and 3) to provide environmental performance evaluation of the 3rd Generation wastewater treatment technology in terms of ammonia, phosphorus, odors, pathogens, and heavy metals.

The environmental performance verification of the 3nd generation wastewater treatment facility was completed, and it is summarized in this report for Dr. Mike Williams, PI, North Carolina's Clean Water Management Trust Fund project (CWMTF), Project 2006A-522: “WW/Alternative Swine Waste System, cape Fear Tributary”.

Picture shows view of plant at ground level. Cone bottom tanks are settling tanks used in nitrogen (left) and phosphorus (right) modules.

<u>Results</u>:

1. Permitting

Permit No. AWI960127N was issued Nov. 25, 2009, by NC Department of Environment and Natural Resources (NCDENR) authorizing the construction and operation of an Innovative Animal Waste Treatment System for the Jernigan Farms located in Wayne County, NC. The approval consisted of a two-stage implementation of the Terra Blue technology to replace the lagoon treatment. When fully implemented, the system serves the entire waste stream from 2,285 Farrow to Feeder and 12,960 Feeder to Finish swine operation. Phase One included construction of the total treatment system and implementation for the 12,960 Feeder to Finish swine and 1200 Farrow to Feeder swine (Sow farm B). Phase Two included merging the remaining 1,085 Farrow to Feeder swine waste stream into the Innovative Animal Waste Treatment System contingent upon analyses of Phase One performance (this reporting) and Division approval.

2. Construction

Construction and installation of the wastewater treatment facility was started in 2010. The tanks, pumps and blower were ready April 1, 2012. At this date the biological system was started. The solid-separation facility started receiving and treating waste from the finishing operation on May 31, 2012. During the period June-July 2012, Sow farm B used the clean treated water produced by the system to flush the three barns, but the flushed manure went into the lagoon. Incorporation of this additional waste (from Sow farm B) into the system (decanting tank, connection pipelines and additional lift station) started August 1, 2012 (barns 1 and 2) and was completed September 15, 2012 (barn 3).

3. Sample collection, analytical methods, and monitoring

Liquid samples were collected weekly from 1) the manure in the homogenization tank, 2) the effluent of the decanting tank, 3) the effluent of the separated water tank, 4) the effluent in the clean water tank after nitrification-denitrification treatment, and 5) the effluent after the phosphorus removal treatment. Grab samples were also taken weekly at intermediate points of the nitrogen system to check mixed liquor suspended solids. Liquid samples were transported on ice to the ARS Florence laboratory for analyses. For the separated solids, manure was placed in calibrated 5-gal. buckets and weighed at the farm for calculation of the bulk density of the solids used together with farm solid's removed records for solids production determinations.

Wastewater analyses were performed according to Standard Methods for the Examination of Water and Wastewater (APHA, AWWA & WEF, 1998), as described in the second generation report (Vanotti and Szogi, 2007). Solids analyses of the treated and untreated liquid samples included total solids (TS), total suspended solids (TSS), and volatile suspended solids (VSS). Total solids are TSS plus soluble solids. Chemical analyses consisted of pH, chemical oxygen demand (COD), 5-d biochemical oxygen demand (BOD_5), ammonia-N (NH_3-N), total Kjeldahl N (TKN), orthophosphate-P (PO_4), and total P (TP), nitrite (NO_2-N) and nitrate (NO_3-N) referred in the report as oxidized N or NO_x-N. TKN includes organic N and ammonia-N. TN is the sum of TKN and NO_x-N. Alkalinity was determined by acid titration to the bromocresol green endpoint (pH=4.5) and expressed as mg $CaCO_3$ L^{-1}. Cu, Zn, S, and K were measured in acid digestion extracts using inductively coupled plasma (ICP) analysis. Microelements and P in the solids were measured by ICP analysis after acid digestion. Carbon and N contents in the solids were determined using a dry combustion analyzer.

In this evaluation, we provided tests kits and a laboratory cart to measure on-site the concentration of alkalinity (Hach Company, Loveland, CO), ammonium and nitrite (Quantofix, Macherey-Nagel, Germany) in the nitrogen module (nitrification and denitrification effluent). This provided instant feed-back of process performance. The ammonia data was calibrated with corresponding laboratory determinations using Standard Methods (APHA, 1998) showing good correlation (r=0.97).

Odor analyses determinations were done on liquid samples collected during September and October, 2012 (n = 4) at the five sample locations. Liquid samples were analyzed in the laboratory of Dr. John Loughrin in Bowling Green, KY using the odorant extraction and chromatographic method (Loughrin et al., 2009) that was also used for the second-generation evaluation. The method determined concentration of malodorous compounds (Skatole, Phenol, p-Cresol, p-Ethylphenol and Indole) and volatile fatty acids (acetate, propionate and iso-butyric) contained in the liquid manure as it passed through the treatment system. Microbiological analyses of liquid samples from influent and effluent were done by NCSU and private laboratories using the standard protocols for pathogens and indicator microbes for the examination of wastewater.

Volume flows of manure into the treatment system were measured hourly using Doppler flow meters that measured: 1) volumes of manure from the finishing operation into the homogenization tank, and 2) volumes of manure from the sow farm B into the decant tank. These flow meter readings were calibrated using liquid-level ultrasonic probes (SR50 Sonic Ranging Sensor, Campbell Scientific Inc., Logan, UT) placed on top of the homogenization tank, decanting tank, and separated water tank that provided actual volume dynamics based on liquid height and area of the tank. Additional level sensors were placed in the clean water tank and settling tanks. This allowed calculations of manure flushes, separation activity and flow rates, decant tank activity, and sludge wasting. We also monitored air and water temperatures, precipitation, and DO and pH in the nitrification tank. Process data were retrieved from the Florence, SC laboratory using internet and cell phones connected to the field devices, or during weekly visits to the site. Manure volume data processed by the press separator was taken from the flow meter that was installed with the separator and used for separation process control.

Picture at left shows box containing data-logger used to monitor plant liquid levels, temperatures, rain, pH and DO. Picture at right shows evaluation team member downloading data from a Doppler flow meter during weekly visits.

4. Technology Verification Conditions

4.1 Timeframe

Performance verification started August 1, 2012, when the decant tank was brought in-line and the system started receiving manure from Sow Farm B (Figure 5). At that time, the system had been treating all the manure from the finishing barns for the previous two months. The system was evaluated intensively for 84 days (ending 10/23/2012) receiving waste from both farms (Sow farm B and Finishing farm). Additional samples were taken in November 2012 for microbial testing. On-site measurements of ammonia in the nitrogen tanks extending through February 2013 have been included to document cold weather performance.

The start-up of the biological N removal system was done during April, 2012 with goals of having the biology ready in about 30 days. The nitrification tank was both filled with lagoon wastewater that was rich in ammonia and inoculated April 11 with 1-L nitrification sludge HPNS. The tank was recharged with more lagoon liquid using four consecutive batches, as ammonia was consumed, and the nitrification activity increased. With the bacteria fully activated, the N module was put into continuous flow in May 5, 2012 and circulation between nitrification and denitrification tanks started. The continuous treatment first used lagoon liquid, then it was switched to separated liquid May 31, 2012, when the solids separator press module was started.

4.2 Weather and conditions

Monthly air and water temperatures and precipitation monitored at the farm are provided in Table 2. Also shown in Table 2 are dissolved oxygen and pH in nitrification tank that were also monitored continuously.

Table 2. Monthly averages of air temperature (average, Max, Min), water temperature in nitrification tank (average, Max, Min), dissolved oxygen (DO) and pH in nitrification tank, and total precipitation.

Monthly Averages from the Jernigan Wastewater Treatment Facility - Campbell Sci. Datalogger										
Month	**Year**	**Avg. Air Temp (°C)**	**Max**	**Min**	**Avg. Water Temp (°C)**	**Max**	**Min**	**DO (ppm)**	**pH**	**Total precipitation (mm)**
June	2012	24.50	41.01	11.38	27.97	41.73	11.95	4.79	7.41	27.68
July	2012	27.54	39.22	20.29	32.01	41.88	20.20	4.29	6.81	169.42
August	2012	25.31	33.96	15.70	32.16	34.30	28.75	1.63	7.09	15.49
September	2012	22.18	35.64	8.39	29.70	32.52	27.31	2.14	7.34	0.00
October	2012	16.67	30.44	3.77	25.83	30.03	19.34	2.92	7.68	0.51
November	2012	8.72	25.02	-5.55	18.32	20.94	16.50	2.08	7.98	11.94
December	2012	10.39	24.37	-4.00	19.25	23.38	15.91	2.29	8.03	100.58
January	2013	7.79	24.88	-7.70	17.98	22.74	13.96	3.28	8.04	50.80
February	2013	7.06	22.14	-7.18	16.36	20.76	3.51	1.93	8.34	100.84

4.3 Livestock Inventory

The steady state live weight (SSLW) in the 1,200-sow farm operation was about 626,400 lbs. This estimate used table values for Farrow to Feeder production type (522 lbs./sow; Chastain et al., 1999). The SSLW in the finishing operation (Feeder to Finish) was 1,949,044 lbs. based on average weight ((average wt. started + wt. sold)/2) and average number of head (started + sold/2) in each barn during two production cycles (Table 3). The total SSLW treated by the system from both farms was 2,575,444 lbs.

Production records of a complete cycle in the finishing operation January-October 2012 (First Cycle, Table 3) indicates that an average of 736 pigs (47.8 lbs./pig) were transferred about weekly from the sow farm into the finishing operation (buildings 1-18). A complete finishing cycle started with 13,254 pigs and lasted about 21 weeks (2.47 cycles/year). Pigs were sold weighing 256.8 lbs. each. When these records are projected to one year, the complete operation (1200-sow farm Farrow to Finish) produces about 30,450 hogs per year with a total weight of 7,819,577 lbs. The production records for the 2nd cycle from June 2012 to March 2013 shown at the bottom of Table 3 are consistent with the 1st cycle indicating that the animal production was at steady-state during the manure treatment system evaluation.

Table 3. Pig inventory in the Farrow to Finish operation at Jernigan farm . There were 18 units in 4.5 quad buildings (Figure 3). All pigs were supplied from the 1,200 sow farm. Data provided by Prestage Farms (Integrator). Actual building numbers are changed for this table. SSLW = average weight x average # of head. NA = data was not available

1st Cycle Placement Date	Date sold	Building #	Head Started	Wt. Started (lbs.)	Average Wt. Started (lbs./pig)	Head Sold	Wt. Sold (lbs.)	Average Wt. Sold (lbs./hog)	SSLW (lbs.)
1/16/2012	5/30/2012	1	777	37,073	47.7	703	189,769	269.9	117,531
1/23/2012	6/6/2012	2	733	35,340	48.2	705	186,408	264.4	112,387
2/20/2012	7/2/2012	3	738	34,093	46.2	656	168,476	256.8	105,602
2/27/2012	7/9/2012	4	730	34,290	47.0	671	168,878	251.7	104,602
3/5/2012	7/18/2012	5	749	35,743	47.7	689	170,048	246.8	105,880
3/19/2012	8/1/2012	6	719	34,107	47.4	691	172,177	249.2	104,555
3/26/2012	8/7/2012	7	723	34,237	47.4	650	170,101	261.7	106,078
4/2/2012	8/14/2012	8	754	35,471	47.0	694	184,096	265.3	113,056
4/9/2012	8/22/2012	9	734	35,397	48.2	696	180,985	260.0	110,203
4/2/2012	8/22/2012	10	718	34,464	48.0	665	172,127	258.8	106,021
4/16/2012	8/29/2012	11	674	32,329	48.0	622	160,726	258.4	99,264
4/23/2012	9/4/2012	12	714	33,939	47.5	669	173,385	259.2	106,042
4/30/2012	9/11/2012	13	797	38,164	47.9	740	189,705	256.4	116,904
5/7/2012	9/18/2012	14	712	35,173	49.4	682	171,748	251.8	104,623
5/14/2012	9/26/2012	15	729	35,093	48.1	671	168,169	250.6	104,566
5/21/2012	10/2/2012	16	766	36,951	48.2	704	174,182	247.4	108,655
5/28/2012	10/10/2012	17	695	33,627	48.4	647	166,252	257.0	102,442
6/4/2012	10/17/2012	18	792	38,575	48.7	742	190,674	257.0	117,228
Total 1st Cycle			**13,254**	**634,066**		**12,297**	**3,157,906**		**1,945,639**
Average 1st cycle			**736.3**	**35,226**	**47.8**	**683.2**	**175,439**	**256.8**	**108,091**

