ABSTRACT

BENNETT, TODD ALAN. Evaluation of Bench-Scale Sequencing Batch Reactor Swine Waste Treatment Under Continuous and Cyclic Aeration. (Under the direction of John J. Classen and Sarah K. Liehr.)

The objectives of this project were to develop operating conditions for a bench-scale sequencing batch reactor to match the design of a full-scale sequencing batch reactor system for treating swine waste and to determine the effects of continuous, low oxygen versus cyclic aeration schemes on sequencing batch reactor system performance. The low aeration technique was intended to develop conditions for low oxygen nitrification and simultaneous nitrification and denitrification so that a comparison could be made to a typical cyclic aeration reactor for biological nitrogen and phosphorus removal. The performance of the two reactor configurations was measured by the settling efficiency, mass removal efficiency, and accumulation of chemical oxygen demand (COD), suspended solids (SS), total Kjeldahl nitrogen (TKN), and total phosphorus (TP). The performance of the reactors did not meet expectations due to excessive loading and source inconsistency. Operational changes to the solids wasting mechanism and to the cyclic aeration system were made during the experiment in an attempt to stimulate reactor performance, which provided insight into the responses of the two types of reactors to these changes. The performance of the continuous aeration reactors met or exceeded the performance of the cyclic aeration reactors, while receiving a 73% lower supply of oxygen. The results support the potential for equipment and energy savings by utilizing low-oxygen continuous aeration for the treatment of swine waste with sequencing batch reactors.

EVALUATION OF BENCH-SCALE SEQUENCING BATCH REACTOR SWINE WASTE TREATMENT UNDER CONTINUOUS AND CYCLIC AERATION

by
TODD ALAN BENNETT

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

BIOLOGICAL AND AGRICULTURAL ENGINEERING

Raleigh, North Carolina

2007

Sarah K. Liehr	Michael R. Hyman

Chair of Advisory Committee
John J. Classen

BIOGRAPHY

I was born and raised in Wichita, Kansas and attended school in the Goddard Public School System in Goddard, Kansas. I attended Kansas State University, where I received a Degree of Bachelor of Science in Biological and Agricultural Engineering and a Minor Degree in Chemistry. I moved to Raleigh, North Carolina to pursue a Degree of Master of Science in Biological and Agricultural Engineering at North Carolina State University, with an area of emphasis in Microbiology. In 2002, I began working with Cavanaugh & Associates, P.A., a private engineering firm, as a project manager. In 2004, I joined the North Carolina Department of Environment and Natural Resources, Division of Water Quality as an Environmental Engineer in the Animal Feeding Operations Unit. I worked in the Fayetteville Regional Office as an animal operation and innovative waste treatment system inspector. I now work in the Raleigh Central Office in the Animal Feeding Operations Permitting and Compliance Unit as the coordinator for the regulation of North Carolina’s innovative animal waste treatment systems.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Problem

The second half of the twentieth century saw a significant change in the swine industry. Between 1954 and 1996, the number of swine farms within the United States fell from over 2 million to just over 200,000, which corresponds to the ten-fold increase seen in the number of head per farm (Ensminger and Parker, 1997). Not only are the farms increasing in size, the farms themselves are becoming more concentrated in certain regions of the United States. Specifically, over the past decade, swine production in North Carolina has shown a dramatic increase. In 1986, the swine population in the State was around 2.4 million, but by 2004 the population had reached over 10 million (NCDA&CS, 2005). The traditional family swine farm is heading toward extinction; today, swine production consists of producing the largest amount of meat in the smallest amount of space possible.

The shift in farm design, which was brought about in response to economics and public demand, has led to a problem – animal waste. These highly populated facilities lead to high concentrations of solid and liquid waste that must be dealt with. Presently, the treatment system of choice of producers is the anaerobic lagoon system with spray irrigation. This type of system is relatively cheap and easy to operate, however lagoons produce very significant problems and nuisances if there is a lack of proper maintenance. Anaerobic lagoons contain water, organic material, and compounds resulting from the decomposition of that matter, such as ammonia (NH_3), methane (CH_4), and hydrogen sulfide (H_2S), which are released to the atmosphere. This waste treatment method is subject to odor complaints, over-application of treated water to spray fields, groundwater seepage, and structural failure. North Carolina pork producers came under fire from political and environmental groups after storm events in 1999 led to a number of lagoon floods and failures, causing millions of gallons of wastewater to flow into streams and rivers.

Smithfield Foods, based in Smithfield, Virginia, owns Murphy-Brown, LLC, the largest pork-production company in the world (Smithfield, 2005). In response to increasing public pressure regarding the environmental threat of North Carolina's swine production, the Attorney General and representatives from Smithfield Foods came together to develop a plan of action, resulting in what was called the Smithfield Agreement, which was signed July 25, 2000. Smithfield agreed to provide $15 million for the construction, operation, and investigation of full-scale innovative animal waste treatment systems. The intention of the project was to determine whether systems could be considered "environmentally superior technologies" (EST), meaning that they met a set of technical, economical, and operational criteria. The technical-performance criteria are as follows:

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

Once systems are designated as environmentally superior, Smithfield Foods is required to place these systems on their company-owned farms within North Carolina (Agreement, 2000). In addition to Smithfield Foods Inc., Premium Standard Farms agreed to commit $2.5 million to the project, and the swine farmer organization known as Frontline Farmers joined as well.

After a call for proposals and a thorough review process, the selection committee chose sixteen technologies for full-scale demonstration. One of these potential technologies was the sequencing batch reactor. Alternative Natural Technologies, Inc., a company based in Blacksburg, Virginia, submitted the proposal and designed a SBR system, which they believed would meet the EST criteria.

1.2 Sequencing Batch Reactors

The theory behind sequencing batch reactors is fairly simple. Each reactor accepts a certain volume of a wastewater, microbiologically treats the water for a specific amount of time, and releases that original volume as effluent from the reactor. One of the attractive aspects of the SBR is that it is very versatile. It is an activated-sludge process, but all of the treatment occurs in a single reactor. The treatment is based on a timed schedule of filling, mixing/reacting, settling, and drawing (USEPA, 1999). The SBR configuration can be changed to match a certain wastewater, depending upon its characteristics and the treatment goals. Different SBR factors include, but are not limited to, reactor volumes, hydraulic residence times (HRT), solids retention times (SRT), influent/effluent volumes, mixing rates, aeration methods and cycles, microbiological growth-support media, and temperature. Some SBR designs may treat an entire reactor volume of liquid over a long period of time, while other designs may treat partial volumes with a fraction of the reactor volume added and withdrawn before and after the reaction/settling stages. These types of reactors are good for removal of the major constituents of swine wastewater: organics, nitrogen, and phosphorus.

1.3 Chemical Oxygen Demand

The Chemical Oxygen Demand (COD) is an indication of the amount of energy and carbon there is available to the heterotrophic microbial population within the reactors. A well-designed and well-operated biological reactor should maximize the utilization of the COD. COD describes the oxygen requirement to completely oxidize the organic compounds within a wastewater. A portion of this oxidation can occur through biological processes and is called Biochemical Oxygen Demand (BOD). The BOD of a wastewater represents the potential for microorganisms to reduce the COD during an amount of time equal to five or seven days (BOD_5 or BOD_7). The COD is always greater than or equal to the BOD, so there is some COD that is not met by a biological waste treatment system. This non-biodegradable COD leaves the reactors during the wasting of accumulated solids.

1.4 Nitrification

Nitrification is the two-step process for the conversion of nitrogen in the form of ammonia/ammonium to the form of nitrate or nitrite. The total ammoniacal nitrogen (TAN) in the wastewater originates from the breakdown of urea by the enzyme urease, which is present in fecal matter, and the breakdown of proteins in organic matter, which contain amine groups. The combination of the urine and feces releases a large amount of ammonia. Genera of microorganisms that scientists believe play roles in nitrification are *Nitrosomonas, Nitrobacter, Nitrosospira, Nitrosolobus, Nitrosovibrio,* and *Nitrosococcus* (Madigan et al., 2000). These genera of organisms are autotrophic, so their carbon source is carbon dioxide (CO_2). Ammonia oxidizing bacteria, such as *Nitrosomonas,* utilize the reduced nitrogen in ammonia as the electron donor, or energy source. They oxidize it to form nitrite (NO_2^-), using oxygen (O_2) as the terminal electron acceptor (TEA). Nitrite-oxidizing bacteria, such as *Nitrobacter*, then use the nitrite as their energy source with oxygen as the TEA to form nitrate (NO_3^-) (Madigan et al., 2000). One difficult thing about this process is that ammonia-oxidizers grow slower than typical heterotrophic organisms, which compete with them for oxygen. Nitrite-oxidizers have a higher growth rate but are dependent on ammonia-oxidizers for a supply of nitrite. Therefore, the amount of time microbial biomass must remain in nitrifying reactors must be longer than treatment systems designed for COD removal in order to provide enough time for the nitrifying bacteria to grow. Removing the biosolids from the waste treatment system at a high rate (short SRT) would cause the organisms to be flushed out before being able to establish the nitrogen-removal processes. Optimal nitrification occurs at a temperature range between 28 and 33^oC, a dissolved-oxygen content of at least 1 mg/L, and a pH between 7.5 and 8.6 (McGhee, 1991; Crites and Tchobanoglous, 1998).

Given the oxygen-poor environment of anaerobic lagoons, it traditionally has been assumed that nitrogen loss from lagoon surfaces is due to ammonia volatilization. However, recent research investigating gas flux from anaerobic lagoons has revealed that dinitrogen gas is a significant constituent of the total nitrogen losses from the surface (Harper and Sharp, 1998; Harper et al. 2000). Jones et al. (2000) reviewed several potential mechanisms for this unexplained phenomenon, one of which was low oxygen nitrification. Other oxygen-poor environments have been found that support the possibility of low oxygen nitrification. Investigation into the root zone of some wetland plants in saturated soil conditions have shown elevated numbers ammonia-oxidizing and nitrite-oxidizing bacteria (Both et al., 1992). Also, elevated nitrite levels have also been detected in estuary sediment (Helder and de Vries, 1983). The elevated nitrite levels indicate activity of ammonia oxidizers and some suppression of nitrite-oxidation activity, which was supported by an investigation into mixed cultures of *Nitrosomonas europaea* and *Nitrobacter winogradskyi* by Laanbroek and Gerards (1993). They found that nitrite-oxidation activity by *N. winogradskyi* was reduced much more than was for ammonia-oxidation activity by *N. europaea* when the oxygen tension in the environment was dropped to 1.5 – 2.5 kPa.

Additional support for the potential of low oxygen nitrification is found in a study by Bock et al. (1995), where pure cultures of *Nitrosomonas* were developed under oxygen-limitation conditions. The cultures were developed over a period of several months. Dissolved oxygen levels were dropped to as low as 0.2 mg/L, and ammonia oxidation occurred, though at a much slower rate than for a dissolved oxygen concentration of 0.4 mg/L. The study centered on the ability of the nitrifying organisms to adapt to the environment, and provide denitrification capabilities as well, by the development of alternative cellular structures and configurations of those structures. The oxygen-limited *Nitrosomonas* cultures developed layers of membranes with alternating areas of high and low electron density, providing areas within the cells to carry out the denitrification processes. The well-aerated *Nitrosomonas* cultures did not show this same adaptation. Though the study presents the possibility of nitrifiers to adapt to low oxygen environments, it still does not take into account the complicating factor of oxygen competition that exists in mixed-culture environments.

As discussed previously, nitrifying bacteria grow slower than typical heterotrophic microorganisms. A typical measure to compare the growth rates of microorganisms is the half-saturation constant (K_m). For modeling of cell growth, K_m is defined as the nutrient concentration that a population of a particular species grows at half of the maximum rate (Crites and Tchobanoglous, 1998). Typical K_m values for heterotrophic bacteria range from 0.006-0.1 mg/L, while nitrifying bacteria have shown to have K_m values only as low as 0.2-0.5 mg/L (Sharma and Ahler, 1977; Bodelier et al., 1996). However, looking at oxygen-limited situations, Bodelier et al. (1996) investigated the specific affinity of lake sediment nitrifiers. Specific affinity, or competitive ability, is defined as the maximum consumption capacity (V_m) divided by K_m. After converting the specific affinity to a "per cell" basis, they found some of the nitrifier samples to have affinities of 169 nL/cell/hr, which was seven times greater than typical values for *Escherichia coli* and fifty-seven times greater then for pure cultures of *Nitrosomonas europaea*. Hanaki et al. (1990a and 1990b) investigated nitrification suppression by means of organic loading with and without oxygen limitation. When sufficient oxygen was present, a drop in nitrification rate was observed due to competition from the heterotrophic organisms due to their assimilation of the ammonia. With the addition of limited oxygen as a variable, ammonia oxidation was strongly inhibited but not ceased. A wastewater, such as swine wastewater, having a high concentration of ammonia would not see the same suppression due to the removal of competition for the ammonia. Designing a system with an extended SRT would allow for adaptation by the nitrifiers, which could lead to a reduction in observed inhibition of nitrification due to low dissolved oxygen.

The studies reveal the potential for nitrifying bacteria to adapt to oxygen-limited environments, provided there is adequate time. For example, with open-air lagoons, even if they are designed to be anaerobic, there is a constant interface with air, providing a source of oxygen to the liquid surface. This steady supply of low-level oxygen, though in a highly competitive environment, could possibly provide an adequate environment for nitrifiers to grow, since lagoons are designed for extensive retention times. If an activated sludge waste treatment system were developed to utilize a low oxygen nitrification mechanism, there would be potential for considerable energy savings by reducing the requirement for high dissolved oxygen concentrations.

1.5 Denitrification

Denitrification is the conversion of nitrate or nitrite into various reduced nitrogen compounds. Microorganisms utilize the nitrate as an electron acceptor in the absence of oxygen. When microorganisms deplete the dissolved oxygen in a system, the system is often described as anaerobic. In anaerobic conditions, fermentation takes place by those cells that are capable of adaptation to the lack of oxygen. However, if there is nitrate or nitrite present after the oxygen is depleted, some organisms will make metabolic adjustments in order to respire using the nitrate or nitrite instead of being forced to use fermentation, which yields much less energy, or to go dormant. Scientists refer to this environmental state as anoxic. The energy yield for nitrate respiration is not as high as that for aerobic respiration, but nitrate is still an effective terminal electron acceptor (Madigan et al., 2000). The metabolism for this process generally is heterotrophic. Organic compounds act as both the carbon and energy sources. The first step of denitrification is the reduction of nitrate to nitrite. Then, depending on each species, the organisms reduce the nitrite further to various nitrogen oxides and/or dinitrogen gas. Many different species of bacteria have the capability of denitrification, including those from *Pseudomonas, Achromobacter, Bacillus, Rhizobium, Aquaspirillum, Flavobacterium, Aeromonas, Moraxella,* and even some yeasts (Coyne et al., 1989; Carter et al., 1995). In aerobic conditions, the oxygen acts as an inhibitor to the enzymes that are necessary for anoxic respiration to occur. These organisms typically have a quick growth rate so they do not face the same competitive problems as the nitrifying bacteria (Madigan et al., 2000).

An alternative to this oxygen-dependant nitrification process is simultaneous nitrification and denitrification (SND). By providing a constant low-level dissolved oxygen concentration in a waste treatment system, researchers have found that microorganisms can develop floc or granules that have zones that are capable of carrying out both nitrification and denitrification processes (von Schulthess et al., 1994; Bock et al., 1995; Goronszy et al., 1996; Gibbs et al., 2004; de Kreuk et al., 2005). Nitrification occurs on the exterior of the floc where the dissolved oxygen is available, while denitrification occurs within the floc, where dissolved oxygen is not available. For SND, full nitrification to nitrate does not always occur. Due to limited availability of oxygen and inhibition of nitrite oxidizers, nitrite becomes an important factor in SND treatment. Yoo et al. (1999) summarized several factors that may contribute to the inhibition of nitrite oxidation: temperature, dissolved oxygen (DO) to free ammonia (FA) ratio, FA concentration, and free hydroxylamine concentration. Above temperatures from 20 – 25 ^{o}C, the nitrite oxidation rate slows and the ammonia oxidation rate increases. Where DO:FA < 5 during nitrification, the rate of nitrate formation was reduced (Cecen and Gonenc, 1994). Nitrite oxidizers that are given time to acclimate to high FA have been found to tolerate FA concentrations up to 40 mg NH_3-N/L, while non-acclimated nitrite oxidizers tolerate up to 3.5 mg NH_3-N/L (Wong-Chong and Loehr, 1978). Hydoxylamine, which is an intermediate for ammonia oxidation and is likely to accumulate in conditions of high FA, low DO, and high pH, was identified by Yang and Alleman (1992) to inhibit the activity of *Nitrobacter*.

The nitrite that is not oxidized to nitrate can be utilized in two ways. Due to the limited oxygen availability for SND, the nitrite can be utilized by organisms as a TEA in anaerobic respiration, similar to nitrate in the conventional denitrification process (Madigan et al., 2000). The reduction potential for NO_2^- to NO is +0.36 V, which is much lower than for O2 to H2O (+0.82 V) and lower than for NO_3^- to NO_2^- (+0.43 V), but microorganisms will take advantage of the presence of nitrite if it is the most available TEA (Thauer et al., 1977). Nitrite can also be utilized in anaerobic ammonia oxidation, which is carried out according to the following equation (Broda, 1977).

$$NH_4^+ + NO_2^- \rightarrow N_2 + 2\ H_20$$

The ammonium is utilized as the electron donor for the autotrophic process. The simultaneous treatment of ammonium and nitrite in this process would be beneficial with regard to cost since less oxygen would be required to meet the requirements of complete nitrification of the ammonia. Also, the biomass yield for anaerobic ammonia oxidation is low, so there is little sludge accumulation involved with the process (Strous et al., 1997).

1.6 Polyphosphate Accumulating Organisms

Organisms from the groups *Rhodocyclus* and *Actinobacteria* have been identified as polyphosphate accumulating organisms (PAO) (Crocetti et al., 2000, Liu et al., 2001). These organisms store carbon in the form of polyhydroxyalkanoates (PHA). The PHA formed by PAOs has been found to be in the following four forms: 3-hydroxybutyrate, 3-hydroxyvalerate, 3-hydroxy-2-methylbutyrate, and 3-hydroxy-2-methylvalerate (Mino et al., 1998).

In order for this process to take place, there must be a supply of short-chain fatty acids as the carbon source and source of energy to bind them together into PHA. The energy comes from the breaking of polyphosphate (poly-P) molecules or from utilizing stored glycogen. For the case of poly-P, in anaerobic conditions, PAOs generate the PHA utilizing the energy from the hydrolysis of poly-P. The resulting orthophosphate is released into the environment. However, in aerobic conditions, PAOs collect the orthophosphate in high amounts as a luxury uptake for regeneration of poly-P levels (Merzouki et al., 1999). The PHA is used as both a carbon and energy source for the recovery and additional storage of the poly-P (Mino et al., 1998). In wastewater treatment systems, when there are alternating anaerobic and aerobic conditions, the PAOs release the orthophosphate in the anaerobic part of the cycle and then collect a greater amount of it in the aerobic part of the cycle. After a number of cycles of these conditions, a majority of the orthophosphate is incorporated into the biomass of the organisms. The removal of this incorporated phosphorus occurs by the separation of the biomass by means such as filtering and settling.

1.7 Oxygen Balance

The performance of the sequencing batch reactors, in particular the COD removal and nitrification, is dependent on the availability of oxygen within the systems. For SBR wastewater treatment, the goals are maximum COD reduction and maximum removal of total Kjeldahl nitrogen (TKN), while minimizing the energy requirements for providing the oxygen.

The treatment system design must first take into account the particular wastewater to be treated. At a minimum, the oxygen demand from COD and TKN must be met. For a batch reactor, this amount is calculated from the batch mass influent rates of these two parameters. For activated sludge processes utilizing nitrification, the oxygen requirements are 0.8 – 1.1 kg O_2/kg COD and 4.6 – 4.7 kg O_2/kg NH_3-N added (Crites and Tchobanoglous, 1998). This oxygen demand must be provided during each period of the designed batch cycle. However, if a treatment system utilizes low oxygen nitrification and SND techniques, some of the oxygen demand will be met by the utilization of nitrate and nitrite as TEA in place of oxygen. Also, because the nitrite utilized as a TEA will not proceed to nitrate, the oxygen not used for the complete nitrification of nitrite to nitrate would be excluded from the oxygen balance. The oxidation of nitrite is described in the following formula:

$$NO_2^- + ½\ O_2 \rightarrow NO_3^-$$

Therefore, for every mol of nitrite that is utilized as a TEA, 0.5 mol of oxygen, or 1.1 kg O_2/kg NO_2^--N as TEA, is conserved from the nitrification process. The utilization of nitrite and nitrate as TEA then also causes a reduction in the COD that needs to be met by oxygen. In the electron transport processes of respiration, the following formulas describe the reduction of oxygen, nitrate, and nitrite as TEA (Madigan et al., 2000):

$$2\ H^+ + ½\ O_2 + 2\ e^- \rightarrow H_2O$$

$$6\ H^+ + NO_3^- + 5\ e^- \rightarrow ½\ N_2 + 3\ H_2O$$

$$4\ H^+ + NO_2^- + 3\ e^- \rightarrow ½\ N_2 + H_2O$$

These equations indicate that two moles of either nitrate or nitrate is equivalent to one mol of oxygen. Therefore, 0.35 kg of NO3-N and 0.58 kg of NO2-N are equivalent to 1.00 kg of

COD. In other words, 1.00 kg of NO3-N utilized as a TEA accounts for 2.86 kg of COD, and 1.00 kg of NO2-N utilized as a TEA accounts for 1.72 kg of COD.

A key to meeting the minimum oxygen demand of the wastewater is dealing with the oxygen transfer rate (OTR) from a gaseous to dissolved state. The OTR of gaseous oxygen to dissolved oxygen (DO) is based on many factors, including salinity, temperature, diffuser depth, placement, airflow rate, and mixing method. With a longer contact time between the air and liquid surface, more oxygen will be able to diffuse into the wastewater. Depending on the sophistication of the aeration system, there will be a certain efficiency of oxygen transfer from the air to the wastewater as DO. A fraction of the oxygen will move straight through the water column and not be made available to the reactor for COD or TKN treatment. Therefore, a higher amount of oxygen must be supplied to the reactor to account for this oxygen loss. The amount of this additional supply of oxygen is very much dependent on treatment goals. Actual oxygen transfer efficiency (AOTE) is a ratio of the actual amount of oxygen provided to the system by the aeration mechanism compared to the amount of oxygen required by the treatment system. For standard activated sludge processes utilizing nitrification with a diffuser depth of 15 feet, typical AOTE values range from 0.04 – 0.08 for coarse diffusers, 0.08 – 0.14 for fine diffusers, and 0.10 – 0.16 for very fine diffusers (Crites and Tchobanoglous, 1998). The selection of aeration design for wastewater treatment involves the balancing of the AOTE level with the equipment and energy costs willing to be spent to achieve that level.

1.8 High-Strength Wastewater

Another consideration for design and effectiveness of a SBR treatment system is the wastewater strength, meaning the concentration of the COD and nutrients to be removed during treatment. Municipal wastewater typically has COD concentrations ranging from 175 – 600 mg/L, nitrogen concentrations ranging from 13 – 60 mg/L, and phosphorus concentrations ranging from 7-20 mg/L (McGhee, 1991). Agricultural animal wastewater is more concentrated. For instance, swine anaerobic lagoon liquid typically has COD concentrations ranging from 482 – 6869 mg/L, TKN concentrations ranging from 62 – 1400 mg/L, and phosphorus concentrations ranging from 18 – 225 mg/L (Barker et al., 1994). Anaerobic lagoon liquid typically is recycled back to the swine houses to flush the accumulated waste. Fresh waste characteristics for feeder to finish swine average 56 kg total solids/animal, 4.7 kg N/animal, and 0.76 kg P/animal (ASABE, 2006). The loading calculations for the treatment system design must take into account the number of animals, the particular waste characteristics of the animals, the type of flushing mechanism in place, the amount and waste characteristics of recycled wastewater utilized for flushing, and the frequency of flushing. This information provides the basis for the sizing of tanks, pumps, piping as well as mixing and aeration requirements.

High-strength waste also presents potential problems in the performance of the systems. Of particular interest is nitrification inhibition. Factors that have been known to influence the inhibition of nitrification include high COD concentration, high ammoniacal nitrogen concentration, high pH, insufficient DO concentration, excessive wastewater agitation, and high BOD to TKN ratio (Barnes and Bliss, 1983). In order to avoid inhibition of the nitrification process, it is important to closely monitor the treatment results to identify preliminary signs of these factors.

1.9 Sequencing Batch Reactor Treatment of Animal Waste

A great deal of research on the potential of sequencing batch reactors to treat animal wastewater has been conducted. Bortone et al. (1994) compared two SBR systems, an anaerobic-aerobic design and an anaerobic-anoxic design, with nitrification in a secondary reactor. The anaerobic-aerobic system, which had nearly the same characteristics as the systems investigated in this study, was set with a 12-hr cycle, having an HRT of 11 days, an SRT of 15 days, and a temperature of around 20-23 ^{o}C. The aeration was controlled to obtain 2.0 mg/L of dissolved oxygen during the aeration phases. The swine wastewater underwent screening before being applied to the reactors, which significantly reduced the COD. The results showed decreases of 94% soluble COD, 98% TKN, and 92% total P. The experiment shows that the simultaneous biological removal of nitrogen and phosphorus is possible within a single reactor.

Obaja et al. (2003) investigated the treatment of anaerobically digested swine-waste to determine a detailed relationships involving temperature and system performance. Their system was operated on an 8-hr cycle, with an HRT of one day and an SRT of 11 days. They investigated system performance for a temperature range of 8 – 30 ^{o}C. They weakened the wastewater by means of centrifugation and dilution with tap water and added acetate as an additional source of COD. The ammonia utilization reached the maximum rate at around 16 ^{o}C and maintained that utilization rate up to 30 ^{o}C. The nitrogen utilization reached the maximum rate at around 12 ^{o}C and maintained that utilization rate up to 30 ^{o}C. There was no significant effect by temperature on the oxygen utilization rate. Overall, they obtained reductions of 70.2% for COD, 99.7% for nitrogen, and 97.3% for phosphorus. They concluded that there must be a carbon-to-nitrogen (C:N) ratio greater than 1.7 for complete denitrification to occur and that the system should operate at above 16 ^{o}C. This C:N ratio is based on the readily utilizable carbon from acetate. Full strength swine waste is composed of much more complex organic compounds that are not readily available for use as carbon sources for the treatment organisms. Some of these compounds may biodegrade at such a slow rate that they pass through the system. There must be a larger supply of carbon into the system to account for the carbon that is unavailable to the organisms. Therefore, for full-strength swine wastewater treatment would require a higher C:N ratio than the 1.7 calculated by Obaja et al.

Edgerton et al. (2000) developed a pilot-scale sequencing batch reactor for a swine facility in Australia. This system received wastewater that had been screened to remove the large solid particles, but the liquid was still high in suspended solids. They operated an 8-hr cycle with 3.5 hours for the aeration phase and maintained a HRT of 6.7 days. The treatment system resulted in the removal of 99% of total ammoniacal nitrogen (TAN), 79% of COD, and 49% of phosphate-P. The system was subject to foaming problems and struvite crystal formation during operation.

Bicudo et al. (1999) constructed and tested a pilot-scale sequencing batch reactor, investigating its biological nutrient-removal performance with varying aeration cycles and hydraulic retention times. The system was designed to receive 1.5 m^3/d of swine wastewater and to maintain a 35-day solids retention time (SRT). The study determined that a more rapid on/off aeration cycle (1 hr on – 1 hr off) along with a HRT of 10 days provided the best results: 93% COD removal, 75% volatile solids removal, and 95% total nitrogen removal. These same operational conditions resulted in the highest phosphorus removal as well, averaging 70%.

Tilche et al. (2001) designed and installed a full-scale SBR system for the treatment of swine wastewater in Italy. The system was designed to receive 150 – 190 L/d/ton animal live weight, corresponding to a maximum oxygen supply of 1,500 kg/d. Prior to treatment, solids were removed by a centrifuge. The system operated at a SRT of 15 days and five, 4-hr anoxic-anaerobic/oxic cycles per day and one, 4-hr settling/decanting phase per day. The researches found that higher numbers of cycles resulted in improved nutrient removal (Tilche et al., 1999). The system consisted of two parallel SBR units, each with a capacity of 1,250 m^3. The system was operated for one year and had the following average removal performances: 97.9% for TSS, 98.5% for TKN, 98.6% for COD, and 96.0% for TP.

Poo et al. (2004) investigated a full-scale SBR system for the treatment of three types of swine waste: raw swine-slurry wastewater, digested swine-slurry wastewater, and swine-urine wastewater. The wastewater characteristics ranged from 23,000 – 72,000 mg/L COD, 3,500 – 6,000 mg/L ammoniacal nitrogen, and 40 – 160 mg/L orthophosphate. The system operated on five cycles of 1 hr of anoxic conditions and 3 hr of aeration. Three hours were provided for settling and one hour for decanting, desludging, and idling. The system did not utilize pretreatment. Waste was fed to the SBR intermittently, and methanol was added to improve denitrification performance. The evaluation of the anaerobically digested swine-slurry was not completed due to excessive foaming that was not seen during the evaluation of the raw swine-slurry wastewater. The treatment of the swine-urine wastewater yielded total nitrogen levels below the desired 60 mg/L. Effluent phosphorus concentrations averaged 20 mg/L which fell short of the desired 8 mg/L concentration. The treatment of the raw swine-slurry wastewater yielded consistent effluent concentrations of 20 mg/L or less of total nitrogen, 1,000 mg/L of soluble COD, and 8 mg/L or less of orthoposhphate.

Zhang et al. (2006) operated a lab-scale SBR system for the treatment of swine waste under limited oxygen availability. The average influent characteristics were 918 mg/L TKN, 91.8 mg/L TP, and 7,040 mg/L COD. The reactor had a working volume of 8.0 L, and air was supplied at a rate of 1.0 L/m^3/s. The reactor was operated with an HRT of 3.3 days. The operation consisted of an 8-hr cycle: 1.25 hr anaerobic, 2.75 hr aerobic/anoxic, 1.5 hr anaerobic, and 2 hr aerobic/anoxic. The reactor was fed twice during the cycle – 600 mL of waste at the beginning of the cycle and 200 mL of waste at the beginning of the second anaerobic cycle. Treatment resulted in the following average reductions in the effluent: 99.1% for TKN, 97.7% for TP, and 96.3% for COD.

1.10 This Study

This study established lab-scale versions of the sequencing batch reactor system designed by Alternative Natural Technologies (ANT) for the Smithfield Agreement technology evaluation project. The original, full-scale ANT system design consisted of a single sequencing batch reactor tank and an equalization tank to receive the wastewater flushed from the houses. In this tank, a set of mixers worked to maintain homogeneous wastewater conditions. Each day pumps loaded the SBR tank with 14.3% of the weekly supply volume of wastewater from the equalization tank. In the SBR tank, the wastewater experienced alternating aerobic and anaerobic/anoxic conditions by means of jet aerators. The jet aerators combined a shaft mixer, which operated continuously during complete-mixed conditions, and an aerator, which pumped air through the mixer shaft during aeration phases. At the end of the treatment cycle, while mixing was still occurring, pumps withdrew 25% of the daily input volume of the wastewater during mixing conditions to a storage pond.

During non-mixing conditions and after settling, pumps transferred the remaining 75% of the daily input volume as supernatant to the storage pond.

The lab-scale version focused exclusively on the SBR portion of the Alternative Natural Technologies system. The lab-scale reactors received samples of wastewater directly flushed from the swine houses on the farm site chosen for the full-scale system in order to maintain consistency of wastewater inputs. Unlike the full-scale system, the lab-scale reactors were covered. The lab-scale system followed the same influent and effluent patterns as the full-scale system design, with a hydraulic retention time of 7 days. The main goal for this project was to provide low oxygen concentrations to establish low oxygen nitrification and simultaneous nitrification and denitrification processes by utilizing two different aeration techniques. For this purpose, two types of reactors were used: (1) continuous, low aeration and (2) cyclic aeration. The object was to create environments that provided simultaneous COD and nitrogen removal for both a time-controlled alternating aeration/anoxic scheme and a continuous low-level aeration scheme, where both reactor types were receiving the same total airflow per day.

There were two primary objectives in performing this experiment:

1. to develop operating conditions for a bench-scale sequencing batch reactor to match the design of a full-scale sequencing batch reactor system for treating swine waste and

2. to determine the effects of continuous low aeration versus cyclic aeration schemes on sequencing batch reactor COD, suspended solids, nitrogen, and phosphorus removal performance.

The influent wastewater to the reactors was not controlled or designed to provide a consistent source of nutrients for SBR waste treatment. This experiment utilized the same wastewater that was to be used for the full-scale system, direct from the swine house flush system. A goal for this experiment was to mimic – to the extent an indoor, laboratory-scale system can – the operational conditions for the outdoor, full scale system so that alternative operating schemes could be tested in the small-scale systems. The key similarities were a lack of pre-treatment solids separation, mixing mechanism, aeration method, HRT, and solids wasting technique.

2. MATERIALS AND METHODS

2.1 Reactor Design

2.1.1 *Mix-and-Fill Tanks*

For this experiment, there were four reactors: two with cyclic aeration and two with constant low-level aeration. Other than the aeration schemes, the reactors were identical.

The reactor tanks were 60.6-L (16-gal), polyethylene, mix-and-fill tanks, with the bottom of each tank having a slope of 60^o. Based on the selected HRT, the daily batch volume was set at 7.6 L (2 gal) each day per reactor. The slope at the bottom of each tank made it easier to drain the biosolids from the system. The tanks came equipped with 5.08-cm (2-in) adapters at the bases, so 5.08-cm (2-in) by 1.90-cm (0.75-in) reducer bushings were added to reduce the flow rate through 1.90-cm (0.75-in) gate valves. The gate valve control was manually operated in order to remove the proper volume of liquid to obtain the desired HRT.

In order to drain the treated water after solids settling, two spigots were added to the side of each tank. The top spigot was set to operate at a HRT of 7 days, meaning that the spigot was placed where two gallons of liquid were above it when the reactor was completely filled [53 L (14 gal) of treatment volume with 7.6 L (2 gal) in and out per day gives the HRT of 7 days]. The use of this spigot was intended to minimize the occurrence of scouring during the removal of the supernatant. The lower spigot allowed for the possibility of reducing the reactor HRT by making it possible to remove a greater volume than 7.6 L (2 gal). The bulkhead fittings and spigots all had a diameter of 1.90 cm (0.75 in). Tank drainage occurred manually by opening the spigot valve and collecting the proper volume of water to obtain the desired HRT. Figure 1 is an illustration of the configuration of the mix-and-fill tanks with the additional components.

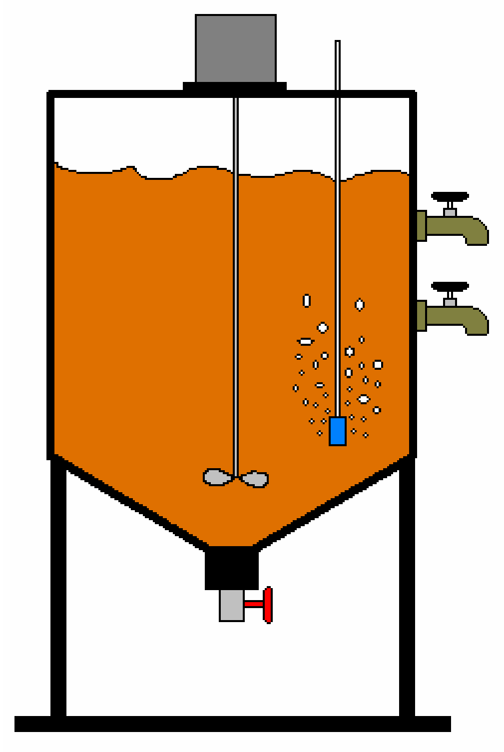


Figure 1. Schematic of laboratory sequencing batch reactors

2.1.2 *Mixers*

Portable shaft mixers kept the solids suspended in the reactors. The motors sat upon thick, rubber gaskets and the shafts entered the reactors via 7.62-cm (3-in) diameter holes in each reactor lid. The mixer shafts descended vertically into the tanks. The rubber gaskets were modified rubber end-caps for 7.62-cm (3-in) PVC piping. The modifications consisted of removing the thinner portion of the cap, leaving a 1.27-cm (0.5-in) thick disk, and then cutting a hole to allow passage of the mixer blade through the newly formed rubber ring. These rubber gaskets acted as seals to minimize leakage of odorous gases and absorb noisy vibrations from the motors during mixing. Elastic bands were stretched across the mixer plates and hooked to the supporting frames of the reactors to secure the mixers in place. Each mixer blade was positioned a few centimeters above the bottom outlet, allowing for the dispersion of the larger solids. The motor operated at 18.7 W (0.025 hp) and 1,550 rpm. The shaft was stainless steel with a length of 45.7 cm (18 in) and a diameter of 0.79 cm (0.3125 in). The propeller blade was also stainless steel with a diameter of 6.35 cm (2.5 in). The mixers operated continuously except during the short time for settling and supernatant draining. The mixer switches also were operated manually.

2.1.3 *Aeration Systems*

For the cyclic aeration reactors, an adequate amount of DO needed to be supplied during the aeration "on" phases to meet the oxygen demand of the COD and TKN while allowing the reactor environment to return to anoxic conditions during the aeration "off" phases. The continuous reactors needed a supply of DO to just meet the COD and TKN oxygen demands while maintaining a constant, low DO concentration in the reactor environments. The objective of establishing this low DO level within the continuous aeration reactors is to provide the opportunity for low oxygen nitrification and simultaneous denitrification to occur, by means of microbial adaptation over time. The following sections provide details of the two aeration system designs.

2.1.3.1 *Continuous, Low Aeration*

The continuous, low-level aeration scheme employed small, fish tank air pumps. The diaphragm air pumps connected to the small fish-tank air diffusers as were used by way of 0.953-cm (0.375-in) plastic tubing, and the diffusers were placed into the liquid from the top of the reactor. To keep the small diffusers from floating freely in the tank, they were fit to the end of a solid, 0.635-cm (0.25-in) diameter plastic tube, which descended vertically into the reactor through a hole in the lid.

The flow rate for the continuous aeration reactors was determined from the original aeration design for the full-scale SBR by scaling it down to the volume of the reactors and spreading the aeration over a continuous basis. The calculations resulted in an airflow rate of 0.75 L/min. For a 24-hr period, accounting 2 hours for the daily settling and drawing phases, the continuous (CON) aeration tanks received 990 L of air per day. Using the 24.3 L/mol @ 23^{o}C as the molar concentration of a simple gas at atmospheric pressure, the CON reactors receive approximately 270,000 mg of O_2 each day. The room temperature averaged around 23^{o}C, The efficiency of the oxygen transfer into the wastewater as dissolved oxygen was unknown and was discussed in the results.

2.1.3.2 *Cyclic Aeration*

A 0.953-cm (0.375-in) diameter flexible, plastic tube and a 0.635-cm (0.25-in) diameter hard, plastic tube connected the diffuser to the air supply and set the diffuser in close proximity to the mixer blades. The goal of this placement was to distribute the air within the reactor as evenly and as quickly as possible, providing a sudden change from anaerobic to aerobic conditions. A vacuum pump provided the airflow into the cyclic reactors. It operated at 115 VAC, 60 Hz, and 1.7 A. The dual head allowed for the simultaneous pumping of air to both cyclic reactors from one pump. A clock-operated switch controlled the power to the air pump and the timing between cycles.

The aeration cycle for the cyclic (CYC) reactors was 2 hr off: 1 hr on (2:1). The airflow rate during the “one hour on” phase was selected to be 2.25 L/min, which is equal to three times the continuous aeration rate of 0.75 L/min. This flow rate provided approximately 300,000 mg O_2 per day. The goal was to keep the same amount of air going into both types of reactors, providing a clear distinction in performances for cyclic and continuous aeration. There was a slight increase in airflow to the CYC reactors compared to the CON reactors, because the CON reactors were shut down for two hours during the settling and decanting phases. The CYC settling and decanting phase took place at the end of an aeration cycle, so no break in the cycle was needed. While observing the performance results of the reactors, it was determined that the CYC reactors were not receiving enough oxygen for either COD removal or nitrogen removal. After Day 161, the airflow rate for the CYC reactors was increased to 7.5 L/min. This new flow rate provided approximately 1,000,000 mg O_2 per day. Again, the efficiency of oxygen transfer into the wastewater was unknown but was discussed in the results. With the change in aeration technique, the CON reactors were then receiving 73% less oxygen per day than the CYC reactors.

2.1.4 *Gas Flow Controllers*

The pumps were connected to the diffusers through mass flow controllers. The controllers limited the amount of air going to the diffusers at a set flow rate so that the amount of air entering the reactors was known. The gas flow controllers operated by heating a portion of the flow in specific locations along a capillary tube in order to create a temperature dependent resistance differential. The circuitry took this differential measurement and compared it to the value for the desirable flow rate. If there was a discrepancy, the circuit controlled a solenoid valve to restrict or release the flow. A small potentiometer in the side of each controller allowed flow rate to be changed easily. Calibration occurred at the factory, and the two ranges were 0-5 L/min and 0-50 L/min. The two 0-5 L/min controllers were used for the continuous, low-flow aeration scheme, and the two 0-50 L/min controllers were used for the cyclic aeration scheme. In-line gas/liquid filters purify the air flowing to the controllers from the pumps to protect the sensitive components.

2.2 Solids Retention Time Calculation

The solids retention time (SRT) determines the average length of time that the microbial biomass remains within the treatment system. A short SRT indicates that the solids are removed at a higher rate, while a longer SRT indicates that the solids are kept from exiting the system quickly. This value is important in biological treatment, including nutrient removal systems. Because the solids of primary interest are the microorganisms that perform the treatment of the wastewater, the biomass must remain in the reactor to metabolize the organic matter in the wastewater. Nitrifying bacteria have slow growth rates compared to other organisms and therefore require higher SRT to allow adequate time for growth within the reactors. Volatile suspended solids (VSS) is a measure of the non-dissolved organic solids. This value was used as an indicator of the amount of biomass with in the system. According to the original ANT SBR design, the solids were to be wasted by daily removing 25% of the batch volume during complete-mixed conditions. Therefore, to estimate the biosolids being wasted, the complete-mixed VSS concentrations were used. This is in contrast to the typical solids wasting technique of removing a portion of the settled solids after the settling phase, which would remove a smaller volume with a higher concentration of VSS. The following formula was used to estimate the SRT for each reactor (Crites and Tchobanoglous, 1998):

$$\text{Solids Retention Time} = \frac{\text{mass of biosolids in reactor}}{\text{mass rate of biosolids removed from reactor}}$$

$$SRT = \frac{(VSS_m)(V_t)}{(VSS_s)(Q_s) + (VSS_m)(Q_m)}$$

VSS_m = complete-mixed condition volatile suspended solids (mg/L)

V_t = reactor treatment volume (L)

VSS_s = supernatant volatile suspended solids (mg/L)

Q_s = supernatant effluent flow rate (L/d)

Q_m = complete-mixed effluent flow rate (L/d)

2.3 Reactor Performance Calculations

Performance of the reactors is based on how well they were able to remove COD, SS, TKN, and TP from the wastewater. Settling efficiencies, mass removal efficiencies, and mass balances were established to quantify the performance.

