

# Full Scale SBR Municipal Wastewater Treatment Facility Utilization of Simultaneous Nitrification/Denitrification Coupled with Traditional Nitrogen Removal to Meet Water Criterion

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## Abstract

Simultaneous nitrification denitrification (SND) is a well-established phenomenon in biological nutrient removal activated sludge systems. Study at a municipal wastewater treatment facility sought to determine nitrogen removal effectiveness within a full-scale sequential batch reactor (SBR) system utilizing SND in conjunction with traditional nitrogen removal. In addition to characterizing extent of SND, the research examined the ability of SND to meet state-based effluent water quality standards. At the selected facility, the average SND efficiency during a two-month sampling period was 52.8%, paralleling results from similar SBR municipal wastewater systems. The observed SBR system had removal efficiencies > 99% for the influent to effluent  $\text{NH}_4^+$ -N concentrations. The SND process also resulted in average  $\text{NO}_3$ - $\text{NO}_2$ -N concentration that was 82% lower than the theoretical concentration under comparable circumstances. Overall, nitrogen removal for this SBR system was >99% which typified results in other SND systems, but at a higher Total Nitrogen removal rate.

## Keywords

Nitrification, Denitrification, Chemical Oxygen Demand (COD), Sequential Batch Reactor, Municipal Wastewater

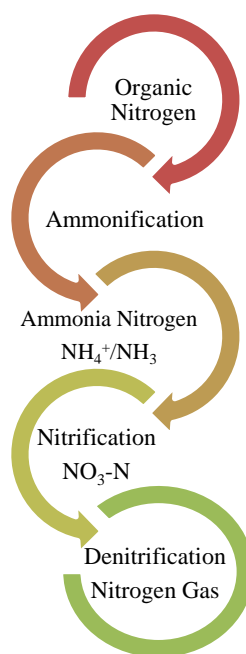
## 1. Introduction

Nitrogen removal within engineered systems, most notably in biological waste-

water treatment plants, utilizes the microbial-driven process described by the nitrogen cycle (**Figure 1**) [1]. Ammonification is the often-used nitrogen removal process in which anaerobic microbes convert organic nitrogen into ammonia within engineered collection systems that convey the wastewater from the service area [2] [3]. The process of ammonification results in 70% - 90% of the nitrogen entering into engineered wastewater treatment systems as ammonia-nitrogen [4] [5]. Within the wastewater treatment plant, the ammonia-nitrogen is converted to nitrate via nitrification, the microbial aerobic process by which autotrophic bacteria convert ammonia-nitrogen to nitrate-nitrogen. Nitrate-nitrogen is converted to nitrogen gas by the microbial anoxic process by which heterotrophic bacteria convert nitrate-nitrogen bacteria to nitrogen gas.

The current paradigm of most engineered systems that are designed for nitrogen removal meet required parameters by promoting nitrification and Carbonaceous Biochemical Oxygen Demand (CBOD) removal simultaneously [4]. Such is counterintuitive to the denitrification process in that CBOD is required by the heterotrophic bacteria to convert the nitrate produced during nitrification to nitrogen gas. As a result, carbon source addition may be required to facilitate denitrification, or the design must incorporate the use of influent CBOD to serve as the food source for the heterotrophic bacteria to convert nitrate to nitrogen gas.

In contrast, nitrification and denitrification can occur simultaneously when the dissolved oxygen concentration is so low such that the result is oxygen not penetrating the entire sludge floc [6]. This well-known phenomenon of simultaneous nitrification denitrification (SND) is present in biological nutrient removal activated sludge systems [6] [7] [8]. While the cause of SND has been linked to



**Figure 1.** Fate of nitrogen within nitrogen removing wastewater engineered systems.

several mechanisms, the two most prevalent include 1) bioreactor macroenvironment, in which anoxic and/or anaerobic zones may develop within the bioreactor, as a result of the mixing patterned caused; and 2) floc microenvironment, in which anoxic and/or anaerobic zones may develop inside the activated sludge flocs [6]. The result is nitrification occurring across the exterior surface of the floc in addition to denitrification occurring within the anoxic interior portions of the floc. SND has been documented in full scale Municipal aerated-anoxic Orbal processes and oxidation ditches [9]. Simultaneous nitrification offers several advantageous.

- The process occurs without the requirement of separate aerobic and anoxic tanks as is the case with many designs.
- For designs that utilize one basin for nitrogen removal, it occurs without the cycling of on and off aeration to promote aerobic and anoxic conditions.
- It eliminates the need for supplemental carbon addition to promote denitrification.
- The current paradigm of nitrogen removal is complex in nature and may be simplified using Supervisory Control and Data Acquisition (SCADA) and instrumentation, however such is often cost prohibitive for small rural communities with limited tax revenue. As a results systems lacking the before mentioned are often subject to operator error.
- It occurs under low DO conditions *i.e.*, 0.5 mg/L or less [4] which stands in contrast to nitrification which requires DO levels at of 1.5 to be efficient [10]. The result is SND reduces the energy requirement of nitrogen removal within biological nitrogen removal facilities.