2nd Cycle Placement Date	Date sold	Building #	Head Started	Wt. Started (lbs.)	Average Wt. Started (lbs./pig)	Head Sold	Wt. Sold (lbs.)	Average Wt. Sold (lbs./hog)	SSLW (lbs.)
6/11/2012	10/23/2012	1	723	35,396	49.0	686	178,762	260.6	109,039
6/18/2012	10/31/2012	2	774	37,189	48.0	717	187,427	261.4	115,347
7/16/2012	11/20/2012	3	728	34,769	47.8	680	176,622	259.7	108,240
7/30/2012	11/29/2012	4	704	33,821	48.0	649	170,159	262.2	104,935
8/6/2012	12/18/2012	5	732	35,264	48.2	670	177,236	264.5	109,601
8/12/2012	12/18/2012	6	722	34,832	48.2	648	172,145	265.7	107,511
8/13/2012	12/26/2012	7	844	40,451	47.9	781	204,585	262.0	125,889
8/20/2012	1/2/2013	8	743	35,813	48.2	627	165,287	263.6	106,798
9/3/2012	1/16/2013	9	732	34,518	47.2	682	177,353	260.0	108,599
8/27/2012	1/8/2013	10	738	35,064	47.5	663	169,897	256.3	106,392

9/10/2012	1/22/2013	11	746	35,248	47.2	678	176,276	260.0	109,377
9/17/2012	1/30/2013	12	733	34,541	47.1	623	158,365	254.2	100,452
9/24/2012	1/3/1900	13	702	33,070	47.1	618	159,393	257.9	100,660
10/1/2012	2/13/2013	14	771	36,561	47.4	692	176,569	255.2	110,669
10/8/2012	2/2/2013	15	701	33,413	47.7	644	167,875	260.7	103,679
10/22/2012	3/7/2012	16	736	34,653	47.1	NA	NA		
10/23/2012	3/7/2013	17	754	35,631	47.3	NA	NA		
10/22/2012	3/13/2013	18	722	33,754	46.8	NA	NA		
Total 2nd Cycle			**13,305**	**633,988**					**1,945,639***
Average 2nd cycle			**739.2**	**35,222**	**47.7**	**670.5**	**174,530.1**	**260.3**	**108,470**

* SSLW for 18 buildings based on average for 15 barns (108,470). NA = data was not available .

4.4 Manure Inventory

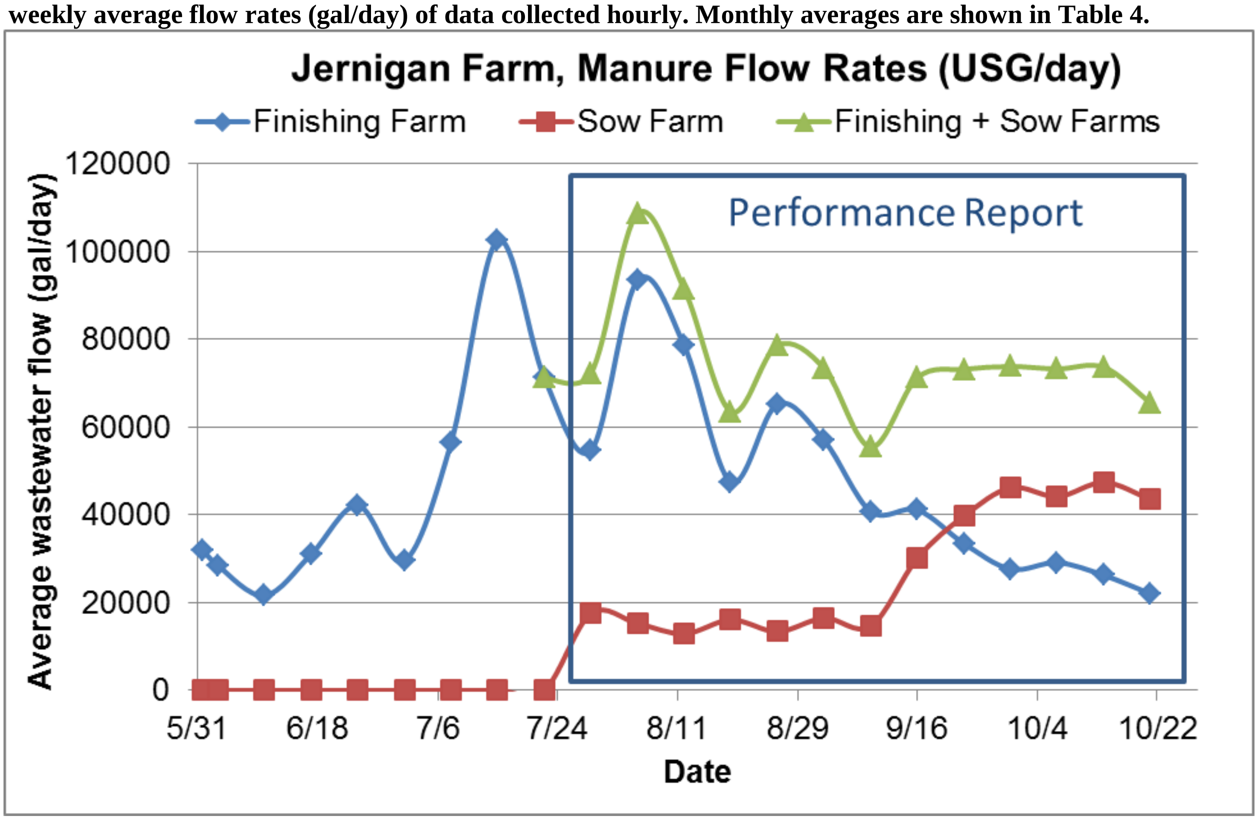
Flow rates of manure into the Gen 3 Terra Blue wastewater treatment system are shown in Figure 5 (weekly averages) for the period May 31-Oct. 23, 2012 that starts when the plant began receiving manure from the finishing farm. Marked within a box in the graph is the period Aug. 1-Oct. 23 that is the timeframe for this report when manure was received from both the finishing farm and the sow farm, and samples were collected intensively. Flow rates of manure during this evaluation period are summarized in Table 4 with total volumes and average flow rates from the two farming units and collectively in the last two columns. Table 4 was updated with manure flows measured Nov. and Dec. 2012 from the two farms.

The manure flow rate varied with time in both operations, even though production data showed about constant SSLW. In the finishing farm, manure volume was 2.2 times higher in August than the average of October-December (Table 4). Similar increase in manure volume generation was documented in previous second generation project in the warmest months (Vanotti and Szogi, 2007). It was attributed to the excess water used to cool the pigs in the summer. During the 84-day evaluation period (August-October) the finishing farm produced 4,064,597 gal of manure or an average flow rate of 48,388 gal per day (Table 4). Manure flushes from sow farm B were incorporated into the system in two steps: at the beginning of August, barn 1 (breeding) and barn 2 (gestation) were connected (each had one flush tank of 1500 gal capacity); by mid-September, the third barn (farrow/nursery) was connected. This barn had five flush tanks of 1000 gal capacity each. We measured the amount of treated water that filled the seven flush tanks in sow farm B with a cylinder and stopwatch in two occasions: it averaged 6,350 gal, 6,540 gal, and 26,320 gal for flush tanks in barns 1, 2 and 3, respectively. During the 84-day evaluation period (August-October) the sow farm generated 2,279,745 gal of flushed manure or an average flow rate of 27,140 gal/day (Table 4). Collectively, during the 84-day evaluation (Aug.-Oct.) the system treated 6,344,342 gal of manure from the two farms or an average flow rate of 75,527 gal of manure per day. Data through December was consistent; the system treated about 12 million gallons of manure in 153 days, or about 78,422 gal of manure per day.

Table 4. Wastewater influent monthly volumes and flow rates from finishing and sow farms into the wastewater treatment system during evaluation at Jernigan farm Aug. 1-Oct. 23 (weekly flow rates shown in Figure 5), with additional data through December, 2012.

Month	days	Total Volume Finishing Farm	Average Flow Rate Finishing Farm	Total Volume Sow Farm	Average Flow Rate Sow Farm	Total Volume Finishing + Sow Farm	Average System Influent Flow Rate
		gal	gal/day	gal	gal/day	gal	gal/day
August	31	2,197,232	70,878	464,379	14,980	2,661,611	85,858
September	30	1,227,635	40,921	768,051	25,602	1,995,687	66,523
October	23	639,730	27,814	1,047,315	45,535	1,687,045	73,350
Aug 1.-Oct 23	**84**	**4,064,597**	**48,388**	**2,279,745**	**27,140**	**6,344,342**	**75,527**
October	31	877,902	28,319	1,460,994	47,129	2,338,896	75,448
November	30	963,555	32,119	1,737,369	57,192	2,700,924	90,030
December	31	1,050,398	33,884	1,250,974	40,354	2,301,370	74,238
Aug.-Dec.	**153**	**6,316,722**	**41,286**	**5,681,767**	**37,136**	**11,998,489**	**78,422**

Figure 5. Flow rates of manure into the wastewater treatment system installed at Jernigan farm. Data are weekly average flow rates (gal/day) of data collected hourly. Monthly averages are shown in Table 4.



5. Water Quality Improvements

The wastewater treatment performance obtained is summarized in Table 5. A pooled influent concentration was calculated based on concentration from two sources and corresponding flow rates. The weekly sampling data are presented in graphics in the appendix B section. The treatment system lowered concentration of constituents in wastewater as follow: 97.3% of total suspended solids (TSS), 97.9% of volatile suspended solids (VSS), 72.5% of total solids (TS), 93.7% of chemical oxygen demand (COD), 97.7 of TKN, 99.0% of Ammonia-N, 87.7% of TN, 88.5% of TP, and 85.3% of alkalinity (Table 5). Concentration of copper (Cu) and zinc (Zn) in the liquid effluent were reduced 95.4% and 97% relative to the concentration in the homogenization tank.

Table 5. Reduction in wastewater concentration of solids, COD, ammonia, total nitrogen, total phosphorus and alkalinity by the new treatment system evaluated at Jernigan farm. System efficiency is the % reduction in concentration between the pooled influent concentration and the plant effluent. Data are means ± standard deviation of weekly samples collected August-October, 2012 (n=11); except Cu and Zn (Sept., 2012, n =2).

Water Quality Parameter [a]	Homogenization Tank [b] (mg/L)	Decant Tank [c] (mg/L)	Pooled Influent [d] (mg/L)	Effluent (mg/L)	Removal Efficiency (%)
TSS	10,082 ± 2,860	1,332 ± 588	6,845	193 ± 37	97.3
VSS	7,932 ± 1,960	1,047 ± 488	5,385	120 ± 17	97.9
TS	11,532 ± 1,764	4,183 ± 749	9,016	2,476 ± 210	72.5
COD	12,762 ± 2,350	4,095 ± 1,249	9,794	620 ± 344	93.7
TKN	1,581 ± 290	493 ± 100	1,209	28 ± 11	97.7
Ammonia-N	775 ± 101	322 ± 92	620	6 ± 7	99.0
Oxidized N	6 ± 6	19 ± 23	10	122 ± 54	--
Total N	1,587 ± 290	512 ± 101	1,219	149 ± 62	87.7
Total P	558 ± 166	166 ± 64	439	50 ± 19	88.5
Alkalinity	3,998 ± 497	1,714 ± 415	3,215	472 ± 181	85.3
Copper (Cu)	15.03 ± 6.04	--	--	0.69 ± 0.13	95.4
Zinc (Zn)	20.09 ± 9.78	--	--	0.61 ± 0.23	97.0

[a] Oxidized N = nitrate + nitrite-N; Total N = TKN + Oxidized N
[b] Homogenization tank (HT) concentration includes finishing farm waste and sludge from decanting tank
[c] Decant tank (DEC) was the concentration measured in the decant tank effluent
[d] Pooled inflow concentration =
[(HT conc. * HT flow) + (DEC conc. * DEC flow)]/[HT flow + DEC flow]
HT flow = 4,172,097 gal [4,064,597 gal from finishing farm (Table 4) plus 107,500 gal from decanting sludge]
DEC flow = 2,172,245 gal [2,279,745 gal from sow farm (Table 4) minus 107,500 gal decanting sludge to HT]

6. System efficiencies based on mass balance

The treatment performance of the system using mass balance approach is summarized in Table 6. The mass balance used data collected Sept 15.-Oct. 28, 2012, when the two farming units were fully connected (treating manure form 2,575,444 lbs. SSLW), and the results were projected to a year basis. On a mass basis, the treatment system removed 98.6% of total suspended solids (TSS), 99.0% of volatile suspended solids (VSS), 83.3% of total solids (TS), 98.1% of chemical oxygen demand (COD), 99.3% of TKN, 100.0% of Ammonia-N, 96.7% of Total Nitrogen (TN), 91.9% of Total Phosphorus (TP), and 89.7% of the alkalinity (Table 6).