Settling efficiency (SE) considers the supernatant, complete-mixed, and dissolved concentrations for each parameter. It provides a measure of performance by comparing the actual supernatant concentration of a particular parameter to the supernatant concentration of that parameter that should result from complete settling of the reactor contents. It is calculated by dividing the difference in the supernatant and complete-mixed values by the difference between the complete-mixed and dissolved values. The difference in the complete-mixed and dissolved values provides the expected drop in a parameter, provided sufficient time for complete settling. The difference in the complete-mixed and supernatant values provides the actual results for the settling that took place. Settling efficiency of 100% would indicate that only the dissolved portion of the parameter in question remained in the supernatant, while 0% efficiency would indicate that no settling occurred. The equation has the following form:

$$\text{Settling Efficiency} = \frac{\text{actual change in parameter value after settling}}{\text{potential change in parameter value due to settling}}$$

$$SE = \frac{C_m - C_s}{C_m - C_d}$$

C_m = complete-mixed parameter concentration (mg/L)

C_s = supernatant parameter concentration (mg/L)

C_d = dissolved parameter concentration (mg/L)

Mass removal rate was calculated based on mass balance calculations of the parameters. The accumulation of a parameter within the reactors is equal to the balance of the mass entering the system in the influent, the mass leaving the system either as complete-mixed or supernatant, and the mass removed by biological transformations or by volatilization. After rearrangement, the following equation for mass removal rate resulted:

$$\text{Mass Removal Rate} = \text{sum of mass inputs} - \text{sum of mass outputs} - \text{mass accumulation in reactor}$$

$$\text{Mass Removal Rate} = Q_i C_i - Q_m C_m - Q_s C_s - V\frac{\Delta C_m}{\Delta t}$$

Q_i = influent flow rate (L/d)

C_i = influent parameter concentration (mg/L)

Q_s = supernatant effluent flow rate (L/d)

V = volume of reactor (L)

t = time (d)

The change in complete-mixed concentration over change in time expression was calculated by taking the difference in the measured complete-mixed concentration of each parameter divided by the number of days between each sampling period.

Mass removal efficiency (MRE) was a calculation to determine the fraction of the influent parameter mass that was removed by treatment between sampling periods. It compares the mass removal rate of the parameter to the mass influent rate into the reactors. The equation has the following form:

$$\text{Mass Removal Efficiency} = \frac{\text{mass rate of parameter removal}}{\text{mass rate of parameter entering system}}$$

$$\text{MRE} = \frac{Q_i C_i - Q_m C_m - Q_s C_s - V\dfrac{\Delta C_m}{\Delta t}}{Q_i C_i}$$

The mass removal rate and mass removal efficiency equations were used for the evaluation of reactor performance for COD, SS, and TKN parameters. For phosphorus, there is no removal from the system by biological transformation or by volatilization. The phosphorus that enters the reactors either leaves the system in the complete-mixed or supernatant effluent streams or accumulates within the reactors. Therefore, the accumulation of phosphorus within the system is the indicator for reactor performance. This accumulation is calculated the same as for the “mass accumulation in reactor” term for the mass removal rate equation.

2.4 Reactor Start-Up

The organisms that performed the various processes necessary for this treatment system are ubiquitous. Given enough time and the proper conditions, using only the source wastewater as the influent, the microbial populations and environment would reach a state where nitrification, denitrification, and phosphorus accumulation would occur. However, the goal was to get the system operational as soon as possible, so the reactors were seeded with lagoon water from a different farm where nitrifying bacteria had been found. Gradually combining the source wastewater with the seed wastewater during the initial filling of the reactors, the nitrifiers were given the best opportunity to establish their niche. During the start-up phase, the seed wastewater, tested by polymerase chain reaction analysis, gave a positive result for the presence of nitrifiers, verifying the presence of nitrifying organisms.

The filling process took place over a span of 12 days. The first day, each reactor received 13.2 L (3.5 gal) of seed water (25% of the eventual 53-L volume). The mixing and aeration also began on that day in order to begin acclimating the organisms to the new environment. Each day, the reactors received a portion of seed lagoon water and source swine wastewater. The first three additions were 50% seed and 50% wastewater; the next three additions were 40% seed and 60% wastewater; and the last five additions were 25% seed and 75% wastewater. The schedule is displayed in Table 1.

Table 1. Schedule of seed wastewater and source wastewater loading for each sequencing batch reactor during start-up phase

day	fraction of influent as seed	seed volume influent (L)	source volume influent (L)	total volume influent (L)	accumulated volume (L)
1	1.00	13.25	0.00	13.25	13.25
2	0.50	0.95	0.95	1.90	15.15
3	0.50	1.10	1.10	2.20	17.35
4	0.50	1.25	1.25	2.50	19.85
5	0.40	1.14	1.70	2.84	22.69
6	0.40	1.29	1.93	3.22	25.91
7	0.40	1.48	2.20	3.68	29.59
8	0.25	1.06	3.18	4.24	33.83
9	0.25	1.21	3.60	4.81	38.64
10	0.25	1.36	4.13	5.49	44.13
11	0.25	1.59	4.73	6.32	50.45
12	0.25	0.64	1.93	2.57	53.02
sum =		**26.32**	**26.70**	**53.02**	

Because a different wastewater was used to seed the reactors than the source farm wastewater, a period of time elapsed before the reactors operated solely on the source wastewater. A graph of the seed wastewater fraction of the overall reactor volume of 53 L (14 gal) verses time was constructed to determine the length of time required for the seed wastewater portion to be flushed from the reactors, based on the 7.57 L/d (2 gal/d) influent volume (Figure 2). At around Day 40 there is essentially no contribution to the reactor volume from the seed wastewater. Day 40, therefore, was determined to be the end of the start-up phase.

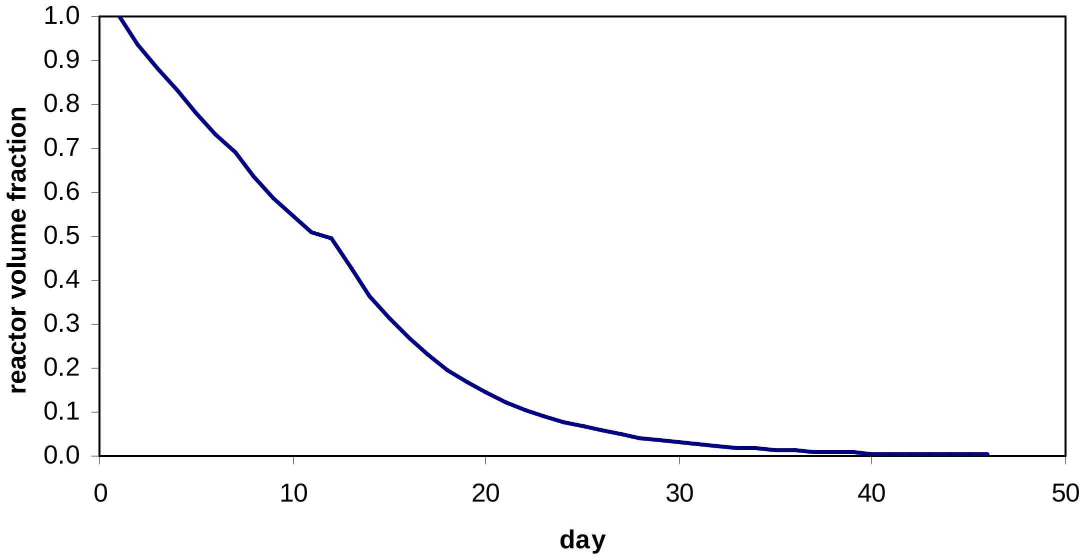


Figure 2. Calculated fraction of sequencing batch reactor volume as seed wastewater during start-up

2.5 Source

2.5.1 *Farm Location*

The source farm is about 16 km (10 mi) east of Wilson, North Carolina, just north of NC Highway 42. The area is within what is considered to be the Coastal Plain of North Carolina and is primarily flat with some areas of rolling hills. The farm is surrounded by agricultural land used as spray fields for the lagoon water and is situated in a shallow lowland area away from the road.

2.5.2 *Farm Operations*

The source farm is a 12,800-head, feeder-to-finish operation and has 24 houses with flush style house-cleansing mechanism and slatted floors. Each house collects recycle wastewater in large concrete tanks from the secondary lagoon on the farm. The water fills the tank and continues overflowing the tank to always have at least some water running through each house. Four times a day, a tank valve opens to release the water, flushing the house of the urine and feces that fall through the slatted floors. The water flows out of the barn, down a slope, toward an open pipe, to one of four main pipelines running along each row of houses that transports wastewater into the primary lagoon to the north of the farm. Wastewater from the primary lagoon overflows into a secondary lagoon that provides additional treatment.

2.5.3 *Sampling Techniques*

The lab-scale reactors required a daily supply of wastewater from the farm to operate. Wastewater was transferred to the lab in plastic containers, which provided enough wastewater to feed all four reactors for one week. A pitcher was used to collect the wastewater directly from the pipeline flow from the houses into the lagoon. Also, an open 200-mL sample bottle, placed directly in the flow, captured a sample of the raw wastewater for chemical analysis to determine the source characteristics. Samples were stored on ice and transported to the Biological and Agricultural Engineering Department, where they were stored and refrigerated at 4^{o}C.

A single grab sample was taken half way through each wastewater collection event at the source farm. Each of these samples was used to estimate the overall swine waste characteristics for the entire volume of wastewater collected for that day. These samples were used to determine the *source* characteristics. Each trip yielded the 212 L required to feed the reactors for one week. For ease of transport and storage, the waste was collected in 18.9-L (5-gal) and 22.7-L (6-gal), plastic containers. The collection process from beginning to end took 1 – 1.5 hours to complete.

2.6 Data Collection

Most of the sample analysis was done at the Environmental Analysis Laboratory in the Biological and Agricultural Engineering Department on the NCSU campus. Each sample was collected in a 200-mL, plastic bottle with a screw lid. The samples remained on ice if they were unable to be delivered to the lab immediately. On each trip to the farm site, a sample of the swine wastewater that was to go into the reactors was taken. Once a week, eight samples were taken from the four lab-scale reactors: four samples from each of the bottom valves (full mix) and four from each side spigot (supernatant). Each sample received the same treatment and analysis. The analysis determined the levels of the following parameters: chemical oxygen demand (COD), suspended solids (SS), volatile suspended solids (VSS), conductivity, alkalinity, total Kjeldahl nitrogen (TKN), total ammoniacal nitrogen (TAN), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), total phosphorus (TP), and orthophosphate phosphorus (OPO_4-P). The COD data provided information on the amount of energy available to microorganisms for metabolic activity. The SS and VSS values provided information about the amount of suspended solids inside the reactors. VSS was used as a rough estimate of the amount of biomass within the biological treatment system. The TKN, TAN, and NO_3^-/NO_2^-N numbers indicated the overall amount and form of nitrogen inside the reactors, providing evidence of biological transformations. TP and OPO_4-P data provided a way to show any change in the phosphorus levels, providing evidence of whether or not PAO activity was taking place. Tests for the soluble portion of COD, TKN, and TP in each sample were added after Day 70. These additional numbers provided a way to determine the proportion of these parameters that are incorporated within the biomass to determine actual removal that was not incorporated into biomass.

2.7 Daily Operations

The ANT full-scale system design set the HRT at 7 days and would waste solids by removing 25% of the batch volume during complete-mixed conditions, instead of removing accumulated solids from the bottom of the reactor after settling. For a reactor volume of 53 L (14 gal), a 7-day HRT sets the batch volume at 7.57 L (2 gal). The daily operations began with the removal of 25% of the batch volume from the bottom gate-valves. Therefore, 1.89 L (0.5 gal) was removed daily by way of the bottom valve. This removal occurred during complete-mixed conditions in order to remove a portion of the solids. The target for the solids retention time (SRT) was 30 days, based on the ANT design for the full-scale system (Classen and Liehr, 2005). The complete-mixed removal occurred at the end of the cyclic-reactor aeration time. The reason for selecting this point in the aeration cycle was to analyze samples of the wastewater for nitrate formation and phosphorus accumulation. The gate valves were opened manually, and the wastewater was collected in a 2,000-mL beaker with a marking at the 1.9-L (0.5-gal) level. At times, accumulated solids at the gate-valve opening impeded the flow, so some manual loosening was necessary. Sampling of the effluent occurred by pouring the contents of the beaker into a sampling bottle after vigorous mixing.

After removing the complete-mix volumes, the next step was to turn off the mixers and aerators. The reactors settled for 30 minutes, after which the remaining 75% of the batch volume, 5.68 L (1.5 gal), was drained from one of the side spigots. The spigots drained into a 2,000-mL beaker, which was marked for the appropriate volume to be removed. Supernatant samples for chemical analysis were collected directly from the spigots in 200-mL sample bottles. During daily operation, some solid material would accumulate in the spigot tube, rather than settling with the rest of the solids. In order to avoid incorporating them with the sample, 3.78 L (1 gal) of the supernatant was drained first, allowing for the flushing of any solid material in the tube. The collection of the supernatant sample immediately followed. Once the sample bottle was full, the remaining 1.7 L of supernatant was drained into the beaker.

After removal of the supernatant, the tanks were filled with fresh wastewater. The storage containers were removed from the 4^{o}C-incubator and shaken manually in order to suspend the solids that settled during storage. The influent wastewater was not heated prior to loading. Due to the influent being 14.3% of the total reactor volume, the temperature drop caused by the cold influent was about 3^{o}C. In this experiment, daily influent samples were not taken for analysis. Based on variability in the source wastewater collection schedule, the influent for a particular week did not always come from the same collection period. Therefore the *influent* wastewater values for each week were calculated as a weighted average of the different *source* characteristics of the wastewater used to fill the reactors during each week. Because the HRT for the reactors was set for seven days, the weighted averages were calculated based on the analyses of the particular sources utilized as influent for the previous seven days. The resulting weighted average for each characteristic was set as the influent characteristic for the weekly determination of reactor performance. For example, if the source COD value for the first three reactor fillings was 10,000 mg/L and the source COD value for the last four reactor fillings was 12,000 mg/L, a weighted average (11,140 mg/L) would be used as the characteristic value for the influent into each of the reactors during that week. The influent wastewater was transferred to a 2,000-mL beaker and poured into the reactor through a large funnel in the 6.35-cm (2.5-in) diameter hole in the top of the reactor lid. After the reactors were filled, the mixers and the aerators were returned to normal operation.

During operation of the reactors, layers of scum accumulated at the top of the liquid along the edges of the tanks and on the diffuser stones in the liquid. It was necessary to clean the tanks and change the diffusers regularly. In order to clean the tank, the holes in the tops of the reactor lids were opened. The solids were loosened with a brush and allowed to fall back into the reactor liquid.

To change the air diffusers, the 6.35-cm (2.5-in) holes in the lid of each reactor needed to be cleared. Maintenance of the air diffusers took place after the daily addition of influent, since the reactor lids were open. The plastic tube that positioned the air diffuser in the wastewater was pulled vertically to bring the diffuser above water level. It twisted off of the bottom end of the tube by hand. The new diffuser was twisted onto the end, and the plastic tubing was pushed back into its regular position.

2.8 Odor

The reactors were set in a laboratory that was shared with a number of researchers and students. From the beginning of operation, a great deal of effort was exerted toward odor minimization. All wastewater transfer, including draining, sampling, and filling, occurred during evenings to allow for the dissipation of the odorous gases during the night. Tubing was connected from the tops of the reactor to an air pump positioned within a fume hood so that the odorous gases were drawn out and away from the laboratory environment. However, even with these odor-prevention techniques in place, the reactors were never completely sealed, and odor problems and complaints were continuous throughout the duration of the experiment.

2.9 Statistical Analysis

Analysis of variance was run for the settling efficiency and mass removal efficiency data for each of the performance indicators (COD, SS, TKN, TP) to determine statistical significance between the performance of the CON and CYC reactors. The statistical model that was considered was as follows:

$$Y_{ijkt} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + R_{k(i)} + \tau_{t(j)} + \varepsilon_{ijkt}$$

i = 1, 2 index α_i, the effect of reactor type

j = 1, 2 index β_j, the effect of before/after Day 161

k = 1, 2 index $R_{k(i)}$, the random effect of reactor unit

t = indexes $\tau_{t(j)}$, the effect of time, t = 1, 2,…, 11 for before and t = 1, 2,…, 5 for after (the effect is nested within the before/after effect).

ε_{ijkt} = random effect

Because some performance indicators were very different before and after the operational changes made after Day 161, comparisons of performance based on reactor type were also made on the basis of data after this day. The statistical model above was used to determine the probability that the difference between the performance of CON and CYC reactors was zero, based on least squared means. Due to the more unpredictable nature of biological systems, a p-value of 0.1500 was selected to determine whether or not a difference in means was statistically significant (Laanbroek and Gerards, 1993).

3. RESULTS

3.1 Source Characteristics

One of the challenges encountered during this experiment was the inconsistency of the source wastewater characteristics that fluctuated on a week-to-week basis. The effects of this variability on reactor performance for the various parameters will be discussed in the following sections.

The situation was identified during the first 100 days of reactor operation. Initially, the source wastewater was to be collected from a single, consistent point for the entirety of the experiment to minimize fluctuations in wastewater characteristics, therefore producing more consistent operating conditions within the reactors. The source of choice was one of the four pipelines emptying into the primary anaerobic lagoon, which was selected primarily for its ease of access for wastewater collection. This pipeline received wastewater from a row of six swine houses. The problem was in coordinating the collection time with the flushing schedule. Some of the collections occurred at a peak flushing time, having a high flow rate and high waste concentration, while other collections occurred between flushes, having only a fraction of the flow rate and much weaker waste concentration. Any seasonal effects and/or swine development-cycle effects that may have contributed to the source wastewater inconsistency were not investigated.

The source pipeline was changed on Day 111 (May 23). The adjacent pipeline, which discharged wastewater from a row of ten houses was selected because it consistently had a higher flow rate into the lagoon. COD concentrations increased in the first collection from the new source pipeline, although consistent parameter levels did not follow the sharp increase for Day 111. For example, before Day 111, the average source COD was 13,000 mg/L with a standard deviation of +/- 3,500 mg/L, and, after Day 111, the average source COD was 13,000 mg/L with a standard deviation of +/- 3,600 mg/L. There was no change in the mean values before and after Day 111. The standard deviations were nearly the same as well, even showing a slight increase in the deviation after Day 111. Therefore, no reduction in the source COD variability occurred due to the change of pipeline sources. Table 2 provides a summary of the measured source parameters over the entire time span of the experiment.

Table 2. Summary of source wastewater parameter statistics

Parameter	Mean	Coefficient of Variation	Maximum	Minimum
Chemical Oxygen Demand (mg/L)	13,000	0.26	21,000	6,900
Dissolved (mg/L)	7,700	0.35	14,000	1,700
Suspended Solids (mg/L)	7,900	0.31	15,000	4,200
Volatile suspended solids (mg/L)	6,400	0.32	12,000	3,700
Total Kjeldahl Nitrogen (mg/L)	1,900	0.20	2,900	1,300
Dissolved (mg/L)	1,400	0.19	1,900	1,100
Ammoniacal Nitrogen (mg/L)	1,300	0.17	1,900	940
Total Phosphorus (mg/L)	210	0.28	420	110
Dissolved (mg/L)	97	0.25	180	60
Orthophosphate (mg/L)	160	0.21	260	82
Conductance (μS)	18,000	0.15	28,000	12,000
Alkalinity (mg/L as $CaCO_3$)	8,000	0.09	10,000	6,800

3.2 Solids Retention Time

The goal in operation of the reactors was to obtain solid retention times (SRT) of approximately 30 days to allow for the growth of nitrifying bacteria and maintain the population for oxidation of ammoniacal nitrogen. Figure 3 shows the SRT for each reactor over the duration of operation.

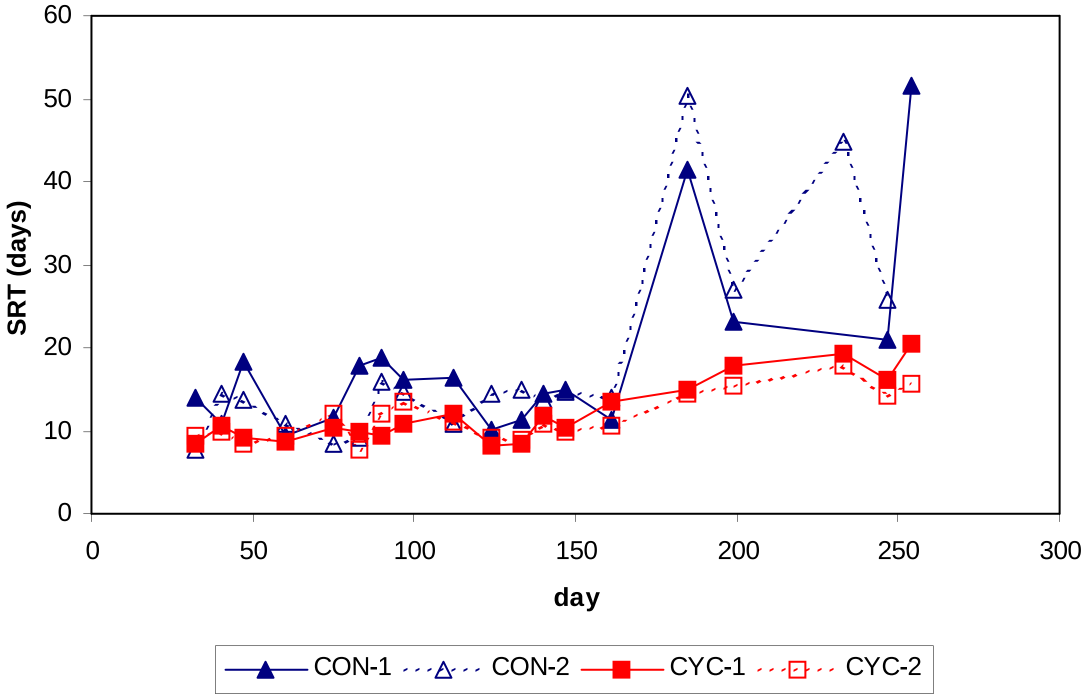


Figure 3. Continuous (CON) and cyclic (CYC) aeration sequencing batch reactor solid retention times (SRT)

Observing the first four months of operation, it became clear that the reactors, particularly the CYC reactors, were not approaching the SRT goal of 30 days. The average VSS settling efficiencies for the reactors during the first 161 days were 62% and 55% for CON-1 and CON-2, respectively, and 38% and 39% for CYC-1 and CYC-2, respectively. Factors that could have contributed to this phenomenon could have been unknown inhibitors, toxic substances, or antibiotics in the wastewater or the very high concentrations of ammonia nitrogen. These factors, if present, could have interfered with biomass growth and the ability of the biomass to develop well-developed floc, which would lead to better settling. The most likely cause was a limitation of dissolved oxygen in the reactor. Originally, both sets of reactors received the same total mass of oxygen, based on the continuous air-flow setting of 0.75 L/min. Therefore, the cyclic reactors, which were operated 1 hour aerators on and two hours aerators off, received an air-flow rate of 2.3 L/min. After the sampling on Day 161, the air-flow rate was increased to attempt to stimulate biomass growth. Due to the laboratory environment and the problem with foaming, the cyclic reactor aeration was limited to a flow rate of only 7.5 L/min. At this same time, after Day 161, the entire 7.57-L (2.0-gal) of daily effluent was drained from the side spigots as supernatant, instead of taking 1.89 L (0.5 gal) of the complete-mixed wastewater from the bottom valve during complete-mix conditions. The goal of this change was to assist the reactors in the accumulation of biomass. Only one time per week the 1.89 L (0.5 gal) of complete-mixed wastewater was removed from the bottom valve in order to provide the weekly complete-mix samples analysis. After these operational changes were made after Day 161, there were clear increases in the average VSS settling efficiencies for all four reactors: 79% and 82% for CON-1 and CON-2, respectively, and 62% and 56% for CYC-1 and CYC-2, respectively. These improvements in VSS settling account for the gradual SRT increase in the CYC reactors and the significant SRT increase in the CON reactors observed in Figure 3 after Day 161. Day 161, consequently, became a clear point of operational change from which to evaluate the reactor performances.

The average SRT for CON-1 prior to Day 161 was 14.0 days, ranging from 9.3 to 18.8 days. The average SRT for CON-2 during this period was 12.7 days, ranging from 7.6 to 15.8 days. After Day 161, the average SRT for CON-1 increased to 34.3 days, ranging from 21.0 to 51.6 days, while the average SRT for CON-2 increased to 37.0 days, ranging from 25.8 to 50.3 days. Both CON reactors provided adequate SRT to support nitrifier growth after Day 161.

For both cyclic reactors, the SRT remained much more constant at a lower level than for the continuous reactors. The average SRT for CYC-1 before Day 161 was 10.1 days, ranging from 8.1 to 13.5 days. The average SRT for CYC-2 before Day 161 was 10.2, ranging from 7.7 to 13.4 days. Toward the end of operation, the retention times were approaching 20 days, so it is possible that conditions were becoming conducive for nitrifier growth. Figure 3 shows that there was a gradual increase in SRT for both CYC reactors after the operational changes. The average SRT increased to 17.7 days for CYC-1, ranging from 15.0 to 20.4 days, and to 15.5 days for CYC-2, ranging from 14.1 to 17.8 days. Even with the additional aeration and the reduction of wasted solids, neither of the CYC reactors approached the target SRT of 30 days after Day 161.

3.3 Foam

The measures taken to reduce odor emissions may have had a significant effect on the operation of the systems. The design for the full-scale system called for an open tank rather than covered tanks used in this experiment. During aeration for both sets of reactors, foam formed at the surface of the wastewater and accumulated in the head space. The growth of a foam-causing organism, such as *Microthrix parvicella*, most likely caused the foam. This organism is a filamentous bacterium that has a hydrophobic cell wall. The organism surrounds air bubbles, keeping the bubbles intact, allowing for the creation and accumulation of the surface foam (Jenkins et al., 1993). At times, the accumulation was so high that it seeped out of the primary access holes in the middle of the lids, where the mixers were positioned. The seepage moved the rubber gaskets and mixers out of alignment, frequently causing damage to the mixer shaft and positioning plate. An open tank would not have been damaged by the foam.

An interesting observation was that the strength of the influent wastewater had a direct effect on the rate of foam accumulation. When reactors received wastewater that was qualitatively clearer, with much less suspended matter than normal, and having much less offensive odor, foaming increased. Likewise, when reactors received wastewater that was much more concentrated with suspended matter and had a stronger odor, the foam formation slowed and even ceased completely in some cases. This observation is supported by Jenkins et al. (1993), who list increasing the loading rate as a means to limit the growth of *Microthrix parvicella*. The more concentrated wastewater would also correspond to a higher food-to-microorganism ratio for the reactors, which was identified by Tsang et al. (2006) as able to put the filamentous microorganisms at a competitive disadvantage with respect to non-filamentous bacteria. Also, Poo et al. (2004) observed uncontrollable foaming conditions for the treatment of anaerobically digested swine-slurry wastewater. The foaming problem was not encountered for the treatment of raw swine-slurry wastewater.

3.4 Chemical Oxygen Demand

3.4.1 *Source Characteristics*

The source wastewater variability, as mentioned previously in Section 3.1, led to difficulties in establishing steady-state conditions in the four reactors. Figure 4 shows the COD and dissolved COD values for the source wastewater for each collection day over the entire experimentation period. It also shows a steady decrease in the COD levels from day 46 (March 19) to day 89 (May 1). This decrease was the primary reason for making the change in how the source wastewater was collected. The average COD concentration for the collected wastewater was 13,000 mg/L with a standard deviation of +/- 3,500 mg/L. The highest COD level for a sample was 21,000 mg/L, and the lowest level was 6,900 mg/L. Figure 5 displays the fraction of dissolved COD with respect to the source COD. The source

COD consisted of an average of 64% dissolved COD, showing no consistent relationship, ranging from 18 – 90%.

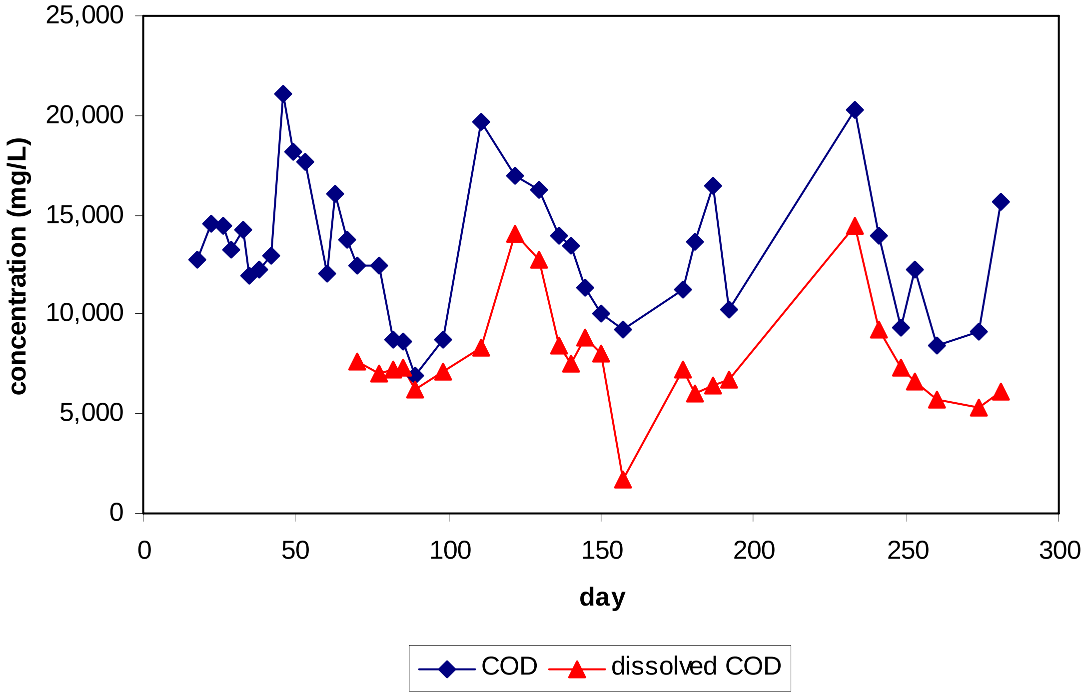


Figure 4. Sampling results of source wastewater chemical oxygen demand (COD) and dissolved chemical oxygen demand concentrations

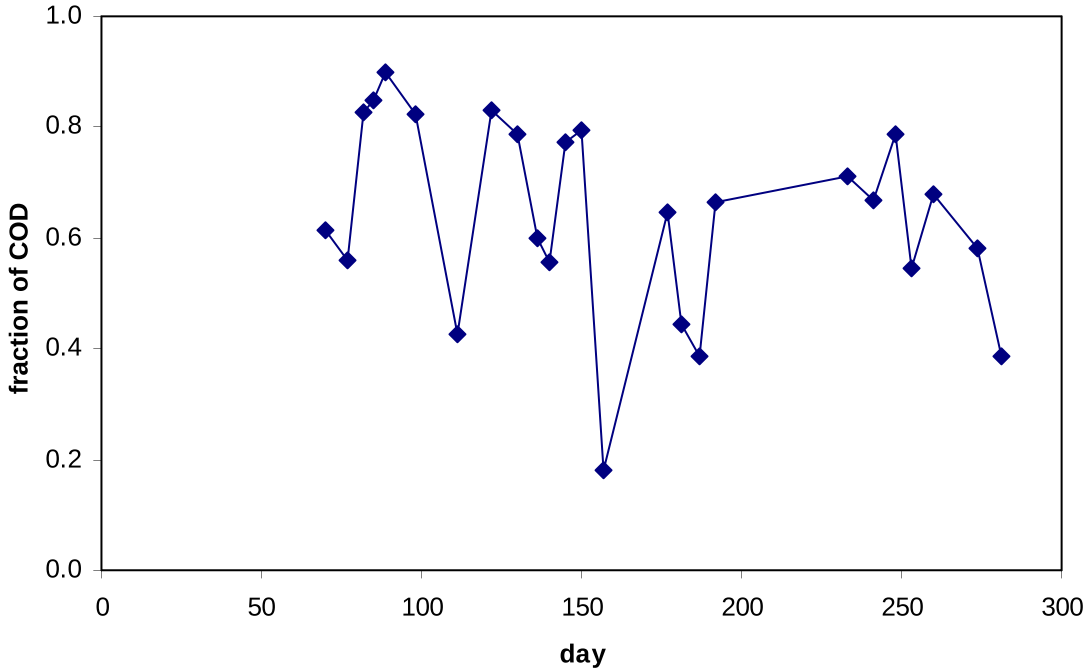


Figure 5. Fraction of source wastewater chemical oxygen demand in dissolved form

3.4.2 *Treatment Characteristics*

Concentrations of the complete-mixed, supernatant, and dissolved COD for the four reactors fluctuated during the first 147 days (Figures 6 – 9). However, at Day 147 each of the reactors begins to stabilize with respect to complete-mixed and supernatant concentrations. The stabilization can be attributed to the relative stabilization of the influent COD entering the reactors observed on Day 147 and Day 161. After the implementation of the operational changes after Day 161, the separation between the complete-mixed and supernatant COD concentrations increased for all four reactors. This corresponds to the anticipated accumulation of COD solids in the complete-mixed concentrations due to the reduction in solids wasting for the CON reactors and due to the combination of the reduction of solids wasting and the increase of oxygen input to enhance biomass production within the CYC reactors. The CON reactors (Figures 6 and 7) had consistently lower supernatant COD concentrations than did the CYC reactors (Figures 8 and 9). This provides an indication of improved COD removal performance by the CON reactors. After Day 161, the average supernatant COD concentrations were 6,100 +/- 1,100 mg/L for CON-1, 4,800 +/- 1,200 mg/L for CON-2, 8,000 +/- 1,300 mg/L for CYC-1, and 8,300 +/- 2,000 mg/L for CYC-2.

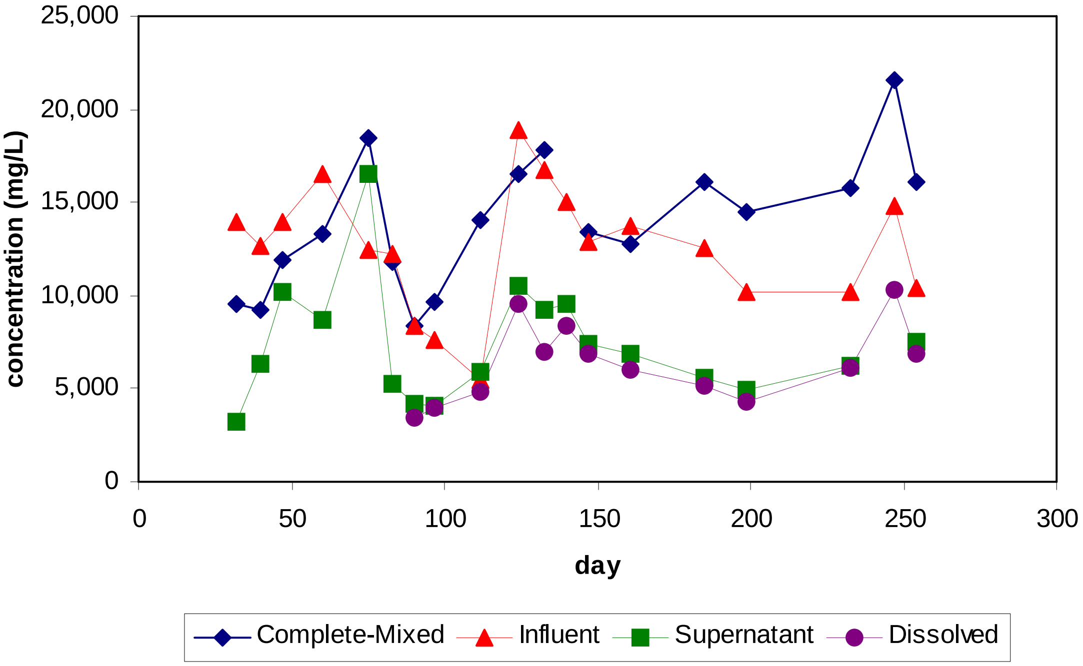


Figure 6. First continuous aeration sequencing batch reactor (CON-1) chemical oxygen demand concentrations for complete-mixed sample, for weekly weighted-average influent, for supernatant sample, and for dissolved portion of complete-mixed sample

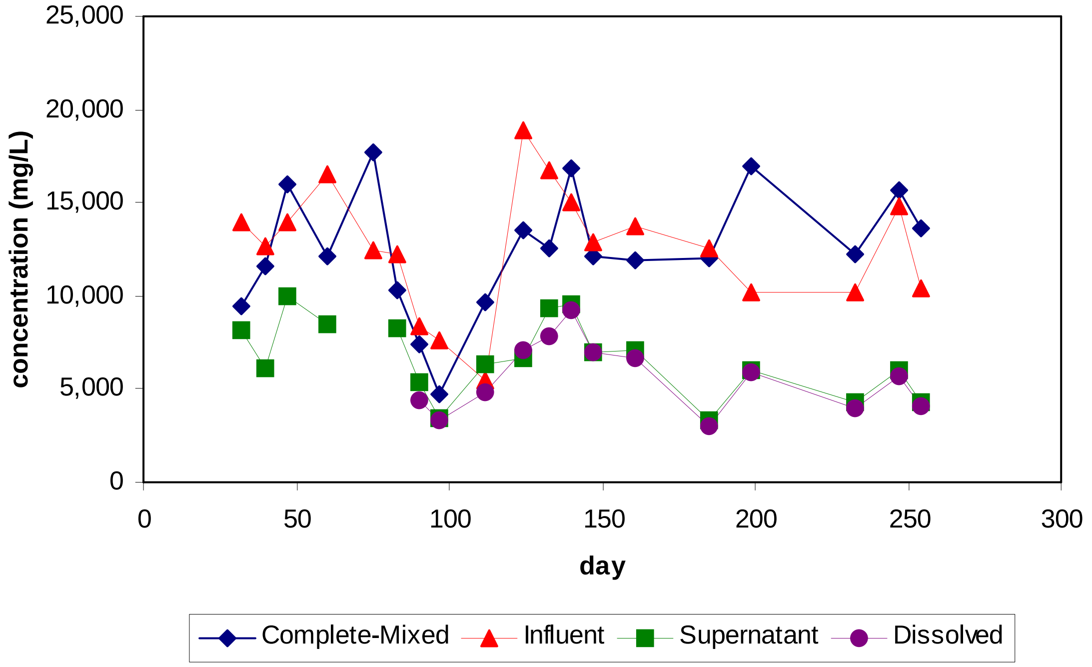


Figure 7. Second continuous aeration sequencing batch reactor (CON-2) chemical oxygen demand concentrations for complete-mixed sample, for weekly weighted-average influent, for supernatant sample, and for dissolved portion of complete-mixed sample

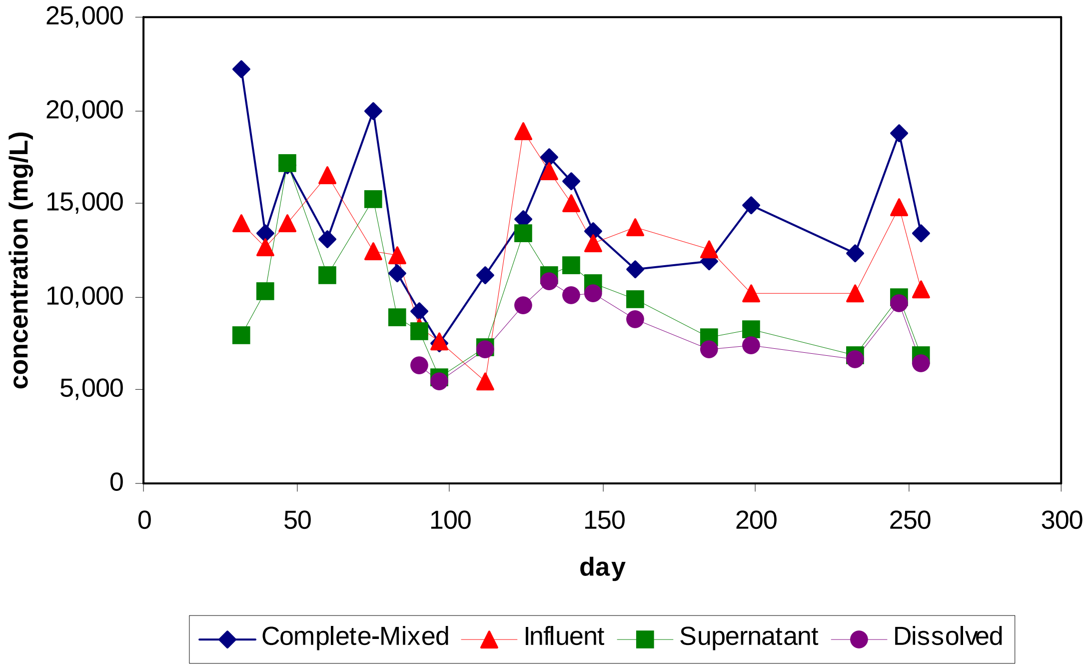


Figure 8. First cyclic aeration sequencing batch reactor (CYC-1) chemical oxygen demand concentrations for complete-mixed sample, for weekly weighted-average influent, for supernatant sample, and for dissolved portion of complete-mixed sample

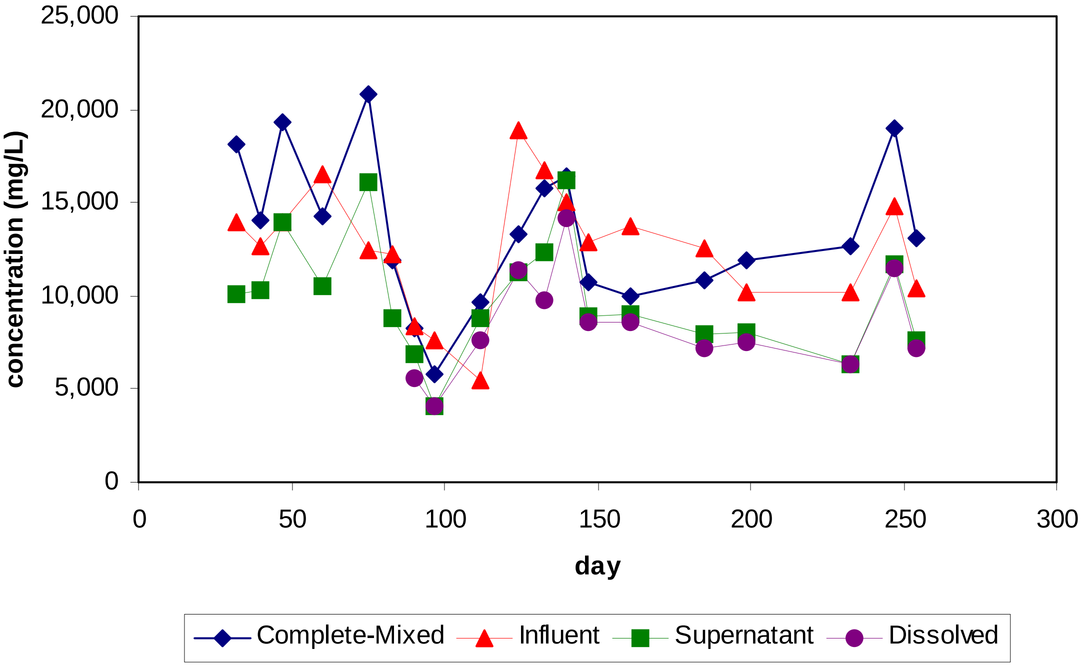


Figure 9. Second cyclic aeration sequencing batch reactor (CYC-2) chemical oxygen demand concentrations for complete-mixed sample, for weekly weighted-average influent, for supernatant sample, and for dissolved portion of complete-mixed sample

According to Table 3, the average settling efficiency of COD for the CON reactors was 86% before and 97% after Day 161. The average settling efficiency for the CYC reactors was 64% before and 92% after Day 161. The operational changes after Day 161 improved the CYC reactor COD settling efficiency performance (*p* = 0.1103). There was no difference between the CON and CYC reactor mean COD settling efficiency performance values after Day 161 (*p* = 0.5144).

Table 3. Continuous (CON) and cyclic (CYC) aeration sequencing batch reactor chemical oxygen demand settling and removal performance summary before and after operational changes made after Day 161

Reactor	Before Day 161				After Day 161[a]			
	Settling Efficiency	Mean	Mass Removal Efficiency	Mean	Settling Efficiency	Mean[b]	Mass Removal Efficiency	Mean[d]
CON-1	0.88	0.86	0.23	0.29	0.96	0.97[c]	0.52	0.52
CON-2	0.83		0.35		0.98		0.52	
CYC-1	0.69	0.64	0.14	0.15	0.92	0.92[c]	0.30	0.30
CYC-2	0.59		0.17		0.92		0.30	

[a] Comparisons of efficiencies for reactor types were only made for data after the operational changes instituted after Day 161.