The overall scope of the present study includes examination the fate and transport of the nitrogen species during the treatment process within a wastewater treatment facility in north Florida; determination of the effectiveness of nitrogen removal within a full-scale sequential batch reactor utilizing SND in conjunction with traditional nitrogen removal; characterization of the extent of SND as compared to separate nitrification denitrification process in the nitrogen removal procedure; and determination of the ability of the SND implemented at this facility to meet the Water Quality Based Effluent Limits or numeric nutrient standards in Florida Administrative Code Chapters 62-302 [11] as implemented by the Florida Department of Environmental Protection.

## 2. Methodology

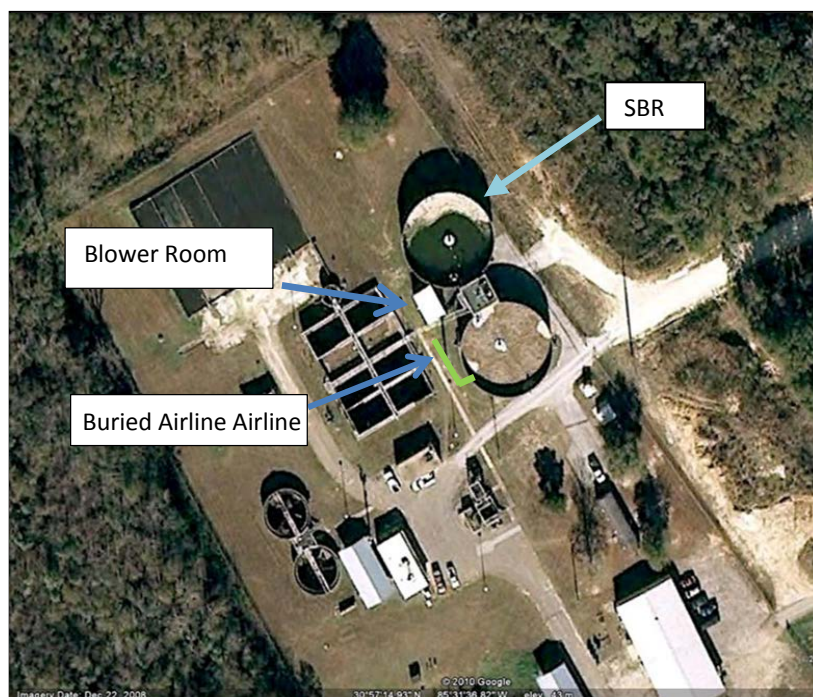
### 2.1. Site Background

The City of Graceville, Florida Advanced Wastewater Treatment Facility was placed into service January 1998. Florida Department of Environmental Protection (FDEP) sets the effluent requirements for this facility, as well as all other wastewater treatment facilities in the state of Florida. The permitted effluent limits include: Total Nitrogen (TN) of 3.0 mg/L, Total Phosphorus (TP) of 1.0 mg/L, Carbonaceous Oxygen Demand (CBOD) of 5.0 mg/L, and Total Sus-

pended Solids (TSS) of 3.0 mg/L. Note that TN consists of organic nitrogen, ammonia nitrogen, and nitrate/nitrite nitrogen. In addition, the sum of the organic nitrogen and the ammonia nitrogen is equal to Total Kjeldahl Nitrogen (TKN).

In the spring of 2009, damaged airlines were repaired and the required aeration time for efficient nitrification returned to those prior to 2008 (average 30%). Examination of the operational data of September 2008 results revealed that SND had occurred for the entire month. Examination this data also revealed that despite constant aeration accompanied with low DO concentrations, the permitted TN concentration limit of 3.0 mg/L was met via SND. In early Summer 2014, air leaks were discovered once again adjacent to the blower room foundation. Further inspection revealed air leaks at joints of airline under the foundation of the blower room located at each airline exit to the SBRs. **Figure 2** provides a plan view of sequential batch reactors (SBRs) and blower room at the wastewater treatment facility, and displays that air lines used for aeration are buried. The airline used in the design consists of 10" ductile iron pipe (bell end with rubber gaskets). It was discovered that the rubber gaskets at each joint of the airline had deteriorated resulting into a loss of air seal. This air loss resulted into a reduced amount of air flow into the reactors and low Dissolved Oxygen (DO) concentrations during aeration. Due to this leak, the required aeration time for efficient nitrification increased to 68%, more than double of the average required aeration time prior to 2008.

In April 2013, FDEP submitted to the Environmental Protection Agency (US EPA) its adopted nutrient standards for streams, spring vents, and lakes. The