Table 6: Mass loadings, removals, and system efficiency at Jernigan farm, North Carolina.[1]

Water quality parameter	System load [2] (manure from barns) [A] kg/year	N Treated effluent recycled to barns [B] kg/year	System effluent for land application [C] kg/year	Total mass removed by system [3] kg/year	System efficiency [4] (Mass basis) (%)
TSS	596,266	82,730	7,111	506,426	98.6
VSS	462,593	66,643	4,063	391,886	99.0
TS	770,681	241,951	88,512	440,218	83.3
COD	796,329	67,825	13,781	714,722	98.1
Alkalinity	264,273	49,835	22,009	192,429	89.7
Ammonia-N	48,344	66	0	48,279	100.0
TKN	98,748	5,450	609	92,689	99.3
Total N	101,337	9,192	3,014	89,131	96.7
Total P	38,893	11,228	2,235	25,431	91.9

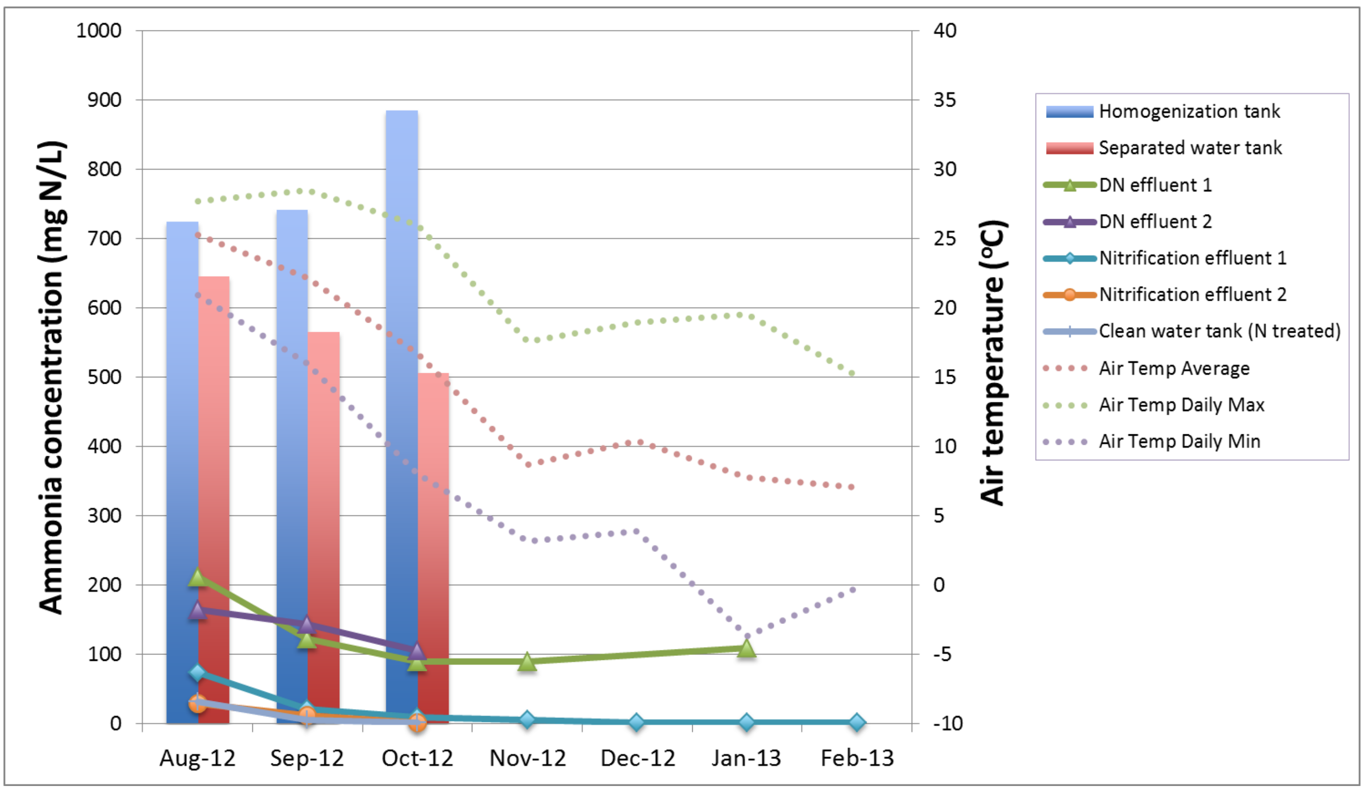
[1] Yearly estimate based on data collected Sept 15.-Oct. 28, 2012 when the two farming units were fully connected. Total SSLW= 2,575,444 lbs. (1,949,044 lbs. in finishing farm and 626,400 lbs. in sow farm B).
[2] System loads consider wastewater concentrations and flow rate from both the finishing farm (27,022 gal/d) and the sow farm B (45,006 gal/day). System effluent volume for land application was estimated at 24,507 gal/day based on NC standards of manure volume per 1000 lbs. (1.35 ft^3/d for feeder-to-finish and 1.03 ft^3/day for farrow-to-feeder). Water recycle concentrations were measured in the clean water tank (N treated water) and system effluent concentrations were determined in the P treated water.
[3] Total mass removed by system = (A – B) – C.
[4] System efficiency (mass removal) = {1-[C/(A-B)]} * 100.

7. Biological N performance during winter

The concentration of ammonia-N in the nitrification tank effluent during cold weather months was <10 mg/L (Figure 6). This was verified using on-site measurements implemented in both nitrification and denitrification effluents to obtain rapid feedback of biological N process performance during the period Aug. 2012 to Feb. 2013.

The N module used a high performance nitrifying sludge (HPNS) for high ammonium concentration and low temperature wastewater treatment (US 8,445,253). The system removed ammonia efficiently during cold weather (Figure 6). The biological N treatment system was designed to treat at least 302 kg/day of ammonia-N from 3 farming units during winter weather in North Carolina (page 11). However, only 2 farming units were connected to the treatment plant during this evaluation, following a two-phase implementation (see Permitting, page 13). The N loads experienced by the N removal module (after solids separation) during this evaluation (Phase One) were at most 204 kg N/day, or about < 70% of design N removal capacity. Based on these results for N module, it would be appropriate to merge the remaining 1085 farrow to feeder swine waste stream into the treatment system (Phase Two). This would increase N load by about 18%, based on Phase One actual SSLW (2,575,444 lbs.) and projected Phase Two SSLW (3,139,200 lbs.).

Figure 6. Concentrations of ammonia as the liquid passes through the system and air temperatures experienced (avg., min and max). Measurements of ammonia in the nitrification and denitrification effluents were performed using two colorimetric methods: on-site measurements using test kits (#1, Aug.-Feb.), and measurements done in the laboratory with autoanalyzer (#2, Aug.-Oct.). Separated water tank contains wastewater before N treatment. Clean water tank receives nitrification effluent water (N treated water).



7. Manure Solids Production by Solid-liquid Separator

A total of 4,131,854 gal of manure were processed by the separator during the 84-day evaluation timeframe (Table 7). The separator was normally operated five days per week (Monday-Friday) with mean daily runs of 9.76 hours and average processing rate of 121.6 gal/minute. A total of 38 bins (540 ft^3 capacity) left the farm during the evaluation that totaled 578 m^3 of separated solids. This amount of manure weighed 377,590 kg (832,430 lbs. or 416 tons) and contained 27.6% dry matter. The separated solids had the following composition (n = 2): 4.95% Total Nitrogen, 37.8% carbon, 2.35% phosphorus, 0.14% copper, and 0.18% zinc. Table 6 was updated through December 31, 2012: data showed higher production of solids during the colder months. However, this higher yield did not require additional hours of operation, suggesting that manure particles were more protected in cold weather. During the period Aug.-Dec. (153 days), the separator processed a total of 6,470,490 gal of manure and was operated 4.99 days/week with daily runs of 8.84 hours and average processing rates of 112 gal/minute (Table 7 update). Using this processing rate and results of decant tank (presented in section 10), it is predicted that incorporation of the remaining farming unit (Sow farm A, about 29,250 gal/day, Table 1) into the plant will increase the manure volume processed by the solids separator after decanting by 43,000 gal/month and will increase hours of operation of the separator by only 0.29 hours/day of operation (total 9.13 hours). Based on these results for solids separation, and the significant reduction of volume with the decant process, it would be appropriate to merge the remaining 1085 farrow to feeder swine waste stream into the treatment system (Phase Two).

It should be noted that the separator press was going to be operated 17.7 hours/day, 7 days/week according to original design (Page 11), which did not consider the lower volumes resulting from decanting tank. With the decant tank, operations hours are reduced to 9.1 hours, 5 days/week. This is one of the largest achievements of this project.

Table 7. Separated manure solids produced during evaluation at Jernigan farm, with additional data through Dec. 2012. Data obtained from daily operational records kept by operator.

Month	Total days	Manure volume processed by solids separator	# Days separator was operated	Total hours of operation	Average Processing Flow Rate	Number of bins that left farm	Separated solids that left farm
		gal	days	hours	gal/min	bins	ft^3
August	31	1,791,848	21	245.5	121.6	16	8,560
September	30	1,505,540	21	204.4	122.8	12	6,460
October	23	834,446	16	116.5	119.4	10	5,400
Aug.-Oct. 23	**84**	**4,131,854**	**58**	**566.4**	**121.6**	**38**	**20,420**
October	31	1,121,647	21	151.5	123.1	14	7,560
November	30	986,055	22	180.9	90.9	17	9,180
December	31	1,065,400	24	181.2	98.0	23	12,420
Aug.-Dec.	**153**	**6,470,490**	**109**	**963.5**	**111.9**	**82**	**44,280**

A standard commercial waste container was used for transporting solids from the farm to the Terra Blue central processing facility near Clinton, N.C., where value-added products were produced to move nutrients out of intensive production regions.

8. Reduction of Odors

The potential of effluent to produce offensive odors was quantified by measuring in the liquid the concentration of compounds typically associated with malodors in animal waste according to the published method of Loughrin et al. (2009). Data are summarized in tables 8 and 9. The largest reduction was observed after the liquid passed through nitrogen treatment. Odor compound removal efficiencies by the treatment system were 100%.

Table 8. Reduction of aromatic malodorant compounds by treatment at Jernigan farm. Data are means (± standard deviation) of samples taken Sept. - Oct. 2012 (n=4).

Aromatic Malodorants	HT Tank (sd)	Decant Tank (sd)	Separated Water Tank (sd)	Clean Water Tank (sd)	Plant Effluent (sd)	Removal Efficiency
	ppb	ppb	ppb	ppb	ppb	%
Phenol	5,937 (3,847)	8,408 (6,497)	935 (398)	0	0	100
Total Cresols	5,888 (6,825)	659 (608)	163 (78)	0	0	100
Indole	627 (598)	459 (169)	0	0	0	100
Skatole	993 (420))	1,606 (1,676)	528 (56)	0	0	100
Total	**13,446 (8,109)**	**11,133 (8,478)**	**1,626 (364)**	**0**	**0**	**100**

Table 9. Reduction of volatile fatty acids contributing to odor by treatment at Jernigan farm. Data are means (± standard deviation) of samples taken Sept. - Oct. 2012 (n=4).