[b] Differences between mean settling efficiency of CON and CYC reactors based on least square means were not significant (p = 0.5144).

[c] Operational changes after Day 161 did not significantly improve the mean settling efficiency of the CON reactors but did improve that of the CYC reactors (p = 0.1103).

[d] Differences between mean mass removal efficiency of CON and CYC reactors based on least square means were significant (p = 0.0251).

The mass removal efficiencies of COD for both reactor types increased after Day 161. The CON reactors increased from an average of 29% to 52% COD removal. The CYC reactors increased from an average of 15% to 30% COD removal. After the operational changes made after Day 161, the mean mass removal efficiency of the CON reactors was significantly greater than that of the CYC reactors ($p = 0.0251$). Nevertheless, both reactor types fell short of the optimum COD removal of roughly 70%, indicating the need for an increase in the amount of oxygen supplied to the microorganisms or that there may have been substances in the wastewater such as heavy metals or antibiotics that may have hindered the activity of the organisms.

Figure 10 displays the COD mass removal efficiencies for the four reactors on a single graph. The graph shows the fluctuation in the performance of the reactors during the first 120-130 days, but, afterwards, there is a clear stabilization within all four reactors. This stabilization of the COD mass removal was the primary justification for declaring that the reactors had achieved steady operation conditions conditions, given the fluctuation of the source characteristics throughout the trial. The negative numbers for COD mass removal efficiency result from a combination of the lag in the reactors adjusting to the decreasing influent concentrations and from poor settling performance. Each mass removal efficiency value that is a negative number corresponds to a point in Figures 6-9 where the supernatant concentration exceeds the influent concentration. In these situations, the actual mass of COD removed due to metabolism by the microorganisms is less than the mass leaving the system in the effluent due to the more concentrated wastewater in the complete-mixed and supernatant effluents than in the influent wastewater. The changes in operation after Day 161 resulted in positive mass removal efficiencies because of the increase in wastewater leaving the reactors as supernatant, the improvement in COD settling efficiencies, and the lack of a substantial drop in the influent COD concentration during that time period.

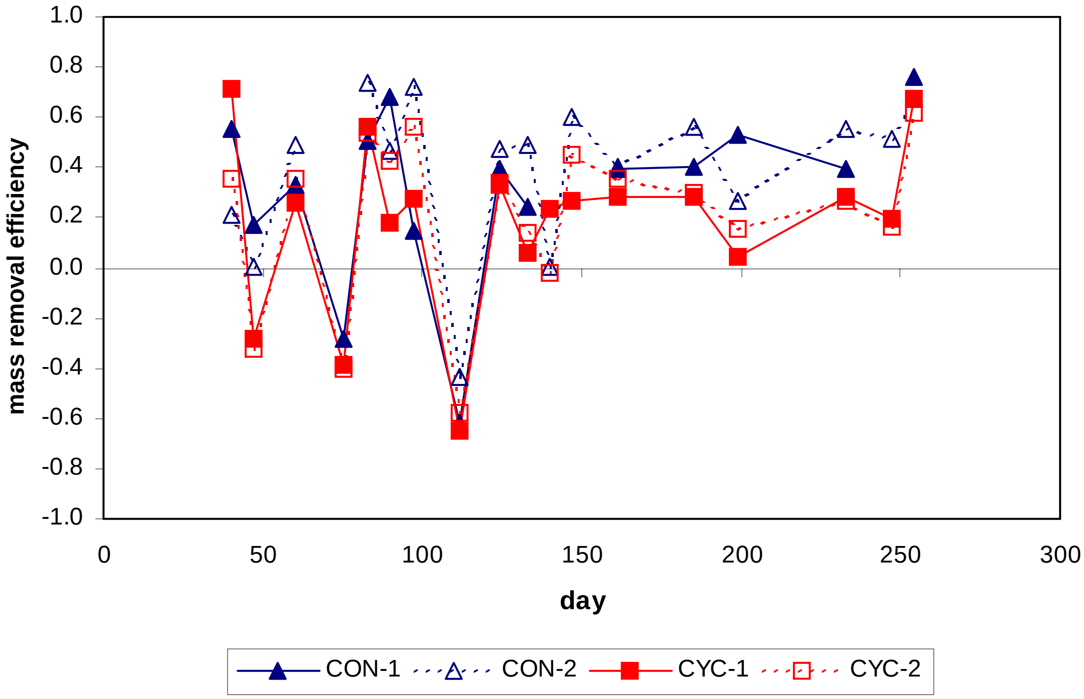


Figure 10. Continuous (CON) and cyclic (CYC) aeration sequencing batch reactor chemical oxygen demand mass removal efficiencies

Figure 11 displays the results of the mass removal rate calculations for COD. The first 120-130 days show significant fluctuation along with the more stable period starting from Day 161. The average COD mass removal rates after Day 161 for the reactors were 42,000 +/- 12,000 mg/d for CON-1, 46,000 +/- 15,000 mg/d for CON-2, 26,000 +/- 18,000 mg/d for CYC-1, and 26,000 +/- 14,000 mg/d for CYC-2.

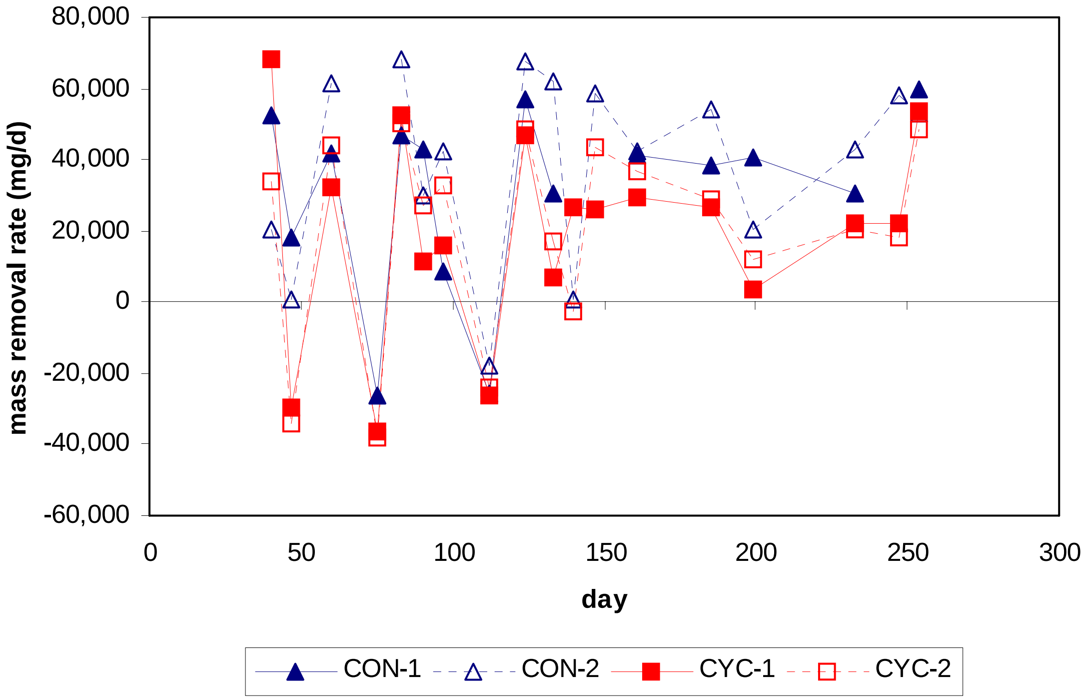


Figure 11. Continuous (CON) and cyclic (CYC) aeration sequencing batch reactor chemical oxygen demand mass removal rates

3.4.3 *COD Loading*

The SBR system was designed in accordance with the design of the full-scale SBR system installed on the source farm. The expectation was that both systems would receive the full volume of waste daily, so there was no consideration of COD loading in designing and operating the lab-scale reactors. However, ANT made changes to the full-scale system after the completion of the data collection for this study. The designers altered the influent rates from an equalization basin so as to load 1,100 kg/d of COD. This loading rate is equivalent to 1.02 kg/m^3/d for the full-scale system. As a result of this modification the full-scale system was able to achieve 83.0% TKN removal, 96.8% total ammoniacal nitrogen (TAN) removal, 63.7% COD removal, and 60.4% suspended COD removal (Classen and Liehr, 2005). With additional biosolids treatment, the overall system was expected to achieve 36.5% TP removal (Classen and Liehr, 2005).

The average COD loading rate for the lab-scale reactors was calculated based on the source COD values. The result was a loading rate of 1.79 kg/m^3/d of COD, which was 75% greater than the target value determined by ANT. Typical volumetric loading rates for sequencing batch reactors are 5 – 15 lb BOD_5/1000 ft^3/d, which based on 33% BOD_5/COD (USDA, 1999), is equivalent to 0.24 – 0.72 kg/m^3/d of COD (Crites and Tchobanoglous, 1998). The loading rate for the lab-scale reactors was 149% greater than the higher end of the typical design loading rates for SBR systems. However, there are some sequencing batch reactors that have been designed to accept a greater COD loading rate, ranging from 0.3 – 3.0 kg/m^3/d of COD (Tchobanoglous et al., 2003). These values are for full-scale systems with much deeper treatment tanks – typically around 4.5 m (15 feet). The lab-scale air diffusers were positioned at a depth of roughly 0.75 m. This difference in depth between full-scale and lab-scale reactors results in a difference in the reactors' abilities to handle COD loading, which is a direct result from a difference in the reactors' abilities to transfer oxygen to the wastewater. The shallow depth of the lab-scale systems do not allow for such high COD loading rates. The mass removal efficiencies in Table 3 support the claim that the reactors were over-loaded with COD. The COD mass removal efficiencies were 52% for the CON reactors and 30% for the CYC reactors. If the design revision made by ANT for the full-scale system had been incorporated in the design and operation of the lab-scale systems, it is likely that the overall performance of the lab-scale reactors would have been improved greatly.

3.5 Suspended Solids

3.5.1 *Source Characteristics*

The suspended solids and volatile suspended solids concentrations followed the same pattern of variability as the COD concentrations (Figure 12). As the COD concentration increased, the suspended solids increased, as can be seen when comparing Figure 4 with Figure 12. The fraction of the suspended solids as volatile suspended solids remained very consistent, though there were large fluctuations in suspended solids concentrations. The volatile suspended solids make up around 81% of the total suspended solids, with a range of 68 – 93% (Figure 13).

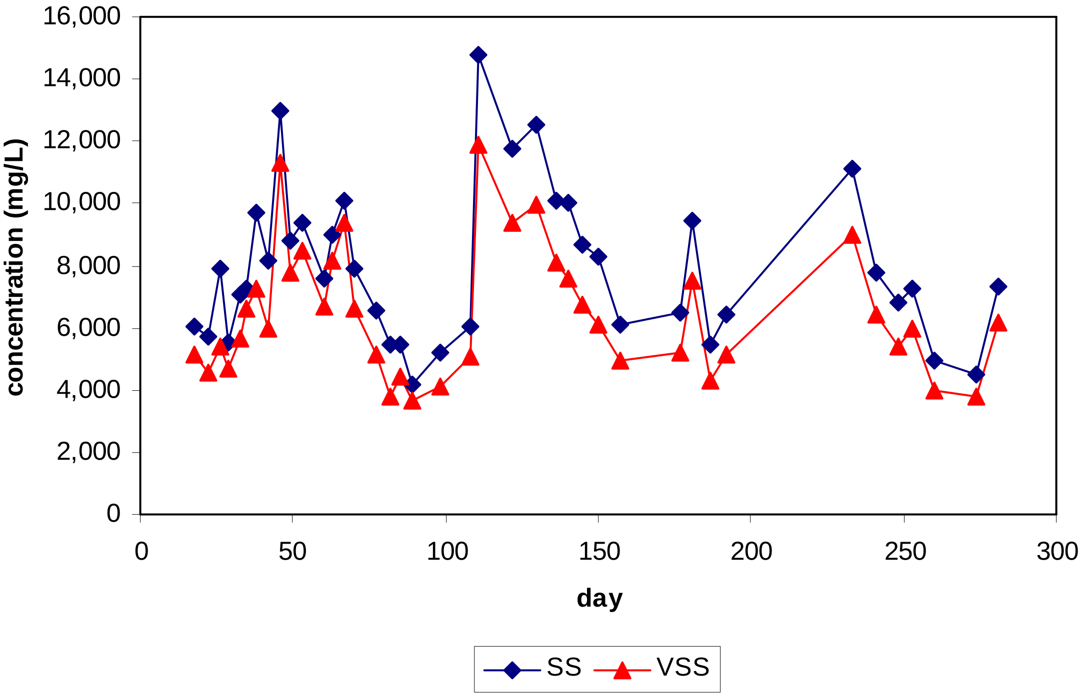


Figure 12. Sampling results of source wastewater suspended solids (SS) and volatile suspended solids (VSS) concentrations

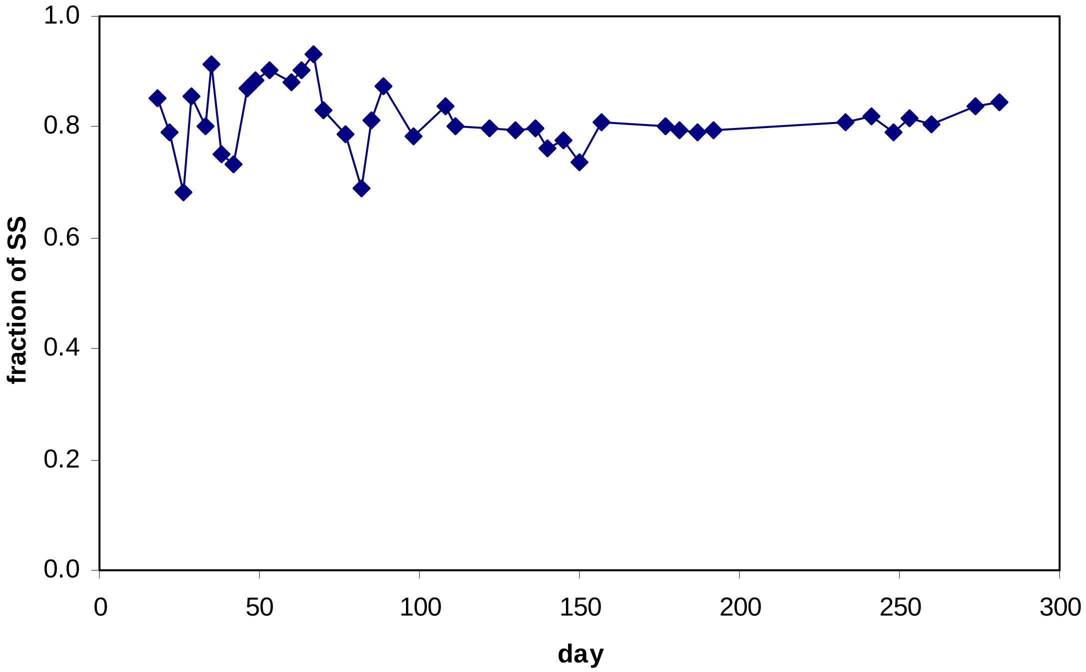


Figure 13. Fraction of source wastewater suspended solids (SS) as volatile suspended solids

3.5.2 *Treatment Characteristics*

VSS concentrations in the influent and the complete-mixed and supernatant effluents were measured in each reactor (Figures 14 – 17). The two CON reactors had higher complete-mixed VSS concentrations than the CYC reactors for the period after Day 161. CON-1 had 11,000 +/- 1,200 mg/L VSS; CON-2 had 10,000 +/- 1,000 mg/L VSS; CYC-1 had 9,400 +/- 800 mg/L VSS; and CYC-2 had 8,500 +/- 770 mg/L VSS. The CON reactors also had lower average supernatant VSS concentrations during this same period, though the results were quite variable. CON-1 had 2,200 +/- 1,100 mg/L VSS; CON-2 had 1,800 +/- 860 mg/L VSS; CYC-1 had 3,500 +/- 530 mg/L VSS; and CYC-2 had 3,700 +/- 620 mg/L VSS.

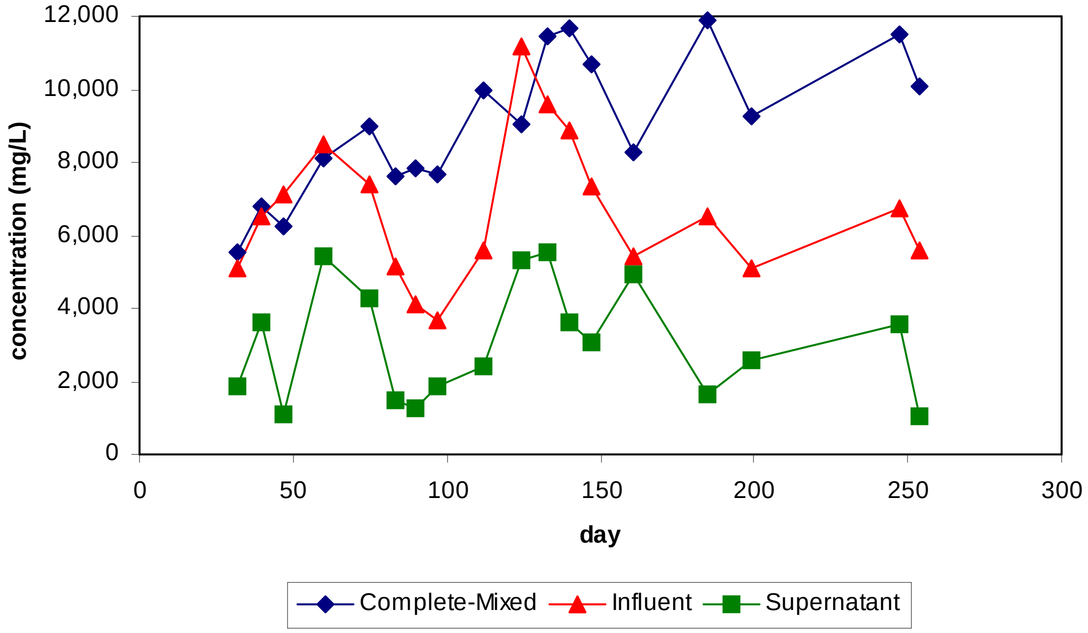


Figure 14. First continuous aeration sequencing batch reactor (CON-1) volatile suspended solids concentrations for complete-mixed sample, for weekly weighted-average influent, and for supernatant sample

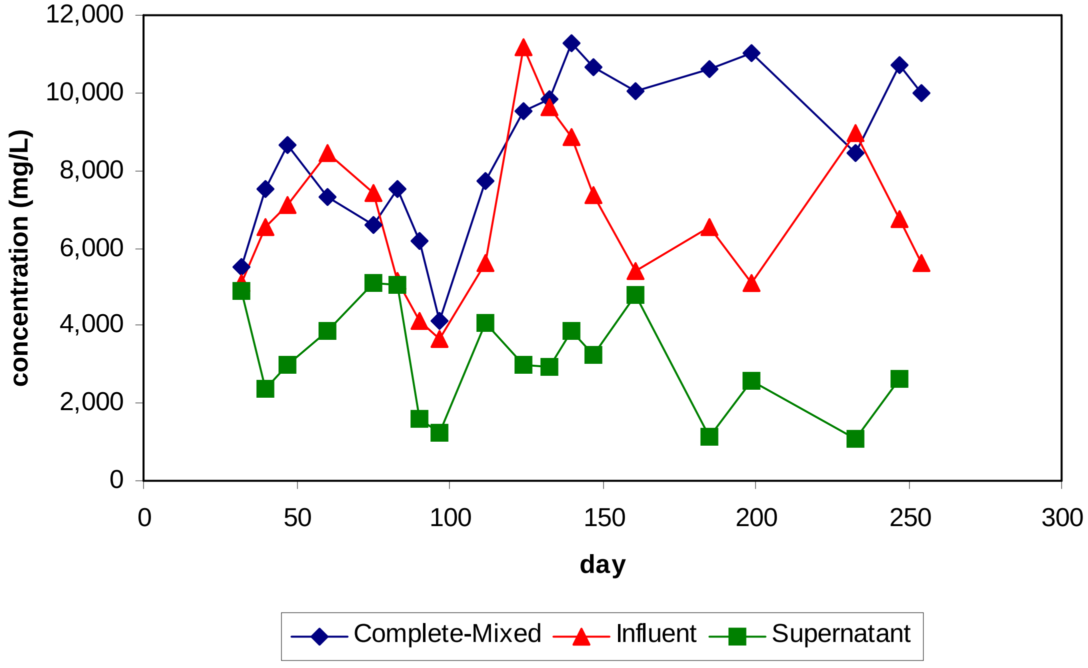


Figure 15. Second continuous aeration sequencing batch reactor (CON-2) volatile suspended solids concentrations for complete-mixed sample, for weekly weighted-average influent, and for supernatant sample

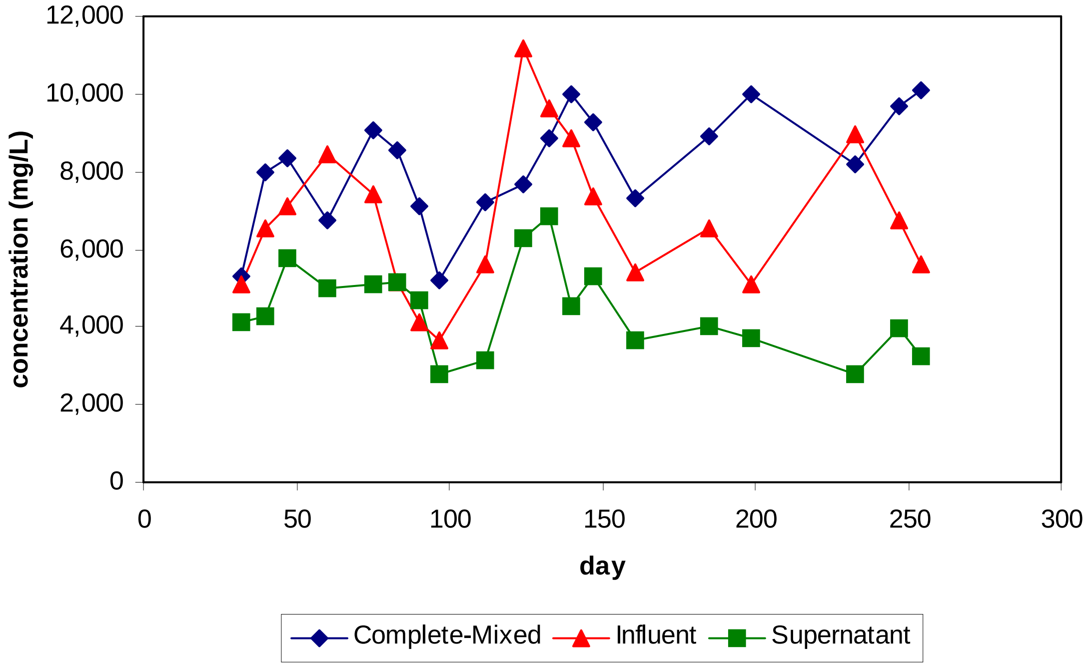


Figure 16. First cyclic aeration sequencing batch reactor (CYC-1) volatile suspended solids concentrations for complete-mixed sample, for weekly weighted-average influent, and for supernatant sample

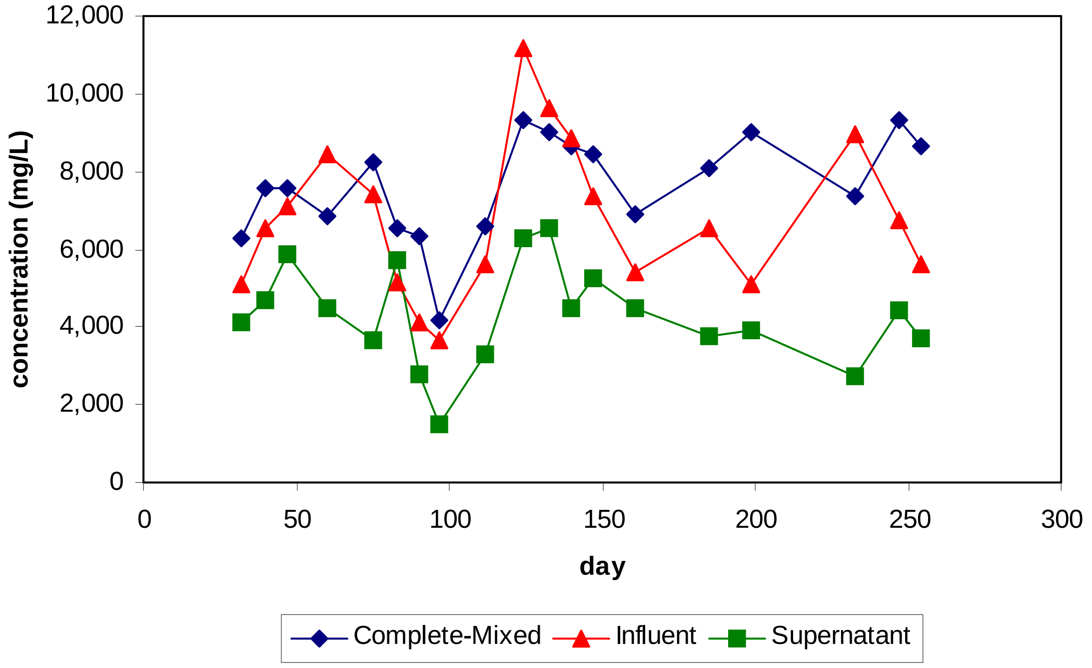


Figure 17. Second cyclic aeration sequencing batch reactor (CYC-2) volatile suspended solids concentrations for complete-mixed sample, for weekly weighted-average influent, and for supernatant sample

The operational changes in the reactors after Day 161 affected the suspended solids in two ways: reducing the wasting of the complete-mixed effluent allowed for the accumulation of the solids within the CON and CYC reactors, and increasing the aeration rate provided more oxygen for the increased growth of heterotrophic biomass suspended within the CYC reactors. A relationship between the SRT and settling efficiency, regardless of the reactor type and relative treatment performance, was observed (Figure 18). The two lines represent the relationship between SRT and SS settling efficiency before and after Day 161. The more elongated curve on the right side of the graph represents the relationship between SRT and settling efficiency after Day 161. The steeper line on the left side represents the same relationship before Day 161.

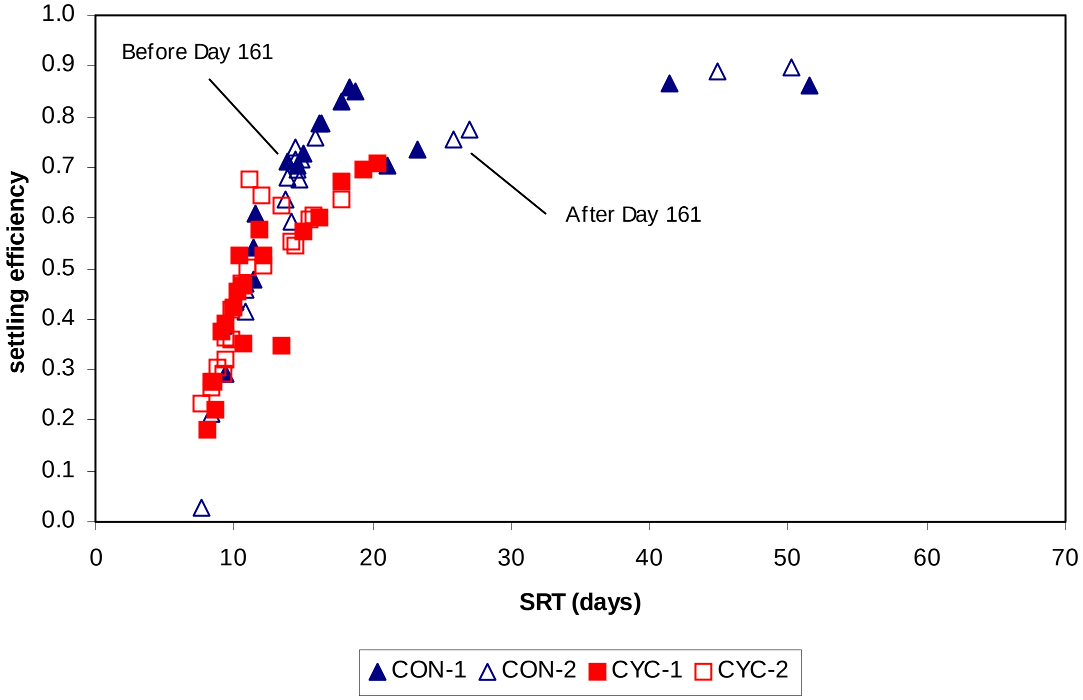


Figure 18. Continuous (CON) and cyclic (CYC) aeration sequencing batch reactor solids retention times (SRT) versus suspended solids (SS) settling efficiencies, identifying differing relationships before and after operational changes made after Day 161

The SRT with respect to settling efficiency should increase due to the changes in the solids wasting technique. Prior to Day 161, 25% of the batch volume was removed during complete-mixed conditions, and 75% of the batch volume was removed as supernatant. After Day 161, 96.4% of the batch volume was removed as supernatant, and 3.6% of the batch volume was removed during complete-mixed conditions. In the equation for SRT in Section 2.2, the denominator of the equation consists of the supernatant and complete-mixed effluent VSS mass rates. Since the operational changes after Day 161 limit the contribution of the complete-mixed component, the SRT became much more sensitive to changes in settling efficiency, which directly affects the supernatant VSS concentration. When the settling performance was 50% or less after Day 161, there was not much of a difference in the resulting SRT from those observed prior to Day 161. However, when settling efficiency was higher after Day 161, there was a large increase in the resulting SRT. More of the VSS was conserved in the reactors, which corresponds to the much higher SRT that were observed.

Table 4 summarizes the SS settling efficiency and SS mass removal efficiency performance of the reactors before and after Day 161. The operational changes resulted in the CON reactor settling efficiency increasing from an average of 60% to 82% and the CYC reactor settling efficiency increasing from 41% to 62%. After Day 161, the CON reactor settling efficiency was significantly greater than the CYC reactor settling efficiency ($p = 0.0077$). Figure 19 provides a visual indication of the improvement in SS settling efficiency performance for all four reactors after the Day 161 operational change.

The SS mass removal efficiency of the CON reactors increased after Day 161 from an average of 33% to 59%, while the CYC reactors had no increase in mass removal performance, averaging 23% before and 25% after Day 161. After the operational changes made after Day 161, the mean mass removal efficiency of the CON reactors was significantly greater than that of the CYC reactors (*p* = 0.0007).

Table 4. Continuous (CON) and cyclic (CYC) aeration sequencing batch reactor suspended solids settling and removal performance summary before and after operational changes made after Day 161

Reactor	Before Day 161				After Day 161[a]			
	Settling Efficiency	Mean	Mass Removal Efficiency	Mean	Settling Efficiency	Mean[b]	Mass Removal Efficiency	Mean[c]
CON-1	0.65	0.60	0.30	0.33	0.79	0.82	0.59	0.59
CON-2	0.55		0.35		0.84		0.59	
CYC-1	0.39	0.41	0.17	0.23	0.65	0.62	0.24	0.25
CYC-2	0.43		0.30		0.59		0.26	

a Comparisons of efficiencies for reactor types were only made for data after the operational changes instituted after Day 161.

b Differences between mean settling efficiency of CON and CYC reactors based on least square means were significant (p = 0.0077).

c Differences between mean mass removal efficiency of CON and CYC reactors based on least square means were significant (p = 0.0007).

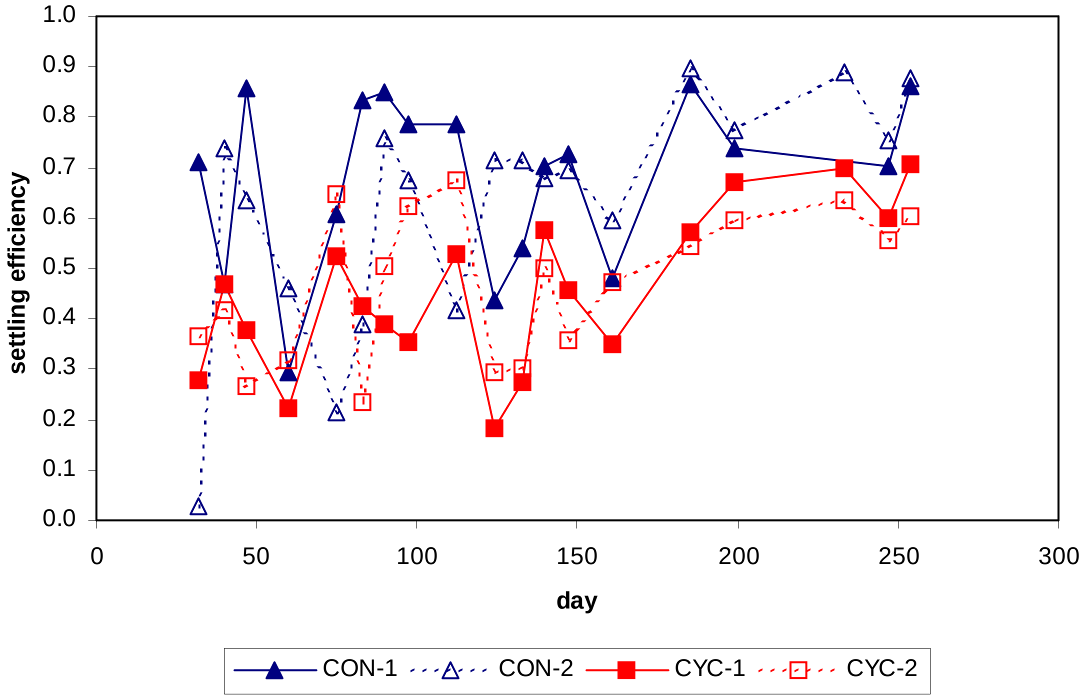


Figure 19. Continuous (CON) and cyclic (CYC) aeration sequencing batch reactor suspended solids (SS) settling efficiencies

3.6 Nitrogen

3.6.1 *Nitrate and Nitrite Analysis*

Chemical analyses were conducted to determine the concentrations of TKN, NH_3-N, NO_3-N, and NO_2-N. However, the chemical analysis laboratory technicians reported that constituents in the wastewater interfered with the tests for both nitrate and nitrite. Therefore the concentrations of these two chemical species were not determined, and the accumulation of nitrification products could not be measured.

3.6.2 *Source Characteristics*

The source TKN concentrations did not follow the same pattern as the COD and SS concentrations of increasing with increasing wastewater COD strength. TKN concentrations gradually decreased over the 281 days of sampling (Figure 20). The cause of this phenomenon is not known. A majority of the TKN was in a dissolved form, averaging 82%, ranging from 56 – 99% (Figure 21). The ammoniacal fraction, even though there was fluctuation in the TKN values over time, was consistently around 70% of the total TKN, having a range of only 53 – 83%. The dissolved concentrations in Figures 20 and 21, as well as for Figures 22 – 25, are the resulting TKN concentrations after filtration of the original samples. Because the filtered values were generally greater than the ammoniacal nitrogen concentrations, which are completely dissolved, it indicates that the filtered samples contain some dissolved, more complex nitrogen-containing compounds, such as amino acids.

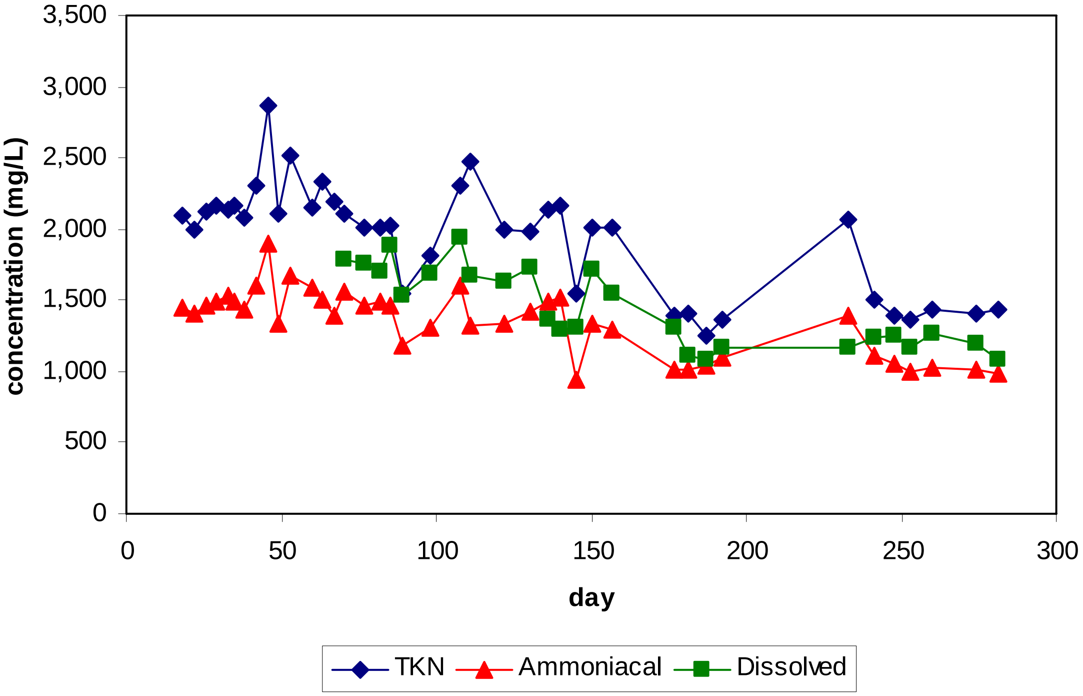


Figure 20. Sampling results of source wastewater total Kjeldahl nitrogen (TKN), ammoniacal nitrogen, and dissolved nitrogen concentrations

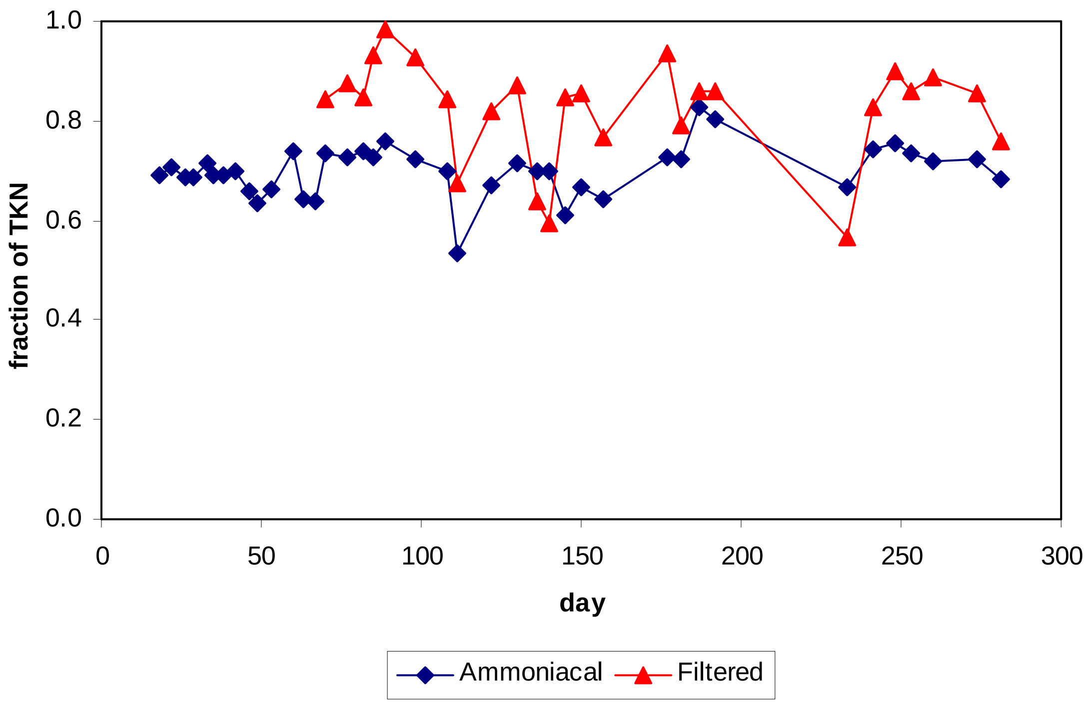


Figure 21. Fractions of source wastewater total Kjeldahl nitrogen (TKN) as dissolved total Kjeldahl nitrogen and as ammoniacal nitrogen

3.6.3 *Treatment Characteristics*

Figures 22 – 25 display the TKN concentrations for the four reactors. For all four reactors, the complete-mixed, supernatant, and dissolved concentrations closely followed the influent TKN levels. The best TKN removal was observed on Day 185 in the CON-2 reactor (Figure 23) when a drop in complete-mixed, supernatant, and dissolved TKN occurred, resulting in a 50% mass removal of TKN. However, this performance level decreased to 35% and then 8% for the next two analysis periods.