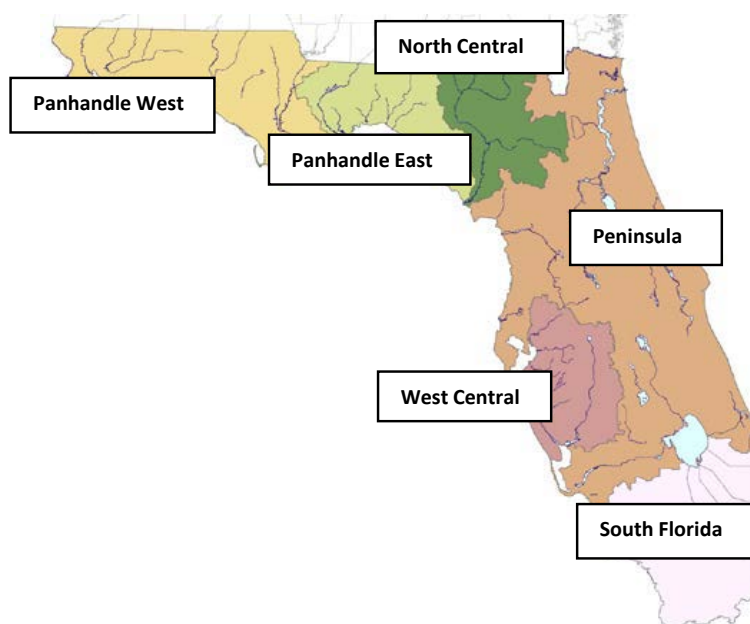


**Figure 2.** Plan view of city of Graceville advanced WWTP.

states chose to use the hierarchical approach to determine the nutrient criterion. In doing so, the department approach gave preference to site specific analyses to provide numeric interpretation. In addition to the above, the FDEP set a goal to maintain the nutrient concentration of the water body as to prevent the imbalance in the natural populations of aquatic flora or fauna. In the case of lakes, the nutrient criterion for TP and TN was determined by the strong stressor response between those values, and the production of Chlorophyll a by phytoplankton. As a result, a criterion was established for using the calculated annual geometric mean for both nutrients and Chlorophyll a. The criteria of a Chlorophyll a, TN, and TP in general were determined by the long term geometric mean lake color and alkalinity. In the case of spring vents, FDEP used the strong stressor-response relationship between Nitrate-Nitrite and the presence of nuisance algal mats and as such the criterion for Nitrate-Nitrite was established to prevent the growth of such mats. The nutrient criterion for streams was established according to region. The criterion for Total Phosphorus and Total Nitrogen as established for using the calculated annual geometric mean for both nutrients. Note that the criterion limits for each region were general in nature. **Figure 3** provides a map for the delineated regions.

## 2.2. Facility Operation

The design of this process within the wastewater treatment plant consists of two sequential batch reactors (SBRs) sharing positive displacement blower aeration. Coarse diffusion is utilized for aeration coupled with AquaDDM<sup>®</sup> mixing (Aqua-Aerobics Systems Inc. patented mixing). The design implements primarily six phases of operation which are as follows:



**Figure 3.** Delineated regions used for stream nutrient criterion (Florida Department of Environmental Protection, 2013).

- Mix Fill: Default time of 60 minutes. Phase in which the influent is mixed with activated sludge; aeration is not provided in that air valve is closed. During this time period, anaerobic conditions are promoted to allow phosphate accumulating bacteria to release phosphorus.
- React Fill: Default time 120 minutes. Phase in which the influent is mixed with activated sludge to include on and off cycling of aeration in order to promote aerobic and anoxic conditions whereby nitrification and denitrification may take place. In addition, CBOD removal and phosphorus removal (luxury uptake) occurs. Note influent valve and air valve to reactor is open.
- React: Default time 60 minutes. Considered to be polishing phase the remaining ammonia, CBOD, P, and nitrate ( $\text{NO}_3^-$ ) not removed during React Fill is reduced to permitted levels. Air valve is open, however, influent valve is closed.
- Settle: Default time 74 minutes. Mixing is halted and activated sludge is allowed to settle were upon suspended and settable solids are removed (clarification). Influent valve and air valve is closed.
- Decant: Default time 46 minutes. Supernatant is removed and the reactor is decanted to predetermined low water level.
- Waste: Default time is 13 minutes. Activated sludge is removed to maintain steady Mean Cell Residence time (MCRT or sludge age).

Default times of above indicate a total of 8 batches a day for this particular facility. The number of batches may be increased or decreased based upon flow.

The two SBRs treat the domestic wastewater with a design flow of 4164 m<sup>3</sup>/day utilizing eight batches per day (each batch volume consisting of 514 m<sup>3</sup>) while sharing three positive displacement blowers. During the aeration period only two blowers would be placed into operation at one time. Two different phase times (Table 1) were utilized for optimum treatment efficiency and resulted in a two-month average daily flow was 1813 m<sup>3</sup>/day with an average hydraulic retention time (HRT) of 41.1 hours which is similar to the Orbal processes described in [9]. The average Mixed Liquor Suspended Solids (MLSS) concentration was 4200 mg/L and the average Mixed Liquor Volatile Suspended Solids (MLVSS) was 3288 mg/L. The Sludge Retention Time (SRT) over the two months averaged 33 days, also comparable to processes detailed by [9]. The Phase Time 1 adjustments resulted into a batch fill time of 396 minutes with 3.63 batches/day or 1.82 batches/basin daily. This phase time consisted of an anaerobic period of 276 minutes (mix fill phase) followed by a 396-minute treatment time (React Fill Phase 120 min. & React Phase 276 min.) with the overall process is summarized