Volatile Fatty Acids	HT Tank (sd)	Decant Tank (sd)	Separated Water Tank (sd)	Clean Water Tank (sd)	Plant Effluent (sd)	Removal Efficiency
	ppm	ppm	ppm	ppm	ppm	%
Acetate	105.7 (25.7)	17.9 (32.2)	11.8 (17.6)	0	0	100
Propianate	130.6 (31.7)	22.2 (39.8)	14.5 (21.7)	0	0	100
Iso-butyric	95.5 (22.5)	151.3 (158.2)	5.7 (6.7)	0	0	100
Total	**331.8 (41.6)**	**191.5 (163.8)**	**32.0 (43.4)**	**0**	**0**	**100**

9. Reduction of Pathogens

Pathogen reporting or maximum standards for effluent were not required by the Permit. However, microbial sampling was done Oct. 31 - Dec. 6, 2012 (Table 10) to obtain information to determine if the system would meet the 15A NCAC 02T.1307 pathogen standard for new or expanding operations (< 7,000 MPN fecal coliforms/100 mL). Samples were taken from raw manure (homogenization) and treated effluent after receiving phosphorus treatment with hydrated lime. Some dates included also clean water tank (after N removal and before phosphorus treatment). A problem encountered in the first sampling date (10/31) was that the P module was modified after Oct. 23 with liquid bypassing the mixing chamber and lime being injected into the settling tank. The system was put back to the original evaluation configuration and the subsequent 5 samples (11/12 to 12/6) were taken with the P module assembled correctly as originally designed and varying process pH. The first sample 11/12 was obtained with pH setting conditions similar to the evaluation Aug-Oct. The following four samples were obtained with higher pH setting (> 10). Results obtained showed that a process pH of 9.3 produced

99.87% Fecal Coliform removal (2.88-$\log_{10}$ reduction) and that a pH 10 or higher produced higher pathogen destruction. With the pH of 10.1, the concentration of Fecal Coliforms was 3,530 MPN/100 mL and the microbial reduction was 99.98%. This will meet 15A NCAC 02T.1307 pathogen standard. With higher pH (10.8-11.4), the concentration of Fecal Coliforms in the effluent was < 182 MPN/100 mL (2.26 $\log_{10}$ MPN/100 mL) and the microbial reduction by the system was 99.997% (4.5-log reduction). Therefore, for this farm, the system would meet 15A NCAC 02T.1307 pathogen standard when the controller in the P module is operated at pH set point of 10 and a pH correction band of +0.1.

Table 10. Microbiological analyses of liquid manure effluent before and after treatment. Data shows the effect of process pH (phosphorus module) on pathogen destruction.

Sampling Date	Lab ID [a]	Indicator Microorganism	Raw Flush (HT Tank) $\log_{10}$ MPN per 100 mL	Clean Water Tank (after biological N Treatment) $\log_{10}$ MPN per 100 mL	Plant Outflow (after P treatment) $\log_{10}$ MPN per 100 mL [b]	Process pH	$\log_{10}$ Reduction
10/31/2012	1	Fecal Coliforms	6.64	--	5.41	9.4	1.23
		E. Coli	6.25	--	5.13		1.12
		Enterococci	6.52	--	4.34		2.17
11/12/2012	1	Fecal Coliforms	7.26	--	4.38	9.3	2.88
		E. Coli	6.89	--	4.21		2.68
		Enterococci	6.76	--	4.03		2.73
11/12/2012	1	Fecal Coliforms	7.26	--	3.55	10.1**	3.71
		E. Coli	6.89	--	3.34		3.56
		Enterococci	6.76	--	3.58		3.18
11/29/2012	2	Fecal Coliforms	6.76	4.62	2.26	10.8**	4.50
12/6/2012	1	Fecal Coliforms	6.78	4.89	< 0.70	11.4**	> 6.09
		E. Coli	6.42	4.73	< 0.70		> 5.72
		Enterococci	6.33	4.46	2.18		4.14
12/6/2012	2	Fecal Coliforms	6.66	4.28	1.07	11.4**	5.59

[a] Lab 1 = NCSU BAE Dept.; Lab 2= Pace Analytical Services, Inc., Raleigh, NC.
[b] To meet 15A NCAC 02T.1307 Swine Waste Management System Performance Standards (2010) for pathogens, Fecal Coliform concentration in the final liquid effluent shall not exceed 7,000 Most Probable Number/100 mL (3.84 $\log_{10}$ MPN per 100 mL). ** Fecal coliform concentration meets 15A NCAC 02T.1307 pathogen standard.

The concentration of Fecal Coliforms at the intermediate point (4.28-4.62 $\log_{10}$ MPN/100 mL, Table 10) was higher than in previous projects (3.01 at Goshen Ridge farm and 3.03 at Tyndall farm) which did not use decanting tank and where all the manure received polymer treatment. This suggests that the use of a decanting tank to incorporate flushing operations to the treatment system may increase the pathogen concentration in the effluent, and that a P module operated at pH 10 would be necessary for reducing effluent pathogen indicator concentrations below 7,000 MPN F.C./100 mL (< 3.84 03 $\log_{10}$ MPN/100 mL) as established in NC for new or expanding swine operations.

Lime needed to raise pH to 10 in P-module to kill pathogens.
We measured in the ARS laboratory the estimated lime consumption by P-module at higher pH (10) needed to meet 15A NCAC 02.1307 pathogen standard. Samples collected from the Clean Water Tank during September and October, 2012 (n = 4) were treated with hydrated lime to reach endpoint pH of 9.2 (Endpoint 1) or 10 (Endpoint 2). Endpoint 1 was the average pH in P-module samples during evaluation (Finishers and Full Sow Farm B). In both tests, the initial pH was 7.34 ±0.03 (Lime applied = 0). It required 0.70 ± 0.13 kg lime/m^3 to reach pH 9.2 (Endpoint 1) and 1.17 ± 0.54 kg/m^3 to reach pH 10 (Endpoint 2). The volumes of phosphorus solids precipitate produced were 84.9 ± 18.2 L/m^3 (pH 9.2) and 93.8 ± 14.9 L/m^3 (pH 10). Corresponding concentrations of total phosphorus in the clarified effluent were 50.5 ± 17.8 mg P/L and 13.9 ± 7.4 mg p/L.

10. Evaluation of Decanting Tank

The use of the decanting tank was an adaptation of the treatment system implemented in the 3rd generation to be able to process high volumes of diluted manure from flushing systems without having to increase the solid separator press capacity. This was the case of the sow operation at Jernigan farm that used flushing system. The decanting tank concentrated the flushed manure about 15 times (from 0.3% to 4.7% TSS). This concentrated manure was subsequently treated with polymer in the separator press, while the clarified flush went to the separated water tank and N module. Approximately 4.7% of the initial flush volume was treated with polymer during the 84-day evaluation and 95.3% of the liquid flush went into N module after the rapid settling (Table 11). Thus, the decanting tank reduced the total volume of manure from the sow farm into the solid separator press by 2,172,245 gal (25,860 gal/day). This volume reduction was about 34% of the total volume of manure generated by the complete farm that was tested (6,344,342 gal or 75,525 gal/day, finishing + sow farm, Table 4). This lower volume is one of the major advances of the project.

Table 11. Sludge volume settled in the decanting tank (continuous flow) compared to total influent flush volume received. The settled sludge from the decanting tank was treated with polymer, and the supernatant effluent went into the separated water tank.

Time period considered Dates	Days & hours	Decanting tank influent volume	Sludge draining times	Sludge volume diverted from decanting into HT [a]	% ratio of separated sludge to influent volume
		gal		gal	gal/100 gal
8/20-8/22	1d 18h	31,550	1	977	3.1

8/25-8/30	5d 5h	73,068	1	1807	2.5
8/1-10/23	84 d	2,279,745	43	107,500	4.7

[a] For 8/20-8/22 and 8/25-8/30 periods, we measured actual depth of sludge in the Decanting tank at the end of the period (16.5 and 30.5", respectivelly) using 15-ft.long sludge sampling probes (Sludge Judge, Nasco, WI). For the total evaluation period 8/1-10/23, we counted times the Decanting tank was evacuated (Appendix B). The sludge in the tank was emptied to a fixed depth (4 ft bottom = 2,500 gal).

The TSS separation efficiency of the decanting tank was 60% (Table 12). This efficiency was obtained during six flush events by collecting influent and effluent samples (composited at beginning, middle and end of the flush). The decanting tank removed about 85% of the maximum TSS removal possible by settling (71%) as determined in laboratory settling tests (Table 12). These results have application only to flushing systems where fresh swine manure is flushed from the barns several times per day using treated water.

Table 12. Reduction of total suspended solids (TSS) from flushing system using settling. Data at left (columns 2-4) show composited influent and effluent samples collected at the decanting tank during six flushes from sow farm at Jernigan farm. Data at right (columns 5-7) show the separation efficiencies obtained in the ARS laboratory using 1-L Imhoff settling cones and 30 minutes settling (Figure 7).

Flush run	**Decanting Tank (Field)**			**Laboratory Tests (30')**		
	Influent TSS	Settled Effluent TSS	Removal Efficiency	Influent TSS	Settled Effluent TSS	Removal Efficiency
	ppm	ppm	%	ppm	ppm	%
1	2,693	970	64	2,110	600	72
2	2,982	912	69	2,320	475	80
3	2,345	749	68	1,510	400	74
4	1,607	951	41	1,010	400	60
5	8,486	2,109	75	8,390	2,300	73
6	2,727	1,647	40	2,160	700	68
Average	**3,473**	**1,223**	**60**	**2,917**	**813**	**71**

The application of polymer to the concentrated sludge instead of the diluted manure saved in polymer expenses. Laboratory experiments at ARS compared polymer use efficiency when applied to all the flushed manure (Table 13) or just to the settled sludge (Table 14). Results showed that application of polymer to the diluted flush resulted in low polymer use efficiency (52 g solids/g polymer) compared to application to the concentrated sludge (279 g solids/g polymer). In terms of polymer usage rates, the concentration strategy reduced potential polymer use (from 2.16 to 0.40 lbs. polymer/100 lbs. solids separated), which is equivalent to 5.4-times reduction in polymer usage.

Table 13. Laboratory study at USDA-ARS showing polymer use efficiency obtained when all the liquid manure from the sow farm is treated with polymer (PAM). Six flush samples were mixed with five rates of polymer (0-150 mg/L) and subsequently screened with 0.25 mm screen. Experiments were duplicated.

Flush run sample	TSS Conc.	Optimum PAM rate	TSS Removed	TSS Rem. Efficiency	PAM Use Efficiency	Polymer Usage Rate	
	(g/L)	(mg/L)	(g/L)	(%)	(g solids/g polymer)	(%) lb/100 lb	(lb/ton)
1	2.11	30	1.95	92	65	1.54	30.8
2	2.32	60	2.19	94	36	2.74	54.8
3	1.51	30	1.37	91	45	2.19	43.8
4	1.01	90	0.87	86	10	1.03	20.6
5	8.39	60	8.18	97	136	0.70	14.0
6	2.16	90	1.85	86	21	4.76	95.2
Average	**2.92**	**60**	**2.73**	**91**	**52**	**2.16**	**43.2**

Table 14. Laboratory study at USDA-ARS showing polymer use efficiency obtained when only the settled sludge from the decanting tank is treated with polymer (PAM). Two sludge samples collected from decanting tank were mixed with five rates of polymer and subsequently screened with 0.25 mm screen. Experiments were duplicated.

Sludge sample date	TSS Conc.	Optimum PAM rate	TSS Removed	TSS Rem. Efficiency	PAM Use Efficiency	Polymer Usage Rate	
	(g/L)	(mg/L)	(g/L)	(%)	(g solids/g polymer)	(%) lb/100 lb	(lb/ton)
8/22	60.7	315	60	99	190	0.52	10.4
8/30	34.1	90	33	99	367	0.27	5.4
Average	**47.4**	**202.5**	**46.5**	**99**	**279**	**0.40**	**7.9**

Although the decanting tank substantially reduced both the volume of liquid into the separator press and the polymer consumption, the solids removal efficiency was lower than applying polymer to all the influent (60 vs. 91%, Tables 12 and 13). Compared with a situation where all the flushing system liquid received polymer treatment, the use of settling (decanting) reduced TKN separation efficiency from 31% to 17% and increased TKN loading into the biological N module by only 20%. In terms of COD, the settling approach (vs. polymer) increased COD concentration in the separated liquid from 1,108 to 3,570 mg/L. This was very beneficial to the overall system performance because denitrification and biological N removal was improved as a result of a more balanced C/N ratio. For example, concentration of oxidized N (nitrite + nitrate) measured in the plant effluent was 300 ± 63 mg/L during the period June-July when only finishing farm was treated, and 122 ± 54 during the period August-October after the sow farm (w/decanting tank) was incorporated.