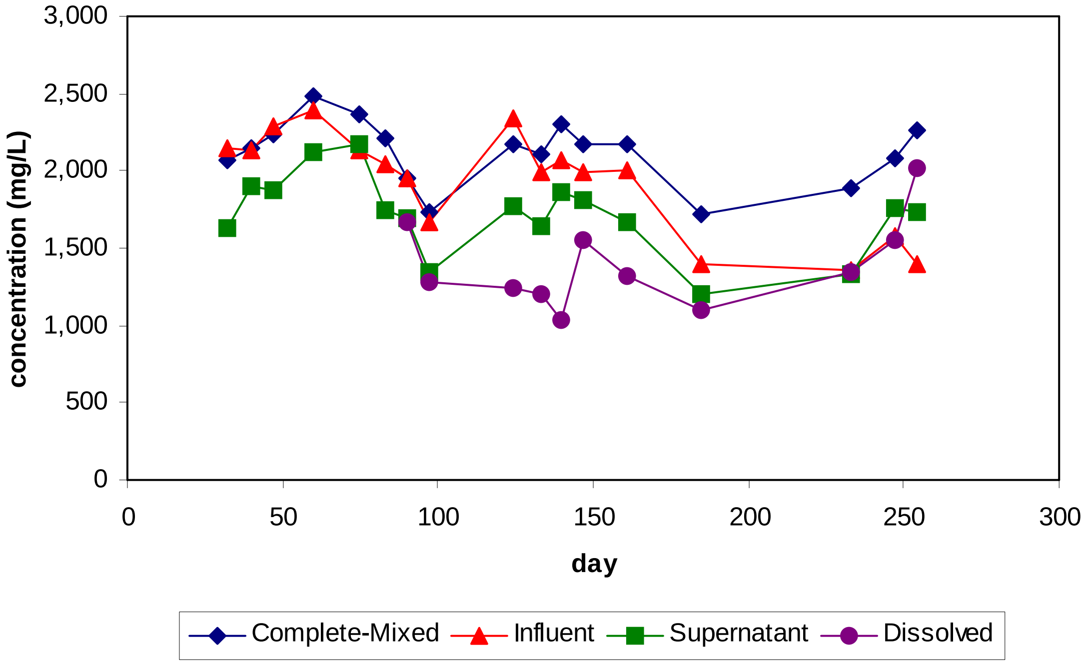


Figure 22. First continuous aeration sequencing batch reactor (CON-1) total Kjeldahl nitrogen concentrations for complete-mixed sample, for weekly weighted-average influent, for supernatant sample, and for dissolved portion of complete-mixed sample

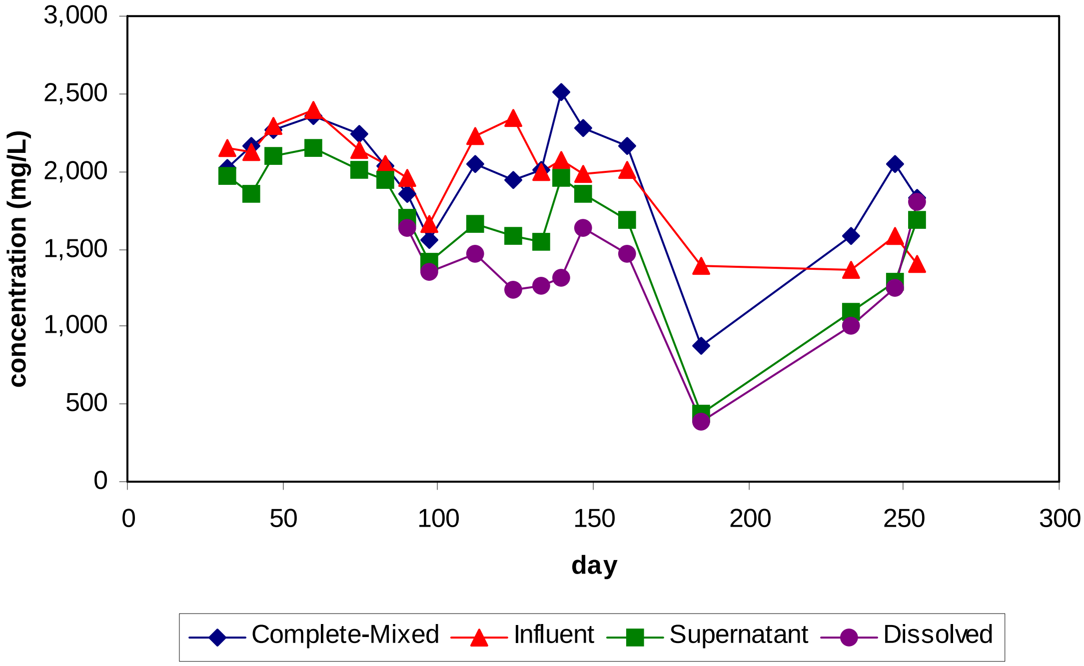


Figure 23. Second continuous aeration sequencing batch reactor (CON-2) total Kjeldahl nitrogen concentrations for complete-mixed sample, for weekly weighted-average influent, for supernatant sample, and for dissolved portion of complete-mixed sample

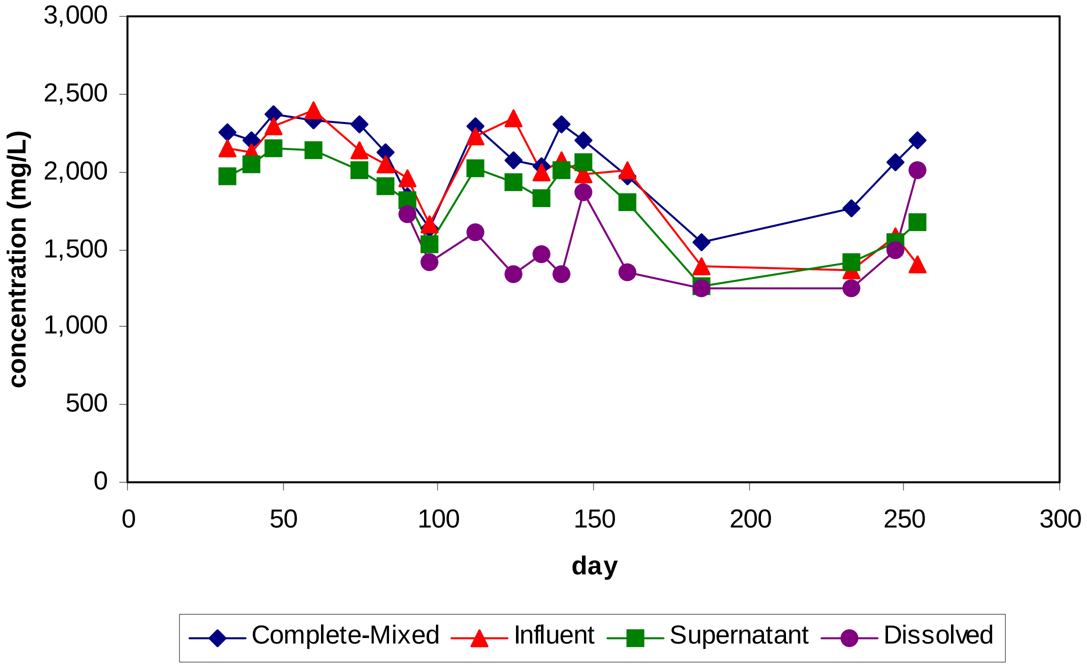


Figure 24. First cyclic aeration sequencing batch reactor (CYC-1) total Kjeldahl nitrogen concentrations for complete-mixed sample, for weekly weighted-average influent, for supernatant sample, and for dissolved portion of complete-mixed sample

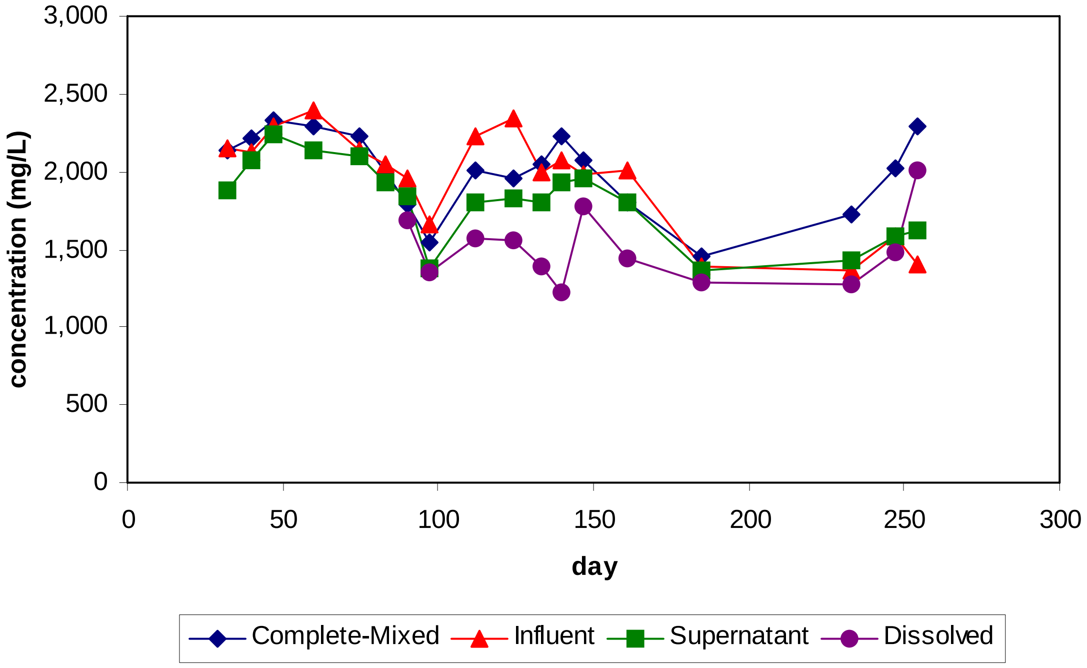


Figure 25. Second cyclic aeration sequencing batch reactor (CYC-2) total Kjeldahl nitrogen concentrations for complete-mixed sample, for weekly weighted-average influent, for supernatant sample, and for dissolved portion of complete-mixed sample

The average TKN settling efficiencies increased from 62% to 86% for the CON reactors and from 30% to 76% for the CYC reactors, after Day 161 (Table 5). There was not a significant difference in the CON and CYC reactor performances for settling efficiency after Day 161 ($p = 0.9610$).

The average TKN mass removal efficiencies dropped from 10% to 9% for the CON reactors and from 7% to -11% for the CYC reactors after Day 161. Though the average value for the CON reactors was nearly the same, the CON-1 mass removal efficiency dropped from 10% to -8%, while the CON-2 removal efficiency increased from 10% to 26%. Even with the drop in performance of the CON-1 reactor, the CON reactors had significantly higher TKN mass removal efficiencies than the CYC reactors after Day 161 ($p = 0.0092$).

Table 5. Continuous (CON) and cyclic (CYC) aeration sequencing batch reactor total Kjeldahl nitrogen settling and removal performance summary before and after operational changes made after Day 161

Reactor	Before Day 161				After Day 161[a]			
	Settling Efficiency	Mean	Mass Removal Efficiency	Mean	Settling Efficiency	Mean[b]	Mass Removal Efficiency	Mean[c]
CON-1	0.61	0.62	0.10	0.10	0.82	0.86	-0.08	0.09
CON-2	0.62		0.10		0.90		0.26	
CYC-1	0.33	0.30	0.06	0.07	0.84	0.76	-0.08	-0.11
CYC-2	0.27		0.09		0.67		-0.13	

a Comparisons of efficiencies for reactor types were only made for data after the operational changes instituted after Day 161.
b Differences between mean settling efficiency of CON and CYC reactors based on least square means were not significant (p = 0.9610).
c Differences between mean mass removal efficiency of CON and CYC reactors based on least square means were significant (p = 0.0092).

The negative values of TKN mass removal efficiency in CON-1 and the two CYC reactors are the result of an excessive accumulation of solids in the reactors together with a drop in influent concentration. The solids accumulation was discussed above in terms of higher values of SRT near the end of the experiment.

Figure 26 displays the mass removal efficiencies for the four reactors, and, as in Figure 23, has points that stand out from among the others, where there is the clear increase in the mass removal efficiency for CON-2 on Day 185 and Day 233. All four reactors had TKN mass removal rates on Day 124 that approached the same level as for CON-2 achieved on Day 185 (Figure 27). This spike in mass removal likely was caused by the reactors responding to fluctuations in the source TKN prior to the sampling, which increased from 13,000 mg/L to 18,000 mg/L. Though the mass removal rate for CON-2 around Day 185 was the same as for the reactors on Day 124 (Figure 27), the mass removal efficiency for CON-2 around Day 185 was nearly double those mass removal efficiencies observed on Day 124 (Figure 26). This can be explained by the overall decreasing trend of the source TKN concentrations over the duration of the experiment (Figure 20). Though the mass removal rates may have been roughly the same, the efficiency for CON-2 around Day 185 increased due to the smaller values of TKN mass entering the reactors at that time.

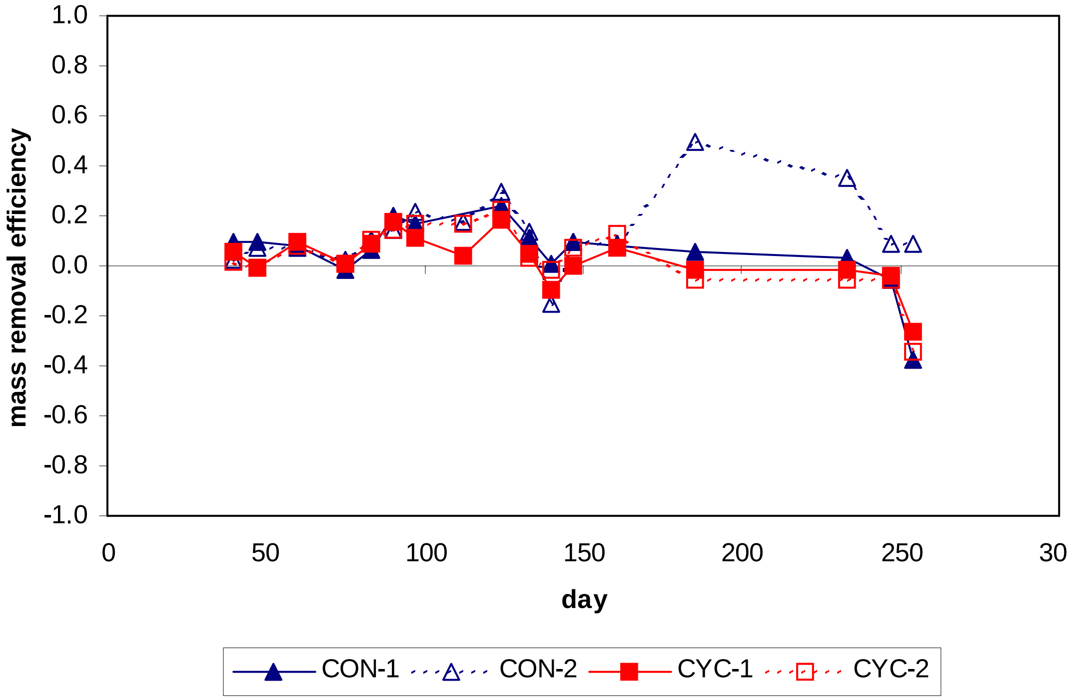


Figure 26. Continuous (CON) and cyclic (CYC) aeration sequencing batch reactor total Kjeldahl nitrogen mass removal efficiencies

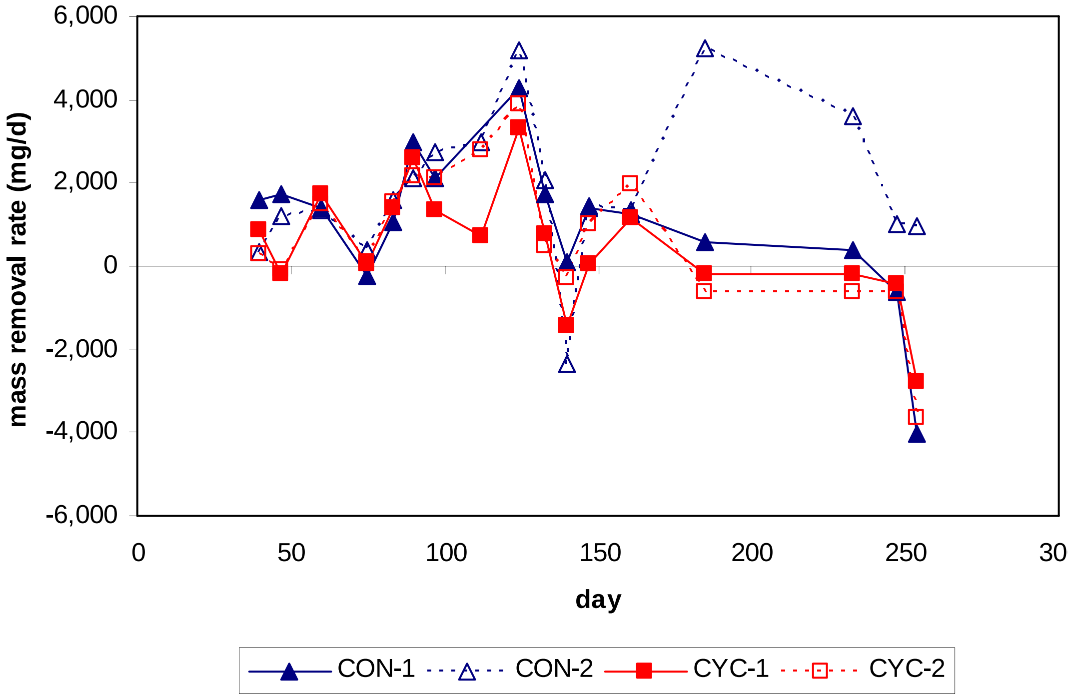


Figure 27. Continuous (CON) and cyclic (CYC) aeration sequencing batch reactor total Kjeldahl nitrogen mass removal rates

The two CON reactors were operated identically, but, as discussed previously, there was a separation of performance for the period of two sampling dates starting on Day 185. The only difference between these two reactors during the experiment involved foaming. As discussed in Section 3.3, the foaming in the reactors was reduced when more concentrated wastewater was added to the reactors. It is possible that, due to the limitations of the source collection and loading technique from the plastic containers, that CON-2 could have unintentionally experienced lower loading rates. The source wastewater was collected in several plastic containers and there would be fluctuations in the pipeline effluent from the swine houses during collection times. Then, when loading the reactors with influent, there was not complete mixing of the source wastewater – achieving mixing when the plastic containers were difficult compared to when they were nearly empty. So there would be more solid material in the batches of influent when the containers were half to nearly empty. Though precautions were taken to maintain a set pattern of loading in an attempt to balance these fluctuations, if CON-2 received weaker influent than CON-1 for a period of time, it could explain why the foaming was so prevalent with CON-2. If the COD was reduced in CON-2, while maintaining a consistent concentration of TKN, this could cause a temporary drop in the BOD_5/TKN, which inhibits nitrification if the ratio is too high. If a lower BOD_5/TKN was maintained in CON-2, it could have provided an opportunity for nitrifying bacteria to compete (Crites and Tchobanoglous, 1998).

Nitrification and denitrification processes did not take place at any significant, consistent rate, based on two key factors. First, the pH levels that were collected revealed that the four reactors consistently maintained pH ranges of 8.3 to 8.5. Due to the disruption in the nitrate and nitrite analyses, analytical proof of production of nitrite or nitrate was not observed. Therefore, other signals were needed to determine whether this activity was occurring. Though the wastewater has high buffering capacity, the lack of a drop in pH supports the theory that the acidifying reactions of nitrification were not occurring. The nitrification reaction produces 2 moles of H^+ for every mole of TAN transformed to nitrate, according to the following summary of the nitrification reaction:

$$NH_4^+ + 2\ O_2 \rightarrow NO_3^- + 2\ H^+ + H_2O$$

For actively nitrifying reactors, pH drops are possible, which have the potential limit or even cease the productivity of the microorganisms. If nitrification was taking place within the CON and CYC reactors, it was not at a significant rate, based on the low TKN mass removal efficiencies. Figure 28 shows the alkalinity levels for the complete-mixed samples within the reactors as well as the source alkalinity. The graph indicates that all the reactors consistently followed the influent alkalinity; there was no separation between the reactors' complete-mixed alkalinities and the source level. The lone exception is for the CON-2 reactor on Day 185. This alkalinity value is 56% of the source value, meaning that there was acid production within the reactor. This finding, along with the mass removal efficiency results discussed previously, indicates that nitrification was occurring around Day 185. The following point on Figure 28 for Day 199 is 86% of the source alkalinity. This is an indication that the nitrification process had slowed in the CON-2 reactor during that two-week interval. This is supported by the drop in mass removal rate of TKN between Day 185 and Day 233 (Figure 27).

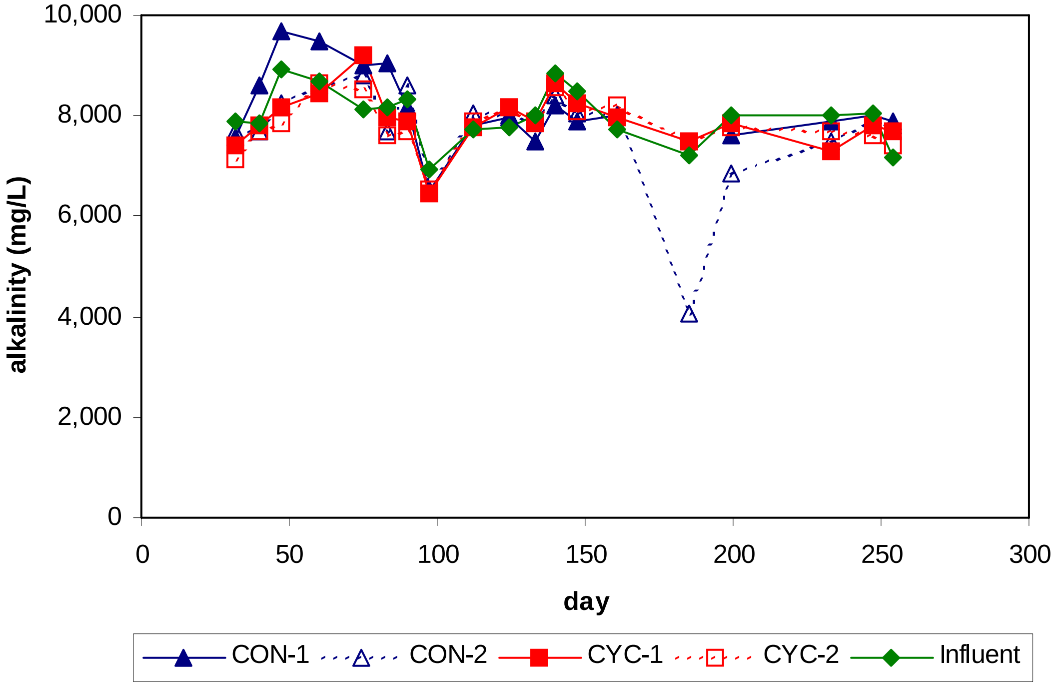


Figure 28. Continuous (CON) and cyclic (CYC) aeration sequencing batch reactor alkalinity concentrations for complete-mixed conditions and weekly weighted-average influent

A second indication for the lack of nitrification and denitrification, excluding CON-2 on and around Day 185, was that the COD removal within the two sets of reactors did not match sequencing batch reactors of similar design and parameters, indicating oxygen limitation. The higher COD removal rates for the CON reactors indicate greater oxygen availability within the systems, which may be why they have slightly higher TKN removal rates. Since the effluent COD was not reduced to levels seen in other similar experiments, it is an indication that there was excessive competition within the reactors for dissolved oxygen, even among heterotrophic organisms. Due to the slow growth rate of nitrifying bacteria, it is probable that the appropriate environment for growth was never established, and the nitrifying bacteria likely were washed out of the systems.

3.6.4 *Oxygen Requirements*

The average COD mass influent rate was 94,000 +/- 26,000 mg/d, and the average TKN mass influent rate was 15,000 +/- 2,500 mg/d. Based on values provided in Section 1.7, the total daily oxygen demand for the influent wastewater was 0.67 mg O_2/mg COD and 4.7 mg O_2/mg NH_3-N. The daily demand for oxygen from COD was 63,000 mg/d and from NH3-N was 71,000 mg/d for a total of 134,000 mg/d. The CON reactors received an oxygen supply of 270,000 mg/d, and the CYC reactors, after Day 161, received 1,000,000 mg/d.

Because of the system was operated to stimulate low oxygen nitrification and SND, the total COD that was to be met by oxygen should have been reduced by anaerobic respiration utilizing nitrate and nitrite. Based on the influent rate TKN, there was the potential for the formation of 15,000 mg/d of nitrogen in the form of either nitrate or nitrite. If nitrite oxidation activity was inhibited, as has been identified in SND systems discussed in Section 1.5, the oxygen requirements for nitrogen removal would drop by 18,000 mg/d for complete nitrite respiration. In a realistic SND situation, the oxygen requirement would fall between 53,000 and 71,000 mg/d.

Due to the high concentration of TKN entering these systems, there was significant potential for nitrate and nitrite to replace oxygen as TEA through anaerobic respiration. If all the influent nitrogen were converted into nitrate, the nitrate would oxidize the equivalent of 43,000 mg COD/d. If all the nitrogen was converted to nitrite, the nitrite would oxidize the equivalent of 26,000 mg COD/d. Again, these values are for complete utilization. According to the TKN performance for the four reactors, nitrification and denitrification activity was negligible, accept in the case of CON-2 around and after Day 185.

The following equation is used to determine the required airflow to meet the wastewater oxygen demand for diffused air aeration systems:

$$Q_{air} = \frac{W_{oxygen}}{(AOTE)(O_2)(\gamma_{air})}$$

Q_{air} = required air flow (L/d)

W_{oxygen} = oxygen requirements (mg/d)

AOTE = actual oxygen transfer efficiency

O_2 = fractional percent of oxygen in air

γ_{air} = specific weight of air (mg/L)

The equation can be rearranged to solve for AOTE by providing actual daily COD removal rates observed. This can be compared to the typical values for AOTE for nitrifying activated sludge processes to evaluate the effectiveness of the CON and CYC aeration systems (Crites and Tchobanoglous, 1998).

Based on meeting the 134,000-mg/d average daily oxygen demand, the CON reactors required an AOTE of 49% and the CYC reactors required an AOTE of 13% for the flow rates set after Day 161. Assuming that nitrification and denitrification activity had taken place, the average daily oxygen demand could have been reduced to around 91,000 mg/d for nitrate respiration and to around 90,000 mg/d for nitrite respiration. For this case, the CON reactors would have required an AOTE of only 33%, and the CYC reactors would have required an AOTE of 9%. For nitrifying activated sludge reactors, a “very fine” diffuser type has a typical AOTE for a full-scale system of 10% to 16%, a “fine” diffuser has values from 8% to 14%, and a “coarse” diffuser has values of 4% to 8% (Crites and Tchobanoglous, 1998). The small fish tank diffusers would be considered coarse. The AOTE requirements for complete COD and TKN removal for the CON and CYC reactor airflows could not be met by the aeration systems established in this study. When looking at the actual COD removal rates, the AOTE values for the two aeration systems can also be determined. For the CON reactors, which had average COD mass removal rates after Day 161 of 39,000 mg/d, the AOTE was calculated to be 14%. For the CYC reactors, which had average COD mass removal rates after Day 161 of 26,000 mg/d, the AOTE was calculated to be only 3%. These results indicate that, for the fish tank diffusers, there is a drop in AOTE with increased flow rate; the diffusers lose their effectiveness in breaking the airflow into tiny bubbles when the airflow rate was higher.

3.7 Phosphorus

3.7.1 *Source Characteristics*

The total phosphorus (TP) source concentrations fluctuated due to the inconsistency of the source wastewater strength discussed previously (Figure 29). The average source TP over the entire experimental period was 210 +/- 58 mg/L. Orthophosphate (O-PO_4) is the soluble form of phosphorus. Figure 29 and Figure 30 show that the majority of the source TP was in the form of O-PO_4, averaging 78% and ranging from 50 – 100%. The dissolved TP values are measurements of the TP concentrations after filtration. Significant fluctuation occurred in the fraction of TP as dissolved TP, but it steadied and averaged around 53% (Figure 30). This indicates that nearly half of the phosphorus was associated with the suspended solids. Assuming that nearly all of the dissolved TP is in the form of the soluble O-PO_4, on average, 29% of the source O-PO_4 is associated with the source SS. This assumption is not completely accurate, because Day 89 in Figure 30 has a dissolved TP fraction of 85% and an orthophosphate fraction of only 77%. This indicates that there were other dissolved phosphorus-containing molecules present. Some of these compounds could have been organic phosphates, including phospholipids, sugar phosphates, nucleotides, or phosphoamides (Snoekink and Jenkins, 1980).

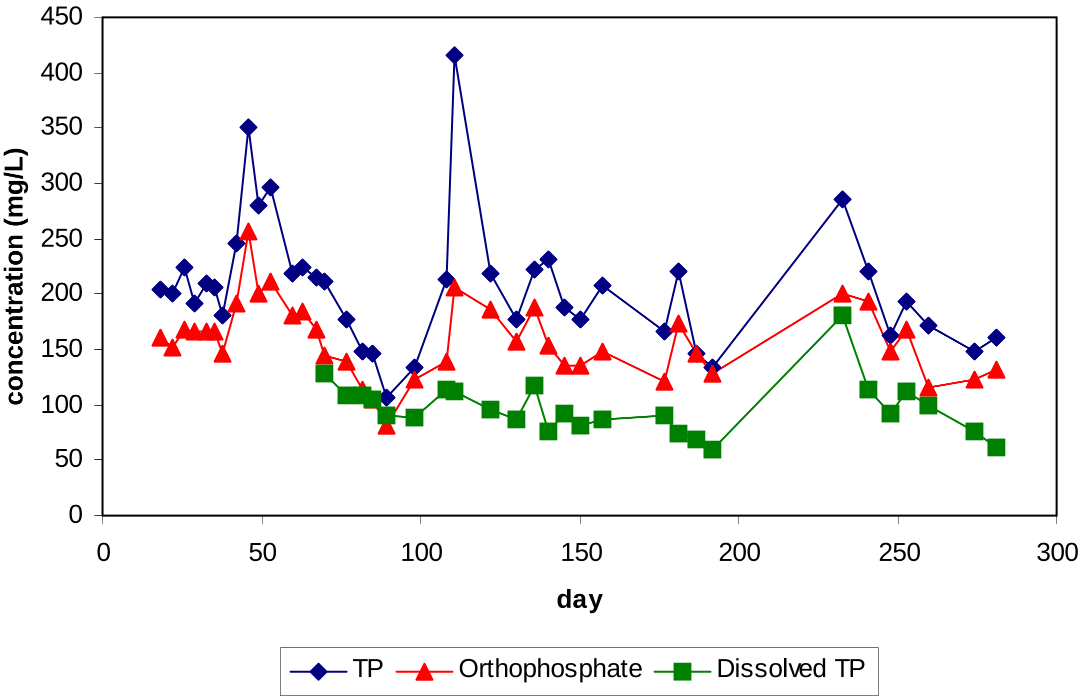


Figure 29. Sampling results of source wastewater total phosphorus (TP), orthophosphate, and dissolved total phosphorus concentrations

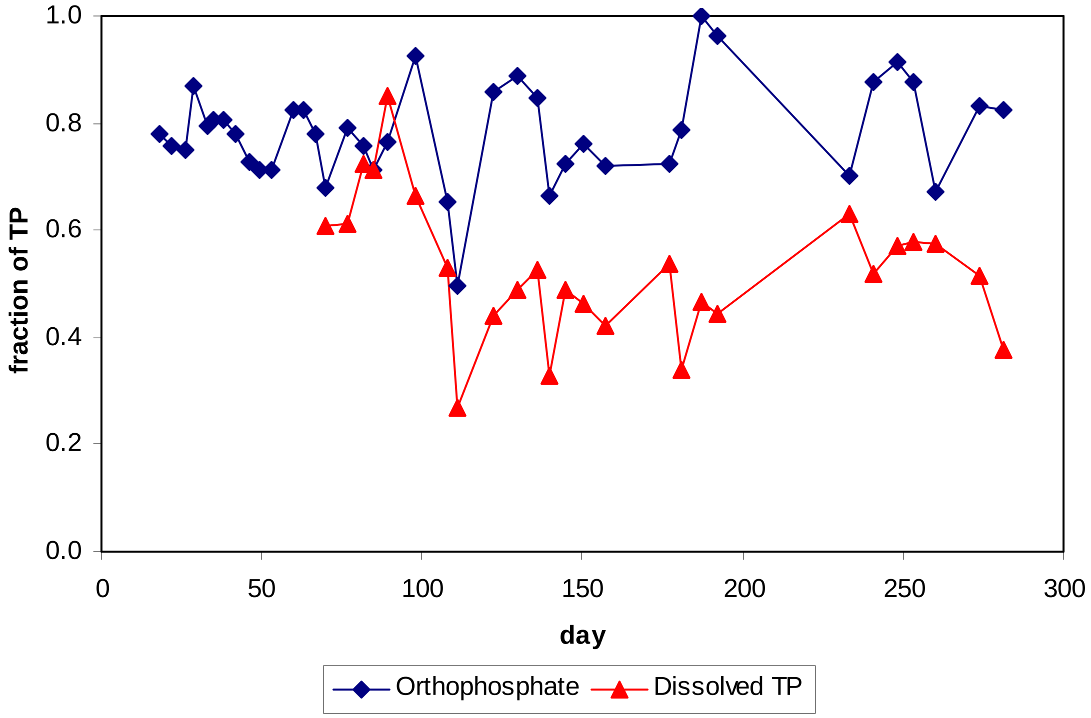


Figure 30. Fractions of source wastewater total phosphorus (TP) as dissolved orthophosphate and as dissolved TP

3.7.2 *Treatment Characteristics*

Because TP is not removed from the treatment system, as are COD, SS, and TKN, reactor performance for TP must be based on the ability to incorporate it within the settled solids to keep it from leaving the reactors in the supernatant. Therefore, settling efficiency and accumulation are the key performance indicators. Figures 31 – 34 display the complete-mixed, influent, supernatant, and dissolved TP concentrations for each of the reactors over the entire investigation. Figures 31 and 32 show that the complete-mixed, supernatant, and dissolved TP concentrations for the CON reactors stabilized after Day 133. The consistency in phosphorus concentration in the source wastewater after Day 133 was the main contributing factor for this observed stability. Figures 33 and 34 show that there was similar consistency within the CYC reactors. The CYC-1 reactor differed from the CON reactor performance in settling efficiency, indicated on Figure 33 by the larger gap between the supernatant and dissolved TP lines. The CYC-2 reactor had lower complete-mixed concentrations until the final days of the experiment. It is not clear why there is a difference in these CYC reactor complete-mixed concentration values, since the reactor performance numbers were similar.

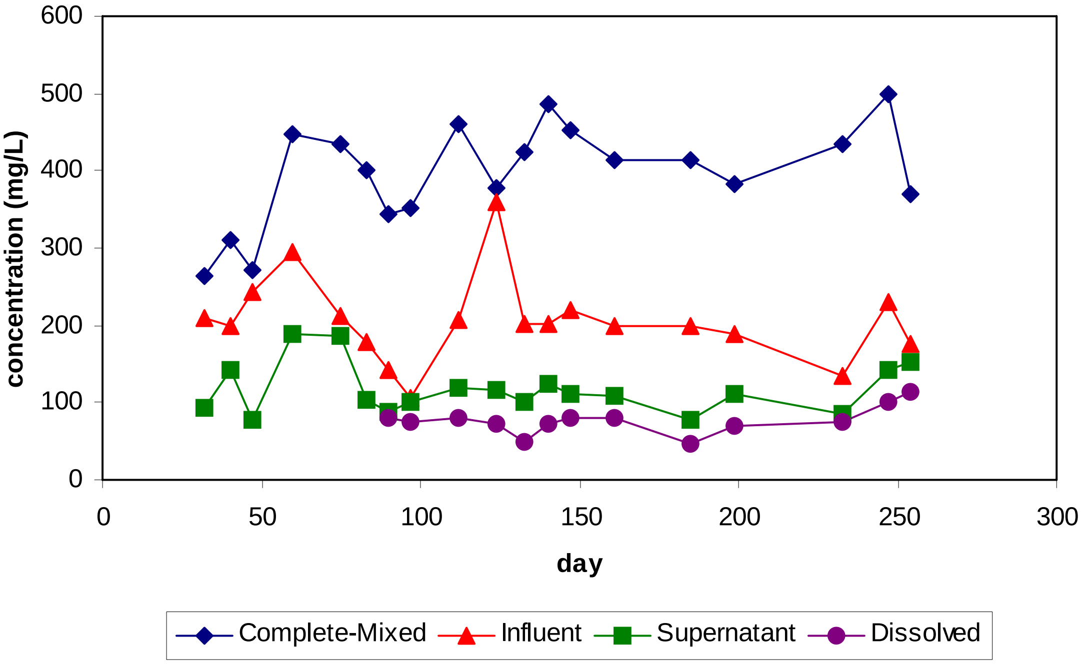


Figure 31. First continuous aeration sequencing batch reactor (CON-1) total phosphorus concentrations for complete-mixed sample, for weekly weighted-average influent, for supernatant sample, and for dissolved portion of complete-mixed sample

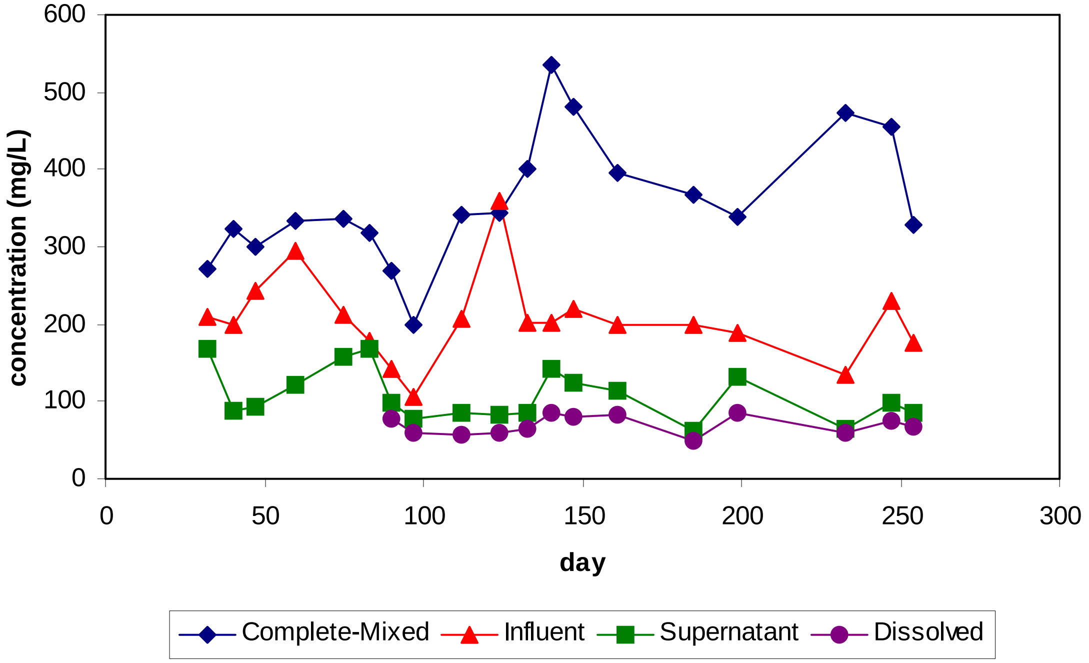


Figure 32. Second continuous aeration sequencing batch reactor (CON-2) total phosphorus concentrations for complete-mixed sample, for weekly weighted-average influent, for supernatant sample, and for dissolved portion of complete-mixed sample

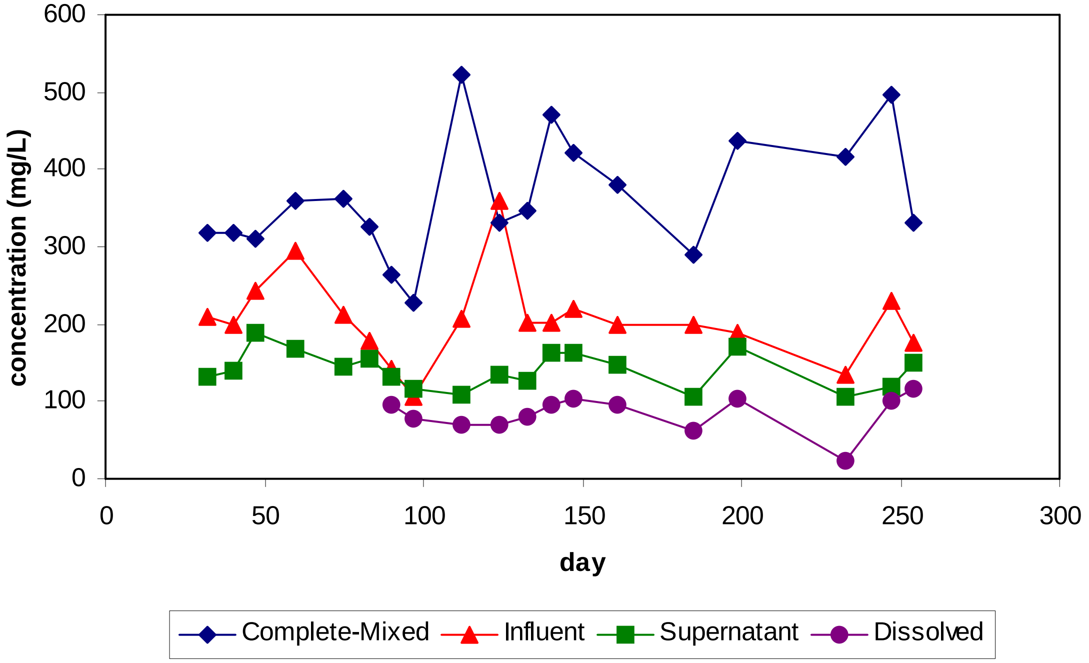


Figure 33. First cyclic aeration sequencing batch reactor (CYC-1) total phosphorus concentrations for complete-mixed sample, for weekly weighted-average influent, for supernatant sample, and for dissolved portion of complete-mixed sample

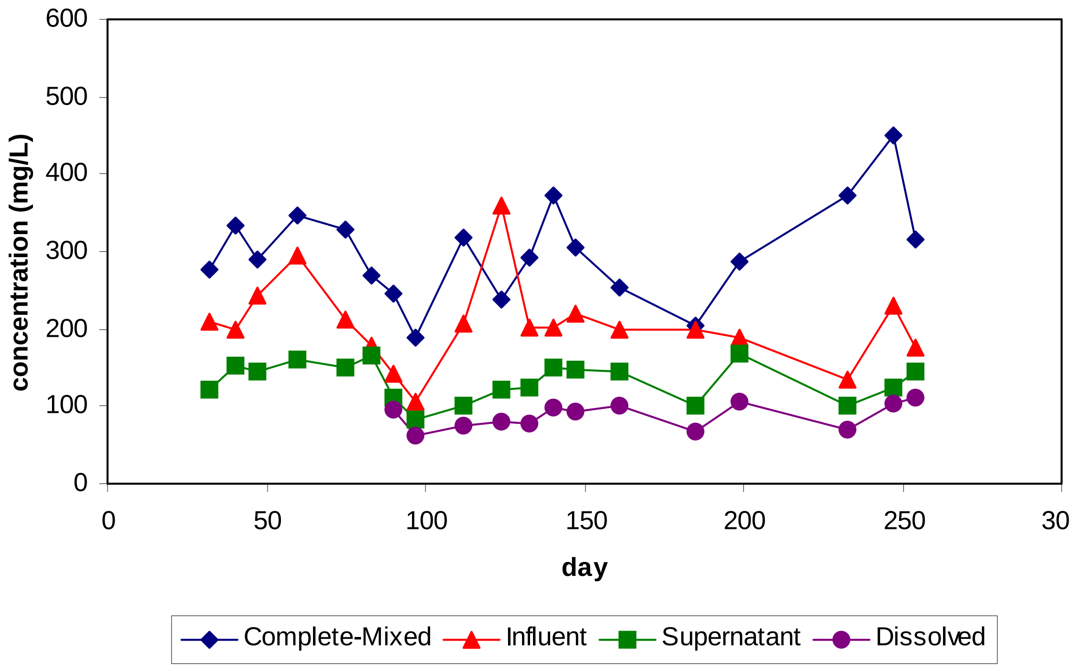


Figure 34. Second cyclic aeration sequencing batch reactor (CYC-2) total phosphorus concentrations for complete-mixed sample, for weekly weighted-average influent, for supernatant sample, and for dissolved portion of complete-mixed sample

The CON reactors had average TP settling efficiencies of 90% before Day 161 and 91% after Day 161 (Table 6). The CYC reactors had average TP settling efficiencies of 80% and 83%, before and after Day 161, respectively. After Day 161, the CON reactors had a significantly higher TP settling efficiency than the CYC reactors ($p = 0.0004$). The consistent high TP settling performance for all four reactors does not match the SS settling performances discussed in Section 3.5.2. The average SS settling efficiencies before Day 161 were 60% for the CON reactors and 41% for the CYC reactors. After Day 161 the average SS settling efficiencies increased to 82% for the CON reactors and 62% for the CYC reactors. These differences in settling performances between SS and TP indicate that the TP was incorporated with solids that had much better settling qualities. In other words, the solids with which the TP was incorporated had a higher density then the other solids in the reactors. The operational changes after Day 161 had no effect on the settling performance of the TP, because these solids were quickly and consistently being separated from the supernatant. Phosphate binds with a variety of metal ions to form many different solids, one of which is magnesium ammonium phosphate, or struvite. Struvite reaches a minimum solubility at a pH range of about 9.0 to 11.5 at 25 ^{o}C (Snoeyink and Jenkins, 1980). The observed pH of about 8.5 within each of the reactors would indicate that conditions were favorable for the formation of struvite as well as other inorganic precipitates.

Table 6. Continuous (CON) and cyclic (CYC) aeration sequencing batch reactor total phosphorus settling performance summary before and after operational changes made after Day 161

Reactor	Before Day 161		After Day 161[a]	
	Settling Efficiency	Mean	Settling Efficiency	Mean[b]
CON-1	0.90	0.90	0.90	0.91
CON-2	0.90		0.93	
CYC-1	0.81	0.80	0.84	0.83
CYC-2	0.80		0.81	

a Comparisons of efficiencies for reactor types were only made for data after the operational changes instituted after Day 161.

b Differences between mean settling efficiency of CON and CYC reactors based on least square means were significant ($p = 0.0004$).

The settling performance was consistent in that 80 – 90 % of the TP incorporated with the SS would be separated from the supernatant effluent. The question of interest then becomes whether or not there is an accumulation of TP within the solids. Because TP can only enter and exit the reactors by means of the influent, complete-mixed effluent, and supernatant, the TP parameter provides the opportunity to investigate accumulation by two methods: (1) comparing the change in complete-mixed concentration over time multiplied by the volume of the reactor and (2) calculating the balance of inputs and outputs for the reactors. Figure 35 displays the TP mass accumulation rates for the four reactors using the first method, which was used in the previous sections in determining the mass removal rates and efficiencies. Based on this first method, the average accumulation rates after Day 161 were -150 mg/d for CON-1, -200 mg/d for CON-2, -125 mg/d for CYC-1, and -79 mg/d for CYC-2. Figure 36 displays the TP mass accumulation rates according to the second method. The average accumulation rates for this case were 490 mg/d for CON-1, 630 mg/d for CON-2, 350 mg/d for CYC-1, and 380 mg/d for CYC-2. Though the data in Figures 35 and 36 follow a similar pattern, the two methods do not agree as they should if all the measurements used in the calculations were correct.