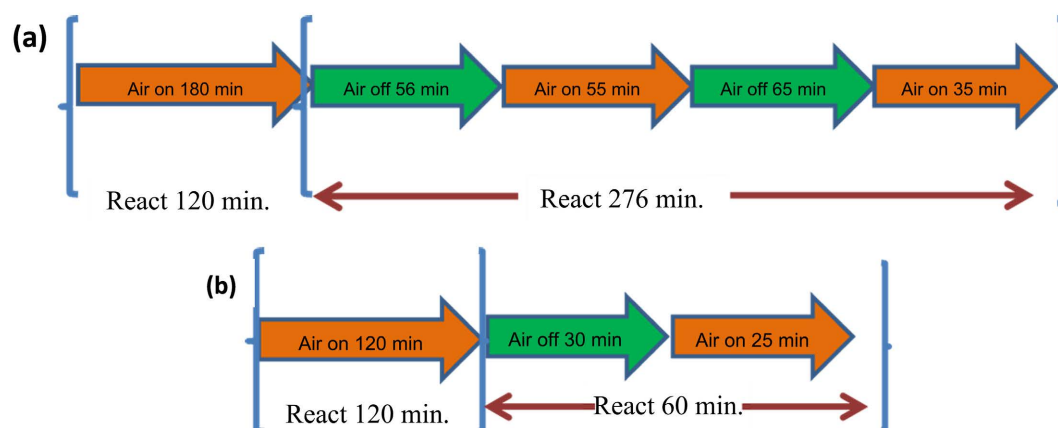
**Table 1.** Summary of phase times for sequencing batch reactors.

Phase	Mix Fill (min)	R Fill (min)	React (min)	Settle (min)	Decant (min)	Batches/day
Phase 1	276	120	276	74	46	3.63
Phase 2	60	120	60	74	46	8

in **Figure 4(a)**. Due to increased influent flows, a Phase Time 2 was implemented with its required associated air structure (summarized in **Table 1** and **Figure 4(b)**).

### 2.3. Sampling & Analysis

Eight (one per week) 24-hour flow-proportioned influent and effluent composite samples were taken during a two-month period at the wastewater treatment facility. Influent and effluent composite samples were analyzed per Standard Methods for the Examination of Water and Wastewater (SM), EPA Methods for Chemical Analysis of Water and Wastes, and HACH® methods. Influent composite samples were analyzed for CBOD (SM5120B), Total Phosphorus as P (SM4500P E), Ammonia as N Salicylate Acid method (HACH®), cadmium reduction method (HACH®), pH, and Total Suspended Solids (SM2540D). Effluent composite samples were also analyzed for NO<sub>3</sub>/NO<sub>2</sub> as N (SM4500NO3 E), Total Phosphorus as P (SM4500P E), Ammonia as N Salicylate Acid method [12], pH, and TKN (EPA 351.2). Influent grab samples were conducted once per shift (twice daily) and were analyzed for pH and temperature using a Fisher scientific model 15 Accumet pH meter, Reactive Phosphorus as P (SM4500P E), NO<sub>3</sub>/NO<sub>2</sub> as N cadmium reduction method (HACH), Ammonia as N Salicylate Acid method (HACH®). Dissolved oxygen and oxidation reduction potential (ORP) measurements were taken within the reactor in at the time of each sample using the HACH sc200 DO meter and the PinPoint ORP meter manufactured by American Marine Inc. Fifteen batches were sampled (7 from SBR1 & 8 from SBR2) during the two-month period. Sampling of batches with Phase Time 1 included samples being at the start and end of the batch, specifically the start of the Mix Fill phase and end of React phase, respectively. Next, was sampling at the end of the Mix Fill and React Fill phase and then at the end aeration periods. Sampling of batches with Phase Time 2 were taken at start of the Mix Fill phase and end of React phase, the end of the Mix Fill and React Fill phase, and the start of the 2nd aeration period.



**Figure 4.** Aeration structures of: (a) Phase 1 and b) Phase 2.

## 2.4. Wastewater Characteristics

During the sampling period, the City of Graceville had a census reported population of 2000 residents; its service area also included a 1500 bed State correctional facility, and a 500-bed work camp. All wastewater received was municipal in nature. **Table 2** summarizes the influent 24-hour composite monthly averages for the two-month sampling period. As stated earlier, influent samples were taken twice per day once shift and analyzed for, pH, Ammonia-Nitrogen, Reactive-Phosphorus as P, NO<sub>3</sub>/NO<sub>2</sub> as N, and temperature. **Table 3** summarizes the average influent grab results for both months as well.

Beyond the data taken from the wastewater treatment plant samples, the effectiveness of the entire simultaneous nitrification denitrification process was also evaluated in this research. The efficiency was calculated based on the following equation [13].

$$\text{SND Efficiency} = \frac{\text{NH}_4^+ \text{-N}_{\text{oxidized}} - \text{NO}_x \text{-N}_{\text{produced}}}{\text{NH}_4^+ \text{-N}_{\text{oxidized}}} \times 100\% \quad (1)$$

where NH<sub>4</sub><sup>+</sup>-N (oxidized) is the amount of ammonia-nitrogen oxidized after the nitrification process, NO<sub>x</sub>-N (produced) is the concentration of NO<sub>2</sub><sup>-</sup>-N and NO<sub>3</sub><sup>-</sup>-N.