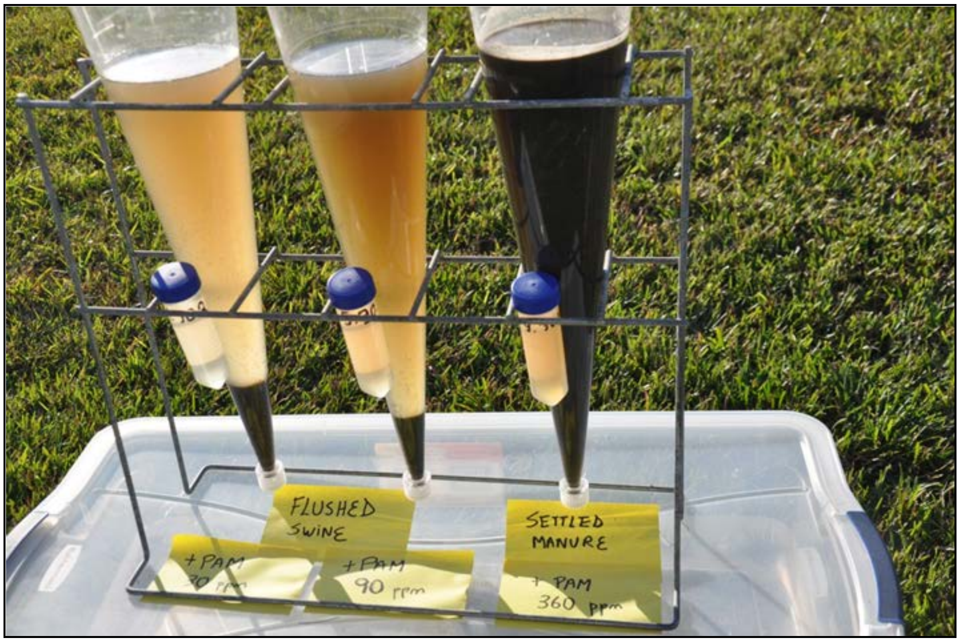


Figure 7. The two cones at left are flushed swine manure from the sow farm after 30 minutes settling in the laboratory (Table 12). The cone at right is settled sludge from decanting tank. The small vials are the effluents after polymer application and screening (Tables 13 and 14).

11. Operational Problems Experienced and Solutions

There were project delays and several challenges bringing the 3nd generation technology to its full potential:

Electrical Connection of Blower
Electrical connections serving the air blowers were redesigned after reoccurring air supply interruptions during start-up that prevented two blowers working at the same time and affected biological N conversion efficiency. The aeration system worked fine after this correcting work.

Breakage of Aeration Pipes
A submerged PVC pipe branch supporting the air diffusers broke in June at the time when the acclimation of the nitrification bacteria was just completed. This was a challenge because the nitrification tank had to be emptied to repair the pipe and the bacterial sludge had to be preserved. The bacterial sludge was moved into both settling tanks (N and P) while repair work in the nitrification tank was completed and returned in about 5 days without losing nitrification capacity.

12. Operation Notes

The 3rd generation system was operated and managed by the farmer with training and oversight provided by Terra Blue personnel. The farmer used a farm worker help. It was reported that each person put about one hour per day, 6 days per week to run the system. Solids removal component was automated to support uninterrupted operation with only periodic checks during the day. The farmer indicated that the type of machinery and equipment involved was similar in complexity to other equipment, pumps and electronic controls already used in the swine production facilities. In this project the company used on-site testing and also monitoring information from this evaluation to obtain rapid feedback on the process performance. This performance data was shared with the farmer to allow him to make adjustments to the system to maximize his objectives as well.

Successful operation of these systems in the future will require ongoing sampling and analysis to provide the operator with real-time process information to ensure optimum system performance. It will be necessary also for the North Carolina Department of Environment and Natural Resources, Division of Water Quality to establish operator training/certification requirements specifically directed towards innovative animal waste treatment systems permitted.

13. Lessons Learned – Jernigan Farm Project

1. System efficiency can be significantly improved and operating expenses significantly lowered by adding a decanting system (rapid gravity settling) to concentrate solids in farms that use flushing systems.
2. The treatment system can be managed efficiently by farm staff.
3. Solids removal component can be automated to support uninterrupted operation with only periodic checks during the day.
4. The fresher the wastewater, the greater the operational efficiency and performance.
5. A standard commercial waste container works very well for transporting solids from the farm to a central processing facility where value-added products can be produced to move nutrients out of intensive production regions.
6. Coordination of flush tanks among barns using timers and valves improves decant tank performance.
7. Lime application during phosphorus treatment using process pH 10 is effective for reduction of pathogens to meet new NC standards.
8. The evaluation of Phase One performance (this report) suggests the remaining waste stream (Sow farm A) can be merged into the treatment system. When fully implemented (Phase Two), the system serves the entire waste stream from three farm units (3,139,200 lbs. SSLW).

14. Swine production changes being done in 2003

The following are updates on Phase Two system implementation at Jernigan farm (7/8/13)

- The initial plan of treating the stream from 2,285 Farrow to Feeder (Sow farms A and B) and 12,960 head Feeder to Finish swine was changed.
- The 1200 Sows in Sow Farm B buildings are all being replaced with 5,440 finishing pigs.
- Sow farm A across the road will not be connected to the treatment system.
- A new barn is being constructed near the treatment plant for 2,600 finishing pigs.
- After these changes are implemented, the same treatment system will serve the entire waste stream from 21,000-head Farrow to Finish operation (12,960 + 5,440 + 2,600).
- Full implementation will be ready October 2013.

Conclusions

Major goals in the demonstration and verification of a third-generation wastewater treatment system for swine manure were achieved. These goals included replacement of anaerobic lagoon treatment, adaptation of the system to receive higher volume of liquid waste typical of flushing systems, and efficient environmental performance when installed in larger swine farms. The treatment provided full-scale treatment to a large swine farm with approximately 2,575,444 lbs. SSLW. It processed all the manure from a 1,200-sow operation (Farrow to Feeder) with flushing system (27,000 gal manure/day) and a 12,960 Feeder to Finish operation with pit recharge system (48,000 gal manure/day). A new decanting tank was effective to concentrate the diluted manure from flushing systems and increase solid separator press capacity and polymer effectiveness. Average reductions obtained were: 97.3% TSS, 93.7% COD, 99.0% Ammonia-N, 87.7% of TN, 88.5% of TP, 95.4% Cu, 97.0% Zn, and 100% odor compounds. On a mass basis, the treatment system removed 98.6% TSS, 99.0% VSS, 83.3% TS, 98.1% COD, 99.3% TKN, 100.0% Ammonia-N, 96.7% of TN, and 91.9% TP. For pathogens, the system reduces F.C. < 7,000 MPN/100 mL when the P module is operated at pH 10. It was verified that the third-generation technology is technically and operationally feasible and can meet the high environmental standards demonstrated in previous versions. The confidence in the technical and environmental achievements by this project is high.

Acknowledgements

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Mr. Doug Jernigan for providing his farm for this demonstration, operation of the system, and help in the evaluation.

Mr. Nelson Renfrow, Terra Blue Inc., for construction of the system, and assistance with mounting evaluation equipment.

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USDA-ARS, Bowling Green, KY, Robert Derrek Brown for his help with odor analyses.

Prestage Farms Inc., for providing the pig production records used in the report.

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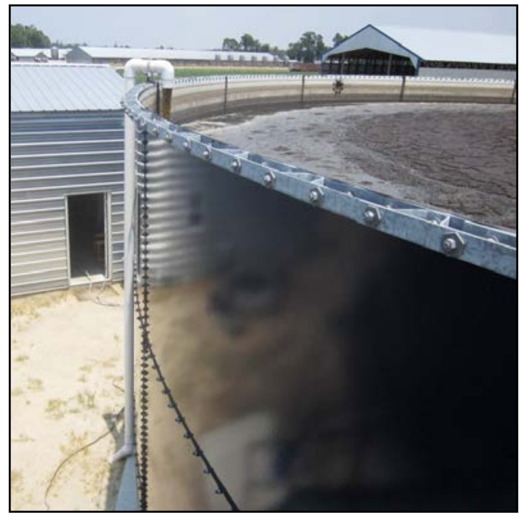
Appendix A: Project Pictures

Rotary press used for solid-liquid separation. Touch-screen process control is shown in upper right photo.

Separated manure solids being collected in a transportation bin.

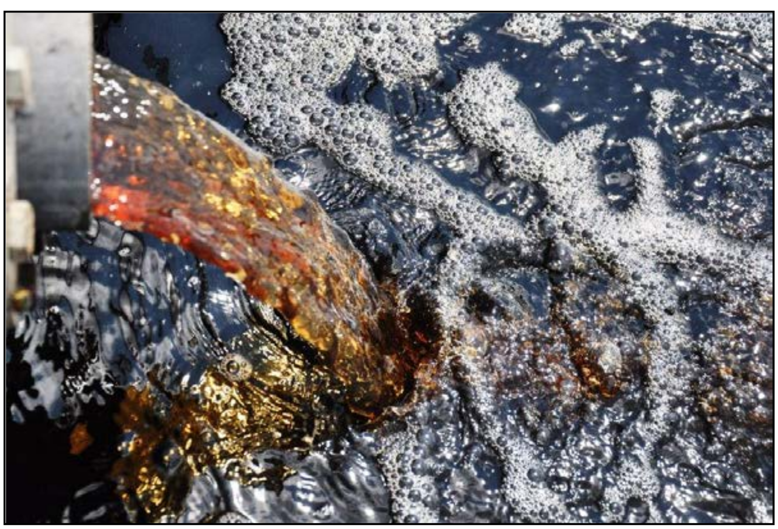


Homogenization tank receiving raw manure flush from finishers (left) and decanting tank sludge (right). In the upper left is the ultrasonic probe that monitored liquid levels.

Decanting tank, clarified effluent, and sludge sampling

Start-up of the biological N removal unit with 1 liter of HPNS high performance nitrification sludge.

Nitrification tank and settled sample.



Effluent from N module into the clean water tank.

Lime preparation tank (green) and settling tank used in the phosphorus removal module.

View of manure treatment system at Jernigan farm. Building contains the solid-liquid separator. Tanks at left are homogenization tank (front) and nitrification tank (back); tall tank at right is decanting tank.

Separated water tank; it is placed after solids separation and before N module.

View of treatment plant from the catwalk.

Denitrification tank hoist that supports submersible mixer.

Separated manure effluent being poured into denitrification tank.

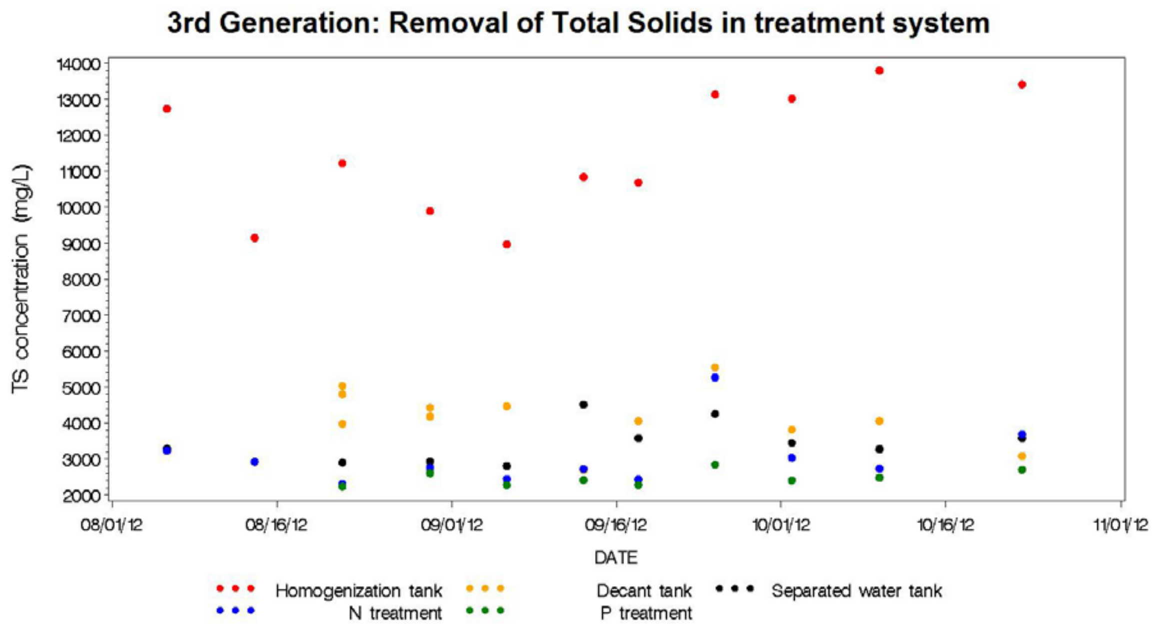
Raw manure from the finishing farm being transferred into the homogenization tank.