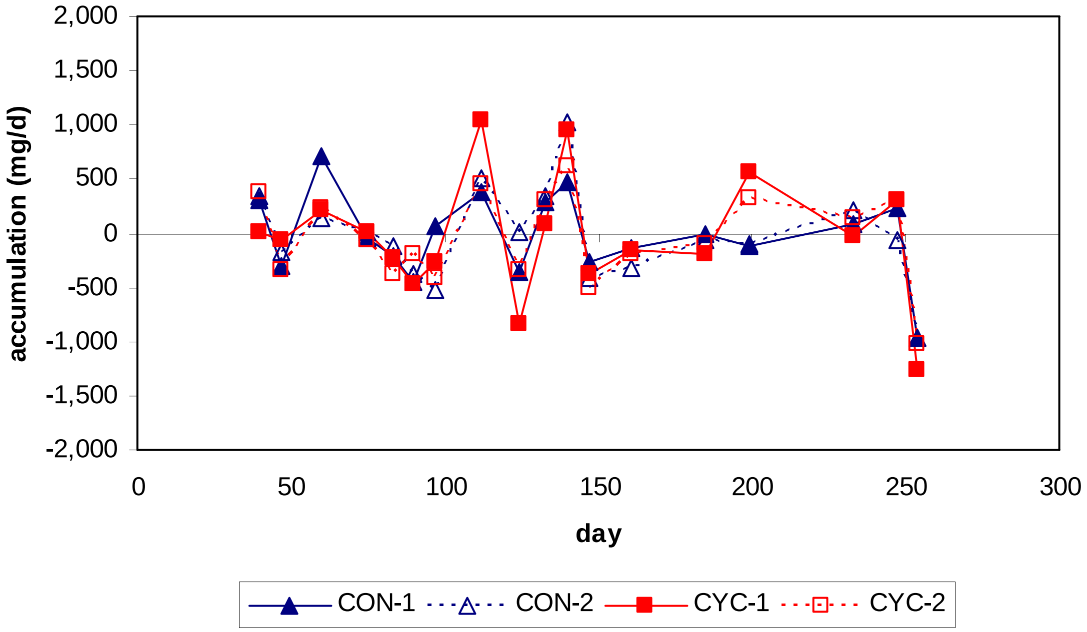


Figure 35. Continuous (CON) and cyclic (CYC) aeration sequencing batch reactor total phosphorus mass accumulation rates calculated by multiplying the volume of the reactor by the change in complete-mixed total phosphorus concentration divided by time

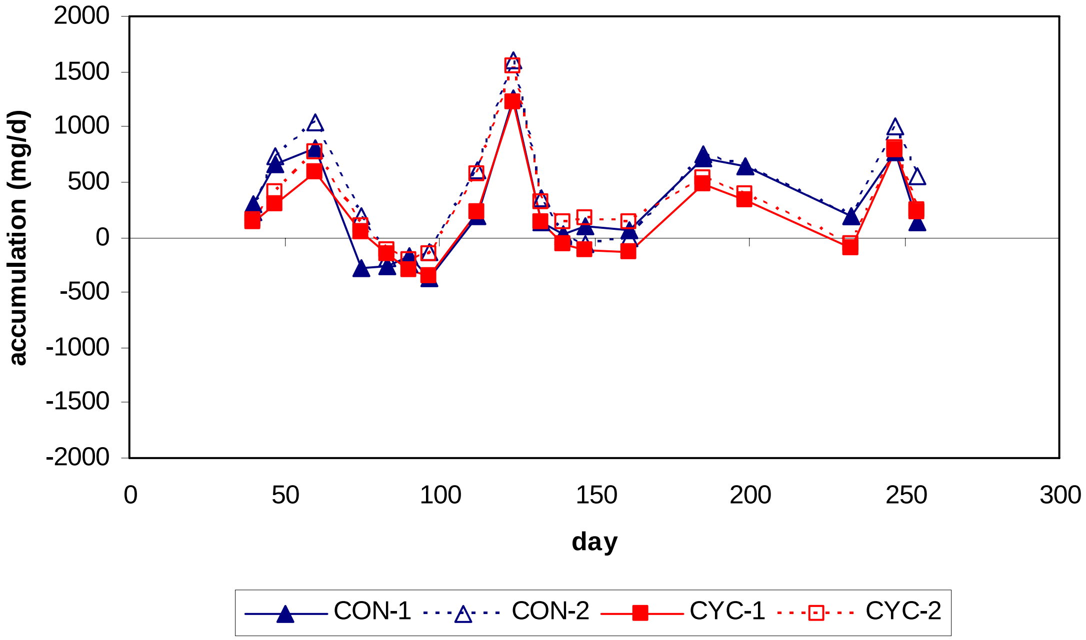


Figure 36. Continuous (CON) and cyclic (CYC) aeration sequencing batch reactor total phosphorus mass accumulation rates calculated as the difference between influent and effluent mass rates

After Day 161, the 96.4% of the effluent leaving the reactor was from the supernatant. TP accumulation would be expected in each of the reactors, since the influent TP was approximately 50% in suspended form. The accumulation results using the second method closely followed the same fluctuations observed in the influent TP concentrations (Figures 31 – 34). The calculation for the first method of determining the TP accumulation in the reactors, which provided negative accumulation results, was based on the change in complete-mixed concentration samples and is another expression of the complete-mixed TP concentrations for the four reactors (Figures 31 – 34). It is not clear why the discrepancy between the two methods exists. It suggests that either less TP was entering the system than was calculated from the source wastewater samples or more TP was leaving the system in the supernatant between sampling periods. Increased sampling of the source wastewater and homogenization and sampling of the influent into the reactors would make the TP accumulation situation much clearer.

The primary question for the phosphorus accumulation is whether it is simply a physical separation due to settling or there is biological phosphorus accumulation occurring. For bioaccumulation to occur, a portion of the dissolved TP would need to be incorporated into the biomass. If this phenomenon was occurring, there should have been a drop in the dissolved TP entering the reactors compared to the dissolved TP leaving the reactors as effluent, since bioaccumulation of the dissolved O-PO_4 occurs during aeration, when the samples were taken. In order to evaluate the possibility of phosphorus accumulation, a dissolved TP mass balance was calculated for all four reactors for conditions after Day 161. The calculations made a balance of the influent dissolved TP and the effluent dissolved TP. The dissolved TP accumulation results were as follows: 26 mg/d for CON-1, -12 mg/d for CON-2, 16 mg/d for CYC-1, and 7 mg/d for CYC-2. These results show no change in the dissolved TP in all four reactors. This indirect method of estimating TP accumulation provides results that fit between the results of the other two accumulation calculation methods. These results indicate that, for the case of TP, equilibrium was established between the dissolved TP and the various phosphorus-containing solids within the reactors. The relatively steady complete-mixed, supernatant, and dissolved TP concentrations in Figures 31 – 34 support this. These concentrations were established early in the experiment, well before the operational changes after Day 161. The fluctuations observed were due to the changes in the influent TP concentrations, which affected the equilibrium concentrations in the reactors.

4. CONCLUSIONS

Though the reactors did not meet the same performance levels as previous sequencing batch reactor studies involving swine waste, the objective of matching the full-scale system in operation parameters was accomplished, but only according to the original design information from ANT. There were operational parameters that could not be verified by a comparison to the full-scale field system because of delays in the implementation of the field system. Nevertheless, the results that were obtained provided insight into the differences between the use of continuous, low-level aeration and the use of cyclic aeration schemes. The CON reactors received 73% less oxygen into the systems yet performed as well as or better than the CYC reactors in the treatment of COD, SS, TKN, and TP. There is an economic incentive for the continued research into the potential for bench-scale and full-scale continuous, low-flow aeration sequencing batch reactors.

A higher degree of certainty with regard to what was going in to the reactors and what was occurring within the reactors would have benefited the analysis of the experiment. Collecting multiple samples during the source wastewater collection would have presented a clearer picture of the true characteristics of the influent wastewater. The addition of a mechanism for homogenization of the source wastewater prior to filling the reactors would reduce the variability observed between the sets of reactors. Sampling of the influent prior to addition into the reactors would also provide more accurate performance calculations. Continuous monitoring of oxidation-reduction potential (ORP), pH, and DO would also provide a much more information about what is occurring within the reactors between the sampling periods. The ORP measurements would give a more sensitive indication of the electron acceptors in low oxygen environments. The pH measurements would provide evidence of nitrification or of shifts in pH that could explain changes in reactor performance. The DO measurements would provide information about the effectiveness of the aeration system and whether conditions were adequate for nitrification or for low oxygen nitrification and simultaneous nitrification and denitrification. Biological treatment system performance is dependant on the characteristics of the influent and the management of the reactor environment. Without a clear understanding of these things, the proper management and optimization of these types of systems becomes difficult.

The reason that the reactors did not reach performance goals was that not enough oxygen was supplied to the systems in order to meet the high COD requirements of the swine wastewater and support the growth of nitrifying bacteria. The combination of high organic loading for the size of the bench-scale reactors and inadequate oxygen transfer from the aeration systems explain that shortage of oxygen supply. Possible ways to prevent this problem in future studies would be to reduce the organic loading into the system by either reducing the amount of waste entering the reactor or increasing the size of the reactor; utilize finer air diffusers or provide greater reactor depth to improve the oxygen transfer rate into the treatment wastewater. The addition of physical or chemical foaming control could have provided an opportunity to increase the airflow rates into the reactors. Improved aeration technique would benefit the CYC reactors, which operated every three hours and had poorer oxygen transfer due to the increased airflow rate, by providing increased COD removal and greater opportunity for the establishment of nitrification and denitrification. Improvement to the overall CYC reactor performance would provide much more insight into the actual benefits of the CON reactor system. Additional research that targets and deals with the deficiencies encountered in this experiment would build upon the results obtained here and clarify the potential for continuous, low-flow aeration sequencing batch reactors in comparison to the more often employed cyclic aeration reactors.

5. REFERENCES

Agreement by and between the Attorney General of North Carolina; Smithfield Foods Inc.; Brown's of Carolina, Inc.; Carroll's Foods, Inc.; Murphy Farms, Inc.; Carroll's Foods of Virginia, Inc.; and Quarter M Farms, Inc.; July 25, 2000.

American Society of Agricultural and Biological Engineers (ASABE). (2006). Manure production and characteristics. ASAE D384.2 MAR2005. *ASABE Standards*, 709-727.

Barker, J.C., Zublena, J.P., Campbell, C.R. (1994). *Agri-Waste Management*. North Carolina Cooperative Extension Service, January 1994.

Barnes, D. and Bliss, P.J. (1983) *Biological Control of Nitrogen in Wastewater Treatment.* E. & F.N. Spon: London, New York.

Bicudo, J.R., Classen, J.J., Goldsmith, C.D., and Smith, T. (1999). Effects of aeration cycles and hydraulic retention time on the sequencing batch treatment of flushed swine manure. *Advances in Environmental Research*, **3**(1), 58-73.

Bock, E., Schmidt, I., Stuven, R., Zart, D. (1995). Nitrogen loss caused by denitrifying *Nitrosomonas* cells using ammonium or hydrogen as electron donors and nitrite as electron acceptor. *Arch. Microbiol.*, 163, 16-20.

Bodelier, P.L.E., Libochant, J., Blom, C.W.P.M., and Laanbroek, H.J. (1996). Dynamics of nitrification and denitrification in root-oxygenated sediments and adaptations for ammonia-oxidizing bacteria to low-oxygen or anoxic habitats. *Appl. Environ. Microbiol.*, **62**(11), 4100-4107.

Bortone, G.F., Malaspina, F., Stante, L., and Tilche, A. (1994). Biological nitrogen and phosphorus removal in an aerobic/anoxic sequencing batch reactor and separated biofilm nitrification. *Water Sci. and Technol.*, **30**(6), pp. 303-313.

Both, G.J., Gerards, S., and Laanbroek, H.J. (1992). The occurrence of chemolitho-autotrophic nitrifiers in water-saturated grassland soils. *Microb. Ecol.*, 23, 15-26.

Broda, E. (1977). Two kinds of lithotrophs missing in nature. *Zeitschrift Fur Allgemeine Mikrobiologie*, 17, 491-493.

Carter, J.P., Hsio, Y.H., Spiro, S., and Richardson, D.J. (1995). Soil and sediment capable of aerobic nitrate respiration. *Appl. Environ. Microbiol*. Washington : American Society for Microbiology. Aug 1995. **61**(8), 2852-2858.

Cecen, F., and Gonenc, I.E. (1994). Nitrogen removal characteristics of nitrification and denitrification filters. *Water. Sci. Technol.*, **29**(10-11), 409-416.

Classen, J.J., and Liehr, S.K. (1995). Alternative Natural Technologies sequencing batch reactor performance verification. *Development of Environmentally Superior Technologies Phase 2 Report for Technology Determination per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers*. Animal & Poultry Waste Management Center: Raleigh, NC.

Coyne, M.S., Arunakumari, A., Averill, B.A., and Tiedje, J.M. (1989). Immunological identification and distribution of dissimilatory heme cd1 and nonheme copper nitrite reductases in denitrifying bacteria. *Appl. Environ. Microbiol.* Washington, D.C. American Society for Microbiology. Nov 1989. **55**(11), 2924-2931.

Crites, R., and Tchobanoglous, G. (1998). *Small and Decentralized Wastewater*

Management Systems. WCB McGraw-Hill: Boston.

Crocetti, G. R., P. Hugenholtz, P. L. Bond, A. Schuler, J. Keller, D. Jenkins, and L. L. Blackall. (2000). Identification of polyphosphate-accumulating organisms and design of 16S rRNA-directed probes for their detection and quantitation. *Appl. Environ. Microbiol.* Mar 2000. **66**(3)**,** 1175-1182.

De Kreuk, M.K., Heijnen, J.J., and van Loosdrecht, M.C..M. (2005). Simultaneous COD, nitrogen, and phosphate removal by aerobic granular sludge. *Biotech. Bioeng.*, **90**(6), 761-769.

Edgerton, B.D., McNevin, D., Wong, C.H., Menoud, P., Barford, J.P., and Mitchell, C.A. (2000). Strategies for dealing with piggery effluent in Australia: the sequencing batch reactor as a solution. *Water Sci. and Technol.* **41**(1), 123-126.

Ensminger, M.E. and Parker, R.O. (1997). *Swine Science*. 6th ed. Interstate Publishers, Inc.: Danville, Illinois.

Gibbs, B.M., Shephard, L.R., Third, K.A., and Cord-Ruwisch, R. (2004). The presence of ammonium facilitates nitrite reduction under PHB driven simultaneous nitrification and denitrification. *Water Sci. Technol.*, **50**(10), 181-188.

Goronszy, M.C., Demoulin, G., and Newland, M. (1996). Aerated denitrification in full-scale activated sludge facilities. *Water Sci. Technol.*, **34**(1-2), 487-491.

Hanaki, K., Wantawin, C., and Ohkagi, S. (1990a). Nitrification at low levels of dissolved oxygen with and without organic loading in a suspended-growth reactor. *Water Res.*, 24, 297-302.

Hanaki, K., Wantawin, C., and Ohkagi, S. (1990b). Effects of the activity of heterotrophs on nitrification in a suspended-growth reactor. *Water Res.*, 24, 289-296.

Harper, L.A., and Sharp, R.R. (1998). Ammonia emissions from swine waste lagoons in the southeastern US coastal plains. 58-6612-7M-022 Division of Air Quality. North Carolina Department of Environment and Natural Resources. Raleigh, NC, 22.

Harper, L.A., Sharpe, R.R, and Parkin, T.B. (2000). Gaseous nitrogen emissions from anaerobic swine lagoons: ammonia, nitrous oxide, and dinitrogen gas. *J. Environ. Qual.* (in press).

Helder, W., and de Vries, R.T.P. (1983). Estuarine nitrite maxima and nitrifying bacteria (Ems-Dollard estuary). *Neth. J. Sea Res.*, 17, 1-18.

Jenkins, D., Richard, M.G., and Daigger, G. (1993). *Manual of the Causes and Control of Activated Sludge Bulking and Foaming,* 2nd ed. Lewis Publishers, Michigan.

Jones, M.L., Liehr, S.K., Classen, J.J., and Robarge, W. (2000). Mechanisms of dinitrogen gas formation in anaerobic lagoons. *Advances in Environmental Research* 4 (2000) 133-139.

Laanbroek, H.J., and Gerards, S. (1993). Competition for limiting amounts of oxygen between *Nitrosomonas europaea* and *Nitrobacter winogradskyi* grown in mixed continuous cultures. *Arch. Microbiol.,* 159, 453-459.

Liu, W. T., A. T. Nielsen, J. H. Wu, C. S. Tsai, Y. Matsuo, and S. Molin**.** (2001). In situ identification of polyphosphate- and polyhydroxyalkanoate-accumulating traits for microbial populations in a biological phosphorus removal process. *Environ. Microbiol.* February 2001. **3**(2), 110-122.

Madigan, M.T., Martinko, J.M., Parker, J. (2000). *Brock Biology of Microorganisms*. 9th ed. Prentice Hall: Upper Saddle River, NJ.

McGhee, T.J. (1991). *Water Supply and Sewerage.* 6th ed. McGraw-Hill, Inc.: New York.

Merzouki, M., Delgenes, J., Bernet, N., Moletta, R., and Benlemlih, M. (1999). Polyphosphate-accumulating and denitrifying bacteria isolated from anaerobic-anoxic and anaerobic-aerobic sequencing batch reactors. *Current Microbiology*, 38, 9-17.

Mino, T., Van Loosdrecht, M.C.M., and Heijnen, J.J. (1998). Microbiology and biochemistry of the enhanced biological phosphate removal process. *Water Res.*, **32**(11), 3193-3207.

North Carolina Department of Agriculture & Consumer Services (2005) website http://www.agr.state.nc.us/stats/general/livestoc.htm.

Obaja, D., Mace, S., Costa, J., Sans, C., and Mata-Alvarez, J. (2003). Nitrification, denitrification and biological phosphorus removal in piggery wastewater using a sequencing batch reactor. *Bioresour. Technol*. Elsevier Science Limited: Oxford, U.K. Mar 2003. **87**(1), 103-111.

Poo, K.M., Jun, B.H., Lee, S.H., Im, J.H., Woo, H.J., and Kim, C.W. (2004). Treatment of strong nitrogen swine wastewater in a full-scale sequencing batch reactor. *Water Sci. Technol.*, **49**(5-6), 315-323.

Sharma, B., and Ahler, R.C. (1977). Nitrification and nitrogen removal. *Water Res.* 11, 897-925.

Smithfield Foods Inc. (2005) website, http://www.smithfieldfoods.com/Brands/See/murphy.asp.

Snoeyink, V.L., and Jenkins, D. (1980). *Water Chemistry*. John Wiley & Sons: New York.

Strous, M., van Gerven, E., Zheng, P., Kuenen, J.G., and Jetten, M.S.M. (1997). Ammonium removal from concentrated waste streams with the anaerobic ammonium oxidation (Anammox) process in different reactor configurations. *Water Res.*, 31(8), 1955-1962.

Tchobanoglous, G., Burton, F.L., and Stensel, H.D. (2003). *Wastewater Engineering Treatment and Reuse*. 4th Ed. McGraw-Hill, Inc.: New York.

Thauer, R.K., Jungermann, K., and Decker, K. (1977). Energy conservation in anaerobic chemotrophic bacteria. *Bacteriol. Rev.*, 41, 100-180.

Tilche, A., Bacilieri, E., Bortone, G., Malaspina, F., Piccinini, S., and Stante, L. (1999). Biological phosphorus and nitrogen removal in a full-scale sequencing batch reactor treating piggery wastewater. *Water Sci. Technol.*, **40**(1), 199-206.

Tilche, A., Bortone, G., Malaspina, F., Piccinini, S., and Stante, L. (2001). Biological nutrient removal in a full-scale SBR treating piggery wastewater: results and modelling. *Water Sci. Technol.*, **43**(3), 363-371.

Tsang, Y.F., Chua, H., Sin, S.N., and Tam, C.Y. (2006). A novel technology for bulking control in biological wastewater treatment plant for pulp and paper making industry. *Biochem. Eng. J.*, 32, 127-134.

United States Department of Agriculture. (1999). *National Engineering Handbook Part 651 – Agricultural Waste Management Field Handbook.* 210-VI, NEH-651.

United States Environmental Protection Agency. *Wastewater Technology Fact Sheet: Sequencing Batch Reactors*. EPA 832-F-99-073, September 1999.

Von Schulthess, R., Wild, D., and Gujer, W. (1994). Nitric and nitrous oxides from denitrifying activated sludge at low oxygen concentration. *Water Sci. Technol.*., **30**(6), 123-132.

Wong-Chong, G.M., and Loehr, R.C. (1978). Kinetics of microbial nitrification: nitrite-nitrogen oxidation. *Water Res.*, 12, 605-609.

Yang, L., and Alleman, J.E. (1992). Investigation of batchwise nitrite build-up by an enriched nitrification culture. *Water Sci. Technol.*, **26**(5-6), 997-1005.

Yoo, H., Ahn, K.H., Lee, H.J., Lee, K.H., Kwak, Y.J. and Song, K.G. (1999). Nitrogen removal from synthetic wastewater by simultaneous nitrification and denitrification (SND) via nitrite in an intermittently aerated reactor. *Water Res.*, **33**(1), 145-154.

Zhang, Z.J., Zhu, J., King, J., and Li, W.H. (2006). A two-step fed SBR for treating swine manure. *Process Biochem.*, **41**(4), 892-900.

APPENDICES

CON-1 and CON-2 Data for ANOVA Organized, Labeled, and Averaged

				COD Settling Eff.	SS Settling Eff.	VSS Settling Eff.	TKN Settling Eff.	TP Settling Eff.	COD Mass Removal Eff.	SS Mass Removal Eff.	VSS Mass Removal Eff.	TKN Mass Removal Eff.
DAY	**TYPE**	**RCTR**	**BA**	**EFF1**	**EFF2**	**EFF3**	**EFF4**	**EFF5**	**EF6**	**EFF7**	**EFF8**	**EFF9**
32	CON	1	0		0.71	0.66						
40	CON	1	0		0.47	0.47			0.55	0.20	0.28	0.10
47	CON	1	0		0.86	0.82			0.17	0.63	0.60	0.10
60	CON	1	0		0.29	0.33			0.33	0.29	0.38	0.08
75	CON	1	0		0.61	0.52			-0.28	0.14	0.16	-0.01
83	CON	1	0		0.83	0.81			0.50	0.26	0.41	0.07
90	CON	1	0	0.85	0.85	0.84	0.93	0.97	0.68	0.25	0.23	0.20
97	CON	1	0	0.98	0.79	0.76	0.87	0.91	0.14	0.51	0.20	0.17
112	CON	1	0	0.88	0.78	0.76		0.90	-0.62	0.14	0.13	
124	CON	1	0	0.86	0.43	0.41	0.43	0.85	0.40	0.49	0.58	0.24
133	CON	1	0	0.80	0.54	0.52	0.52	0.86	0.24	0.11	0.11	0.11
140	CON	1	0		0.70	0.69	0.35	0.87		0.20	0.26	0.00
147	CON	1	0	0.92	0.73	0.71	0.58	0.92		0.33	0.42	0.09
161	CON	1	0	0.88	0.48	0.40	0.59	0.91	0.40	0.42	0.23	0.08
185	CON	1	1	0.96	0.87	0.86	0.84	0.92	0.40	0.29	0.30	0.05
199	CON	1	1	0.94	0.74	0.72		0.87	0.53	0.76	0.79	
233	CON	1	1	0.99			1.00	0.96	0.40			0.04
247	CON	1	1		0.70	0.69	0.62	0.90	0.12	0.41	0.46	-0.05
254	CON	1	1	0.93	0.86	0.90		0.84	0.49	0.89	0.78	-0.38
Average				**0.91**	**0.68**	**0.66**	**0.67**	**0.90**	**0.28**	**0.37**	**0.37**	**0.06**

32	CON	2	0		0.03	0.11						
40	CON	2	0		0.74	0.68			0.21	0.00	0.07	0.02
47	CON	2	0		0.64	0.65			0.01	0.38	0.27	0.07
60	CON	2	0		0.46	0.47			0.49	0.45	0.55	0.07
75	CON	2	0		0.21	0.23				0.42	0.35	0.02
83	CON	2	0		0.39	0.32			0.35	-0.39	-0.24	0.10
90	CON	2	0	0.67	0.76	0.74	0.88	0.90	0.47	0.31	0.30	0.14
97	CON	2	0	0.92	0.68	0.70	0.87	0.87	0.72	1.27	0.92	0.22
112	CON	2	0	0.69	0.42	0.47	0.71	0.90	-0.43	0.06	0.08	0.18
124	CON	2	0		0.71	0.69	0.64	0.92	0.47	0.38	0.48	0.29
133	CON	2	0	0.69	0.71	0.70	0.63	0.94	0.49	0.53	0.49	0.14
140	CON	2	0	0.96	0.68	0.66	0.52	0.88	0.00	0.14	0.25	-0.15
147	CON	2	0	0.99	0.70	0.70	0.72	0.89	0.60	0.39	0.35	0.10
161	CON	2	0	0.91	0.59	0.52	0.68	0.90	0.41	0.14	0.03	0.09
185	CON	2	1	0.97	0.90	0.89	0.44	0.96	0.57	0.46	0.48	0.50
199	CON	2	1	0.98	0.77	0.77		0.81	0.27	0.53	0.53	
233	CON	2	1	0.97	0.89	0.87	0.64	0.99	0.56	0.68	0.83	0.35
247	CON	2	1	0.97	0.75	0.75	0.61	0.94	0.52	0.47	0.52	0.08
254	CON	2	1	0.99	0.88		0.99	0.93	0.67	0.69	0.61	0.09
Average				**0.89**	**0.63**	**0.61**	**0.69**	**0.91**	**0.37**	**0.38**	**0.38**	**0.14**

CYC-1 and CYC-2 Data for ANOVA Organized, Labeled, and Averaged

				COD Settling Eff.	SS Settling Eff.	VSS Settling Eff.	TKN Settling Eff.	TP Settling Eff.	COD Mass Removal Eff.	SS Mass Removal Eff.	VSS Mass Removal Eff.	TKN Mass Removal Eff.
DAY	**TYPE**	**RCTR**	**BA**	**EFF1**	**EFF2**	**EFF3**	**EFF4**	**EFF5**	**EF6**	**EFF7**	**EFF8**	**EFF9**
32	CYC	1	0		0.28	0.22						
40	CYC	1	0		0.47	0.46			0.72	-0.06	-0.10	0.05
47	CYC	1	0		0.38	0.31			-0.28	0.24	0.13	-0.01
60	CYC	1	0		0.22	0.26			0.26	0.32	0.40	0.09
75	CYC	1	0		0.52	0.44			-0.39	0.00	0.07	0.00
83	CYC	1	0		0.42	0.39			0.57	-0.05	-0.08	0.09
90	CYC	1	0	0.34	0.39	0.34	0.94	0.79	0.18	-0.04	-0.02	0.18
97	CYC	1	0	0.93	0.35	0.46	0.87	0.74	0.28	0.62	0.34	0.11
112	CYC	1	0	0.96	0.53	0.56	0.70	0.91	-0.65	0.03	0.16	0.04
124	CYC	1	0	0.17	0.18	0.18	0.64	0.75	0.33	0.40	0.49	0.19
133	CYC	1	0	0.94	0.28	0.23	0.72	0.82	0.06	0.16	0.18	0.05
140	CYC	1	0	0.74	0.58	0.55	0.58	0.82	0.23	0.02	0.13	-0.09
147	CYC	1	0	0.84	0.46	0.43	0.85	0.81	0.27	0.20	0.27	0.00
161	CYC	1	0	0.62	0.35	0.50	0.68	0.81	0.28	0.15	0.18	0.08
185	CYC	1	1	0.88	0.57	0.55	0.81	0.80	0.28	0.18	0.32	-0.02
199	CYC	1	1	0.88	0.67	0.63		0.80	0.05	-0.01	0.10	
233	CYC	1	1	0.95	0.70	0.66	0.71	0.79	0.28	0.36	0.65	-0.02
247	CYC	1	1	0.96	0.60	0.59	0.73	0.95	0.20	0.30	0.36	-0.04
254	CYC	1	1	0.94	0.71	0.68	0.91	0.84	0.68	0.30	0.24	-0.26
Average				**0.78**	**0.46**	**0.44**	**0.76**	**0.82**	**0.18**	**0.17**	**0.21**	**0.03**
32	CYC	2	0		0.36	0.34						
40	CYC	2	0		0.42	0.38			0.35	-0.10	0.05	0.02
47	CYC	2	0		0.27	0.22			-0.33	0.35	0.18	-0.01
60	CYC	2	0		0.32	0.34			0.35	0.26	0.37	0.08
75	CYC	2	0		0.65	0.55			-0.40	0.21	0.24	0.01
83	CYC	2	0		0.23	0.12			0.54	0.26	0.25	0.10
90	CYC	2	0	0.52	0.50	0.56		0.91	0.43	-0.03	-0.11	0.14
97	CYC	2	0	0.99	0.62	0.64	0.86	0.83	0.56	1.02	0.79	0.17
112	CYC	2	0	0.42	0.68	0.50	0.49	0.89	-0.58	0.17	0.24	0.17
124	CYC	2	0		0.29	0.33	0.31	0.74	0.34	0.40	0.36	0.22
133	CYC	2	0	0.58	0.30	0.27	0.37	0.79	0.14	0.25	0.29	0.03
140	CYC	2	0	0.09	0.50	0.48	0.29	0.81	-0.02	0.25	0.33	-0.02
147	CYC	2	0	0.85	0.36	0.38	0.41	0.74	0.45	0.19	0.24	0.07
161	CYC	2	0	0.67	0.47	0.35		0.71	0.35	0.23	0.11	0.13
185	CYC	2	1	0.81	0.55	0.53	0.55	0.74	0.30	0.31	0.30	-0.06
199	CYC	2	1	0.89	0.60	0.57		0.65	0.15	0.07	0.13	
233	CYC	2	1	1.00	0.64	0.63	0.66	0.90	0.27	0.35	0.65	-0.06
247	CYC	2	1	0.97	0.55	0.52	0.81	0.94	0.16	0.22	0.30	-0.05
254	CYC	2	1	0.92	0.60	0.57		0.83	0.62	0.38	0.36	-0.35
Average				**0.73**	**0.47**	**0.44**	**0.53**	**0.81**	**0.20**	**0.27**	**0.28**	**0.03**

Semicolon-Delineated Text File Data for ANOVA

File Name: ben041507.txt

```
32;CON;1;0;.;0.71;0.66;.;.;.;.;.;.
40;CON;1;0;.;0.47;0.47;.;.;0.55;0.20;0.28;0.10
47;CON;1;0;.;0.86;0.82;.;.;0.17;0.63;0.60;0.10
60;CON;1;0;.;0.29;0.33;.;.;0.33;0.29;0.38;0.08
75;CON;1;0;.;0.61;0.52;.;.;-0.28;0.14;0.16;-0.01
83;CON;1;0;.;0.83;0.81;.;.;0.50;0.26;0.41;0.07
90;CON;1;0;0.85;0.85;0.84;0.93;0.97;0.68;0.25;0.23;0.20
97;CON;1;0;0.98;0.79;0.76;0.87;0.91;0.14;0.51;0.20;0.17
112;CON;1;0;0.88;0.78;0.76;.;0.90;-0.62;0.14;0.13;.
124;CON;1;0;0.86;0.43;0.41;0.43;0.85;0.40;0.49;0.58;0.24
133;CON;1;0;0.80;0.54;0.52;0.52;0.86;0.24;0.11;0.11;0.11
140;CON;1;0;.;0.70;0.69;0.35;0.87;.;0.20;0.26;0.00
147;CON;1;0;0.92;0.73;0.71;0.58;0.92;.;0.33;0.42;0.09
161;CON;1;0;0.88;0.48;0.40;0.59;0.91;0.40;0.42;0.23;0.08
185;CON;1;1;0.96;0.87;0.86;0.84;0.92;0.40;0.29;0.30;0.05
199;CON;1;1;0.94;0.74;0.72;.;0.87;0.53;0.76;0.79;.
233;CON;1;1;0.99;.;.;1.00;0.96;0.40;.;.;0.04
247;CON;1;1;.;0.70;0.69;0.62;0.90;0.12;0.41;0.46;-0.05
254;CON;1;1;0.93;0.86;0.90;.;0.84;0.49;0.89;0.78;-0.38
32;CON;2;0;.;0.03;0.11;.;.;.;.;.;.
40;CON;2;0;.;0.74;0.68;.;.;0.21;0.00;0.07;0.02
47;CON;2;0;.;0.64;0.65;.;.;0.01;0.38;0.27;0.07
60;CON;2;0;.;0.46;0.47;.;.;0.49;0.45;0.55;0.07
75;CON;2;0;.;0.21;0.23;.;.;.;0.42;0.35;0.02
83;CON;2;0;.;0.39;0.32;.;.;0.35;-0.39;-0.24;0.10
90;CON;2;0;0.67;0.76;0.74;0.88;0.90;0.47;0.31;0.30;0.14
97;CON;2;0;0.92;0.68;0.70;0.87;0.87;0.72;1.27;0.92;0.22
112;CON;2;0;0.69;0.42;0.47;0.71;0.90;-0.43;0.06;0.08;0.18
124;CON;2;0;.;0.71;0.69;0.64;0.92;0.47;0.38;0.48;0.29
133;CON;2;0;0.69;0.71;0.70;0.63;0.94;0.49;0.53;0.49;0.14
140;CON;2;0;0.96;0.68;0.66;0.52;0.88;0.00;0.14;0.25;-0.15
147;CON;2;0;0.99;0.70;0.70;0.72;0.89;0.60;0.39;0.35;0.10
161;CON;2;0;0.91;0.59;0.52;0.68;0.90;0.41;0.14;0.03;0.09
185;CON;2;1;0.97;0.90;0.89;0.44;0.96;0.57;0.46;0.48;0.50
199;CON;2;1;0.98;0.77;0.77;.;0.81;0.27;0.53;0.53;.
233;CON;2;1;0.97;0.89;0.87;0.64;0.99;0.56;0.68;0.83;0.35
247;CON;2;1;0.97;0.75;0.75;0.61;0.94;0.52;0.47;0.52;0.08
254;CON;2;1;0.99;0.88;.;0.99;0.93;0.67;0.69;0.61;0.09
32;CYC;1;0;.;0.28;0.22;.;.;.;.;.;.
40;CYC;1;0;.;0.47;0.46;.;.;0.72;-0.06;-0.10;0.05
47;CYC;1;0;.;0.38;0.31;.;.;-0.28;0.24;0.13;-0.01
60;CYC;1;0;.;0.22;0.26;.;.;0.26;0.32;0.40;0.09
```

```
75;CYC;1;0;.;0.52;0.44;.;.;-0.39;0.00;0.07;0.00
83;CYC;1;0;.;0.42;0.39;.;.;0.57;-0.05;-0.08;0.09
90;CYC;1;0;0.34;0.39;0.34;0.94;0.79;0.18;-0.04;-0.02;0.18
97;CYC;1;0;0.93;0.35;0.46;0.87;0.74;0.28;0.62;0.34;0.11
112;CYC;1;0;0.96;0.53;0.56;0.70;0.91;-0.65;0.03;0.16;0.04
124;CYC;1;0;0.17;0.18;0.18;0.64;0.75;0.33;0.40;0.49;0.19
133;CYC;1;0;0.94;0.28;0.23;0.72;0.82;0.06;0.16;0.18;0.05
140;CYC;1;0;0.74;0.58;0.55;0.58;0.82;0.23;0.02;0.13;-0.09
147;CYC;1;0;0.84;0.46;0.43;0.85;0.81;0.27;0.20;0.27;0.00
161;CYC;1;0;0.62;0.35;0.50;0.68;0.81;0.28;0.15;0.18;0.08
185;CYC;1;1;0.88;0.57;0.55;0.81;0.80;0.28;0.18;0.32;-0.02
199;CYC;1;1;0.88;0.67;0.63;.;0.80;0.05;-0.01;0.10;.
233;CYC;1;1;0.95;0.70;0.66;0.71;0.79;0.28;0.36;0.65;-0.02
247;CYC;1;1;0.96;0.60;0.59;0.73;0.95;0.20;0.30;0.36;-0.04
254;CYC;1;1;0.94;0.71;0.68;0.91;0.84;0.68;0.30;0.24;-0.26
32;CYC;2;0;.;0.36;0.34;.;.;.;.;.;.
40;CYC;2;0;.;0.42;0.38;.;.;0.35;-0.10;0.05;0.02
47;CYC;2;0;.;0.27;0.22;.;.;-0.33;0.35;0.18;-0.01
60;CYC;2;0;.;0.32;0.34;.;.;0.35;0.26;0.37;0.08
75;CYC;2;0;.;0.65;0.55;.;.;-0.40;0.21;0.24;0.01
83;CYC;2;0;.;0.23;0.12;.;.;0.54;0.26;0.25;0.10
90;CYC;2;0;0.52;0.50;0.56;.;0.91;0.43;-0.03;-0.11;0.14
97;CYC;2;0;0.99;0.62;0.64;0.86;0.83;0.56;1.02;0.79;0.17
112;CYC;2;0;0.42;0.68;0.50;0.49;0.89;-0.58;0.17;0.24;0.17
124;CYC;2;0;.;0.29;0.33;0.31;0.74;0.34;0.40;0.36;0.22
133;CYC;2;0;0.58;0.30;0.27;0.37;0.79;0.14;0.25;0.29;0.03
140;CYC;2;0;0.09;0.50;0.48;0.29;0.81;-0.02;0.25;0.33;-0.02
147;CYC;2;0;0.85;0.36;0.38;0.41;0.74;0.45;0.19;0.24;0.07
161;CYC;2;0;0.67;0.47;0.35;.;0.71;0.35;0.23;0.11;0.13
185;CYC;2;1;0.81;0.55;0.53;0.55;0.74;0.30;0.31;0.30;-0.06
199;CYC;2;1;0.89;0.60;0.57;.;0.65;0.15;0.07;0.13;.
233;CYC;2;1;1.00;0.64;0.63;0.66;0.90;0.27;0.35;0.65;-0.06
247;CYC;2;1;0.97;0.55;0.52;0.81;0.94;0.16;0.22;0.30;-0.05
254;CYC;2;1;0.92;0.60;0.57;.;0.83;0.62;0.38;0.36;-0.35
```

SAS Program for ANOVA – First Run

```
options ls=85;
data one;
  infile "ben041507.txt" dlm=";";
  input day type $ rctr ba @;
  do response = 1 to 9;
    input y @;
    output;
  end;
run;
proc sort;
  by response rctr type day;
run;
/*
symbol value=dot;
proc gplot;
  by response rctr;
  *plot y*day=type;
  plot y*day=type/href=161;
run;
*/
data one;
  set one;
  if ((response=2) and (rctr=1) and (type="CON")) then delete;
  *if response=9 then delete;
run;

ods listing close;   *remove this line see output from PROC MIXED;

proc mixed data=one method=type3;
  by response;
  class day type rctr ba;
  model y=type|ba day(ba)/outp=two;
  *model y=type ba/outp=two;
  random rctr(type);
  lsmeans type|ba;
  lsmeans type*ba/slice=type;
  *lsmeans type ba;
  ods output tests3=testsm3;
run;
proc mixed data=one;
  by response;
  class day type rctr ba;
  model y=type|ba day(ba)/outp=two;
  *model y=type ba/outp=two;
```

```
  random rctr(type);
   lsmeans type|ba;
   lsmeans type*ba/slice=type;
   *lsmeans type ba;
   ods output tests3=testsml;
run;

data testsm3;
   set testsm3(rename=(probf=pvaluem3));
   keep response effect pvaluem3;
run;
data testsml;
   set testsml(rename=(probf=pvalueml));
   keep response effect pvalueml;
run;
data tests;
   merge testsm3 testsml;
run;
ods listing ;
proc print;run;
```

SAS ANOVA Results – First Run

Obs	response	Effect	pvaluem3	pvalueml
1	1	type	0.1155	0.1176*
2	1	ba	<.0001	<.0001*
3	1	type*ba	0.1106	0.1103*
4	1	day(ba)	0.0792	0.0783*
5	2	type	0.0852	0.155
6	2	ba	<.0001	<.0001*
7	2	type*ba	0.4245	0.4186
8	2	day(ba)	0.2728	0.2524
9	3	type	0.0237	0.0290*
10	3	ba	<.0001	<.0001*
11	3	type*ba	0.7117	0.7103
12	3	day(ba)	0.0574	0.0543*
13	4	type	0.8514	0.8528
14	4	ba	0.0117	0.0117*
15	4	type*ba	0.7126	0.7125
16	4	day(ba)	0.0004	0.0004*
17	5	type	0.0092	0.0242*
18	5	ba	0.2822	0.2734
19	5	type*ba	0.814	0.8106
20	5	day(ba)	0.0139	0.0112*
21	6	type	0.0701	0.0850*
22	6	ba	<.0001	<.0001*
23	6	type*ba	0.51	0.5039
24	6	day(ba)	<.0001	<.0001*
25	7	type	0.0499	0.0502*
26	7	ba	0.0007	0.0007*
27	7	type*ba	0.0079	0.0079*
28	7	day(ba)	<.0001	<.0001*
29	8	type	0.0476	0.0502*
30	8	ba	<.0001	<.0001*
31	8	type*ba	0.0363	0.0359*
32	8	day(ba)	0.0002	0.0002*
33	9	type	0.1131	0.1139*
34	9	ba	0.0002	0.0002*
35	9	type*ba	0.0013	0.0013*
36	9	day(ba)	<.0001	<.0001*

SAS Program for ANOVA – Second Run

```
options ls=85;
data one;
   infile "todd-sdt.txt" dlm=";";
   input day type $ rctr ba @;
   do response = 1 to 9;
      input y @;
      output;
   end;
run;
proc sort;
   by response rctr type day;
run;
/*
symbol value=dot;
proc gplot;
   by response rctr;
   *plot y*day=type;
   plot y*day=type/href=161;
run;
*/
data one;
   set one;
   if ((response=2) and (rctr=1) and (type="CON")) then delete;
   *if response=9 then delete;
run;

ods listing close;    *remove this line see output from PROC MIXED;

/*
proc mixed data=one method=type3;
   by response;
   class day type rctr ba;
   model y=type|ba day(ba)/outp=two;
   *model y=type ba/outp=two;
   random rctr(type);
   *estimate "reactor type effect after day 161" type -1 1 type*day(b);
   lsmeans type|ba;
   lsmeans type*ba/slice=type;
   lsmeans type*ba/slice=ba;
   *lsmeans type ba;
   ods output tests3=testsm3;
run;
*/
proc mixed data=one;
```

```
  by response;
  class day type rctr ba;
  model y=type|ba day(ba)/outp=two ddfm=kr;
  *model y=type ba/outp=two;
  random rctr(type);
  *lsmeans type|ba;
  *lsmeans type*ba/slice=type;
  lsmeans type*ba/diffs;
  *lsmeans type*ba/slice=ba;
  *lsmeans type ba;
  ods output tests3=testsml lsmeans=lsmml diffs=diffsml;
run;
/*
data testsm3;
  set testsm3(rename=(probf=pvaluem3));
  keep response effect pvaluem3;
run;
*/
data testsml;
  set testsml(rename=(probf=pvalueml));
  keep response effect pvalueml;
run;
/*
data tests;
  merge testsm3 testsml;
run;
*/
ods listing ;
proc print data=lsmml;
  title "this is a printout of LSMEANS for each of the four ba*type combos (before/after) X
(con/cyc)";
run;
data diffsml;  set diffsml;  if ba=1 and _ba=1;run;
proc print data=diffsml;
  title "this is a printout of the reactor type comparisons at time=after";
run;

proc sort data=two;
  by response;
run;
proc gplot data=two;
  title "these are diagnostic plots to check for any problems";
  by response;
  plot resid*pred;
run;
```