## 3. Results and Discussion

### 3.1. Bacterial Communities in SBR

The processes of nitrification and denitrification involve multiple bacterial communities. Pyrosequencing was used to identify the microorganism communities found in different stages of the SBR tanks, and the SBR 1 and SBR 2 tanks were evaluated both at the beginning and end of their treatment cycles. Prior to treatment, both SBRs' microbial communities were dominated by Proteobacteria and Bacteroidetes, combined being over 80% of the totals in each. In SBR 1 before treatment (**Figure 5(a)**), the Proteobacteria was 44% compared to 41% of Bacteroidetes; while prior to treatment in the SBR 2, the percentages

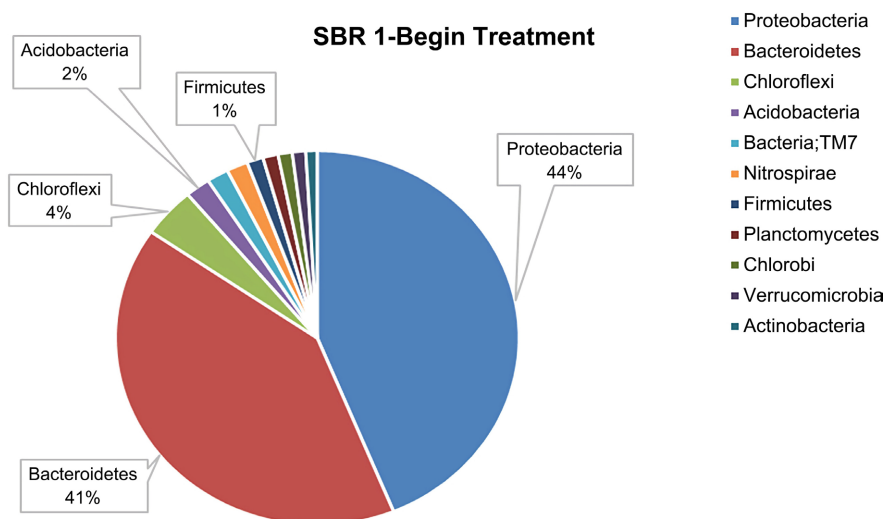
**Table 2.** Influent composite monthly averages for the 2-month sampling period.

	CBOD (mg/L)	TSS (mg/L)	NH <sub>4</sub> -N (mg/L)	NO <sub>3</sub> /NO <sub>2</sub> -N (mg/L)	Total P (mg/L)	Flow (m <sup>3</sup> /day)
1 <sup>st</sup> Month	163.4	47.7	23	0.55	3	1870
2 <sup>nd</sup> Month	132.2	56.4	28	0.89	2.9	1768

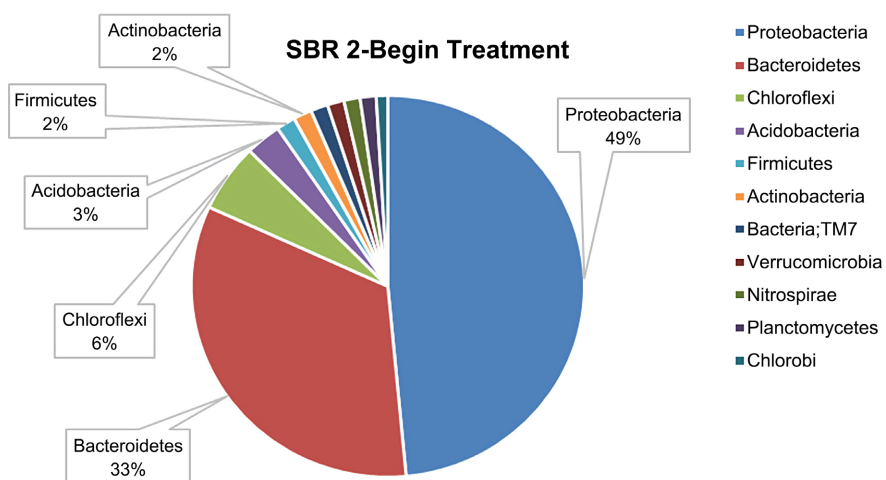
**Table 3.** Summary of the average influent grab results for 2-month sampling period.

	NO <sub>3</sub> /NO <sub>2</sub> (mg/L)	NH <sub>3</sub> (mg/L)	Orth.-P (mg/L)	pH	Temp (°C)
1 <sup>st</sup> Month	0.80	27.7	3.13	7.23	26.7
2 <sup>nd</sup> Month	0.80	27.4	2.84	7.04	27.1