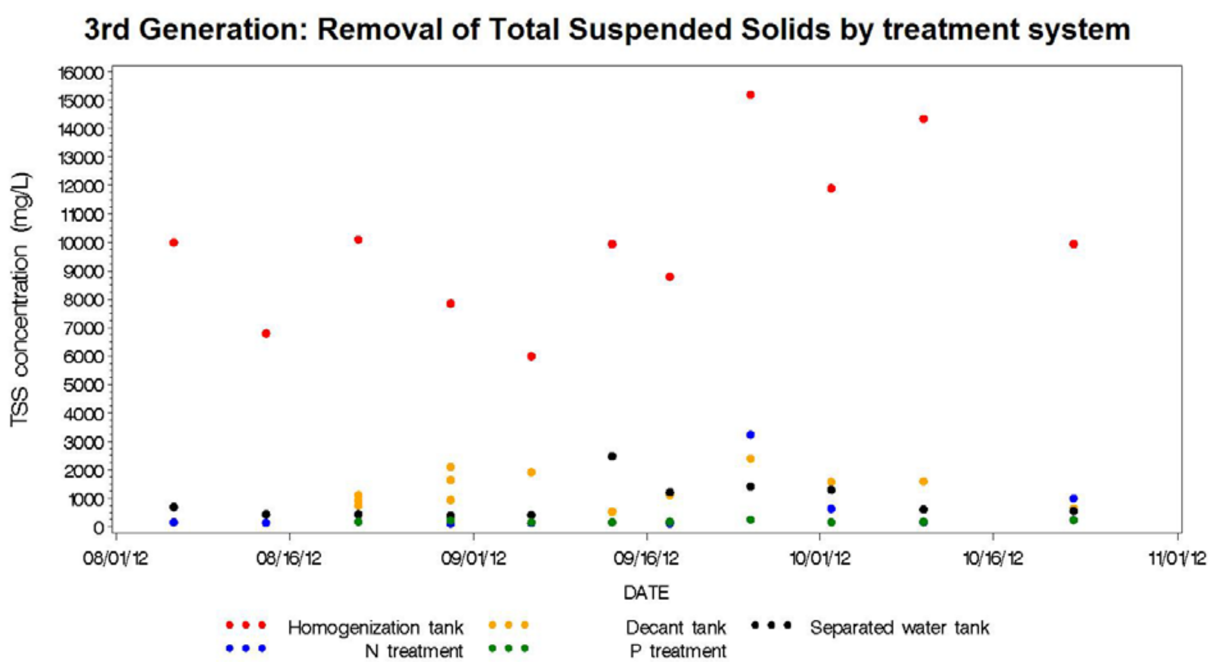
Clean water tank. It stored N treated water for recycling into the barns.

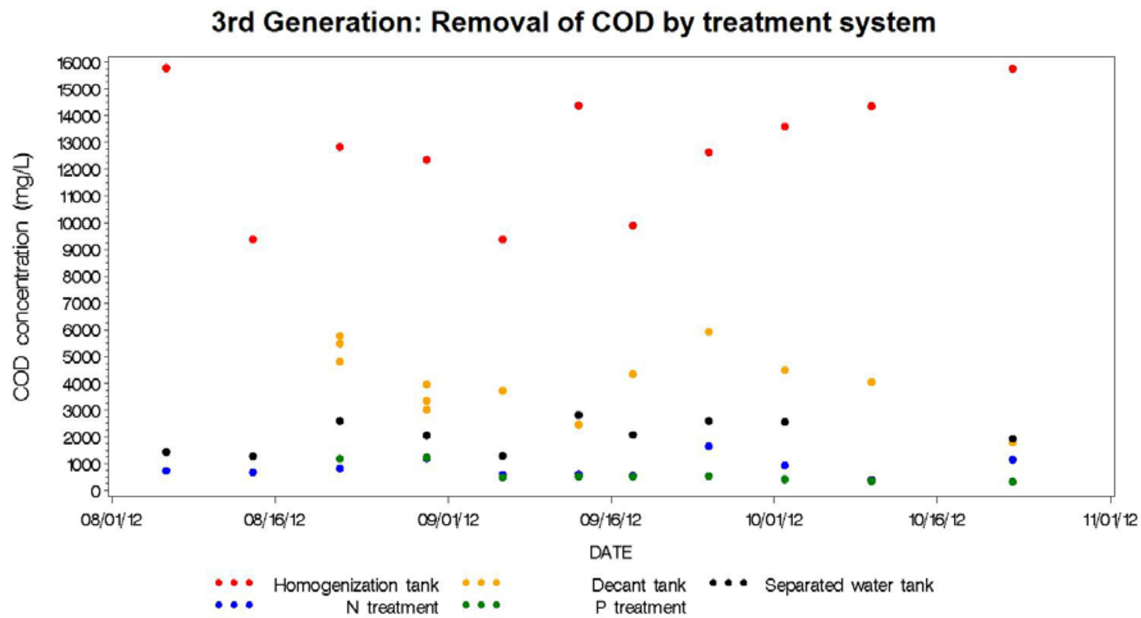
Visit of third generation project at Jernigan farm by industry and media. October 2013.

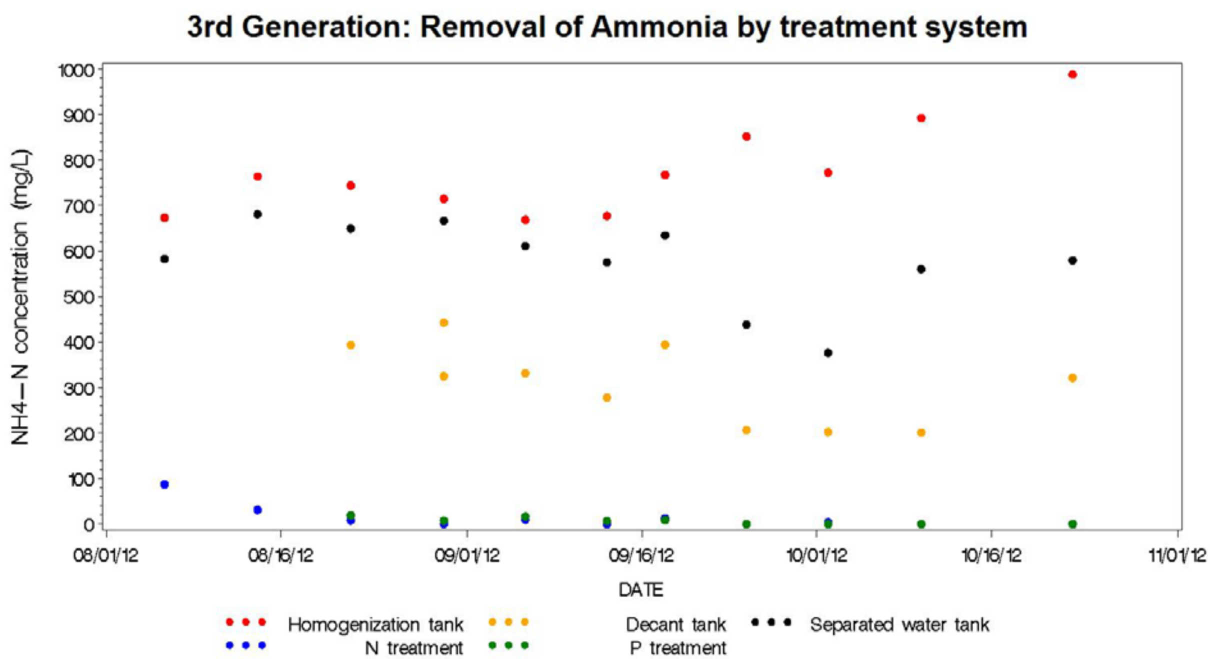
Terra Blue's centralized solids processing facility where the separated swine solids from this project were composted and used for the manufacture of value added products

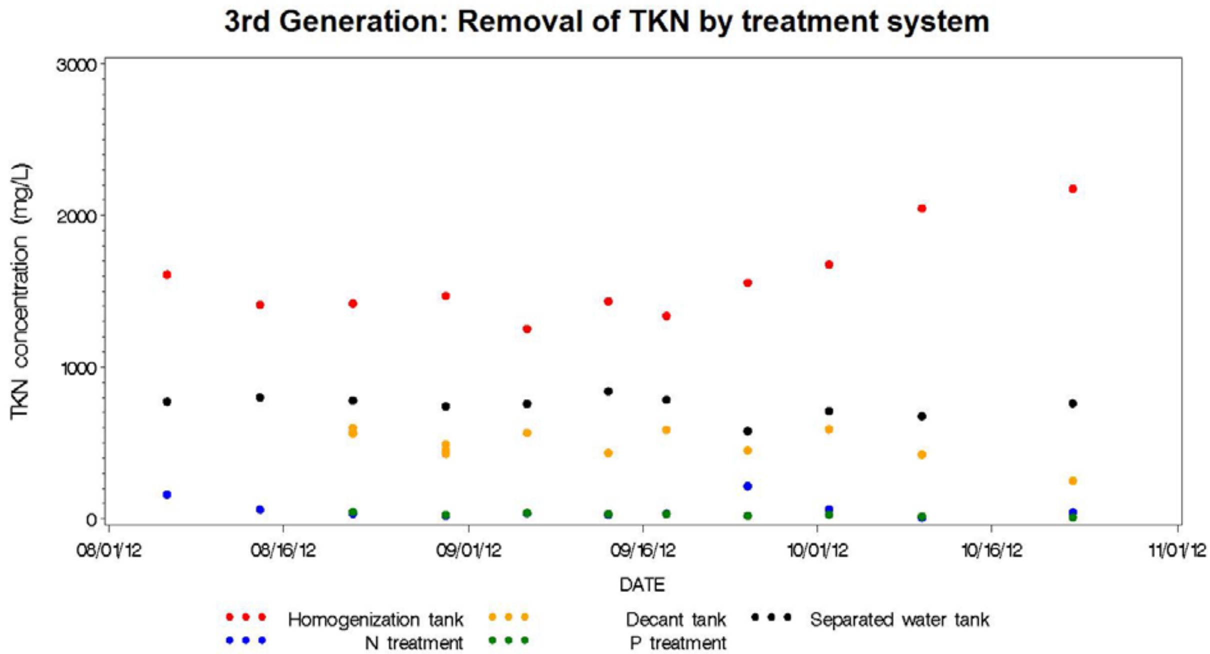
Appendix B: Graphs of Water Quality Changes with Treatment System (weekly sampling)