SAS ANOVA Results – Second Run

```
Obs response Effect  type ba _type _ba Estimate   StdErr   DF  tValue  Probt

 1      1    type*ba CON  1   CYC   1   0.05010  0.07425 10.5    0.67 0.5144
 2      2    type*ba CON  1   CYC   1    0.2190  0.07760   36    2.82 0.0077
 3      3    type*ba CON  1   CYC   1    0.2258  0.06446   53    3.50 0.0009
 4      4    type*ba CON  1   CYC   1  0.005794   0.1100 3.29    0.05 0.9610
 5      5    type*ba CON  1   CYC   1   0.08800  0.02274   37    3.87 0.0004
 6      6    type*ba CON  1   CYC   1    0.1540  0.06666   49    2.31 0.0251
 7      7    type*ba CON  1   CYC   1    0.3412  0.07965 14.5    4.28 0.0007
 8      8    type*ba CON  1   CYC   1    0.2786  0.07408   51    3.76 0.0004
 9      9    type*ba CON  1   CYC   1    0.1925  0.05324 6.69    3.62 0.0092
```

Source Data

Chemical Oxygen Demand

Date	Day	COD (mg/L)	Dissolved (mg/L)	Dissolved Fraction	
2/18/2002	18	12790			
2/22/2002	22	14600			
2/26/2002	26	14500			
3/2/2002	29	13300			
3/6/2002	33	14240			
3/8/2002	35	11900			
3/11/2002	38	12250			
3/15/2002	42	13000			
3/19/2002	46	21080			
3/22/2002	49	18200			
3/26/2002	53	17700			
4/2/2002	60	12050			
4/5/2002	63	16100			
4/9/2002	67	13800			
4/12/2002	70	12400	7600	0.61	
4/19/2002	77	12500	7000	0.56	
4/24/2002	82	8700	7200	0.83	
4/27/2002	85	8600	7300	0.85	
5/1/2002	89	6900	6200	0.90	up to Day 111
5/10/2002	98	8700	7160	0.82	3460
5/23/2002	111	19660	8350	0.42	
6/3/2002	122	17000	14100	0.83	
6/11/2002	130	16300	12800	0.79	after Day 111
6/17/2002	136	14000	8400	0.60	3586
6/21/2002	140	13500	7500	0.56	
6/26/2002	145	11380	8800	0.77	
7/1/2002	150	10060	8000	0.80	
7/8/2002	157	9240	1680	0.18	
7/28/2002	177	11200	7220	0.64	
8/1/2002	181	13620	6060	0.44	
8/7/2002	187	16500	6400	0.39	
8/12/2002	192	10200	6760	0.66	
9/22/2002	233	20280	14430	0.71	
9/30/2002	241	13920	9280	0.67	
10/7/2002	248	9360	7360	0.79	
10/12/2002	253	12200	6660	0.55	
10/19/2002	260	8390	5700	0.68	
11/2/2002	274	9150	5310	0.58	
11/9/2002	281	15670	6080	0.39	3475.175488
Total	**average =**	**1.3E+04**	**7.7E+03**	**0.64**	

	maximum =	**2.1E+04**	**1.4E+04**	**0.90**
	minimum =	**6.9E+03**	**1.7E+03**	**0.18**
	COV =	**2.6E-01**	**3.5E-01**	**2.8E-01**
From Day 111	average =	1.3E+04	7.9E+03	0.60
	maximum =	2.0E+04	1.4E+04	0.83
	minimum =	8.4E+03	1.7E+03	0.18
	COV =	2.7E-01	3.9E-01	2.9E-01
Before Day 111	average =	1.3E+04	7.1E+03	0.76
	maximum =	2.1E+04	7.6E+03	0.90
	minimum =	6.9E+03	6.2E+03	0.56
	COV =	2.6E-01	6.7E-02	1.8E-01

Suspended Solids

Date	Day	SS mg/L	VSS mg/L	VSS Fraction
2/18/2002	18	6017	5117	0.85
2/22/2002	22	5750	4550	0.79
2/26/2002	26	7933	5400	0.68
3/2/2002	29	5500	4700	0.85
3/6/2002	33	7067	5667	0.80
3/8/2002	35	7267	6633	0.91
3/11/2002	38	9700	7267	0.75
3/15/2002	42	8133	5967	0.73
3/19/2002	46	13000	11332	0.87
3/22/2002	49	8832	7800	0.88
3/26/2002	53	9367	8467	0.90
4/2/2002	60	7567	6667	0.88
4/5/2002	63	9000	8133	0.90
4/9/2002	67	10067	9367	0.93
4/12/2002	70	7933	6600	0.83
4/19/2002	77	6533	5133	0.79
4/24/2002	82	5467	3767	0.69
4/27/2002	85	5467	4433	0.81
5/1/2002	89	4200	3667	0.87
5/10/2002	98	5200	4083	0.79
5/20/2002	108	6050	5061	0.84
5/23/2002	111	14800	11867	0.80
6/3/2002	122	11733	9367	0.80
6/11/2002	130	12500	9933	0.79
6/17/2002	136	10100	8067	0.80
6/21/2002	140	10000	7600	0.76
6/26/2002	145	8700	6767	0.78
7/1/2002	150	8300	6100	0.73
7/8/2002	157	6100	4922	0.81
7/28/2002	177	6475	5200	0.80
8/1/2002	181	9450	7517	0.80
8/7/2002	187	5450	4300	0.79

8/12/2002	192	6450	5117	0.79
9/22/2002	233	11100	8967	0.81
9/30/2002	241	7800	6400	0.82
10/7/2002	248	6783	5367	0.79
10/12/2002	253	7283	5950	0.82
10/19/2002	260	4950	3982	0.80
11/2/2002	274	4500	3766	0.84
11/9/2002	281	7350	6200	0.84
Total	**average =**	**7.9E+03**	**6.4E+03**	**0.81**
	maximum =	**1.5E+04**	**1.2E+04**	**0.93**
	minimum =	**4.2E+03**	**3.7E+03**	**0.68**
	COV =	**3.1E-01**	**3.2E-01**	**6.8E-02**
From Day 111	average =	8.4E+03	6.7E+03	0.80
	maximum =	1.5E+04	1.2E+04	0.84
	minimum =	4.5E+03	3.8E+03	0.73
	COV =	3.3E-01	3.2E-01	3.1E-02
Before Day 111	average =	7.4E+03	6.2E+03	0.83
	maximum =	1.3E+04	1.1E+04	0.93
	minimum =	4.2E+03	3.7E+03	0.68
	COV =	2.8E-01	3.2E-01	8.7E-02

Total Kjeldahl Nitrogen

Date	Day	TKN mg/L	Dissolved mg/L	NH3-N mg/L	Dissolved Fraction	NH3-N Fraction
2/18/2002	18	2099		1450		0.69
2/22/2002	22	1990		1408		0.71
2/26/2002	26	2122		1461		0.69
3/2/2002	29	2162		1484		0.69
3/6/2002	33	2132		1528		0.72
3/8/2002	35	2166		1494		0.69
3/11/2002	38	2079		1436		0.69
3/15/2002	42	2299		1607		0.70
3/19/2002	46	2873		1894		0.66
3/22/2002	49	2104		1337		0.64
3/26/2002	53	2521		1672		0.66
4/2/2002	60	2153		1590		0.74
4/5/2002	63	2338		1502		0.64
4/9/2002	67	2187		1395		0.64
4/12/2002	70	2112	1780	1554	0.84	0.74
4/19/2002	77	2013	1760	1464	0.87	0.73
4/24/2002	82	2012	1702	1490	0.85	0.74
4/27/2002	85	2020	1886	1467	0.93	0.73
5/1/2002	89	1550	1527	1179	0.99	0.76
5/10/2002	98	1811	1681	1309	0.93	0.72
5/20/2002	108	2304	1946	1608	0.84	0.70
5/23/2002	111	2474	1668	1320	0.67	0.53
6/3/2002	122	1998	1634	1342	0.82	0.67

6/11/2002	130	1983	1729	1421	0.87	0.72
6/17/2002	136	2136	1362	1490	0.64	0.70
6/21/2002	140	2166	1291	1512	0.60	0.70
6/26/2002	145	1541	1304	942	0.85	0.61
7/1/2002	150	2007	1718	1334	0.86	0.66
7/8/2002	157	2013	1546	1291	0.77	0.64
7/28/2002	177	1391	1302	1009	0.94	0.73
8/1/2002	181	1399	1108	1011	0.79	0.72
8/7/2002	187	1258	1080	1039	0.86	0.83
8/12/2002	192	1360	1170	1094	0.86	0.80
9/22/2002	233	2073	1170	1386	0.56	0.67
9/30/2002	241	1500	1241	1117	0.83	0.74
10/7/2002	248	1390	1248	1050	0.90	0.76
10/12/2002	253	1366	1173	1005	0.86	0.74
10/19/2002	260	1433	1271	1030	0.89	0.72
11/2/2002	274	1402	1198	1013	0.85	0.72
11/9/2002	281	1435	1088	978	0.76	0.68
Total	**average =**	**1.9E+03**	**1.4E+03**	**1.3E+03**	**0.82**	**0.70**
	maximum =	**2.9E+03**	**1.9E+03**	**1.9E+03**	**0.99**	**0.83**
	minimum =	**1.3E+03**	**1.1E+03**	**9.4E+02**	**0.56**	**0.53**
	COV =	**2.0E-01**	**1.9E-01**	**1.7E-01**	**1.3E-01**	**7.3E-02**
From Day 111	average =	1.7E+03	1.3E+03	1.2E+03	0.80	0.70
	maximum =	2.5E+03	1.7E+03	1.5E+03	0.94	0.83
	minimum =	1.3E+03	1.1E+03	9.4E+02	0.56	0.53
	COV =	2.2E-01	1.6E-01	1.6E-01	1.3E-01	9.4E-02
Before Day 111	average =	2.1E+03	1.8E+03	1.5E+03	0.89	0.70
	maximum =	2.9E+03	1.9E+03	1.9E+03	0.99	0.76
	minimum =	1.6E+03	1.5E+03	1.2E+03	0.84	0.64
	COV =	1.2E-01	7.9E-02	9.7E-02	6.3E-02	5.1E-02

Total Phosphorus

Date	Day	TP mg/L	Dissolved mg/L	O-PO4 mg/L	Dissolved Fraction	O-PO4 Fraction
2/18/2002	18	205		160		0.78
2/22/2002	22	201		152		0.76
2/26/2002	26	224		168		0.75
3/2/2002	29	192		167		0.87
3/6/2002	33	210		167		0.80
3/8/2002	35	206		166		0.81
3/11/2002	38	181		146		0.81
3/15/2002	42	245		191		0.78
3/19/2002	46	351		256		0.73
3/22/2002	49	280		200		0.71
3/26/2002	53	296		211		0.71
4/2/2002	60	218		180		0.83
4/5/2002	63	224		185		0.83
4/9/2002	67	215		168		0.78

4/12/2002	70	212	129	144	0.61	0.68
4/19/2002	77	177	108	140	0.61	0.79
4/24/2002	82	149	108	113	0.72	0.76
4/27/2002	85	147	105	105	0.71	0.71
5/1/2002	89	107	91	82	0.85	0.77
5/10/2002	98	133	88	123	0.66	0.92
5/20/2002	108	214	113	140	0.53	0.65
5/23/2002	111	416	112	206	0.27	0.50
6/3/2002	122	218	96	187	0.44	0.86
6/11/2002	130	178	87	158	0.49	0.89
6/17/2002	136	222	117	188	0.53	0.85
6/21/2002	140	232	77	154	0.33	0.66
6/26/2002	145	188	92	136	0.49	0.72
7/1/2002	150	177	82	135	0.46	0.76
7/8/2002	157	207	87	149	0.42	0.72
7/28/2002	177	167	90	121	0.54	0.72
8/1/2002	181	221	75	174	0.34	0.79
8/7/2002	187	147	68	147	0.46	1.00
8/12/2002	192	134	60	129	0.44	0.96
9/22/2002	233	285	180	200	0.63	0.70
9/30/2002	241	220	114	193	0.52	0.88
10/7/2002	248	163	93	149	0.57	0.91
10/12/2002	253	193	111	169	0.58	0.88
10/19/2002	260	172	99	116	0.57	0.67
11/2/2002	274	148	76	123	0.51	0.83
11/9/2002	281	160	61	132	0.38	0.83
Total	**average =**	**2.1E+02**	**9.7E+01**	**1.6E+02**	**0.53**	**0.78**
	maximum =	**4.2E+02**	**1.8E+02**	**2.6E+02**	**0.85**	**1.00**
	minimum =	**1.1E+02**	**6.0E+01**	**8.2E+01**	**0.27**	**0.50**
	COV =	**2.8E-01**	**2.5E-01**	**2.1E-01**	**2.5E-01**	**1.2E-01**
From Day 111	average =	2.0E+02	9.3E+01	1.6E+02	0.47	0.80
	maximum =	4.2E+02	1.8E+02	2.1E+02	0.63	1.00
	minimum =	1.3E+02	6.0E+01	1.2E+02	0.27	0.50
	COV =	3.1E-01	2.9E-01	1.8E-01	2.0E-01	1.5E-01
Before Day 111	average =	2.1E+02	1.1E+02	1.6E+02	0.67	0.77
	maximum =	3.5E+02	1.3E+02	2.6E+02	0.85	0.92
	minimum =	1.1E+02	8.8E+01	8.2E+01	0.53	0.65
	COV =	2.6E-01	1.3E-01	2.4E-01	1.6E-01	8.1E-02

Source Statistics

Parameter	Units	Mean	Coefficient of Variation	Maximum	Minimum
Chemical Oxygen Demand	mg/L	13000	2.6E-01	21000	6900
Dissolved	mg/L	7700	3.5E-01	14000	1700
Suspended Solids	mg/L	7900	3.1E-01	15000	4200
Volatile suspended solids	mg/L	6400	3.2E-01	12000	3700
Total Kjeldahl Nitrogen	mg/L	1900	2.0E-01	2900	1300

Dissolved	mg/L	1400	1.9E-01	1900	1100
Ammoniacal Nitrogen	mg/L	1300	1.7E-01	1900	940
Total Phosphorus	mg/L	210	2.8E-01	420	110
Dissolved	mg/L	97	2.5E-01	180	60
Ortho-Phosphate	mg/L	160	2.1E-01	260	82
Conductance	µS	18000	1.5E-01	28000	12000
Alkalinity	mg/L $CaCO_3$	8000	9.4E-02	10000	6800

Source Statistics From Day 111

Parameter	Units	Mean	Coefficient of Variance	Maximum	Minimum
Chemical Oxygen Demand	mg/L	1.3E+04	2.7E-01	2.0E+04	8.4E+03
Dissolved	mg/L	7.9E+03	3.9E-01	1.4E+04	1.7E+03
Suspended Solids	mg/L	8.4E+03	3.3E-01	1.5E+04	4.5E+03
Volatile suspended solids	mg/L	6.7E+03	3.2E-01	1.2E+04	3.8E+03
Total Kjeldahl Nitrogen	mg/L	1.7E+03	2.2E-01	2.5E+03	1.3E+03
Dissolved	mg/L	1.3E+03	1.6E-01	1.7E+03	1.1E+03
Ammoniacal Nitrogen	mg/L	1.2E+03	1.6E-01	1.5E+03	9.4E+02
Total Phosphorus	mg/L	2.0E+02	3.1E-01	4.2E+02	1.3E+02
Dissolved	mg/L	9.3E+01	2.9E-01	1.8E+02	6.0E+01
Ortho-Phosphate	mg/L	1.6E+02	1.8E-01	2.1E+02	1.2E+02
Conductance	µS	1.8E+04	3.3E+03	2.8E+04	1.2E+04
Alkalinity	mg/L $CaCO_3$	7.8E+03	7.3E+02	9.2E+03	6.8E+03

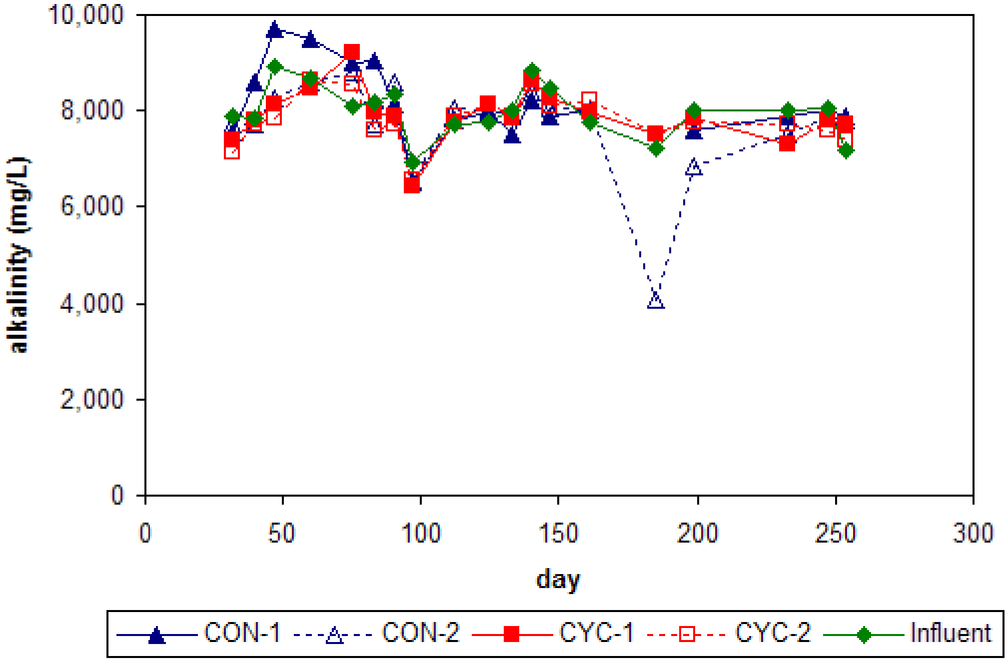
Source Statistics Before Day 111

Parameter	Units	Average	Coefficient of Variance	Maximum	Minimum
Chemical Oxygen Demand	mg/L	1.3E+04	2.6E-01	2.1E+04	6.9E+03
Dissolved	mg/L	7.1E+03	6.7E-02	7.6E+03	6.2E+03
Suspended Solids	mg/L	7.4E+03	2.8E-01	1.3E+04	4.2E+03
Volatile suspended solids	mg/L	6.2E+03	3.2E-01	1.1E+04	3.7E+03
Total Kjeldahl Nitrogen	mg/L	2.1E+03	1.2E-01	2.9E+03	1.6E+03
Dissolved	mg/L	1.8E+03	7.9E-02	1.9E+03	1.5E+03
Ammoniacal Nitrogen	mg/L	1.5E+03	9.7E-02	1.9E+03	1.2E+03
Total Phosphorus	mg/L	2.1E+02	2.6E-01	3.5E+02	1.1E+02
Dissolved	mg/L	1.1E+02	1.3E-01	1.3E+02	8.8E+01
Ortho-Phosphate	mg/L	1.6E+02	2.4E-01	2.6E+02	8.2E+01
Conductance	µS	1.7E+04	1.7E+03	2.0E+04	1.4E+04
Alkalinity	mg/L $CaCO_3$	8.1E+03	7.4E+02	1.0E+04	6.8E+03

Alkalinity Data

ALKALINITY

Date	Day	Source	CON-1 T	CON-2 T	CYC-1 T	CYC-2 T
3/5/2002	32	7890	7550	7700	7400	7150
3/13/2002	40	7860	8600	7700	7800	7700
3/20/2002	47	8930	9700	8250	8150	7850
4/2/2002	60	8690	9500	8600	8450	8650
4/17/2002	75	8110	9010	8800	9200	8530
4/25/2002	83	8160	9050	7700	7950	7600
5/2/2002	90	8340	8150	8600	7900	7700
5/9/2002	97	6950	6500	6550	6450	6550
5/24/2002	112	7730	7800	8050	7750	7900
6/5/2002	124	7750	7950	8000	8150	8150
6/14/2002	133	7990	7500	7900	7900	7850
6/21/2002	140	8850	8200	8400	8650	8550
6/28/2002	147	8480	7900	8050	8250	8100
7/12/2002	161	7740	8000	8000	7950	8200
8/5/2002	185	7230		4050	7500	7500
8/19/2002	199	8000	7600	6850	7850	7750
9/22/2002	233	8000	7900	7500	7300	7700
10/6/2002	247	8060	8000	7900	7800	7600
10/13/2002	254	7190	7900	7800	7700	7400



Chemical Oxygen Demand Data

CON-1

Date	Day	INFLUENT		
		COD (mg/L)	Dissolved COD (mg/L)	Dissolved Fraction
3/5/2002	32	13986		
3/13/2002	40	12619		
3/20/2002	47	13940		
4/2/2002	60	16487		
4/17/2002	75	12400		
4/25/2002	83	12268	7114	0.58
5/2/2002	90	8386	7114	0.85
5/9/2002	97	7671	6200	0.81
5/24/2002	112	5421	4721	0.87
6/5/2002	124	18900	9993	0.53
6/14/2002	133	16700	13543	0.81
6/21/2002	140	14986	10286	0.69
6/28/2002	147	12894	7871	0.61
7/12/2002	161	13740	4389	0.32
8/5/2002	185	12583	6557	0.52
8/19/2002	199	10200	6760	0.66
9/22/2002	233	10200	6760	0.66
10/6/2002	247	14829	9280	0.63
10/13/2002	254	10417	5750	0.55
Total	**average =**	**1.3E+04**	**7.6E+03**	**0.65**
	maximum =	**1.9E+04**	**1.4E+04**	**0.87**
	minimum =	**5.4E+03**	**4.4E+03**	**0.32**
	variance =	**1.1E+07**	**6.0E+06**	**2.3E-02**
Before Day 161	average =	1.3E+04	7.9E+03	0.67
	maximum =	1.9E+04	1.4E+04	0.87
	minimum =	5.4E+03	4.4E+03	0.32
	variance =	3.7E+03	2.9E+03	1.8E-01
After Day 161	average =	1.2E+04	7.0E+03	0.60
	maximum =	1.5E+04	9.3E+03	0.66
	minimum =	1.0E+04	5.8E+03	0.52
	variance =	2.0E+03	1.3E+03	6.5E-02

MIXED			SUPERNATANT		Settling Efficiency
COD (mg/L)	Dissolved COD (mg/L)	Dissolved Fraction	COD (mg/L)	Dissolved Fraction	
9500			3200		
9200			6380		
11900			10200		
13300			8720		
18500			16500		
11800			5300		
8400	3450	0.41	4200	0.82	0.85
9620	3940	0.41	4040	0.98	0.98
14100	4800	0.34	5900	0.81	0.88
16500	9500	0.58	10500	0.90	0.86
17800	7000	0.39	9200	0.76	0.80
	8400		9600	0.88	
13360	6900	0.52	7400	0.93	0.92
12740	6020	0.47	6840	0.88	0.88
16120	5180	0.32	5620	0.92	0.96
14480	4330	0.30	4900	0.88	0.94
15720	6140	0.39	6200	0.99	0.99
21580	10320	0.48			
16140	6880	0.43	7560	0.91	0.93
1.4E+04	**6.4E+03**	**0.42**	**7.3E+03**	**0.89**	**0.91**
2.2E+04	**1.0E+04**	**0.58**	**1.7E+04**	**0.99**	**0.99**
8.4E+03	**3.5E+03**	**0.30**	**3.2E+03**	**0.76**	**0.80**
1.3E+07	**4.4E+06**	**6.6E-03**	**9.9E+06**	**4.4E-03**	**3.8E-03**
1.3E+04	6.3E+03	0.45	7.7E+03	0.87	0.88
1.9E+04	9.5E+03	0.58	1.7E+04	0.98	0.98
8.4E+03	3.5E+03	0.34	3.2E+03	0.76	0.80
3.3E+03	2.1E+03	8.1E-02	3.5E+03	6.9E-02	5.9E-02
1.7E+04	6.6E+03	0.38	6.1E+03	0.93	0.96
2.2E+04	1.0E+04	0.48	7.6E+03	0.99	0.99
1.4E+04	4.3E+03	0.30	4.9E+03	0.88	0.93
2.8E+03	2.3E+03	7.4E-02	1.1E+03	4.5E-02	2.9E-02

COD Inputs (mg/d)	COD Outputs (mg/d)	COD Accumulation (mg/d)	COD Mass Removal Rate (mg/d)	Mass Removal Efficiency	COD Removal (mg/d)
95526	44890	-1988	52623	0.55	52623
105526	67032	20443	18051	0.17	18051
124807	77555	5708	41544	0.33	41544
93868	101684	18373	-26189	-0.28	-26189
92869	90556	-44388	46700	0.50	46700
63482	46082	-25743	43143	0.68	43143
58069	40443	9237	8390	0.14	8390
41037	50662	15829	-25455	-0.62	-25455
143073	75511	10600	56962	0.40	56962
126419	88380	7656	30384	0.24	30384
104012	65121	-2347	41238	0.40	41238
95253	49363	7464	38426	0.40	38426
77214	42520	-6209	40903	0.53	40903
77214	44582	1933	30699	0.40	30699
78857	60266	-41189	59779	0.76	59779
91815	**62976**	**-1641**	**30480**	**0.31**	**3.0E+04**
				0.76	**6.0E+04**
				-0.62	**-2.6E+04**
				1.3E-01	**7.0E+08**
95335	67992	1216	26126	0.23	2.6E+04
				0.68	5.7E+04
				-0.62	-2.6E+04
				3.8E-01	2.9E+04
82135	49183	-9500	42452	0.52	4.2E+04
				0.76	6.0E+04
				0.40	3.1E+04
				1.7E-01	1.2E+04

CON-2

3/5/2002	32	13986		
3/13/2002	40	12619		
3/20/2002	47	13940		
4/2/2002	60	16487		
4/17/2002	75	12400		
4/25/2002	83	12268	7114	0.58
5/2/2002	90	8386	7114	0.85
5/9/2002	97	7671	6200	0.81
5/24/2002	112	5421	4721	0.87
6/5/2002	124	18900	9993	0.53
6/14/2002	133	16700	13543	0.81
6/21/2002	140	14986	10286	0.69
6/28/2002	147	12894	7871	0.61
7/12/2002	161	13740	4389	0.32
8/5/2002	185	12583	6557	0.52
8/19/2002	199	10200	6760	0.66
9/22/2002	233	10200	6760	0.66
10/6/2002	247	14829	9280	0.63
10/13/2002	254	10417	5750	0.55
Total	**average =**	**1.3E+04**	**7.6E+03**	**0.65**
	maximum =	**1.9E+04**	**1.4E+04**	**0.87**
	minimum =	**5.4E+03**	**4.4E+03**	**0.32**
	variance =	**1.1E+07**	**6.0E+06**	**2.3E-02**
Before Day 161	average =	1.3E+04	7.9E+03	0.67
	maximum =	1.9E+04	1.4E+04	0.87
	minimum =	5.4E+03	4.4E+03	0.32
	variance =	3.7E+03	2.9E+03	1.8E-01
After Day 161	average =	1.2E+04	7.0E+03	0.60
	maximum =	1.5E+04	9.3E+03	0.66
	minimum =	1.0E+04	5.8E+03	0.52
	variance =	2.0E+03	1.3E+03	6.5E-02

9400			8200		
11640			6080		
16000			10000		
12100			8480		
17700					
10300			8300		
7400	4400	0.59	5400	0.81	0.67
4680	3360	0.72	3460	0.97	0.92
9660	4800	0.50	6300	0.76	0.69
13500	7100	0.53	6600	1.08	
12600	7800	0.62	9300	0.84	0.69
16800	9200	0.55	9500	0.97	0.96
12160	6980	0.57	7020	0.99	0.99
11900	6600	0.55	7080	0.93	0.91
12000	3020	0.25	3320	0.91	0.97
16900	5870	0.35	6060	0.97	0.98
12200	4000	0.33	4240	0.94	0.97
15700	5660	0.36	5980	0.95	0.97
13660	4120	0.30	4240	0.97	0.99
1.2E+04	**5.6E+03**	**0.48**	**6.6E+03**	**0.93**	**0.89**
1.8E+04	**9.2E+03**	**0.72**	**1.0E+04**	**1.08**	**0.99**
4.7E+03	**3.0E+03**	**0.25**	**3.3E+03**	**0.76**	**0.67**
1.1E+07	**3.5E+06**	**2.1E-02**	**4.2E+06**	**6.9E-03**	**1.7E-02**
1.2E+04	6.3E+03	0.58	7.4E+03	0.92	0.83
1.8E+04	9.2E+03	0.72	1.0E+04	1.08	0.99
4.7E+03	3.4E+03	0.50	3.5E+03	0.76	0.67
3.6E+03	1.9E+03	6.8E-02	1.8E+03	1.1E-01	1.4E-01
1.4E+04	4.5E+03	0.32	4.8E+03	0.95	0.98
1.7E+04	5.9E+03	0.36	6.1E+03	0.97	0.99
1.2E+04	3.0E+03	0.25	3.3E+03	0.91	0.97
2.2E+03	1.2E+03	4.3E-02	1.2E+03	2.5E-02	9.4E-03

95526	60446	14840	20239	0.21	20239
105526	71801	33011	713	0.01	713
124807	79050	-15900	61657	0.49	61657
92869	73618	-49025	68276	0.74	68276
63482	55640	-21957	29800	0.47	29800
58069	36582	-20594	42082	0.72	42082
41037	41275	17596	-17834	-0.43	-17834
143073	58535	16960	67578	0.47	67578
126419	69833	-5300	61886	0.49	61886
113444	81188	31800	456	0.00	456
97608	74300	-35131	58439	0.60	58439
104012	62793	-984	42203	0.41	42203
95253	41176	221	53856	0.57	53856
77214	38130	18550	20534	0.27	20534
77214	41514	-7326	43026	0.56	43026
112256	41060	13250	57945	0.52	57945
78857	41257	-15446	53045	0.67	53045
94510	**56953**	**-1496**	**39053**	**0.40**	**3.9E+04**
				0.74	**6.8E+04**
				-0.43	**-1.8E+04**
				9.3E-02	**6.8E+08**
97156	63755	-2890	36291	0.35	3.6E+04
				0.74	6.8E+04
				-0.43	-1.8E+04
				3.4E-01	3.0E+04
88159	40628	1850	45681	0.52	4.6E+04
				0.67	5.8E+04
				0.27	2.1E+04
				1.5E-01	1.5E+04

CYC-1

3/5/2002	32	13986		
3/13/2002	40	12619		
3/20/2002	47	13940		
4/2/2002	60	16487		
4/17/2002	75	12400		
4/25/2002	83	12268	7114	0.58
5/2/2002	90	8386	7114	0.85
5/9/2002	97	7671	6200	0.81
5/24/2002	112	5421	4721	0.87
6/5/2002	124	18900	9993	0.53
6/14/2002	133	16700	13543	0.81
6/21/2002	140	14986	10286	0.69
6/28/2002	147	12894	7871	0.61
7/12/2002	161	13740	4389	0.32
8/5/2002	185	12583	6557	0.52
8/19/2002	199	10200	6760	0.66
9/22/2002	233	10200	6760	0.66
10/6/2002	247	14829	9280	0.63
10/13/2002	254	10417	5750	0.55
Total	**average =**	**1.3E+04**	**7.6E+03**	**0.65**
	maximum =	**1.9E+04**	**1.4E+04**	**0.87**
	minimum =	**5.4E+03**	**4.4E+03**	**0.32**
	variance =	**1.1E+07**	**6.0E+06**	**2.3E-02**
Before Day 161	average =	1.3E+04	7.9E+03	0.67
	maximum =	1.9E+04	1.4E+04	0.87
	minimum =	5.4E+03	4.4E+03	0.32
	variance =	3.7E+03	2.9E+03	1.8E-01
After Day 161	average =	1.2E+04	7.0E+03	0.60
	maximum =	1.5E+04	9.3E+03	0.66
	minimum =	1.0E+04	5.8E+03	0.52
	variance =	2.0E+03	1.3E+03	6.5E-02

22200			7900		
13400			10320		
17100			17200		
13100			11140		
20000			15200		
11300			8900		
9200	6280	0.68	8200	0.77	0.34
7480	5500	0.74	5640	0.98	0.93
11200	7150	0.64	7300	0.98	0.96
14200	9500	0.67	13400	0.71	0.17
17500	10800	0.62	11200	0.96	0.94
16200	10100	0.62	11700	0.86	0.74
13520	10240	0.76	10780	0.95	0.84
11500	8840	0.77	9840	0.90	0.62
11940	7240	0.61	7800	0.93	0.88
14940	7410	0.50	8300	0.89	0.88
12380	6620	0.53	6920	0.96	0.95
18780	9660	0.51	10000	0.97	0.96
13440	6480	0.48	6880	0.94	0.94
1.4E+04	**8.1E+03**	**0.63**	**9.9E+03**	**0.91**	**0.78**
2.2E+04	**1.1E+04**	**0.77**	**1.7E+04**	**0.98**	**0.96**
7.5E+03	**5.5E+03**	**0.48**	**5.6E+03**	**0.71**	**0.17**
1.4E+07	**3.1E+06**	**9.5E-03**	**8.8E+06**	**7.0E-03**	**6.5E-02**
1.4E+04	8.6E+03	0.69	1.1E+04	0.89	0.69
2.2E+04	1.1E+04	0.77	1.7E+04	0.98	0.96
7.5E+03	5.5E+03	0.62	5.6E+03	0.71	0.17
4.1E+03	2.0E+03	6.0E-02	3.1E+03	1.0E-01	3.0E-01
1.4E+04	7.5E+03	0.53	8.0E+03	0.94	0.92
1.9E+04	9.7E+03	0.61	1.0E+04	0.97	0.96
1.2E+04	6.5E+03	0.48	6.9E+03	0.89	0.88
2.8E+03	1.3E+03	4.9E-02	1.3E+03	2.9E-02	3.9E-02

95526	85409	-58300	68417	0.72	68417
105526	106983	28014	-29472	-0.28	-29472
124807	109027	-16308	32087	0.26	32087
93868	106094	24380	-36606	-0.39	-36606
92869	98032	-57638	52475	0.57	52475
63482	67941	-15900	11441	0.18	11441
58069	55072	-13023	16021	0.28	16021
41037	54409	13144	-26516	-0.65	-26516
143073	82797	13250	47026	0.33	47026
126419	99829	19433	7156	0.06	7156
113444	96896	-9843	26391	0.23	26391
97608	91938	-20291	25961	0.27	25961
104012	82210	-7647	29449	0.28	29449
95253	67531	972	26751	0.28	26751
77214	62377	11357	3480	0.05	3480
77214	59225	-3991	21979	0.28	21979
112256	65947	24229	22080	0.20	22080
78857	65944	-40431	53344	0.68	53344
94474	**80981**	**-6033**	**19526**	**0.18**	**2.0E+04**
				0.72	**6.8E+04**
				-0.65	**-3.7E+04**
				1.2E-01	**8.2E+08**
96903	87434	-7748	17218	0.14	1.7E+04
				0.72	6.8E+04
				-0.65	-3.7E+04
				3.8E-01	3.2E+04
88159	64205	-1573	25527	0.30	2.6E+04
				0.68	5.3E+04
				0.05	3.5E+03
				2.3E-01	1.8E+04

CYC-2

3/5/2002	32	13986		
3/13/2002	40	12619		
3/20/2002	47	13940		
4/2/2002	60	16487		
4/17/2002	75	12400		
4/25/2002	83	12268	7114	0.58
5/2/2002	90	8386	7114	0.85
5/9/2002	97	7671	6200	0.81
5/24/2002	112	5421	4721	0.87
6/5/2002	124	18900	9993	0.53
6/14/2002	133	16700	13543	0.81
6/21/2002	140	14986	10286	0.69
6/28/2002	147	12894	7871	0.61
7/12/2002	161	13740	4389	0.32
8/5/2002	185	12583	6557	0.52
8/19/2002	199	10200	6760	0.66
9/22/2002	233	10200	6760	0.66
10/6/2002	247	14829	9280	0.63
10/13/2002	254	10417	5750	0.55
Total	**average =**	**1.3E+04**	**7.6E+03**	**0.65**
	maximum =	**1.9E+04**	**1.4E+04**	**0.87**
	minimum =	**5.4E+03**	**4.4E+03**	**0.32**
	variance =	**1.1E+07**	**6.0E+06**	**2.3E-02**
Before Day 161	average =	1.3E+04	7.9E+03	0.67
	maximum =	1.9E+04	1.4E+04	0.87
	minimum =	5.4E+03	4.4E+03	0.32
	variance =	3.7E+03	2.9E+03	1.8E-01
After Day 161	average =	1.2E+04	7.0E+03	0.60
	maximum =	1.5E+04	9.3E+03	0.66
	minimum =	1.0E+04	5.8E+03	0.52
	variance =	2.0E+03	1.3E+03	6.5E-02

18100			10100		
14100			10260		
19300			14000		
14300			10520		
20800			16100		
11900			8800		
8300	5620	0.68	6900	0.81	0.52
5800	4040	0.70	4060	1.00	0.99
9680	7600	0.79	8800	0.86	0.42
13300	11400	0.86	11300	1.01	
15800	9800	0.62	12300	0.80	0.58
16400	14200	0.87	16200	0.88	0.09
10740	8540	0.80	8860	0.96	0.85
9980	8580	0.86	9040	0.95	0.67
10800	7240	0.67	7900	0.92	0.81
11920	7520	0.63	8000	0.94	0.89
12620	6320	0.50	6340	1.00	1.00
18980	11480	0.60	11680	0.98	0.97
13120	7140	0.54	7600	0.94	0.92
1.3E+04	**8.4E+03**	**0.70**	**9.9E+03**	**0.93**	**0.73**
2.1E+04	**1.4E+04**	**0.87**	**1.6E+04**	**1.01**	**1.00**
5.8E+03	**4.0E+03**	**0.50**	**4.1E+03**	**0.80**	**0.09**
1.6E+07	**7.5E+06**	**1.5E-02**	**1.0E+07**	**4.8E-03**	**7.8E-02**
1.3E+04	8.7E+03	0.77	1.1E+04	0.91	0.59
2.1E+04	1.4E+04	0.87	1.6E+04	1.01	0.99
5.8E+03	4.0E+03	0.62	4.1E+03	0.80	0.09
4.4E+03	3.2E+03	9.4E-02	3.3E+03	8.2E-02	2.9E-01
1.3E+04	7.9E+03	0.59	8.3E+03	0.96	0.92
1.9E+04	1.1E+04	0.67	1.2E+04	1.00	1.00
1.1E+04	6.3E+03	0.50	6.3E+03	0.92	0.81
3.2E+03	2.0E+03	6.8E-02	2.0E+03	3.3E-02	7.2E-02

95526	88266	-26500	33760	0.35	33760
105526	100473	39371	-34318	-0.33	-34318
124807	101400	-20385	43791	0.35	43791
93868	108781	22967	-37880	-0.40	-37880
92869	101627	-58963	50204	0.54	50204
63482	63683	-27257	27057	0.43	27057
58069	44455	-18929	32543	0.56	32543
41037	51154	13709	-23827	-0.58	-23827
143073	78804	15988	48281	0.34	48281
126419	94530	14722	17166	0.14	17166
113444	111374	4543	-2472	-0.02	-2472
97608	96820	-42854	43642	0.45	43642
104012	70420	-2877	36469	0.35	36469
95253	64618	1811	28825	0.30	28825
77214	61085	4240	11889	0.15	11889
77214	55639	1091	20484	0.27	20484
112256	70020	24077	18158	0.16	18158
78857	74685	-44369	48540	0.62	48540
94474	**79880**	**-5534**	**20128**	**0.20**	**2.0E+04**
				0.62	**5.0E+04**
				-0.58	**-3.8E+04**
				1.1E-01	**7.8E+08**
96903	85522	-6651	18032	0.17	1.8E+04
				0.56	5.0E+04
				-0.58	-3.8E+04
				3.8E-01	3.2E+04
88159	65209	-2630	25579	0.30	2.6E+04
				0.62	4.9E+04
				0.15	1.2E+04
				1.9E-01	1.4E+04

Suspended Solids Data

CON-1

Date	Day	INFLUENT			
		SS (mg/L)	VSS (mg/L)	FSS (mg/L)	VSS Fraction
3/5/2002	32	6890	5100	1790	0.74
3/13/2002	40	7905	6538	1367	0.83
3/20/2002	47	9276	7105	2171	0.77
4/2/2002	60	9367	8467	900	0.90
4/17/2002	75	8543	7391	1152	0.87
4/25/2002	83	6581	5147	1434	0.78
5/2/2002	90	5286	4133	1153	0.78
5/9/2002	97	4200	3667	533	0.87
5/24/2002	112	6936	5614	1322	0.81
6/5/2002	124	13924	11153	2771	0.80
6/14/2002	133	12062	9610	2452	0.80
6/21/2002	140	11129	8867	2262	0.80
6/28/2002	147	9629	7362	2267	0.76
7/12/2002	161	7043	5427	1616	0.77
8/5/2002	185	8175	6524	1651	0.80
8/19/2002	199	6450	5117	1333	0.79
10/6/2002	247	8271	6767	1504	0.82
10/13/2002	254	7000	5598	1402	0.80
Total	**average =**	**8.3E+03**	**6.6E+03**	**1.6E+03**	**0.80**
	maximum =	**1.4E+04**	**1.1E+04**	**2.8E+03**	**0.90**
	minimum =	**4.2E+03**	**3.7E+03**	**5.3E+02**	**0.74**
	variance =	**5.7E+06**	**3.8E+06**	**3.3E+05**	**1.7E-03**
Before Day 161	average =	8.5E+03	6.8E+03	1.7E+03	0.81
	maximum =	1.4E+04	1.1E+04	2.8E+03	0.90
	minimum =	4.2E+03	3.7E+03	5.3E+02	0.74
	variance =	7.1E+06	4.7E+06	4.2E+05	2.2E-03
After Day 161	average =	7.5E+03	6.0E+03	1.5E+03	0.80
	maximum =	8.3E+03	6.8E+03	1.7E+03	0.82
	minimum =	6.5E+03	5.1E+03	1.3E+03	0.79
	variance =	8.0E+05	6.0E+05	1.9E+04	1.2E-04

MIXED				SUPERNATANT			
SS (mg/L)	**VSS (mg/L)**	**FSS (mg/L)**	**VSS Fraction**	**SS (mg/L)**	**VSS (mg/L)**	**FSS (mg/L)**	**VSS Fraction**
7300	5533	1767	0.76	2111	1867	244	0.88
9167	6800	2367	0.74	4867	3633	1234	0.75
8200	6232	1968	0.76	1167	1107	60	0.95
10367	8100	2267	0.78	7333	5400	1933	0.74
10967	9000	1967	0.82	4300	4300	0	1.00
10833	7633	3200	0.70	1820	1473	347	0.81
10800	7833	2967	0.73	1627	1280	347	0.79
9033	7667	1366	0.85	1933	1867	66	0.97
12400	10000	2400	0.81	2667	2400	267	0.90
12800	9067	3733	0.71	7233	5333	1900	0.74
15267	11467	3800	0.75	7000	5533	1467	0.79
15900	11667	4233	0.73	4717	3617	1100	0.77
15167	10667	4500	0.70	4133	3083	1050	0.75
10000	8275	1725	0.83	5200	4950	250	0.95
16167	11867	4300	0.73	2150	1640	510	0.76
12933	9233	3700	0.71	3400	2553	847	0.75
16083	11483	4600	0.71	4778	3544	1234	0.74
13150	10100	3050	0.77	1803	1050	753	0.58
1.2E+04	**9.0E+03**	**3.0E+03**	**0.76**	**3.8E+03**	**3.0E+03**	**7.6E+02**	**0.81**
1.6E+04	**1.2E+04**	**4.6E+03**	**0.85**	**7.3E+03**	**5.5E+03**	**1.9E+03**	**1.00**
7.3E+03	**5.5E+03**	**1.4E+03**	**0.70**	**1.2E+03**	**1.1E+03**	**0.0E+00**	**0.58**
8.0E+06	**3.7E+06**	**1.1E+06**	**2.0E-03**	**4.1E+06**	**2.5E+06**	**3.9E+05**	**1.2E-02**
1.1E+04	8.6E+03	2.7E+03	0.76	4.0E+03	3.3E+03	7.3E+02	0.84
1.6E+04	1.2E+04	4.5E+03	0.85	7.3E+03	5.5E+03	1.9E+03	1.00
7.3E+03	5.5E+03	1.4E+03	0.70	1.2E+03	1.1E+03	0.0E+00	0.74
7.2E+06	3.5E+06	1.0E+06	2.3E-03	4.7E+06	2.7E+06	4.8E+05	9.4E-03
1.5E+04	1.1E+04	3.9E+03	0.73	3.0E+03	2.2E+03	8.4E+02	0.71
1.6E+04	1.2E+04	4.6E+03	0.77	4.8E+03	3.5E+03	1.2E+03	0.76
1.3E+04	9.2E+03	3.1E+03	0.71	1.8E+03	1.1E+03	5.1E+02	0.58
3.2E+06	1.5E+06	4.7E+05	6.5E-04	1.8E+06	1.2E+06	9.1E+04	7.3E-03