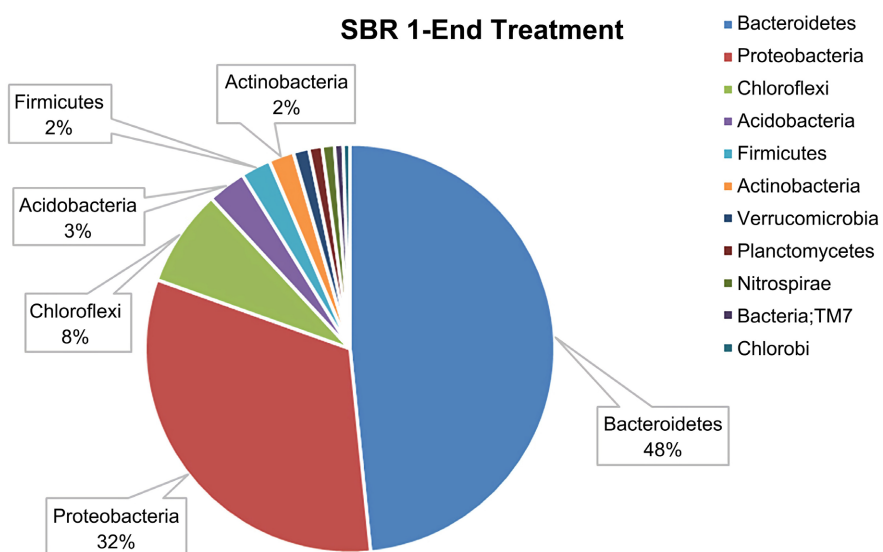




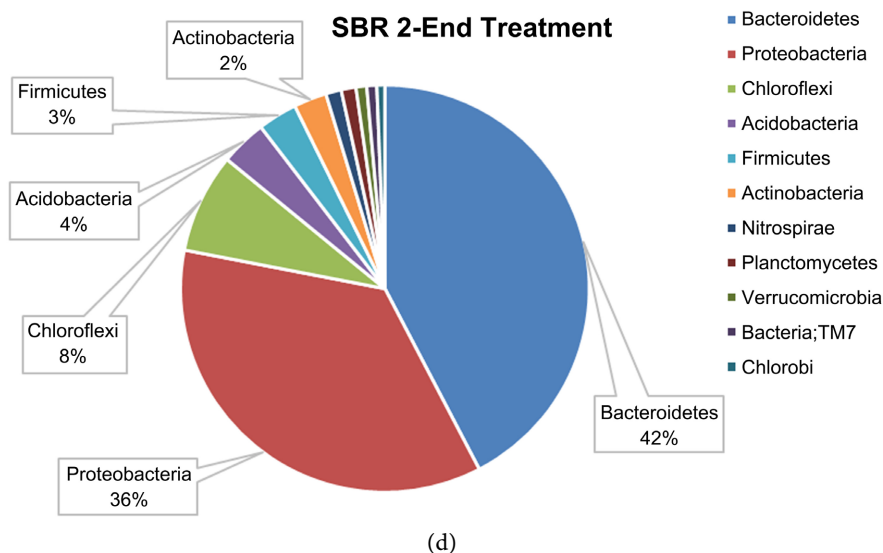
(a)



(b)



(c)



**Figure 5.** Pyrosequencing data of SBRs; (a) Beginning of Aeration cycle (SBR-1); (b) Beginning of Anaerobic cycle (SBR-2); (c) End of Aeration cycle; and (d) End of Anaerobic cycle.

were 49% and 33% (**Figure 5(b)**), respectively. These percentages of the Proteobacteria also paralleled what was seen in other municipal wastewater systems [14] [15]. In the initial SBRs, the predominance of Proteobacteria was expected as it is a phylum that includes bacteria that contributes to and involved in nitrogen fixation [14] [16]. After treatment, the percentage of the overall microbial communities remained ~80% Proteobacteria and Bacteroidetes, however, the Bacteroidetes became the larger component. After treatment, SBR 1 had levels of 48% Bacteroidetes and 32% Proteobacteria (**Figure 5(c)**); while these levels were 42% and 36% for the SBR 2 (**Figure 5(d)**), respectively. This does not mean that the Bacteroidetes' amount increased, but rather, research has shown this phylum is not completely eliminated by the activated sludge technology when compared to other bacterial groups [17]. In each of these situations, the microbial results noted from the examined SND system were parallel to those seen in similar systems [15].

### 3.2. Simultaneous Nitrification Denitrification

The data related to the 1<sup>st</sup> aeration period of both Phase Times was examined for SND as the aeration periods were either preceded and/or followed by anoxic conditions (halt in aeration). The DO concentration at the end of the React Fill *i.e.*, the end of the 1<sup>st</sup> aeration period for Phase Time 2 or two hours into the 1<sup>st</sup> aeration period of Phase Time 1 within both SBR1 and SBR2 was below detectable levels (<0.01 mg/L). DO concentration after the 1<sup>st</sup> aeration period for Phase Time 1 (180 minutes) was also <0.01 mg/L. The Ammonia-Nitrogen ( $\text{NH}_4^+$ -N) concentration at the end of the Mix Fill phase (end of the anaerobic period) and the  $\text{NO}_3\text{-NO}_2\text{-Nitrogen}$  ( $\text{NO}_3\text{-NO}_2\text{-N}$ ) concentration at the end of the 1<sup>st</sup> aeration period was used to calculate the SND efficiency. The average SND efficiency

for 17 batches sampled during the two-month period was 52.8%, as compared to the SND rates of 7.7% and 44.9% respectively within the lab-scale sequencing batch reactors described in [18]. This average SND efficiency did, however, parallel the SND efficiencies of 50.8% and 61.2% seen in another municipal wastewater treatment SBR system as detailed by [19].

The  $\text{NH}_4^+$ -N % removal was also calculated for each batch during the 1<sup>st</sup> aeration period as shown in Figure 6. It was noted that the SBR-2 (Figure 7), the influent  $\text{NH}_4^+$ -N concentration was in the range between 4 - 6 mg/L during the