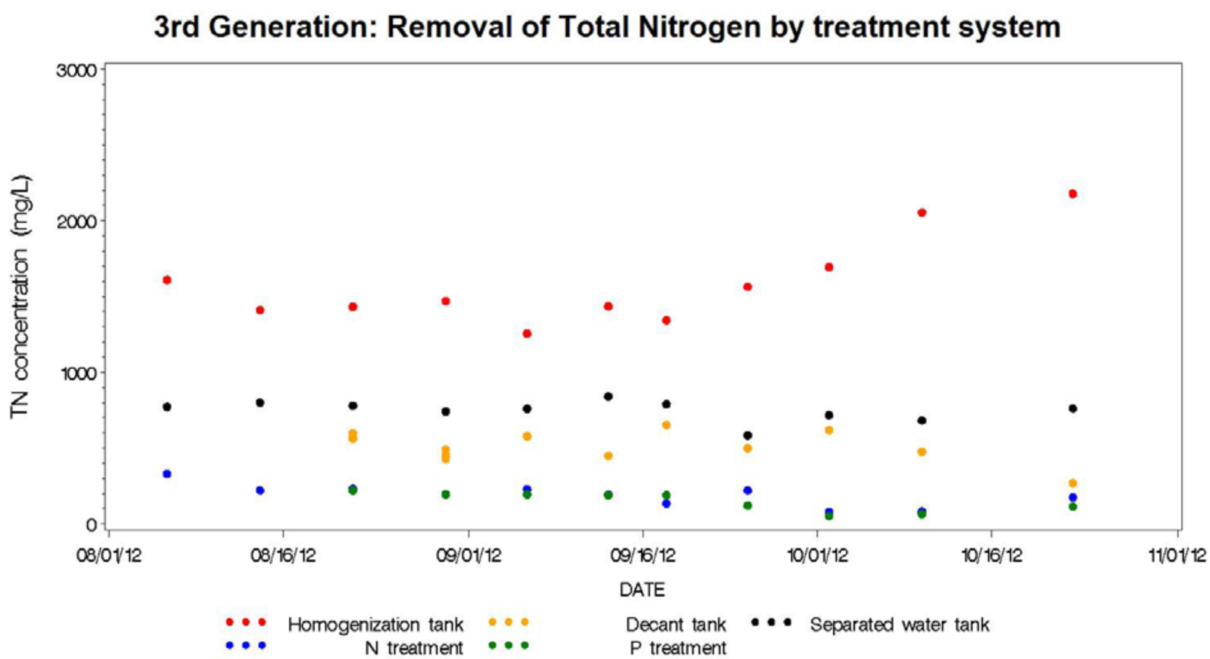


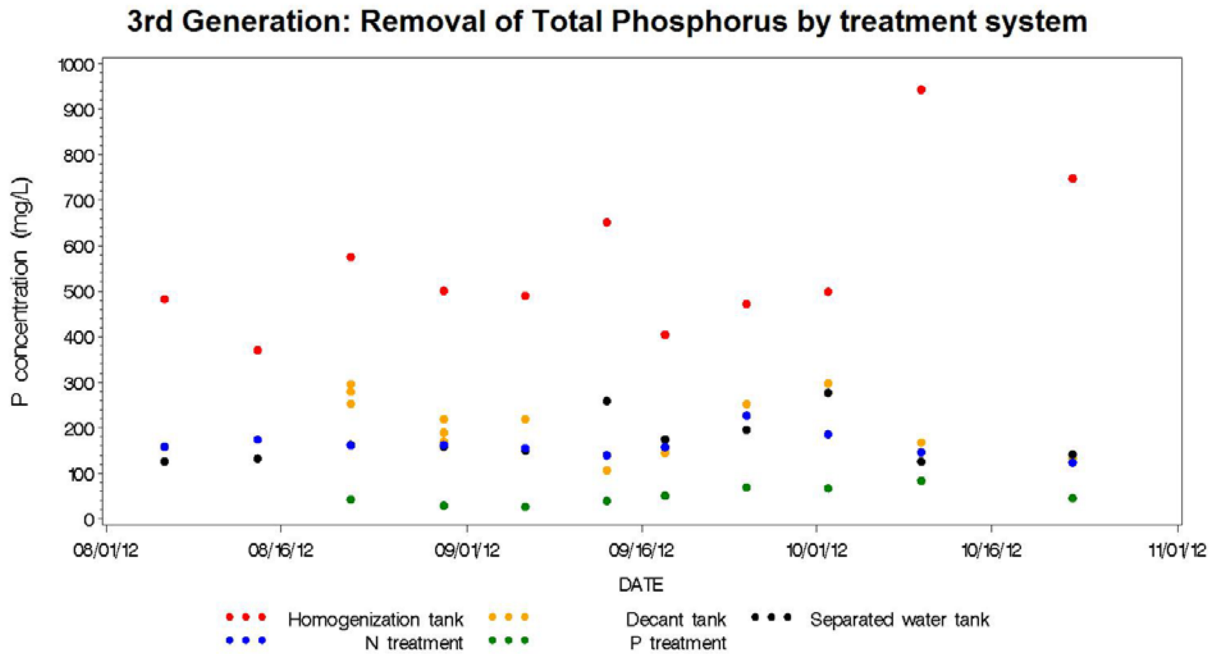


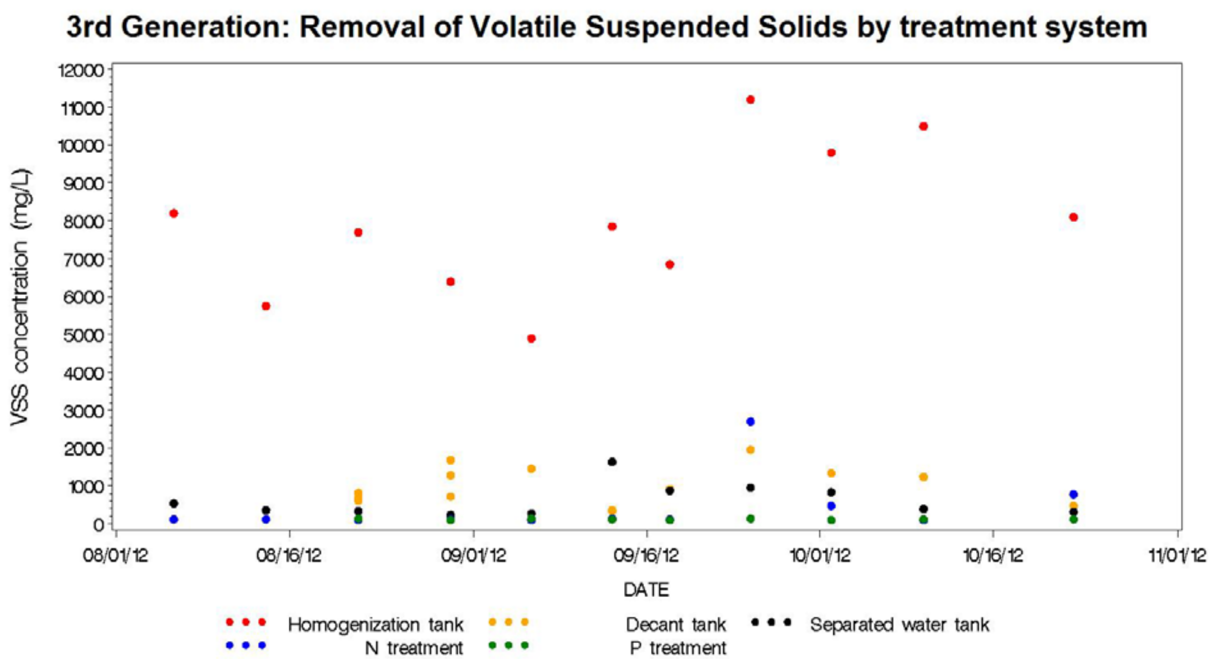

3rd Generation: Removal of COD by treatment system
COD concentration (mg/L)
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
08/01/12
08/16/12
09/01/12
09/16/12
10/01/12
10/16/12
11/01/12
DATE
Homogenization tank
Decant tank
Separated water tank
N treatment
P treatment

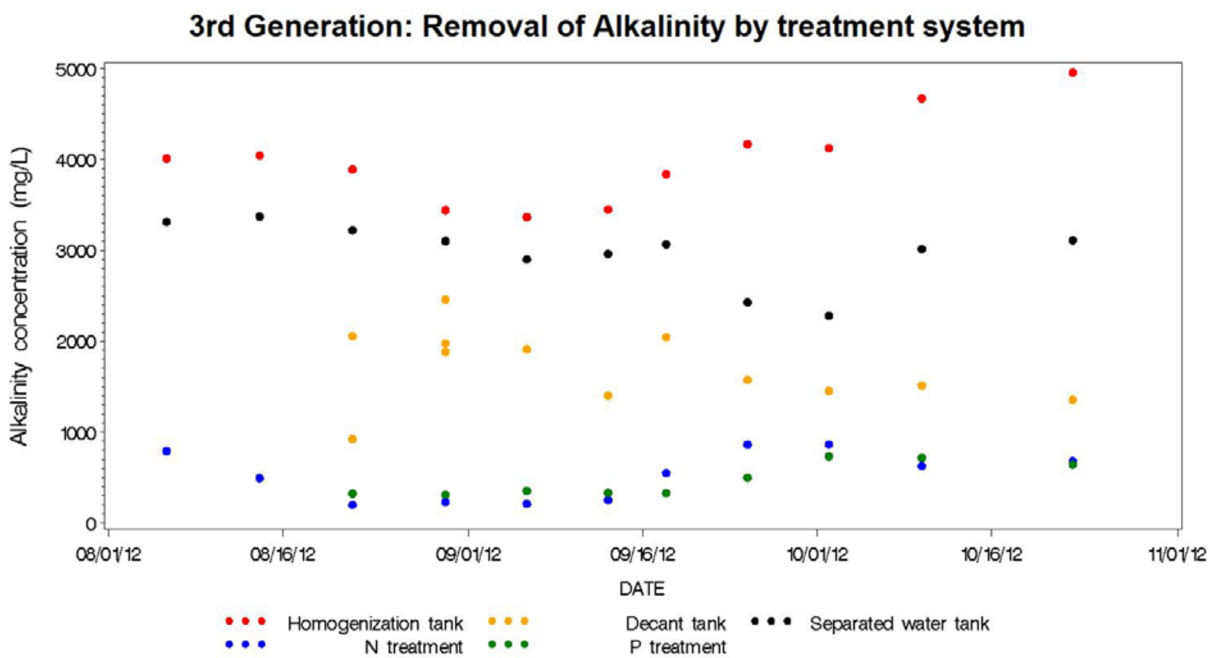

3rd Generation: Removal of Ammonia by treatment system
NH4—N concentration (mg/L)
1000
900
800
700
600
500
400
300
200
100
0
08/01/12
08/16/12
09/01/12
09/16/12
10/01/12
10/16/12
11/01/12
DATE
Homogenization tank
Decant tank
Separated water tank
N treatment
P treatment


3rd Generation: Removal of TKN by treatment system
TKN concentration (mg/L)
3000
2000
1000
0
08/01/12
08/16/12
09/01/12
09/16/12
10/01/12
10/16/12
11/01/12
DATE
Homogenization tank
Decant tank
Separated water tank
N treatment
P treatment


3rd Generation: Removal of Total Nitrogen by treatment system
TN concentration (mg/L)
3000
2000
1000
0
08/01/12
08/16/12
09/01/12
09/16/12
10/01/12
10/16/12
11/01/12
DATE
Homogenization tank
Decant tank
Separated water tank
N treatment
P treatment


3rd Generation: Removal of Total Phosphorus by treatment system
P concentration (mg/L)
0
100
200
300
400
500
600
700
800
900
1000
08/01/12
08/16/12
09/01/12
09/16/12
10/01/12
10/16/12
11/01/12
DATE
Homogenization tank
Decant tank
Separated water tank
N treatment
P treatment


3rd Generation: Removal of Volatile Suspended Solids by treatment system
VSS concentration (mg/L)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
08/01/12
08/16/12
09/01/12
09/16/12
10/01/12
10/16/12
11/01/12
DATE
Homogenization tank
Decant tank
Separated water tank
N treatment
P treatment



3rd Generation: Removal of Alkalinity by treatment system
Alkalinity concentration (mg/L)
5000
4000
3000
2000
1000
0
08/01/12
08/16/12
09/01/12
09/16/12
10/01/12
10/16/12
11/01/12
DATE
Homogenization tank
Decant tank
Separated water tank
N treatment
P treatment

Appendix C: Monitoring of liquid level dynamics using ultrasonic probes in various tanks.