SRT (days)	SS Settling Efficiency	VSS Settling Efficiency	FSS Settling Efficiency	SS Mass Removal Efficiency	VSS Mass Removal Efficiency
13.9	0.71	0.66	0.86	0.77	0.73
10.8	0.47	0.47	0.48	0.54	0.58
18.3	0.86	0.82	0.97	0.91	0.88
9.3	0.29	0.33	0.15	0.41	0.52
11.5	0.61	0.52	1.00	0.62	0.56
17.7	0.83	0.81	0.89	0.79	0.79
18.8	0.85	0.84	0.88	0.77	0.77
16.2	0.79	0.76	0.95	0.65	0.62
16.3	0.78	0.76	0.89	0.71	0.68
10.1	0.43	0.41	0.49	0.61	0.64
11.4	0.54	0.52	0.61	0.56	0.57
14.5	0.70	0.69	0.74	0.68	0.69
15.0	0.73	0.71	0.77	0.68	0.69
11.4	0.48	0.40	0.86	0.45	0.32
41.5	0.87	0.86	0.88	0.74	0.75
23.2	0.74	0.72	0.77	0.47	0.50
21.0	0.70	0.69	0.73	0.42	0.48
51.6	0.86	0.90	0.75	0.74	0.81
18.5	**0.68**	**0.66**	**0.76**	**0.64**	**0.64**
51.6	**0.87**	**0.90**	**1.00**	**0.91**	**0.88**
9.3	**0.29**	**0.33**	**0.15**	**0.41**	**0.32**
1.2E+02	**2.9E-02**	**3.0E-02**	**4.5E-02**	**2.0E-02**	**2.0E-02**
14.0	0.65	0.62	0.75	0.65	0.65
18.8	0.86	0.84	1.00	0.91	0.88
9.3	0.29	0.33	0.15	0.41	0.32
1.0E+01	3.2E-02	3.0E-02	5.8E-02	1.8E-02	1.9E-02
34.3	0.79	0.79	0.78	0.59	0.63
51.6	0.87	0.90	0.88	0.74	0.81
21.0	0.70	0.69	0.73	0.42	0.48
2.2E+02	7.2E-03	1.0E-02	4.4E-03	2.9E-02	2.9E-02

VSS Inputs (mg/d)	VSS Outputs (mg/d)	VSS Accumulation (mg/d)	VSS Mass Removal Rate (mg/d)	VSS Mass Removal Efficiency
49493	27283	8394	13816	0.28
53785	25787	-4301	32298	0.60
64095	32033	7616	24446	0.38
55950	43717	3180	9053	0.16
38963	32127	-9056	15892	0.41
31287	22450	1514	7323	0.23
27759	23600	-1257	5416	0.20
42498	28830	8243	5424	0.13
84428	39994	-4121	48555	0.58
72748	50276	14133	8338	0.11
67123	47865	1514	17744	0.26
55730	40153	-7571	23149	0.42
41082	40728	-9055	9410	0.23
49387	26767	7932	14687	0.30
38736	18150	-9972	30557	0.79
51226	25046	2484	23696	0.46
42377	19679	-10471	33169	0.78
50980	**32029**	**-47**	**18998**	**0.37**
52688	34988	710	16989	0.31
45431	22410	-2507	25528	0.58

SS Inputs (mg/d)	SS Outputs (mg/d)	SS Accumulation (mg/d)	SS Mass Removal Rate (mg/d)	SS Mass Removal Efficiency
59841	35391	12369	12081	0.20
70219	33563	-7322	43978	0.63
70908	41698	8835	20375	0.29
64671	53210	2120	9340	0.14
49818	38001	-888	12705	0.26
40015	30255	-250	10009	0.25
31794	28873	-13379	16300	0.51
52506	33339	11897	7270	0.14
105405	51949	1767	51689	0.49
91309	66962	14528	9819	0.11
84247	62753	4793	16700	0.20
72892	54520	-5550	23921	0.33
53316	50308	-19561	22568	0.42
61885	30354	13619	17912	0.29
48827	24183	-12243	36887	0.76
62611	33760	3478	25373	0.41
52990	27962	-22207	47235	0.89
63132	**41005**	**-470**	**22598**	**0.37**
65149	44679	720	19750	0.30
56578	29065	-4338	31852	0.59

CON-2

3/5/2002	32	6890	5100	1790	0.74
3/13/2002	40	7905	6538	1367	0.83
3/20/2002	47	9276	7105	2171	0.77
4/2/2002	60	9367	8467	900	0.90
4/17/2002	75	8543	7391	1152	0.87
4/25/2002	83	6581	5147	1434	0.78
5/2/2002	90	5286	4133	1153	0.78
5/9/2002	97	4200	3667	533	0.87
5/24/2002	112	6936	5614	1322	0.81
6/5/2002	124	13924	11153	2771	0.80
6/14/2002	133	12062	9610	2452	0.80
6/21/2002	140	11129	8867	2262	0.80
6/28/2002	147	9629	7362	2267	0.76
7/12/2002	161	7043	5427	1616	0.77
8/5/2002	185	8175	6524	1651	0.80
8/19/2002	199	6450	5117	1333	0.79
9/22/2002	233	6450	8967	-2517	1.39
10/6/2002	247	8271	6767	1504	0.82
10/13/2002	254	7000	5598	1402	0.80
Total	**average =**	**8.2E+03**	**6.8E+03**	**1.4E+03**	**0.84**
	maximum =	**1.4E+04**	**1.1E+04**	**2.8E+03**	**1.39**
	minimum =	**4.2E+03**	**3.7E+03**	**-2.5E+03**	**0.74**
	variance =	**5.6E+06**	**3.9E+06**	**1.3E+06**	**2.0E-02**
Before Day 161	average =	8.5E+03	6.8E+03	1.6E+03	0.81
	maximum =	1.4E+04	1.1E+04	2.8E+03	0.90
	minimum =	4.2E+03	3.7E+03	5.3E+02	0.74
	variance =	7.1E+06	4.7E+06	4.2E+05	2.2E-03
After Day 161	average =	7.3E+03	6.6E+03	4.3E+02	0.92
	maximum =	8.3E+03	9.0E+03	1.5E+03	1.39
	minimum =	6.5E+03	5.1E+03	-2.5E+03	0.79
	variance =	8.1E+05	2.2E+06	3.9E+06	6.9E-02

6000	5500	500	0.92	5833	4900	933	0.84
9333	7500	1833	0.80	2433	2367	66	0.97
10332	8632	1700	0.84	3767	2992	775	0.79
9233	7300	1933	0.79	5000	3867	1133	0.77
7033	6600	433	0.94	5533	5100	433	0.92
10033	7500	2533	0.75	6133	5067	1066	0.83
8333	6200	2133	0.74	2007	1587	420	0.79
4333	4133	200	0.95	1407	1240	167	0.88
9200	7733	1467	0.84	5367	4067	1300	0.76
13333	9533	3800	0.71	3803	2967	836	0.78
12833	9833	3000	0.77	3667	2917	750	0.80
15567	11300	4267	0.73	5000	3850	1150	0.77
14233	10667	3566	0.75	4333	3250	1083	0.75
12575	10025	2550	0.80	5100	4800	300	0.94
15100	10600	4500	0.70	1580	1140	440	0.72
15267	11033	4234	0.72	3447	2560	887	0.74
11800	8467	3333	0.72	1300	1060	240	0.82
14900	10717	4183	0.72	3667	2627	1040	0.72
13967	10017	3950	0.72	1727		1727	
1.1E+04	**8.6E+03**	**2.8E+03**	**0.78**	**3.7E+03**	**3.1E+03**	**7.7E+02**	**0.81**
1.6E+04	**1.1E+04**	**4.5E+03**	**0.95**	**6.1E+03**	**5.1E+03**	**1.7E+03**	**0.97**
4.3E+03	**4.1E+03**	**2.0E+02**	**0.70**	**1.3E+03**	**1.1E+03**	**6.6E+01**	**0.72**
1.1E+07	**4.3E+06**	**1.8E+06**	**6.3E-03**	**2.6E+06**	**1.8E+06**	**2.0E+05**	**5.6E-03**
1.0E+04	8.0E+03	2.4E+03	0.81	4.2E+03	3.5E+03	7.1E+02	0.83
1.6E+04	1.1E+04	4.5E+03	0.95	6.1E+03	5.1E+03	1.3E+03	0.97
4.3E+03	4.1E+03	2.0E+02	0.71	1.4E+03	1.2E+03	6.6E+01	0.75
1.0E+07	4.3E+06	1.7E+06	6.2E-03	2.2E+06	1.6E+06	1.6E+05	5.3E-03
1.4E+04	1.0E+04	3.9E+03	0.72	2.3E+03	1.8E+03	9.7E+02	0.75
1.5E+04	1.1E+04	4.2E+03	0.72	3.7E+03	2.6E+03	1.7E+03	0.82
1.2E+04	8.5E+03	3.3E+03	0.70	1.3E+03	1.1E+03	2.4E+02	0.72
2.1E+06	1.0E+06	1.7E+05	6.4E-05	1.3E+06	7.5E+05	3.7E+05	2.1E-03

7.6	0.03	0.11	-0.87	0.37	0.28
14.4	0.74	0.68	0.96	0.77	0.73
13.7	0.64	0.65	0.54	0.70	0.68
10.8	0.46	0.47	0.41	0.60	0.66
8.4	0.21	0.23	0.00	0.51	0.48
9.3	0.39	0.32	0.58	0.30	0.26
15.8	0.76	0.74	0.80	0.72	0.71
14.7	0.68	0.70	0.17	0.75	0.75
10.9	0.42	0.47	0.11	0.42	0.46
14.5	0.71	0.69	0.78	0.80	0.80
14.8	0.71	0.70	0.75	0.77	0.77
13.9	0.68	0.66	0.73	0.66	0.67
14.6	0.70	0.70	0.70	0.66	0.67
14.1	0.59	0.52	0.88	0.46	0.34
50.3	0.90	0.89	0.90	0.81	0.83
27.0	0.77	0.77	0.79	0.47	0.50
44.8	0.89	0.87	0.93	0.80	0.88
25.8	0.75	0.75	0.75	0.56	0.61
	0.88		0.56	0.75	1.00
18.1	**0.63**	**0.61**	**0.63**	**0.62**	**0.64**
50.3	**0.90**	**0.89**	**0.96**	**0.81**	**1.00**
7.6	**0.03**	**0.11**	**0.00**	**0.30**	**0.26**
1.4E+02	**5.3E-02**	**4.6E-02**	**8.2E-02**	**2.6E-02**	**4.1E-02**
12.7	0.55	0.55	0.59	0.61	0.59
15.8	0.76	0.74	0.96	0.80	0.80
7.6	0.03	0.11	0.00	0.30	0.26
7.3E+00	4.9E-02	4.1E-02	9.6E-02	2.7E-02	3.1E-02
37.0	0.84	0.82	0.76	0.68	0.76
50.3	0.90	0.89	0.93	0.81	1.00
25.8	0.75	0.75	0.56	0.47	0.50
1.5E+02	4.6E-03	5.1E-03	2.3E-02	2.4E-02	4.2E-02

49493	32930	13250	3312	0.07
53785	30478	8571	14736	0.27
64095	34547	-5430	34979	0.55
55950	38608	-2473	19815	0.35
38963	42204	5963	-9203	-0.24
31287	31853	-9843	9277	0.30
27759	17803	-15650	25607	0.92
42498	26293	12720	3485	0.08
84428	36306	7950	40172	0.48
72748	35028	1767	35953	0.49
67123	39207	11107	16809	0.25
55730	40941	-4793	19582	0.35
41082	42432	-2430	1081	0.03
49387	24460	1270	23656	0.48
38736	16423	1639	20673	0.53
67880	15843	-4000	56037	0.83
51226	16045	8518	26663	0.52
42377	21972	-5300	25705	0.61
51919	**30187**	**1269**	**20463**	**0.40**
52688	34510	1593	16585	0.33
49921	18949	425	30547	0.62

59841	37974	22081	-214	0.00
70219	36208	7564	26447	0.38
70908	43401	-4481	31988	0.45
64671	45292	-7773	27152	0.42
49818	49266	19875	-19322	-0.39
40015	40486	-12871	12400	0.31
31794	21677	-30286	40403	1.27
52506	32035	17197	3273	0.06
105405	47353	18254	39797	0.38
91309	45965	-2944	48289	0.53
84247	51477	20700	12069	0.14
72892	54692	-10100	28300	0.39
53316	52145	-6277	7447	0.14
61885	28113	5576	28196	0.46
48827	22446	632	25749	0.53
48827	20978	-5404	33253	0.68
62611	21731	11736	29145	0.47
52990	23582	-7064	36472	0.69
62485	**37462**	**843**	**24180**	**0.41**
65306	42162	1110	22034	0.35
53314	22184	-25	31155	0.59

CYC-1

3/5/2002	32	6890	5100	1790	0.74
3/13/2002	40	7905	6538	1367	0.83
3/20/2002	47	9276	7105	2171	0.77
4/2/2002	60	9367	8467	900	0.90
4/17/2002	75	8543	7391	1152	0.87
4/25/2002	83	6581	5147	1434	0.78
5/2/2002	90	5286	4133	1153	0.78
5/9/2002	97	4200	3667	533	0.87
5/24/2002	112	6936	5614	1322	0.81
6/5/2002	124	13924	11153	2771	0.80
6/14/2002	133	12062	9610	2452	0.80
6/21/2002	140	11129	8867	2262	0.80
6/28/2002	147	9629	7362	2267	0.76
7/12/2002	161	7043	5427	1616	0.77
8/5/2002	185	8175	6524	1651	0.80
8/19/2002	199	6450	5117	1333	0.79
9/22/2002	233	6450	8967	-2517	1.39
10/6/2002	247	8271	6767	1504	0.82
10/13/2002	254	7000	5598	1402	0.80
Total	**average =**	**8.2E+03**	**6.8E+03**	**1.4E+03**	**0.84**
	maximum =	**1.4E+04**	**1.1E+04**	**2.8E+03**	**1.39**
	minimum =	**4.2E+03**	**3.7E+03**	**-2.5E+03**	**0.74**
	variance =	**5.6E+06**	**3.9E+06**	**1.3E+06**	**2.0E-02**
Before Day 161	average =	8.5E+03	6.8E+03	1.6E+03	0.81
	maximum =	1.4E+04	1.1E+04	2.8E+03	0.90
	minimum =	4.2E+03	3.7E+03	5.3E+02	0.74
	variance =	7.1E+06	4.7E+06	4.2E+05	2.2E-03
After Day 161	average =	7.3E+03	6.6E+03	4.3E+02	0.92
	maximum =	8.3E+03	9.0E+03	1.5E+03	1.39
	minimum =	6.5E+03	5.1E+03	-2.5E+03	0.79
	variance =	8.1E+05	2.2E+06	3.9E+06	6.9E-02

6867	5283	1584	0.77	4967	4100	867	0.83
9700	8000	1700	0.82	5167	4300	867	0.83
10000	8367	1633	0.84	6232	5767	465	0.93
8567	6767	1800	0.79	6667	5000	1667	0.75
11700	9067	2633	0.77	5567	5100	467	0.92
11167	8533	2634	0.76	6433	5167	1266	0.80
9500	7100	2400	0.75	5800	4667	1133	0.80
5667	5200	467	0.92	3667	2783	884	0.76
9500	7233	2267	0.76	4500	3167	1333	0.70
10833	7667	3166	0.71	8867	6267	2600	0.71
11867	8867	3000	0.75	8600	6833	1767	0.79
14100	9967	4133	0.71	5967	4517	1450	0.76
13400	9267	4133	0.69	7300	5300	2000	0.73
9500	7300	2200	0.77	6200	3667	2533	0.59
12267	8933	3334	0.73	5250	4000	1250	0.76
14600	10000	4600	0.68	4800	3733	1067	0.78
12267	8200	4067	0.67	3713	2787	926	0.75
13917	9667	4250	0.69	5567	3978	1589	0.71
13683	10083	3600	0.74	4011	3222	789	0.80
1.1E+04	**8.2E+03**	**2.9E+03**	**0.75**	**5.8E+03**	**4.4E+03**	**1.3E+03**	**0.77**
1.5E+04	**1.0E+04**	**4.6E+03**	**0.92**	**8.9E+03**	**6.8E+03**	**2.6E+03**	**0.93**
5.7E+03	**5.2E+03**	**4.7E+02**	**0.67**	**3.7E+03**	**2.8E+03**	**4.7E+02**	**0.59**
6.1E+06	**2.1E+06**	**1.3E+06**	**3.7E-03**	**2.1E+06**	**1.3E+06**	**3.7E+05**	**5.7E-03**
1.0E+04	7.8E+03	2.5E+03	0.77	6.1E+03	4.8E+03	1.4E+03	0.78
1.4E+04	1.0E+04	4.1E+03	0.92	8.9E+03	6.8E+03	2.6E+03	0.93
5.7E+03	5.2E+03	4.7E+02	0.69	3.7E+03	2.8E+03	4.7E+02	0.59
5.2E+06	2.0E+06	9.9E+05	3.4E-03	2.1E+06	1.3E+06	4.4E+05	7.5E-03
1.3E+04	9.4E+03	4.1E+03	0.70	4.7E+03	3.5E+03	1.1E+03	0.76
1.5E+04	1.0E+04	4.6E+03	0.74	5.6E+03	4.0E+03	1.6E+03	0.80
1.2E+04	8.2E+03	3.6E+03	0.67	3.7E+03	2.8E+03	7.9E+02	0.71
1.1E+06	6.4E+05	1.7E+05	8.4E-04	6.3E+05	2.8E+05	1.2E+05	1.1E-03

8.4	0.28	0.22	0.45	0.46	0.40
10.7	0.47	0.46	0.49	0.51	0.51
9.1	0.38	0.31	0.72	0.50	0.39
8.7	0.22	0.26	0.07	0.47	0.56
10.4	0.52	0.44	0.82	0.51	0.48
9.9	0.42	0.39	0.52	0.27	0.25
9.4	0.39	0.34	0.53	0.18	0.15
10.8	0.35	0.46	-0.89	0.35	0.43
12.1	0.53	0.56	0.41	0.51	0.58
8.1	0.18	0.18	0.18	0.52	0.58
8.5	0.28	0.23	0.41	0.47	0.47
11.9	0.58	0.55	0.65	0.60	0.62
10.3	0.46	0.43	0.52	0.43	0.46
13.5	0.35	0.50	-0.15	0.34	0.49
15.0	0.57	0.55	0.63	0.36	0.39
17.7	0.67	0.63	0.77	0.26	0.27
19.3	0.70	0.66	0.77	0.42	0.69
16.2	0.60	0.59	0.63	0.33	0.41
20.4	0.71	0.68	0.78	0.43	0.42
12.1	**0.45**	**0.44**	**0.44**	**0.42**	**0.45**
20.4	**0.71**	**0.68**	**0.82**	**0.60**	**0.69**
8.1	**0.18**	**0.18**	**-0.89**	**0.18**	**0.15**
1.5E+01	**2.5E-02**	**2.4E-02**	**1.8E-01**	**1.2E-02**	**1.7E-02**
10.1	0.39	0.38	0.35	0.44	0.45
13.5	0.58	0.56	0.82	0.60	0.62
8.1	0.18	0.18	-0.89	0.18	0.15
2.5E+00	1.4E-02	1.5E-02	2.0E-01	1.3E-02	1.7E-02
17.7	0.65	0.62	0.74	0.36	0.44
20.4	0.71	0.68	0.78	0.43	0.69
15.0	0.57	0.55	0.63	0.26	0.27
4.8E+00	3.6E-03	2.7E-03	5.5E-03	5.1E-03	2.4E-02

49493	36415	18000	-4922	-0.10
53785	44065	2779	6941	0.13
64095	44885	-6523	25733	0.40
55950	43654	8127	4169	0.07
38963	45799	-3538	-3299	-0.08
31287	42709	-10850	-572	-0.02
27759	32788	-14386	9357	0.34
42498	28655	7183	6659	0.16
84428	40880	1917	41631	0.49
72748	52833	7067	12848	0.18
67123	50041	8329	8753	0.13
55730	46068	-5300	14962	0.27
41082	41132	-7447	7397	0.18
49387	30168	3606	15612	0.32
38736	30774	4039	3922	0.10
67880	26249	-2806	44437	0.65
51226	27098	5554	18575	0.36
42377	28940	3150	10288	0.24
51919	**38509**	**1050**	**12361**	**0.23**
52688	42302	412	9974	0.20
49921	28646	2709	18567	0.34

59841	44444	18769	-3372	-0.06
70219	51000	2271	16948	0.24
70908	54186	-5842	22564	0.32
64671	53907	11070	-306	0.00
49818	55703	-3531	-2354	-0.05
40015	54283	-12622	-1646	-0.04
31794	41226	-29021	19589	0.62
52506	37536	13543	1426	0.03
105405	57186	5887	42332	0.40
91309	71064	6089	14156	0.16
84247	65923	16907	1416	0.02
72892	63684	-5300	14508	0.20
53316	59992	-14764	8088	0.15
61885	44719	6110	11055	0.18
48827	40300	8832	-306	-0.01
48827	34692	-3637	17771	0.36
62611	37398	6246	18967	0.30
52990	38677	-1772	16085	0.30
62485	**50675**	**28**	**11782**	**0.19**
65306	54647	-708	11367	0.17
53314	37767	2418	13129	0.24

CYC-2

3/5/2002	32	6890	5100	1790	0.74
3/13/2002	40	7905	6538	1367	0.83
3/20/2002	47	9276	7105	2171	0.77
4/2/2002	60	9367	8467	900	0.90
4/17/2002	75	8543	7391	1152	0.87
4/25/2002	83	6581	5147	1434	0.78
5/2/2002	90	5286	4133	1153	0.78
5/9/2002	97	4200	3667	533	0.87
5/24/2002	112	6936	5614	1322	0.81
6/5/2002	124	13924	11153	2771	0.80
6/14/2002	133	12062	9610	2452	0.80
6/21/2002	140	11129	8867	2262	0.80
6/28/2002	147	9629	7362	2267	0.76
7/12/2002	161	7043	5427	1616	0.77
8/5/2002	185	8175	6524	1651	0.80
8/19/2002	199	6450	5117	1333	0.79
9/22/2002	233	6450	8967	-2517	1.39
10/6/2002	247	8271	6767	1504	0.82
10/13/2002	254	7000	5598	1402	0.80
Total	**average =**	**8.2E+03**	**6.8E+03**	**1.4E+03**	**0.84**
	maximum =	**1.4E+04**	**1.1E+04**	**2.8E+03**	**1.39**
	minimum =	**4.2E+03**	**3.7E+03**	**-2.5E+03**	**0.74**
	variance =	**5.6E+06**	**3.9E+06**	**1.3E+06**	**2.0E-02**
Before Day 161	average =	8.5E+03	6.8E+03	1.6E+03	0.81
	maximum =	1.4E+04	1.1E+04	2.8E+03	0.90
	minimum =	4.2E+03	3.7E+03	5.3E+02	0.74
After Day 161	average =	7.3E+03	6.6E+03	4.3E+02	0.92
	maximum =	8.3E+03	9.0E+03	1.5E+03	1.39
	minimum =	6.5E+03	5.1E+03	-2.5E+03	0.79
	variance =	8.1E+05	2.2E+06	3.9E+06	6.9E-02

7800	6267	1533	0.80	4967	4133	834	0.83
10433	7567	2866	0.73	6067	4700	1367	0.77
9167	7567	1600	0.83	6732	5867	865	0.87
8900	6833	2067	0.77	6067	4500	1567	0.74
10333	8233	2100	0.80	3667	3667	0	1.00
8733	6533	2200	0.75	6700	5733	967	0.86
8067	6333	1734	0.79	4000	2789	1211	0.70
4333	4167	166	0.96	1633	1506	127	0.92
9267	6567	2700	0.71	3000	3300	-300	1.10
11850	9300	2550	0.78	8367	6267	2100	0.75
11767	9000	2767	0.76	8200	6533	1667	0.80
11867	8633	3234	0.73	5933	4483	1450	0.76
11700	8433	3267	0.72	7500	5233	2267	0.70
8525	6925	1600	0.81	4500	4500	0	1.00
11000	8067	2933	0.73	5000	3783	1217	0.76
12500	9000	3500	0.72	5050	3900	1150	0.77
10233	7383	2850	0.72	3720	2747	973	0.74
13067	9333	3734	0.71	5817	4450	1367	0.76
11867	8650	3217	0.73	4700	3683	1017	0.78
1.0E+04	**7.6E+03**	**2.5E+03**	**0.77**	**5.3E+03**	**4.3E+03**	**1.1E+03**	**0.82**
1.3E+04	**9.3E+03**	**3.7E+03**	**0.96**	**8.4E+03**	**6.5E+03**	**2.3E+03**	**1.10**
4.3E+03	**4.2E+03**	**1.7E+02**	**0.71**	**1.6E+03**	**1.5E+03**	**-3.0E+02**	**0.70**
4.5E+06	**1.8E+06**	**7.5E+05**	**3.6E-03**	**3.1E+06**	**1.6E+06**	**5.0E+05**	**1.2E-02**
9.5E+03	7.3E+03	2.3E+03	0.78	5.5E+03	4.5E+03	1.0E+03	0.84
1.2E+04	9.3E+03	3.3E+03	0.96	8.4E+03	6.5E+03	2.3E+03	1.10
4.3E+03	4.2E+03	1.7E+02	0.71	1.6E+03	1.5E+03	-3.0E+02	0.70
1.2E+04	8.5E+03	3.3E+03	0.72	4.9E+03	3.7E+03	1.1E+03	0.76
1.3E+04	9.3E+03	3.7E+03	0.73	5.8E+03	4.5E+03	1.4E+03	0.78
1.0E+04	7.4E+03	2.9E+03	0.71	3.7E+03	2.7E+03	9.7E+02	0.74
1.3E+06	6.0E+05	1.5E+05	5.7E-05	5.7E+05	3.8E+05	3.1E+04	2.9E-04

9.4	0.36	0.34	0.46	0.46	0.39
9.8	0.42	0.38	0.52	0.42	0.46
8.4	0.27	0.22	0.46	0.46	0.38
9.4	0.32	0.34	0.24	0.51	0.60
12.0	0.65	0.55	1.00	0.68	0.63
7.7	0.23	0.12	0.56	0.24	0.16
12.1	0.50	0.56	0.30	0.43	0.49
13.4	0.62	0.64	0.23	0.71	0.69
11.2	0.68	0.50	1.11	0.68	0.56
9.3	0.29	0.33	0.18	0.55	0.58
8.8	0.30	0.27	0.40	0.49	0.49
11.0	0.50	0.48	0.55	0.60	0.62
9.8	0.36	0.38	0.31	0.42	0.47
10.6	0.47	0.35	1.00	0.52	0.38
14.4	0.55	0.53	0.59	0.39	0.42
15.5	0.60	0.57	0.67	0.22	0.24
17.8	0.64	0.63	0.66	0.42	0.69
14.1	0.55	0.52	0.63	0.30	0.34
15.7	0.60	0.57	0.68	0.33	0.34
11.6	**0.47**	**0.44**	**0.56**	**0.46**	**0.47**
17.8	**0.68**	**0.64**	**1.11**	**0.71**	**0.69**
7.7	**0.23**	**0.12**	**0.18**	**0.22**	**0.16**
8.0E+00	**2.1E-02**	**2.1E-02**	**7.4E-02**	**2.0E-02**	**2.2E-02**
10.2	0.43	0.39	0.53	0.51	0.49
13.4	0.68	0.64	1.11	0.71	0.69
7.7	0.23	0.12	0.18	0.24	0.16
15.5	0.59	0.56	0.66	0.33	0.41
17.8	0.64	0.63	0.68	0.42	0.69
14.1	0.55	0.52	0.63	0.22	0.24
2.1E+00	1.4E-03	1.7E-03	4.6E-04	6.5E-03	3.0E-02

49493	38165	8613	2715	0.05
53785	44318	0	9467	0.18
64095	43055	-2992	24032	0.37
55950	37440	4947	13563	0.24
38963	40657	-11263	9569	0.25
31287	36366	-1514	-3565	-0.11
27759	22128	-16400	22031	0.79
42498	23800	8480	10218	0.24
84428	42172	12071	30185	0.36
72748	53652	-1767	20862	0.29
67123	47957	-2779	21945	0.33
55730	43730	-1514	13515	0.24
41082	42162	-5709	4629	0.11
49387	32248	2522	14616	0.30
38736	30339	3532	4864	0.13
67880	26467	-2521	43934	0.65
51226	28519	7382	15325	0.30
42377	32105	-5171	15443	0.36
51919	**36960**	**-227**	**15186**	**0.30**
52688	39662	-756	13782	0.28
49921	29936	1149	18837	0.36

59841	48576	17444	-6179	-0.10
70219	54880	-9585	24925	0.35
70908	53429	-1089	18568	0.26
64671	45832	5063	13776	0.21
49818	47471	-10600	12948	0.26
40015	46272	-5043	-1214	-0.03
31794	27724	-28272	32342	1.02
52506	26021	17433	9051	0.17
105405	52250	11408	41746	0.40
91309	69377	-489	22421	0.25
84247	62484	757	21006	0.25
72892	60433	-1264	13723	0.19
53316	53203	-12020	12132	0.23
61885	37301	5466	19118	0.31
48827	39845	5679	3303	0.07
48827	35071	-3534	17289	0.35
62611	37946	10729	13936	0.22
52990	41743	-9086	20333	0.38
62485	**46546**	**-1438**	**17377**	**0.29**
65306	48975	-2172	18503	0.30
53314	38651	947	13715	0.26

Total Kjeldahl Nitrogen Data

CON-1

Day	Date	INFLUENT				
		TKN (mg/L)	Dissolved TKN (mg/L)	NH3-N (mg/L)	Dissolved TKN Fraction	NH3-N Fraction
3/5/2002	32	2145		1471		0.69
3/13/2002	40	2129		1487		0.70
3/20/2002	47	2287		1599		0.70
4/2/2002	60	2397		1672		0.70
4/17/2002	75	2133		1509		0.71
4/25/2002	83	2043	1756	1481	0.86	0.72
5/2/2002	90	1951	1782	1432	0.91	0.73
5/9/2002	97	1662	1527	1179	0.92	0.71
6/5/2002	124	2338	1658	1326	0.71	0.57
6/14/2002	133	1992	1675	1376	0.84	0.69
6/21/2002	140	2070	1519	1460	0.73	0.71
6/28/2002	147	1987	1294	1349	0.65	0.68
7/12/2002	161	2010	1374	1309	0.68	0.65
8/5/2002	185	1396	1191	1010	0.85	0.72
9/22/2002	233	1360	1170	1094	0.86	0.80
10/6/2002	247	1582	1248	1155	0.79	0.73
10/13/2002	254	1402	1236	1053	0.88	0.75
Total	**average =**	**1.9E+03**	**1.5E+03**	**1.4E+03**	**0.81**	**0.70**
	maximum =	**2.4E+03**	**1.8E+03**	**1.7E+03**	**0.92**	**0.80**
	minimum =	**1.4E+03**	**1.2E+03**	**1.0E+03**	**0.65**	**0.57**
	variance =	**1.1E+05**	**5.2E+04**	**3.7E+04**	**8.5E-03**	**2.3E-03**
Before Day 161	average =	2.1E+03	1.6E+03	1.4E+03	0.79	0.69
	maximum =	2.4E+03	1.8E+03	1.7E+03	0.92	0.73
	minimum =	1.7E+03	1.3E+03	1.2E+03	0.65	0.57
	variance =	3.6E+04	3.1E+04	1.7E+04	1.1E-02	1.7E-03
After Day 161	average =	1.4E+03	1.2E+03	1.1E+03	0.85	0.75
	maximum =	1.6E+03	1.2E+03	1.2E+03	0.88	0.80
	minimum =	1.4E+03	1.2E+03	1.0E+03	0.79	0.72
	variance =	9.9E+03	1.4E+03	3.8E+03	1.6E-03	1.3E-03

MIXED				
TKN (mg/L)	**Dissolved TKN (mg/L)**	**NH3-N (mg/L)**	**Dissolved Fraction**	**NH3-N Fraction**
2064		1368		0.66
2142		1437		0.67
2241		1473		0.66
2478		1588		0.64
2363		1504		0.64
2206		1421		0.64
1956	1669	1339	0.85	0.68
1738	1286	996	0.74	0.57
2174	1244	1344	0.57	0.62
2110	1198	1238	0.57	0.59
2306	1032	1339	0.45	0.58
2171	1554	1227	0.72	0.57
2168	1319	1284	0.61	0.59
1716	1097	262	0.64	0.15
1882	1340	1082	0.71	0.57
2088	1554	1284	0.74	0.61
2263	2019	1004	0.89	0.44
2.1E+03	**1.4E+03**	**1.2E+03**	**0.68**	**0.58**
2.5E+03	**2.0E+03**	**1.6E+03**	**0.89**	**0.68**
1.7E+03	**1.0E+03**	**2.6E+02**	**0.45**	**0.15**
4.2E+04	**8.2E+04**	**9.1E+04**	**1.7E-02**	**1.5E-02**
2.2E+03	1.3E+03	1.4E+03	0.64	0.62
2.5E+03	1.7E+03	1.6E+03	0.85	0.68
1.7E+03	1.0E+03	1.0E+03	0.45	0.57
3.4E+04	4.7E+04	2.2E+04	1.8E-02	1.6E-03
2.0E+03	1.5E+03	9.1E+02	0.75	0.45
2.3E+03	2.0E+03	1.3E+03	0.89	0.61
1.7E+03	1.1E+03	2.6E+02	0.64	0.15
5.7E+04	1.5E+05	2.0E+05	1.1E-02	4.4E-02

SUPERNATANT			
TKN (mg/L)	**NH3-N (mg/L)**	**Dissolved Fraction**	**NH3-N Fraction**
1633	1317		0.81
1903	1380		0.73
1870	1416		0.76
2120	1450		0.68
2175	1500		0.69
1749	1288		0.74
1688	1320	0.99	0.78
1343	919	0.96	0.68
1773	1266	0.70	0.71
1638	1156	0.73	0.71
1861	1263	0.55	0.68
1811	1203	0.86	0.66
1668	1212	0.79	0.73
1199	240	0.91	0.20
1338	961	1.00	0.72
1755	1217	0.89	0.69
1730	919	1.17	0.53
1.7E+03	**1.2E+03**	**0.87**	**0.68**
2.2E+03	**1.5E+03**	**1.17**	**0.81**
1.2E+03	**2.4E+02**	**0.55**	**0.20**
6.5E+04	**8.8E+04**	**2.8E-02**	**1.8E-02**
1.8E+03	1.3E+03	0.80	0.72
2.2E+03	1.5E+03	0.99	0.81
1.3E+03	9.2E+02	0.55	0.66
4.6E+04	2.2E+04	2.3E-02	1.8E-03
1.5E+03	8.3E+02	0.99	0.54
1.8E+03	1.2E+03	1.17	0.72
1.2E+03	2.4E+02	0.89	0.20
7.8E+04	1.7E+05	1.6E-02	5.7E-02

Settling Efficiency	TKN Inputs (mg/d)	TKN Outputs (mg/d)	TKN Accumulation (mg/d)	TKN Mass Removal Rate (mg/d)	TKN Mass Removal Efficiency
	16117	14018	517	1582	0.10
	17313	14858	750	1705	0.10
	18145	15792	966	1387	0.08
	16147	16773	-406	-220	-0.01
	15466	15463	-1040	1043	0.07
0.93	14769	13695	-1893	2967	0.20
0.87	12581	12100	-1651	2132	0.17
0.43	17699	12547	856	4296	0.24
0.52	15079	13737	-377	1720	0.11
0.35	15670	14111	1484	74	0.00
0.58	15042	14660	-1022	1403	0.09
0.59	15216	13982	-11	1245	0.08
0.84	10568	10986	-998	580	0.05
1.00	10295	9743	183	369	0.04
0.62	11976	11822	780	-626	-0.05
	10613	13304	1325	-4016	-0.38
0.67	**14543**	**13599**	**-34**	**9.8E+02**	**0.06**
1.00				**4.3E+03**	**0.24**
0.35				**-4.0E+03**	**-0.38**
5.0E-02				**3.2E+06**	**1.9E-02**
0.61	15770	14311	-152	1.6E+03	0.10
0.93				4.3E+03	0.24
0.35				-2.2E+02	-0.01
4.7E-02				1.4E+06	5.4E-03
0.82	10863	11464	322	-9.2E+02	-0.08
1.00				5.8E+02	0.05
0.62				-4.0E+03	-0.38
3.6E-02				4.5E+06	4.0E-02

CON-2

3/5/2002	32	2145		1471		0.69
3/13/2002	40	2129		1487		0.70
3/20/2002	47	2287		1599		0.70
4/2/2002	60	2397		1672		0.70
4/17/2002	75	2133		1509		0.71
4/25/2002	83	2043	1756	1481	0.86	0.72
5/2/2002	90	1951	1782	1432	0.91	0.73
5/9/2002	97	1662	1527	1179	0.92	0.71
5/24/2002	112	2223	1793	1439	0.81	0.65
6/5/2002	124	2338	1658	1326	0.71	0.57
6/14/2002	133	1992	1675	1376	0.84	0.69
6/21/2002	140	2070	1519	1460	0.73	0.71
6/28/2002	147	1987	1294	1349	0.65	0.68
7/12/2002	161	2010	1374	1309	0.68	0.65
8/5/2002	185	1396	1191	1010	0.85	0.72
9/22/2002	233	1360	1170	1094	0.86	0.80
10/6/2002	247	1582	1248	1155	0.79	0.73
10/13/2002	254	1402	1236	1053	0.88	0.75
Total	**average =**	**1.9E+03**	**1.5E+03**	**1.3E+03**	**0.81**	**0.70**
	maximum =	**2.4E+03**	**1.8E+03**	**1.7E+03**	**0.92**	**0.80**
	minimum =	**1.4E+03**	**1.2E+03**	**1.0E+03**	**0.65**	**0.57**
	variance =	**1.1E+05**	**5.6E+04**	**3.7E+04**	**7.7E-03**	**2.5E-03**
Before Day 161	average =	2.1E+03	1.6E+03	1.4E+03	0.79	0.69
	maximum =	2.4E+03	1.8E+03	1.7E+03	0.92	0.73
	minimum =	1.7E+03	1.3E+03	1.2E+03	0.65	0.57
	variance =	3.7E+04	3.3E+04	1.7E+04	1.0E-02	1.9E-03
After Day 161	average =	1.4E+03	1.2E+03	1.1E+03	0.85	0.75
	maximum =	1.6E+03	1.2E+03	1.2E+03	0.88	0.80
	minimum =	1.4E+03	1.2E+03	1.0E+03	0.79	0.72
	variance =	9.9E+03	1.4E+03	3.8E+03	1.6E-03	1.3E-03

2018		1335		0.66
2164		1422		0.66
2261		1447		0.64
2350		1622		0.69
2238		1444		0.65
2032		1365		0.67
1853	1637	1313	0.88	0.71
1557	1356	1099	0.87	0.71
2046	1462	1308	0.71	0.64
1938	1237	1277	0.64	0.66
2006	1268	1188	0.63	0.59
2513	1312	1385	0.52	0.55
2278	1640	1328	0.72	0.58
2167	1464	1334	0.68	0.62
875	385	68	0.44	0.08
1580	1006	794	0.64	0.50
2052	1249	1107	0.61	0.54
1824	1797	912	0.99	0.50
2.0E+03	**1.3E+03**	**1.2E+03**	**0.69**	**0.59**
2.5E+03	**1.8E+03**	**1.6E+03**	**0.99**	**0.71**
8.8E+02	**3.9E+02**	**6.8E+01**	**0.44**	**0.08**
1.5E+05	**1.3E+05**	**1.3E+05**	**2.4E-02**	**2.2E-02**
2.1E+03	1.4E+03	1.3E+03	0.71	0.64
2.5E+03	1.6E+03	1.6E+03	0.88	0.71
1.6E+03	1.2E+03	1.1E+03	0.52	0.55
6.0E+04	2.5E+04	1.6E+04	1.5E-02	2.3E-03
1.6E+03	1.1E+03	7.2E+02	0.67	0.40
2.1E+03	1.8E+03	1.1E+03	0.99	0.54
8.8E+02	3.9E+02	6.8E+01	0.44	0.08
2.6E+05	3.4E+05	2.1E+05	5.2E-02	4.8E-02

1968	1339		0.68
1848	1327		0.72
2097	1427		0.68
2152	1614		0.75
2009	1392		0.69
1943	1319		0.68
1704	1258	0.96	0.74
1414	1019	0.96	0.72
1658	1230	0.88	0.74
1588	1216	0.78	0.77
1539	1125	0.82	0.73
1957	1305	0.67	0.67
1859	1220	0.88	0.66
1690	1245	0.87	0.74
437	55	0.88	0.13
1098	730	0.92	0.66
1283	956	0.97	0.75
1688	819	1.06	0.49
1.6E+03	**1.1E+03**	**0.89**	**0.66**
2.2E+03	**1.6E+03**	**1.06**	**0.77**
4.4E+02	**5.5E+01**	**0.67**	**0.13**
1.8E+05	**1.3E+05**	**1.0E-02**	**2.3E-02**
1.8E+03	1.3E+03	0.85	0.71
2.2E+03	1.6E+03	0.96	0.77
1.4E+03	1.0E+03	0.67	0.66
5.1E+04	2.1E+04	9.2E-03	1.2E-03
1.1E+03	6.4E+02	0.96	0.51
1.7E+03	9.6E+02	1.06	0.75
4.4E+02	5.5E+01	0.88	0.13
2.7E+05	1.6E+05	6.4E-03	7.6E-02

CYC-1

3/5/2002	32	2145		1471		0.69
3/13/2002	40	2129		1487		0.70
3/20/2002	47	2287		1599		0.70
4/2/2002	60	2397		1672		0.70
4/17/2002	75	2133		1509		0.71
4/25/2002	83	2043	1756	1481	0.86	0.72
5/2/2002	90	1951	1782	1432	0.91	0.73
5/9/2002	97	1662	1527	1179	0.92	0.71
5/24/2002	112	2223	1793	1439	0.81	0.65
6/5/2002	124	2338	1658	1326	0.71	0.57
6/14/2002	133	1992	1675	1376	0.84	0.69
6/21/2002	140	2070	1519	1460	0.73	0.71
6/28/2002	147	1987	1294	1349	0.65	0.68
7/12/2002	161	2010	1374	1309	0.68	0.65
8/5/2002	185	1396	1191	1010	0.85	0.72
9/22/2002	233	1360	1170	1094	0.86	0.80
10/6/2002	247	1582	1248	1155	0.79	0.73
10/13/2002	254	1402	1236	1053	0.88	0.75
Total	**average =**	**1.9E+03**	**1.5E+03**	**1.3E+03**	**0.81**	**0.70**
	maximum =	**2.4E+03**	**1.8E+03**	**1.7E+03**	**0.92**	**0.80**
	minimum =	**1.4E+03**	**1.2E+03**	**1.0E+03**	**0.65**	**0.57**
	variance =	**1.1E+05**	**5.6E+04**	**3.7E+04**	**7.7E-03**	**2.5E-03**
Before Day 161	average =	2.1E+03	1.6E+03	1.4E+03	0.79	0.69
	maximum =	2.4E+03	1.8E+03	1.7E+03	0.92	0.73
	minimum =	1.7E+03	1.3E+03	1.2E+03	0.65	0.57
	variance =	3.7E+04	3.3E+04	1.7E+04	1.0E-02	1.9E-03
After Day 161	average =	1.4E+03	1.2E+03	1.1E+03	0.85	0.75
	maximum =	1.6E+03	1.2E+03	1.2E+03	0.88	0.80
	minimum =	1.4E+03	1.2E+03	1.0E+03	0.79	0.72
	variance =	9.9E+03	1.4E+03	3.8E+03	1.6E-03	1.3E-03