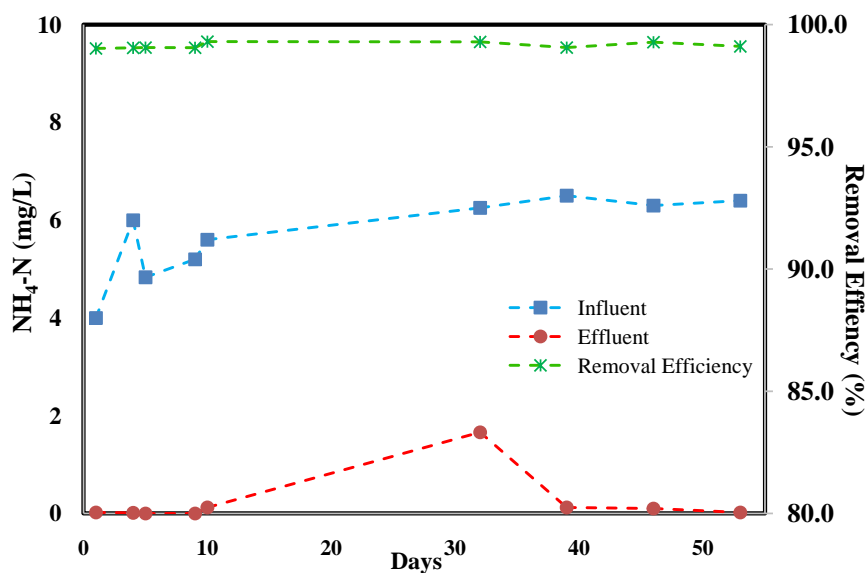


Figure 6. SBR influent  $\text{NH}_4^+$  and nitrogen removal efficiency as a function of time.

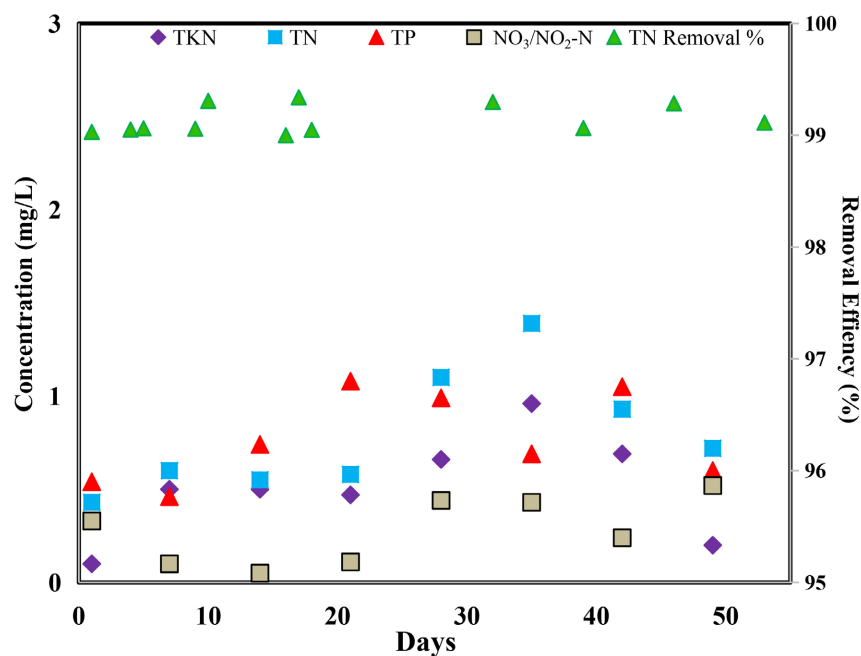


Figure 7. Various permitted effluent components and the nitrogen removal efficiency as a function of time.

normal operation period. Though the  $\text{NH}_4^+$ -N concentration varied moderately on the influent side, the effluent  $\text{NH}_4^+$ -N concentration was relatively stable at concentrations below 0.15 mg/L. Despite this spike, for the SBR-2, the removal efficiencies for  $\text{NH}_4^+$ -N concentration were always >99%. This level of removal agrees with similar results shown by Baek and Pagilla [20] and Wang [21] similar influent concentrations. This data displayed the effectiveness of this system to remove  $\text{NH}_4^+$ -N regardless of the usual variability often seen in influent waste to a treatment facility. In addition, the average effluent was found to have CBOD and TSS concentrations of 4.0 mg/L and 1.1 mg/L, respectively. Based on the reported criteria, it can be noted that SND removed the necessary amounts of these components as well.

Most notably, comparison of the theoretical  $\text{NO}_3\text{-NO}_2\text{-N}$  concentration to the actual  $\text{NO}_3\text{-NO}_2\text{-N}$  concentration indicated that the combination of both SND processes provided a synergistic effect on the treatment of waste. Based on the samples examined, the SND process resulted in an average  $\text{NO}_3\text{-NO}_2\text{-N}$  concentration that was 82% lower than the theoretical concentration under the same circumstances. Furthermore, it was shown that overall nitrogen removal was generally > 99% (Figure 7), as all major nitrogen species in the effluent concentrations were less than 2 mg/L. TN was mostly comprised of the TKN, the sum of organic nitrogen and ammonia nitrogen, and  $\text{NO}_3\text{-NO}_2\text{-N}$ . The presence of these components clearly corresponds to one another as noted in the analyses of the wastewater samples seen in Figure 7. This overall relationship in the present study is similar to that of other SND systems [9] [21], but with higher removal of the total nitrogen; and the TN removal efficiency in this present study was higher than what was noted in other municipal wastewater treatment SBRs [19]. This could be attributed to the wastewater treatment design and the coupling of SND and the traditional nitrogen removal process.