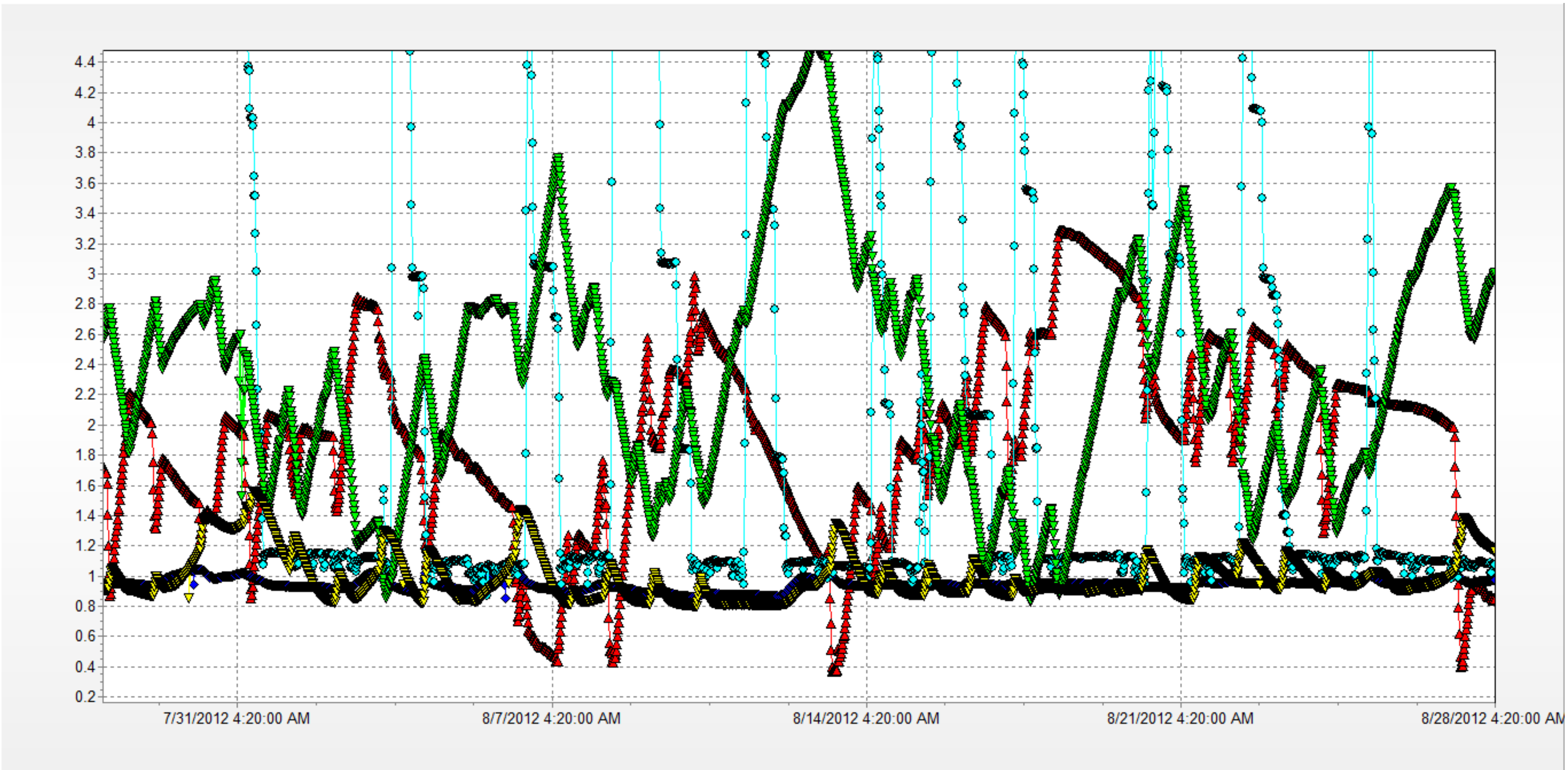


Figure C1. Liquid level changes in various system tanks during August 2012. Red = homogenization tank; Green = separated water tank; Light Blue: Decant tank; Yellow = clean water tank; Blue = N settling tank. Y axis show distance (meters) from probes on top of tank. Lines going up or down indicate a tank being emptied or filled, respectively.

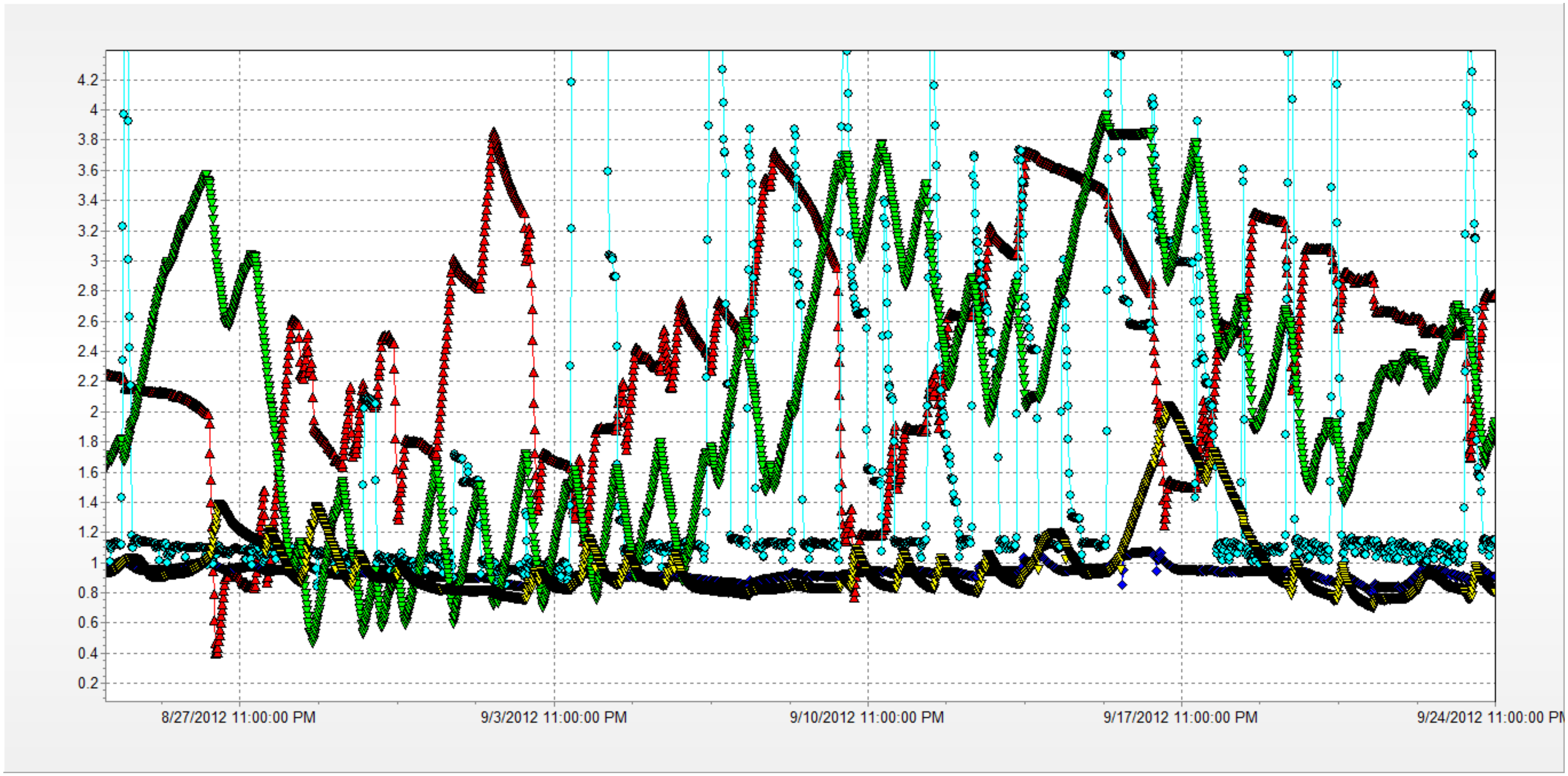


Figure C2. Liquid level changes in various system tanks during September 2012. Red = homogenization tank; Green = separated water tank; Light Blue: Decant tank; Yellow = clean water tank; Blue = N settling tank. Y axis show distance (meters) from probes on top of tank. Lines going up or down indicate a tank being emptied or filled, respectively.

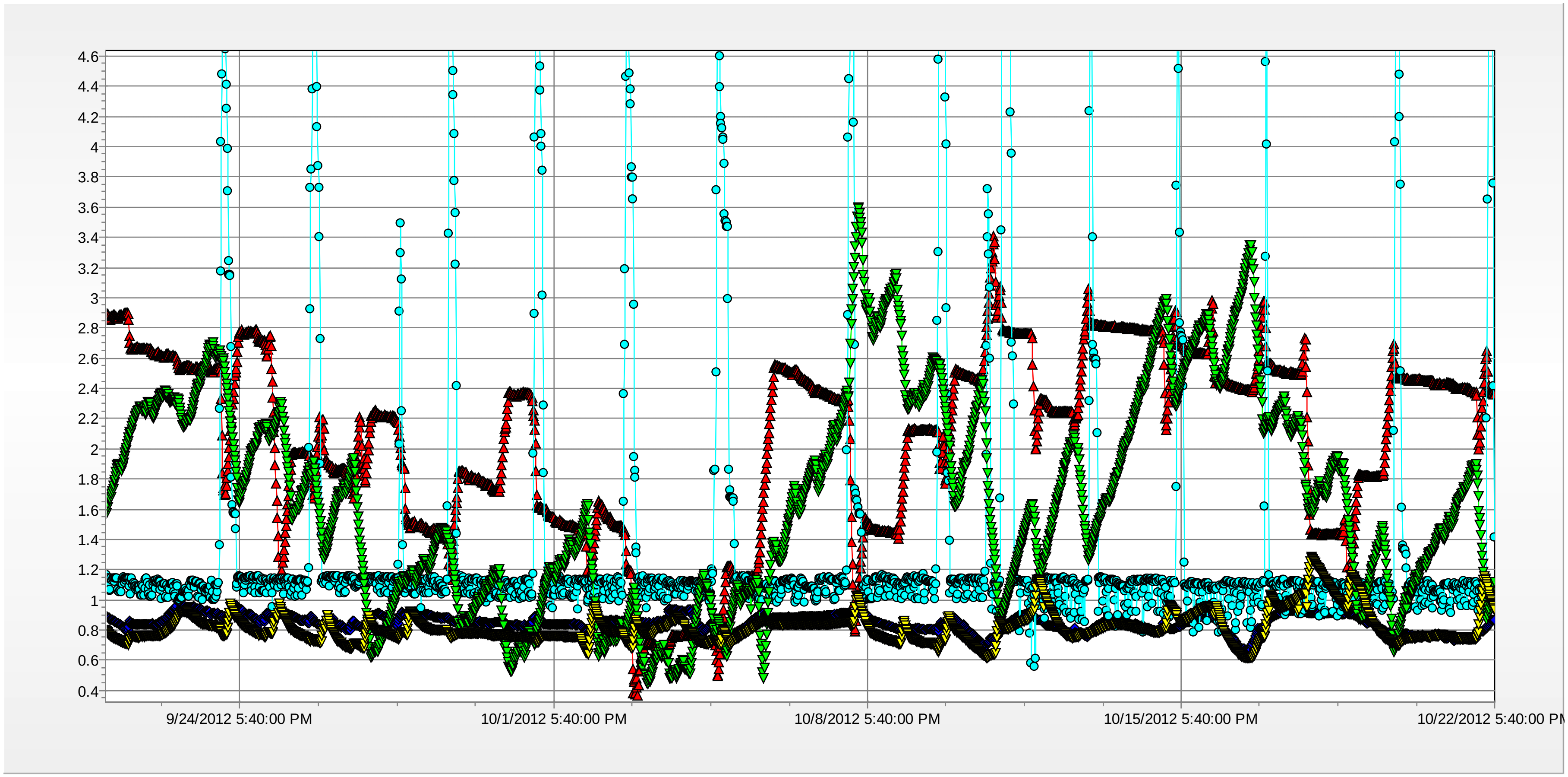


Figure C3. Liquid level changes in various system tanks during October 2012. Red = homogenization tank; Green = separated water tank; Light Blue: Decant tank; Yellow = clean water tank; Blue = N settling tank. Y axis show distance (meters) from probes on top of tank. Lines going up or down indicate a tank being emptied or filled, respectively.