2251		1487		0.66
2201		1499		0.68
2368		1612		0.68
2326		1622		0.70
2308		1550		0.67
2120		1399		0.66
1836	1731	1320	0.94	0.72
1630	1414	1017	0.87	0.62
2286	1604	1414	0.70	0.62
2074	1334	1439	0.64	0.69
2030	1464	1373	0.72	0.68
2310	1341	1482	0.58	0.64
2204	1864	1413	0.85	0.64
1975	1350	1406	0.68	0.71
1541	1250	274	0.81	0.18
1759	1251	511	0.71	0.29
2054	1496	1240	0.73	0.60
2198	2006	1018	0.91	0.46
2.1E+03	**1.5E+03**	**1.3E+03**	**0.76**	**0.60**
2.4E+03	**2.0E+03**	**1.6E+03**	**0.94**	**0.72**
1.5E+03	**1.3E+03**	**2.7E+02**	**0.58**	**0.18**
6.3E+04	**6.0E+04**	**1.4E+05**	**1.3E-02**	**2.3E-02**
2.1E+03	1.5E+03	1.4E+03	0.75	0.67
2.4E+03	1.9E+03	1.6E+03	0.94	0.72
1.6E+03	1.3E+03	1.0E+03	0.58	0.62
4.7E+04	4.0E+04	2.3E+04	1.5E-02	1.0E-03
1.9E+03	1.5E+03	7.6E+02	0.79	0.38
2.2E+03	2.0E+03	1.2E+03	0.91	0.60
1.5E+03	1.3E+03	2.7E+02	0.71	0.18
8.7E+04	1.3E+05	2.0E+05	8.5E-03	3.5E-02

1968	1422		0.72
2042	1491		0.73
2149	1570		0.73
2137	1600		0.75
2005	1460		0.73
1909	1307		0.68
1811	1282	0.96	0.71
1536	1020	0.92	0.66
2020	1278	0.79	0.63
1930	1424	0.69	0.74
1832	1304	0.80	0.71
2006	1388	0.67	0.69
2058	1316	0.91	0.64
1808	1326	0.75	0.73
1268	259	0.99	0.20
1416	953	0.88	0.67
1540	1155	0.97	0.75
1671	921	1.20	0.55
1.8E+03	**1.2E+03**	**0.88**	**0.67**
2.1E+03	**1.6E+03**	**1.20**	**0.75**
1.3E+03	**2.6E+02**	**0.67**	**0.20**
6.8E+04	**1.0E+05**	**2.2E-02**	**1.7E-02**
1.9E+03	1.4E+03	0.81	0.70
2.1E+03	1.6E+03	0.96	0.75
1.5E+03	1.0E+03	0.67	0.63
2.8E+04	2.3E+04	1.2E-02	1.5E-03
1.5E+03	8.2E+02	1.01	0.54
1.7E+03	1.2E+03	1.20	0.75
1.3E+03	2.6E+02	0.88	0.20
3.0E+04	1.5E+05	1.8E-02	5.8E-02

	16117	15596	-331	852	0.05
	17313	16221	1264	-172	-0.01
	18145	16609	-171	1708	0.09
	16147	16143	-64	67	0.00
	15466	15301	-1246	1410	0.09
0.24	14769	14304	-2150	2616	0.18
0.44	12581	12781	-1560	1360	0.11
0.39	16828	13800	2318	710	0.04
0.19	17699	15339	-936	3296	0.19
0.35	15079	14563	-259	776	0.05
0.31	15670	15002	2120	-1452	-0.09
0.43	15042	15808	-803	36	0.00
0.27	15216	14929	-867	1154	0.08
0.94	10568	11699	-958	-172	-0.02
0.68	10295	10239	241	-185	-0.02
0.92	11976	11301	1117	-442	-0.04
	10613	12291	1090	-2768	-0.26
0.47	**14678**	**14231**	**-70**	**5.2E+02**	**0.03**
0.94				**3.3E+03**	**0.19**
0.19				**-2.8E+03**	**-0.26**
6.8E-02				**2.1E+06**	**1.1E-02**
0.33	15852	15107	-206	9.5E+02	0.06
0.44				3.3E+03	0.19
0.19				-1.5E+03	-0.09
8.0E-03				1.5E+06	5.8E-03
0.84	10863	11382	372	-8.9E+02	-0.08
0.94				-1.7E+02	-0.02
0.68				-2.8E+03	-0.26
2.2E-02				1.6E+06	1.4E-02

CYC-2

3/5/2002	32	2145		1471		0.69
3/13/2002	40	2129		1487		0.70
3/20/2002	47	2287		1599		0.70
4/2/2002	60	2397		1672		0.70
4/17/2002	75	2133		1509		0.71
4/25/2002	83	2043	1756	1481	0.86	0.72
5/2/2002	90	1951	1782	1432	0.91	0.73
5/9/2002	97	1662	1527	1179	0.92	0.71
5/24/2002	112	2223	1793	1439	0.81	0.65
6/5/2002	124	2338	1658	1326	0.71	0.57
6/14/2002	133	1992	1675	1376	0.84	0.69
6/21/2002	140	2070	1519	1460	0.73	0.71
6/28/2002	147	1987	1294	1349	0.65	0.68
7/12/2002	161	2010	1374	1309	0.68	0.65
8/5/2002	185	1396	1191	1010	0.85	0.72
9/22/2002	233	1360	1170	1094	0.86	0.80
10/6/2002	247	1582	1248	1155	0.79	0.73
10/13/2002	254	1402	1236	1053	0.88	0.75
Total	**average =**	**1.9E+03**	**1.5E+03**	**1.3E+03**	**0.81**	**0.70**
	maximum =	**2.4E+03**	**1.8E+03**	**1.7E+03**	**0.92**	**0.80**
	minimum =	**1.4E+03**	**1.2E+03**	**1.0E+03**	**0.65**	**0.57**
	variance =	**1.1E+05**	**5.6E+04**	**3.7E+04**	**7.7E-03**	**2.5E-03**
Before Day 161	average =	2.1E+03	1.6E+03	1.4E+03	0.79	0.69
	maximum =	2.4E+03	1.8E+03	1.7E+03	0.92	0.73
	minimum =	1.7E+03	1.3E+03	1.2E+03	0.65	0.57
	variance =	3.7E+04	3.3E+04	1.7E+04	1.0E-02	1.9E-03
After Day 161	average =	1.4E+03	1.2E+03	1.1E+03	0.85	0.75
	maximum =	1.6E+03	1.2E+03	1.2E+03	0.88	0.80
	minimum =	1.4E+03	1.2E+03	1.0E+03	0.79	0.72
	variance =	9.9E+03	1.4E+03	3.8E+03	1.6E-03	1.3E-03

2136		1500		0.70
2214		1530		0.69
2332		1614		0.69
2298		1616		0.70
2229		1524		0.68
2000		1336		0.67
1784	1689	1280	0.95	0.72
1545	1353	1003	0.88	0.65
2014	1570	1312	0.78	0.65
1955	1552	1372	0.79	0.70
2044	1385	1368	0.68	0.67
2222	1218	1452	0.55	0.65
2079	1781	1296	0.86	0.62
1798	1436	1265	0.80	0.70
1449	1287	281	0.89	0.19
1725	1275	547	0.74	0.32
2023	1477	1294	0.73	0.64
2287	2010	974	0.88	0.43
2.0E+03	**1.5E+03**	**1.2E+03**	**0.79**	**0.61**
2.3E+03	**2.0E+03**	**1.6E+03**	**0.95**	**0.72**
1.4E+03	**1.2E+03**	**2.8E+02**	**0.55**	**0.19**
7.0E+04	**5.4E+04**	**1.3E+05**	**1.2E-02**	**2.3E-02**
2.0E+03	1.5E+03	1.4E+03	0.78	0.68
2.3E+03	1.8E+03	1.6E+03	0.95	0.72
1.5E+03	1.2E+03	1.0E+03	0.55	0.62
5.3E+04	3.4E+04	2.8E+04	1.5E-02	7.6E-04
1.9E+03	1.5E+03	7.7E+02	0.81	0.39
2.3E+03	2.0E+03	1.3E+03	0.89	0.64
1.4E+03	1.3E+03	2.8E+02	0.73	0.19
1.3E+05	1.2E+05	2.0E+05	7.4E-03	3.6E-02

1878	1449		0.77
2067	1479		0.72
2236	1596		0.71
2133	1604		0.75
2098	1471		0.70
1927	1287		0.67
1837	1243	0.92	0.68
1379	966	0.98	0.70
1797	1259	0.87	0.70
1830	1337	0.85	0.73
1802	1256	0.77	0.70
1928	1372	0.63	0.71
1957	1274	0.91	0.65
1800	1310	0.80	0.73
1360	265	0.95	0.19
1426	925	0.89	0.65
1581	1187	0.93	0.75
1624	930	1.24	0.57
1.8E+03	**1.2E+03**	**0.90**	**0.67**
2.2E+03	**1.6E+03**	**1.24**	**0.75**
1.4E+03	**2.7E+02**	**0.63**	**0.19**
6.9E+04	**1.0E+05**	**2.1E-02**	**1.7E-02**
1.9E+03	1.3E+03	0.84	0.70
2.2E+03	1.6E+03	0.98	0.75
1.4E+03	9.7E+02	0.63	0.65
4.6E+04	2.9E+04	1.2E-02	7.3E-04
1.5E+03	8.3E+02	1.00	0.54
1.6E+03	1.2E+03	1.24	0.75
1.4E+03	2.7E+02	0.89	0.19
1.6E+04	1.6E+05	2.5E-02	5.9E-02

	16117	15315	517	285	0.02
	17313	16517	893	-98	-0.01
	18145	16784	-139	1500	0.08
	16147	16294	-244	96	0.01
	15466	15428	-1517	1555	0.10
-0.56	14769	14266	-1635	2139	0.14
0.86	12581	12279	-1810	2111	0.17
0.49	16828	12384	1657	2787	0.17
0.31	17699	14052	-261	3907	0.22
0.37	15079	14094	524	461	0.03
0.29	15670	14625	1348	-303	-0.02
0.41	15042	15098	-1083	1026	0.07
-0.01	15216	14334	-1064	1946	0.13
0.55	10568	11969	-771	-630	-0.06
0.66	10295	10594	305	-604	-0.06
0.81	11976	11478	1128	-631	-0.05
	10613	12277	1999	-3662	-0.35
0.38	**14678**	**13988**	**-9**	**7.0E+02**	**0.03**
0.86				**3.9E+03**	**0.22**
-0.56				**-3.7E+03**	**-0.35**
1.6E-01				**3.0E+06**	**1.7E-02**
0.27	15852	14728	-216	1.3E+03	0.09
0.86				3.9E+03	0.22
-0.56				-3.0E+02	-0.02
1.7E-01				1.6E+06	5.9E-03
0.67	10863	11579	665	-1.4E+03	-0.13
0.81				-6.0E+02	-0.05
0.55				-3.7E+03	-0.35
1.7E-02				2.3E+06	2.1E-02

Total Phosphorus Data

CON-1

Day	Date	INFLUENT				
		TP (mg/L)	Dissolved TP (mg/L)	O-PO4 (mg/L)	Dissolved TP Fraction	O-PO4 Fraction
3/5/2002	32	210		168		0.80
3/13/2002	40	200		161		0.81
3/20/2002	47	242		187		0.77
4/2/2002	60	296		211		0.71
4/17/2002	75	213		151		0.71
4/25/2002	83	178		137		0.77
5/2/2002	90	141	104	104	0.74	0.74
5/9/2002	97	107	91	82	0.85	0.77
5/24/2002	112	208	102	142	0.49	0.68
6/5/2002	124	359	107	201	0.30	0.56
6/14/2002	133	201	92	176	0.46	0.88
6/21/2002	140	203	104	175	0.51	0.86
6/28/2002	147	219	81	149	0.37	0.68
7/12/2002	161	198	85	143	0.43	0.72
8/5/2002	185	198	81	151	0.41	0.76
8/19/2002	199	190	60	129	0.31	0.68
9/22/2002	233	134	60	129	0.44	0.96
10/6/2002	247	229	123	170	0.54	0.74
10/13/2002	254	175	99	158	0.56	0.90
Total	**average =**	**2.1E+02**	**9.1E+01**	**1.5E+02**	**0.49**	**0.76**
	maximum =	**3.6E+02**	**1.2E+02**	**2.1E+02**	**0.85**	**0.96**
	minimum =	**1.1E+02**	**6.0E+01**	**8.2E+01**	**0.30**	**0.56**
	variance =	**3.1E+03**	**3.4E+02**	**9.7E+02**	**2.5E-02**	**8.6E-03**
Before Day 161	average =	2.1E+02	9.6E+01	1.6E+02	0.52	0.75
	maximum =	3.6E+02	1.1E+02	2.1E+02	0.85	0.88
	minimum =	1.1E+02	8.1E+01	8.2E+01	0.30	0.56
	variance =	3.6E+03	9.8E+01	1.2E+03	3.4E-02	6.5E-03
After Day 161	average =	1.9E+02	8.4E+01	1.5E+02	0.45	0.81
	maximum =	2.3E+02	1.2E+02	1.7E+02	0.56	0.96
	minimum =	1.3E+02	6.0E+01	1.3E+02	0.31	0.68
	variance =	1.2E+03	7.4E+02	3.3E+02	1.0E-02	1.4E-02

MIXED				
TP (mg/L)	**Dissolved TP (mg/L)**	**O-PO4 (mg/L)**	**Dissolved TP Fraction**	**O-PO4 Fraction**
265		203		0.77
310		245		0.79
271		240		0.89
447		321		0.72
435		309		0.71
402		302		0.75
343	80	255	0.23	0.74
352	75	287	0.21	0.82
460	80	316	0.17	0.69
377	72	277	0.19	0.73
424	50	300	0.12	0.71
487	72	324	0.15	0.67
452	81	254	0.18	0.56
414	79	257	0.19	0.62
414	48	74	0.12	0.18
383	69	247	0.18	0.64
435	74	289	0.17	0.66
498	102	328	0.20	0.66
370	113	298	0.30	0.81
4.0E+02	**7.7E+01**	**2.7E+02**	**0.19**	**0.69**
5.0E+02	**1.1E+02**	**3.3E+02**	**0.30**	**0.89**
2.7E+02	**4.8E+01**	**7.4E+01**	**0.12**	**0.18**
4.4E+03	**3.0E+02**	**3.4E+03**	**2.4E-03**	**2.1E-02**
3.9E+02	7.4E+01	2.8E+02	0.18	0.73
4.9E+02	8.1E+01	3.2E+02	0.23	0.89
2.7E+02	5.0E+01	2.0E+02	0.12	0.56
5.0E+03	1.0E+02	1.3E+03	1.3E-03	6.5E-03
4.2E+02	8.1E+01	2.5E+02	0.19	0.59
5.0E+02	1.1E+02	3.3E+02	0.30	0.81
3.7E+02	4.8E+01	7.4E+01	0.12	0.18
2.6E+03	6.9E+02	1.0E+04	4.8E-03	5.7E-02

SUPERNATANT				Dissolved TP Inputs (mg/d)	Dissolved TP Outputs (mg/d)	Dissolved TP Accumulation (mg/d)
TP (mg/L)	O-PO4 (mg/L)	Dissolved TP Fraction	O-PO4 Fraction			
93	56		0.61			
142	110		0.77			
79	71		0.91			
189	136		0.72			
185	130		0.70			
103	72		0.70			
88	67	0.91	0.76	605.60		
100	93	0.76	0.93	570.78	588	-17.41
118	85	0.68	0.72	606.36	589	17.79
117	95	0.62	0.81	547.31	577	-29.52
102	80	0.49	0.78	381.53	464	-82.89
125	98	0.58	0.78	547.31	464	82.89
110	81	0.73	0.73	609.39	578	31.04
109	78	0.72	0.71	597.27	603	-6.06
78	44	0.62	0.57	361.39	479	-117.80
110	67	0.63	0.61	522.33	442	80.60
87		0.85		558.67	540	18.33
143	56	0.71	0.39	772.14	665	106.94
153	71	0.74	0.47	852.38	812	40.36
1.2E+02	**8.3E+01**	**0.70**	**0.70**	**579**	**567**	**10**
1.9E+02	**1.4E+02**	**0.91**	**0.93**			
7.8E+01	**4.4E+01**	**0.49**	**0.39**			
1.0E+03	**6.0E+02**	**1.3E-02**	**1.9E-02**			
1.2E+02	8.9E+01	0.69	0.76	558	552	-1
1.9E+02	1.4E+02	0.91	0.93			
7.9E+01	5.6E+01	0.49	0.61			
1.1E+03	5.3E+02	1.6E-02	7.0E-03			
1.1E+02	6.0E+01	0.71	0.51	613	588	26
1.5E+02	7.1E+01	0.85	0.61			
7.8E+01	4.4E+01	0.62	0.39			
1.1E+03	1.5E+02	9.3E-03	9.6E-03			

Settling Efficiency	TP Inputs (mg/d)	TP Outputs (mg/d)	TP Accumulation by Mixed Changes (mg/d)	*TP Accumulation by Input/Ouput (mg/d)*
	1514	1210	298	304
	1832	1176	-295	656
	2241	1439	718	801
	1612	1896	-42	-284
	1347	1610	-219	-262
0.97	1067	1246	-447	-178
0.91	810	1189	68	-379
0.90	1575	1386	382	188
0.85	2718	1459	-367	1259
0.86	1522	1380	277	142
0.87	1537	1506	477	30
0.92	1658	1556	-265	102
0.91	1499	1441	-144	58
0.92	1499	793	0	706
0.87	1438	792	-117	646
0.96	1014	828	81	187
0.90	1734	963	239	770
0.84	1325	1196	-973	129
0.90	**1552**	**1281**	**-18**	**271**
0.97				
0.84				
1.6E-03				
0.90	1610	1423	34	187
0.97				
0.85				
1.5E-03				
0.90	1402	914	-154	488
0.96				
0.84				
2.2E-03				

CON-2

3/5/2002	32	210		168		0.80
3/13/2002	40	200		161		0.81
3/20/2002	47	242		187		0.77
4/2/2002	60	296		211		0.71
4/17/2002	75	213		151		0.71
4/25/2002	83	178		137		0.77
5/2/2002	90	141	104	104	0.74	0.74
5/9/2002	97	107	91	82	0.85	0.77
5/24/2002	112	208	102	142	0.49	0.68
6/5/2002	124	359	107	201	0.30	0.56
6/14/2002	133	201	92	176	0.46	0.88
6/21/2002	140	203	104	175	0.51	0.86
6/28/2002	147	219	81	149	0.37	0.68
7/12/2002	161	198	85	143	0.43	0.72
8/5/2002	185	198	81	151	0.41	0.76
8/19/2002	199	190	60	129	0.31	0.68
9/22/2002	233	134	60	129	0.44	0.96
10/6/2002	247	229	123	170	0.54	0.74
10/13/2002	254	175	99	158	0.56	0.90
Total	**average =**	**2.1E+02**	**9.1E+01**	**1.5E+02**	**0.49**	**0.76**
	maximum =	**3.6E+02**	**1.2E+02**	**2.1E+02**	**0.85**	**0.96**
	minimum =	**1.1E+02**	**6.0E+01**	**8.2E+01**	**0.30**	**0.56**
	variance =	**3.1E+03**	**3.4E+02**	**9.7E+02**	**2.5E-02**	**8.6E-03**
Before Day 161	average =	2.1E+02	9.6E+01	1.6E+02	0.52	0.75
	maximum =	3.6E+02	1.1E+02	2.1E+02	0.85	0.88
	minimum =	1.1E+02	8.1E+01	8.2E+01	0.30	0.56
	variance =	3.6E+03	9.8E+01	1.2E+03	3.4E-02	6.5E-03
After Day 161	average =	1.9E+02	8.4E+01	1.5E+02	0.45	0.81
	maximum =	2.3E+02	1.2E+02	1.7E+02	0.56	0.96
	minimum =	1.3E+02	6.0E+01	1.3E+02	0.31	0.68
	variance =	1.2E+03	7.4E+02	3.3E+02	1.0E-02	1.4E-02

271		222		0.82
323		250		0.77
299		256		0.86
334		262		0.78
336		252		0.75
318		255		0.80
268	79	192	0.29	0.72
199	59	178	0.30	0.89
342	56	241	0.16	0.70
343	59	254	0.17	0.74
401	65	278	0.16	0.69
536	86	303	0.16	0.57
481	81	300	0.17	0.62
395	83	256	0.21	0.65
366	50	66	0.14	0.18
339	85	220	0.25	0.65
474	59	307	0.12	0.65
456	76	272	0.17	0.60
328	68	236	0.21	0.72
3.6E+02	**7.0E+01**	**2.4E+02**	**0.19**	**0.69**
5.4E+02	**8.6E+01**	**3.1E+02**	**0.30**	**0.89**
2.0E+02	**5.0E+01**	**6.6E+01**	**0.12**	**0.18**
6.8E+03	**1.6E+02**	**3.0E+03**	**3.1E-03**	**2.3E-02**
3.5E+02	7.1E+01	2.5E+02	0.20	0.74
5.4E+02	8.6E+01	3.0E+02	0.30	0.89
2.0E+02	5.6E+01	1.8E+02	0.16	0.57
7.5E+03	1.5E+02	1.2E+03	3.5E-03	8.2E-03
3.9E+02	6.8E+01	2.2E+02	0.18	0.56
4.7E+02	8.5E+01	3.1E+02	0.25	0.72
3.3E+02	5.0E+01	6.6E+01	0.12	0.18
4.6E+03	1.9E+02	8.6E+03	2.7E-03	4.7E-02

169	125		0.74			
89	60		0.67			
92	75		0.82			
122	83		0.68			
157	99		0.63			
167	128		0.77			
97	72	0.81	0.74	595.76		
78	70	0.76	0.90	448.14	522	-73.81
85	65	0.66	0.76	423.92	436	-12.11
82	56	0.71	0.68	443.60	434	9.84
84	60	0.78	0.71	494.32	469	25.36
142	104	0.61	0.73	652.53	573	79.11
125	88	0.64	0.70	609.39	631	-21.57
115	84	0.73	0.73	631.34	620	10.98
61	15	0.82	0.25	378.73	505	-126.15
133	61	0.64	0.46	642.69	511	132.14
64	39	0.92	0.61	447.39	545	-97.49
99	65	0.77	0.65	575.32	511	64.12
85	28	0.80	0.33	514.76	545	-30.12
1.1E+02	**7.2E+01**	**0.74**	**0.66**	**528**	**525**	**-3**
1.7E+02	**1.3E+02**	**0.92**	**0.90**			
6.1E+01	**1.5E+01**	**0.61**	**0.25**			
1.1E+03	**8.5E+02**	**8.0E-03**	**2.5E-02**			
1.1E+02	8.3E+01	0.71	0.73	537	526	3
1.7E+02	1.3E+02	0.81	0.90			
7.8E+01	5.6E+01	0.61	0.63			
1.1E+03	5.4E+02	5.0E-03	4.4E-03			
8.8E+01	4.2E+01	0.79	0.46	512	523	-12
1.3E+02	6.5E+01	0.92	0.65			
6.1E+01	1.5E+01	0.64	0.25			
8.6E+02	4.5E+02	1.1E-02	3.0E-02			

	1514	1294	345	220
	1832	1104	-182	728
	2241	1208	143	1033
	1612	1426	7	186
	1347	1539	-119	-191
0.90	1067	1304	-379	-237
0.87	810	938	-522	-128
0.90	1575	972	505	602
0.92	2718	1122	4	1596
0.94	1522	1176	342	345
0.88	1537	1528	1022	8
0.89	1658	1720	-416	-62
0.90	1499	1510	-326	-11
0.96	1499	745	-64	753
0.81	1438	803	-102	635
0.99	1014	828	210	186
0.94	1734	720	-68	1013
0.93	1325	778	-969	546
0.91	**1552**	**1151**	**-32**	**401**
0.99				
0.81				
2.1E-03				
0.90	1610	1295	33	315
0.94				
0.87				
5.6E-04				
0.93	1402	775	-199	627
0.99				
0.81				
4.7E-03				

CYC-1

3/5/2002	32	210		168		0.80
3/13/2002	40	200		161		0.81
3/20/2002	47	242		187		0.77
4/2/2002	60	296		211		0.71
4/17/2002	75	213		151		0.71
4/25/2002	83	178		137		0.77
5/2/2002	90	141	104	104	0.74	0.74
5/9/2002	97	107	91	82	0.85	0.77
5/24/2002	112	208	102	142	0.49	0.68
6/5/2002	124	359	107	201	0.30	0.56
6/14/2002	133	201	92	176	0.46	0.88
6/21/2002	140	203	104	175	0.51	0.86
6/28/2002	147	219	81	149	0.37	0.68
7/12/2002	161	198	85	143	0.43	0.72
8/5/2002	185	198	81	151	0.41	0.76
8/19/2002	199	190	60	129	0.31	0.68
9/22/2002	233	134	60	129	0.44	0.96
10/6/2002	247	229	123	170	0.54	0.74
10/13/2002	254	175	99	158	0.56	0.90
Total	**average =**	**2.1E+02**	**9.1E+01**	**1.5E+02**	**0.49**	**0.76**
	maximum =	**3.6E+02**	**1.2E+02**	**2.1E+02**	**0.85**	**0.96**
	minimum =	**1.1E+02**	**6.0E+01**	**8.2E+01**	**0.30**	**0.56**
	variance =	**3.1E+03**	**3.4E+02**	**9.7E+02**	**2.5E-02**	**8.6E-03**
Before Day 161	average =	2.1E+02	9.6E+01	1.6E+02	0.52	0.75
	maximum =	3.6E+02	1.1E+02	2.1E+02	0.85	0.88
	minimum =	1.1E+02	8.1E+01	8.2E+01	0.30	0.56
	variance =	3.6E+03	9.8E+01	1.2E+03	3.4E-02	6.5E-03
After Day 161	average =	1.9E+02	8.4E+01	1.5E+02	0.45	0.81
	maximum =	2.3E+02	1.2E+02	1.7E+02	0.56	0.96
	minimum =	1.3E+02	6.0E+01	1.3E+02	0.31	0.68
	variance =	1.2E+03	7.4E+02	3.3E+02	1.0E-02	1.4E-02

318		242		0.76
319		257		0.81
310		273		0.88
360		278		0.77
363		269		0.74
327		247		0.76
264	96	192	0.36	0.73
228	78	194	0.34	0.85
522	70	271	0.13	0.52
331	70	222	0.21	0.67
346	80	260	0.23	0.75
471	95	271	0.20	0.58
422	104	250	0.25	0.59
379	95	242	0.25	0.64
290	61	52	0.21	0.18
437	103	254	0.24	0.58
417	23	145	0.05	0.35
497	100	279	0.20	0.56
331	117	278	0.35	0.84
3.6E+02	**8.4E+01**	**2.4E+02**	**0.23**	**0.66**
5.2E+02	**1.2E+02**	**2.8E+02**	**0.36**	**0.88**
2.3E+02	**2.3E+01**	**5.2E+01**	**0.05**	**0.18**
6.2E+03	**6.0E+02**	**3.2E+03**	**7.3E-03**	**3.2E-02**
3.5E+02	8.6E+01	2.5E+02	0.25	0.72
5.2E+02	1.0E+02	2.8E+02	0.36	0.88
2.3E+02	7.0E+01	1.9E+02	0.13	0.52
5.9E+03	1.7E+02	7.7E+02	5.5E-03	1.1E-02
3.9E+02	8.1E+01	2.0E+02	0.21	0.50
5.0E+02	1.2E+02	2.8E+02	0.35	0.84
2.9E+02	2.3E+01	5.2E+01	0.05	0.18
6.9E+03	1.5E+03	1.0E+04	1.1E-02	6.3E-02

132	97		0.73			
139	114		0.82			
190	152		0.80			
169	138		0.82			
145	102		0.70			
156	123		0.79			
131	102	0.74	0.78	728.99		
117	89	0.66	0.76	586.68	658	-71.16
109	85	0.64	0.78	529.90	558	-28.39
135	114	0.52	0.84	532.17	531	1.14
127	101	0.63	0.80	607.87	570	37.85
164	130	0.58	0.79	717.64	663	54.88
164	122	0.63	0.74	787.28	752	34.82
148	112	0.64	0.76	722.18	755	-32.55
106	23	0.58	0.22	464.80	593	-128.51
170	82	0.61	0.48	779.71	622	157.64
106	74	0.21	0.70	171.84	476	-303.79
118	88	0.85	0.74	757.00	464	292.72
151	63	0.77	0.42	882.66	820	63.08
1.4E+02	**1.0E+02**	**0.62**	**0.71**	**636**	**622**	**6**
1.9E+02	**1.5E+02**	**0.85**	**0.84**			
1.1E+02	**2.3E+01**	**0.21**	**0.22**			
5.8E+02	**8.6E+02**	**2.2E-02**	**2.6E-02**			
1.4E+02	1.1E+02	0.63	0.78	652	641	0
1.9E+02	1.5E+02	0.74	0.84			
1.1E+02	8.5E+01	0.52	0.70			
4.9E+02	3.5E+02	3.9E-03	1.4E-03			
1.3E+02	6.6E+01	0.60	0.51	611	595	16
1.7E+02	8.8E+01	0.85	0.74			
1.1E+02	2.3E+01	0.21	0.22			
8.3E+02	6.6E+02	6.0E-02	4.7E-02			

	1514	1372	7	142
	1832	1529	-68	303
	2241	1653	204	588
	1612	1576	11	37
	1347	1507	-239	-160
0.79	1067	1374	-477	-307
0.74	810	1170	-273	-360
0.91	1575	1351	1039	223
0.75	2718	1500	-844	1218
0.82	1522	1384	88	137
0.82	1537	1599	946	-62
0.81	1658	1776	-371	-118
0.81	1499	1644	-163	-145
0.80	1499	1017	-197	482
0.80	1438	1105	557	333
0.79	1014	1122	-31	-108
0.95	1734	941	303	793
0.84	1325	1093	-1255	232
0.82	**1552**	**1373**	**-42**	**179**
0.95				
0.74				
3.4E-03				
0.81	1610	1495	-11	115
0.91				
0.74				
2.8E-03				
0.84	1402	1056	-125	346
0.95				
0.79				
4.7E-03				

CYC-2

3/5/2002	32	210		168		0.80
3/13/2002	40	200		161		0.81
3/20/2002	47	242		187		0.77
4/2/2002	60	296		211		0.71
4/17/2002	75	213		151		0.71
4/25/2002	83	178		137		0.77
5/2/2002	90	141	104	104	0.74	0.74
5/9/2002	97	107	91	82	0.85	0.77
5/24/2002	112	208	102	142	0.49	0.68
6/5/2002	124	359	107	201	0.30	0.56
6/14/2002	133	201	92	176	0.46	0.88
6/21/2002	140	203	104	175	0.51	0.86
6/28/2002	147	219	81	149	0.37	0.68
7/12/2002	161	198	85	143	0.43	0.72
8/5/2002	185	198	81	151	0.41	0.76
8/19/2002	199	190	60	129	0.31	0.68
9/22/2002	233	134	60	129	0.44	0.96
10/6/2002	247	229	123	170	0.54	0.74
10/13/2002	254	175	99	158	0.56	0.90
Total	**average =**	**2.1E+02**	**9.1E+01**	**1.5E+02**	**0.49**	**0.76**
	maximum =	**3.6E+02**	**1.2E+02**	**2.1E+02**	**0.85**	**0.96**
	minimum =	**1.1E+02**	**6.0E+01**	**8.2E+01**	**0.30**	**0.56**
	variance =	**3.1E+03**	**3.4E+02**	**9.7E+02**	**2.5E-02**	**8.6E-03**
Before Day 161	average =	2.1E+02	9.6E+01	1.6E+02	0.52	0.75
	maximum =	3.6E+02	1.1E+02	2.1E+02	0.85	0.88
	minimum =	1.1E+02	8.1E+01	8.2E+01	0.30	0.56
	variance =	3.6E+03	9.8E+01	1.2E+03	3.4E-02	6.5E-03
After Day 161	average =	1.9E+02	8.4E+01	1.5E+02	0.45	0.81
	maximum =	2.3E+02	1.2E+02	1.7E+02	0.56	0.96
	minimum =	1.3E+02	6.0E+01	1.3E+02	0.31	0.68
	variance =	1.2E+03	7.4E+02	3.3E+02	1.0E-02	1.4E-02

276		229		0.83
333		251		0.75
289		258		0.89
347		282		0.81
328		237		0.72
270		218		0.81
245	97	165	0.39	0.67
190	62	167	0.32	0.88
318	74	196	0.23	0.62
239	81	174	0.34	0.73
291	77	219	0.27	0.75
373	98	236	0.26	0.63
305	93	190	0.30	0.62
254	102	181	0.40	0.71
204	66	44	0.32	0.22
288	105	222	0.36	0.77
372	69	131	0.19	0.35
451	104	280	0.23	0.62
315	111	242	0.35	0.77
3.0E+02	**8.8E+01**	**2.1E+02**	**0.31**	**0.69**
4.5E+02	**1.1E+02**	**2.8E+02**	**0.40**	**0.89**
1.9E+02	**6.2E+01**	**4.4E+01**	**0.19**	**0.22**
3.9E+03	**2.8E+02**	**3.2E+03**	**4.4E-03**	**2.8E-02**
2.9E+02	8.5E+01	2.1E+02	0.32	0.75
3.7E+02	1.0E+02	2.8E+02	0.40	0.89
1.9E+02	6.2E+01	1.7E+02	0.23	0.62
2.4E+03	2.0E+02	1.3E+03	3.8E-03	8.2E-03
3.3E+02	9.1E+01	1.8E+02	0.29	0.55
4.5E+02	1.1E+02	2.8E+02	0.36	0.77
2.0E+02	6.6E+01	4.4E+01	0.19	0.22
8.5E+03	4.6E+02	9.1E+03	6.2E-03	6.3E-02

122	95		0.78			
152	119		0.78			
144	142		0.99			
160	127		0.79			
150	105		0.70			
166	130		0.78			
110	81	0.88	0.74	730.51		
84	73	0.74	0.87	465.56	598	-132.48
102	84	0.73	0.83	560.94	513	47.69
122	102	0.66	0.84	613.93	587	26.50
123	103	0.63	0.84	585.16	600	-14.38
149	117	0.65	0.79	738.08	662	76.46
147	103	0.63	0.70	701.74	720	-18.17
146	110	0.70	0.75	772.14	737	35.20
102	25	0.65	0.24	499.62	636	-136.07
169	80	0.62	0.47	794.85	647	147.81
100	68	0.70	0.68	525.36	660	-134.55
124	93	0.84	0.75	787.28	656	131.16
145	54	0.76	0.37	836.49	812	24.85
1.3E+02	**9.5E+01**	**0.71**	**0.72**	**662**	**652**	**5**
1.7E+02	**1.4E+02**	**0.88**	**0.99**			
8.4E+01	**2.5E+01**	**0.62**	**0.24**			
6.1E+02	**8.0E+02**	**6.5E-03**	**3.2E-02**			
1.3E+02	1.1E+02	0.70	0.80	646	631	3
1.7E+02	1.4E+02	0.88	0.99			
8.4E+01	7.3E+01	0.63	0.70			
5.7E+02	3.8E+02	6.7E-03	5.4E-03			
1.3E+02	6.4E+01	0.71	0.50	689	682	7
1.7E+02	9.3E+01	0.84	0.75			
1.0E+02	2.5E+01	0.62	0.24			
8.6E+02	6.9E+02	7.9E-03	4.5E-02			

	1514	1354	378	160
	1832	1429	-333	403
	2241	1465	236	776
	1612	1519	-67	94
	1347	1463	-384	-115
0.91	1067	1271	-189	-203
0.83	810	961	-416	-151
0.89	1575	1008	452	567
0.74	2718	1163	-349	1555
0.79	1522	1197	306	325
0.81	1537	1400	621	136
0.74	1658	1482	-515	176
0.71	1499	1361	-193	138
0.74	1499	967	-110	532
0.65	1438	1055	318	383
0.90	1014	1069	131	-55
0.94	1734	927	299	806
0.83	1325	1084	-1031	241
0.81	**1552**	**1232**	**-47**	**320**
0.94				
0.65				
7.7E-03				
0.80	1610	1313	-35	297
0.91				
0.71				
5.0E-03				
0.81	1402	1020	-79	382
0.94				
0.65				
1.4E-02				

Start-Up Data

day	fraction of influent as seed	seed volume in gal	source volume in gal	total volume in gal	accumulated volume gal
1	1.00	3.50	0.00	3.50	3.50
2	0.50	0.25	0.25	0.50	4.00
3	0.50	0.29	0.29	0.58	4.58
4	0.50	0.33	0.33	0.66	5.24
5	0.40	0.30	0.45	0.75	5.99
6	0.40	0.34	0.51	0.85	6.84
7	0.40	0.39	0.58	0.97	7.81
8	0.25	0.28	0.84	1.12	8.93
9	0.25	0.32	0.95	1.27	10.20
10	0.25	0.36	1.09	1.45	11.65
11	0.25	0.42	1.25	1.67	13.32
12	0.25	0.17	0.51	0.68	14.00
sum =		**6.95**	**7.05**	**14.00**	

day	total seed volume gal	fraction
1	3.50	1.00
2	3.75	0.94
3	4.04	0.88
4	4.37	0.83
5	4.67	0.78
6	5.01	0.73
7	5.40	0.69
8	5.68	0.64
9	6.00	0.59
10	6.36	0.55
11	6.78	0.51
12	6.95	0.50
13	5.96	0.43
14	5.11	0.36
15	4.38	0.31
16	3.75	0.27
17	3.22	0.23
18	2.76	0.20
19	2.36	0.17
20	2.02	0.14
21	1.74	0.12
22	1.49	0.11
23	1.28	0.09
24	1.09	0.08
25	0.94	0.07
26	0.80	0.06
27	0.69	0.05
28	0.59	0.04
29	0.51	0.04
30	0.43	0.03
31	0.37	0.03
32	0.32	0.02
33	0.27	0.02
34	0.23	0.02
35	0.20	0.01
36	0.17	0.01
37	0.15	0.01
38	0.13	0.01
39	0.11	0.01
40	0.09	0.01
41	0.08	0.01
42	0.07	0.00
43	0.06	0.00
44	0.05	0.00
45	0.04	0.00
46	0.04	0.00

Loading Data

L/day= 7.5708
vol= 52.9958 L

date	day	COD	kg/d	kg/m3/d	kg/m2/d
2/18/2002	18	12790	0.0968	1.827	0.590
2/22/2002	22	14600	0.1105	2.086	0.674
2/26/2002	26	14500	0.1098	2.071	0.669
3/2/2002	29	13300	0.1007	1.900	0.614
3/6/2002	33	14240	0.1078	2.034	0.657
3/8/2002	35	11900	0.0901	1.700	0.549
3/11/2002	38	12250	0.0927	1.750	0.565
3/15/2002	42	13000	0.0984	1.857	0.600
3/19/2002	46	21080	0.1596	3.011	0.973
3/22/2002	49	18200	0.1378	2.600	0.840
3/26/2002	53	17700	0.1340	2.529	0.817
4/2/2002	60	12050	0.0912	1.721	0.556
4/5/2002	63	16100	0.1219	2.300	0.743
4/9/2002	67	13800	0.1045	1.971	0.637
4/12/2002	70	12400	0.0939	1.771	0.572
4/19/2002	77	12500	0.0946	1.786	0.577
4/24/2002	82	8700	0.0659	1.243	0.401
4/27/2002	85	8600	0.0651	1.229	0.397
5/1/2002	89	6900	0.0522	0.986	0.318
5/10/2002	98	8700	0.0659	1.243	0.401
	108				
5/23/2002	111	19660	0.1488	2.809	0.907
6/3/2002	122	17000	0.1287	2.429	0.784
6/11/2002	130	16300	0.1234	2.329	0.752
6/17/2002	136	14000	0.1060	2.000	0.646
6/21/2002	140	13500	0.1022	1.929	0.623
6/26/2002	145	11380	0.0862	1.626	0.525
7/1/2002	150	10060	0.0762	1.437	0.464
7/8/2002	157	9240	0.0700	1.320	0.426
7/28/2002	177	11200	0.0848	1.600	0.517
8/1/2002	181	13620	0.1031	1.946	0.628
8/7/2002	187	16500	0.1249	2.357	0.761
8/12/2002	192	10200	0.0772	1.457	0.471
9/22/2002	233	20280	0.1535	2.897	0.936
9/30/2002	241	13920	0.1054	1.989	0.642
10/7/2002	248	9360	0.0709	1.337	0.432
10/12/2002	253	12200	0.0924	1.743	0.563
10/19/2002	260	8390	0.0635	1.199	0.387
11/2/2002	274	9150	0.0693	1.307	0.422
11/9/2002	281	15670	0.1186	2.239	0.723

full scale:	**1100**	**kg/d**	vol=	1082	m3
	2.902	kg/m2/d	area=	379	m2
	1.017	**kg/m3/d**			

date	day	COD	kg/d	kg/m3/d	kg/m2/d
3/5/2002	32	13986	0.106	1.998	0.645
3/13/2002	40	12619	0.096	1.803	0.582
3/20/2002	47	13940	0.106	1.991	0.643
4/2/2002	60	16487	0.125	2.355	0.761
4/17/2002	75	12400	0.094	1.771	0.572
4/25/2002	83	12268	0.093	1.753	0.566
5/2/2002	90	8386	0.063	1.198	0.387
5/9/2002	97	7671	0.058	1.096	0.354
5/24/2002	112	5421	0.041	0.774	0.250
6/5/2002	124	18900	0.143	2.700	0.872
6/14/2002	133	16700	0.126	2.386	0.771
6/21/2002	140	14986	0.113	2.141	0.691
6/28/2002	147	12894	0.098	1.842	0.595
7/12/2002	161	13740	0.104	1.963	0.634
8/5/2002	185	12583	0.095	1.798	0.581
8/19/2002	199	10200	0.077	1.457	0.471
9/22/2002	233	10200	0.077	1.457	0.471
10/6/2002	247	14829	0.112	2.118	0.684
10/13/2002	254	10417	0.079	1.488	0.481

Airflow Data

CON Reactors
Qair = 990 L/d
Woxygen = 134000 mg/d
O2 = 0.2315
γair = 1203.775 mg/L
AOTE = 0.485706

CON Reactors
Qair = 990 L/d
Woxygen = 39000 mg/d
O2 = 0.2315
γair = 1203.775 mg/L
AOTE = 0.141362

CYC Reactors
Qair = 3600 L/d
Woxygen = 134000 mg/d
O2 = 0.2315
γair = 1203.775 mg/L
AOTE = 0.133569

CYC Reactors
Qair = 3600 L/d
Woxygen = 26000 mg/d
O2 = 0.2315
γair = 1203.775 mg/L
AOTE = 0.025916

CON Reactors
Qair = 990 L/d
Woxygen = 90000 mg/d
O2 = 0.2315
γair = 1203.775 mg/L
AOTE = 0.32622

CYC Reactors
Qair = 3600 L/d
Woxygen = 90000 mg/d
O2 = 0.2315
γair = 1203.775 mg/L
AOTE = 0.089711

0.75 L/min	273778	270000	mg/d oxygen
2.25 L/min	298667	300000	mg/d oxygen
7.5 L/min	995556	1000000	mg/d oxygen