### 3.3. Total Phosphorus

The effluent composite average for TP was calculated as 0.77 mg/L and its presence in the effluent paralleled that of the TN, as noted in Figure 7. All of the effluent sample amounts were below the level of 1.0 mg/L which is/was the current concentration permitted by the state of Florida (current NPDES permit #: FL0038555 from <https://floridadep.gov/>). However, the averages were considerably higher than the proposed Geometric mean for TP for lakes with a range of 0.05 - 0.01 mg/L and for streams with a range of 0.06 - 0.49 mg/L [22]. Consequently, it should be noted that the facility primarily removes phosphorus biologically via the luxury uptake process. The use of metallic salts such aluminum sulfate would lower the TP concentration to that of the proposed criterion of lakes and streams to alleviate effluent concerns regarding that nutrient. However, the lower the  $\text{NO}_3\text{-NO}_2\text{-N}$  concentrations that were observed facilitates the luxury uptake process in that the lower the nitrate concentrations at the start of each batch. Shorter denitrification periods allow for longer anaerobic periods which optimize the luxury uptake process in the facility.

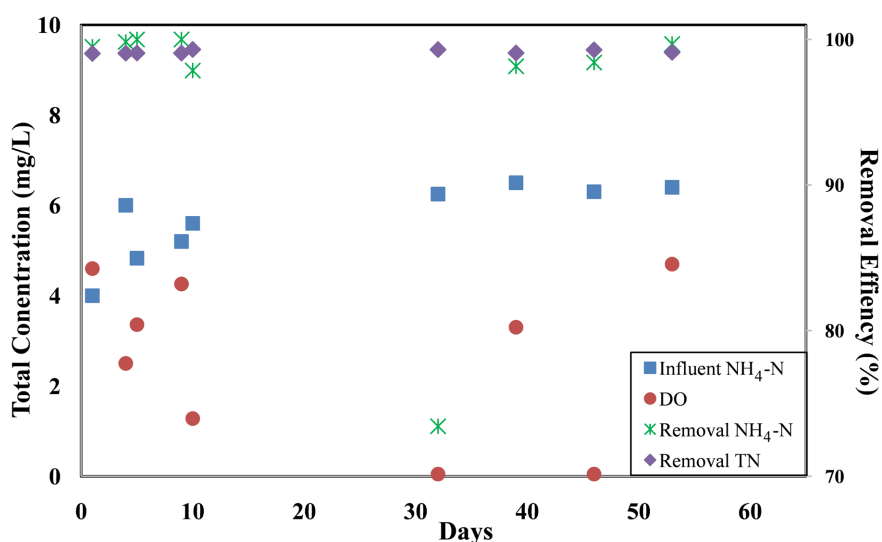
### 3.4. DO Concentrations vs. Nitrogen Removal

The average dissolved oxygen concentration at the end of the batches was 2.1 mg/L (**Figure 8**); however, three of the batches had a dissolved oxygen concentration of 0.0 mg/L which is contrary to the accepted dissolved oxygen concentration of 1.5 mg/L required for efficient nitrification [10]. It should be noted that the recommended DO residuals to remove ammonia require substantial aeration thus, in increase in overall operational cost and increase carbon footprint as compared to conventional facilities. Therefore, reducing the minimum DO residual required for nitrification without having a deleterious effect on overall treatment would reduce both cost and greenhouse gas emissions.

### 3.5. Proposed Criteria Comparison

The threshold limit submitted to the EPA for TN for water bodies defined as streams was delimited according to region with the state of Florida [22]. The allowable TN within the state highlights the importance of SND efficiency to reduce these amounts in discharges to these water bodies which is greatly affected by effluents from municipal wastewater treatment plants. **Table 4** summarizes the threshold limits submitted to the USEPA for TN in regional water bodies within the state of Florida defined as streams compared to the effluent TN from the examined SND process. As noted, of the 6 Florida regions evaluated, the explored SND process met the criteria for 5 of them. Only the region denoted as Panhandle West, which is known for shellfish harvesting, would require further treatment to meet the criteria.

Overall, the data suggests that the City of Graceville Wastewater Treatment plant may be able to meet the proposed FDEP's minimum TN annual geometric mean. Also, the coupling of the SND had no adverse effect on this facility to meet the current effluent permitted criterion for CBOD, TSS, and TP.



**Figure 8.** SBR nitrogen and DO removal as a function of time.

**Table 4.** Comparison of the threshold limit total nitrogen for streams by region and the effluent total nitrogen of the batches examined.

Nutrient Region	Annual Geometric Mean	Effluent batch Geometric Mean (2-month sampling period)
	Total Nitrogen mg/L	Total Nitrogen mg/L
Panhandle West	0.67	0.73
Panhandle East	1.03	0.73
North Central	1.87	0.73
Peninsula	1.54	0.73
West Central	1.65	0.73
South Florida	No numeric Threshold	0.73

#### 4. Conclusions

A SND process was conducted at a wastewater treatment facility in north Florida to examine the fate and transport of the nitrogen species within the facility, the effectiveness of nitrogen removal in a sequential batch reactor utilizing SND, characterize the extent of SND in the process, and determine if this implementation would meet state of Florida water quality-based standards.

The average SND efficiency sampled during two months was 52.8% at the north Florida facility, which paralleled the SND efficiencies of other SBR municipal wastewater treatment systems. Overall, the examined SBR system had removal efficiencies > 99% for the influent to effluent  $\text{NH}_4^+$ -N concentrations. The SND process studied resulted in average  $\text{NO}_3$ - $\text{NO}_2$ -N concentration that was 82% lower than the theoretical concentration under the same circumstances. Overall nitrogen removal was >99% which typified what was seen in other SND systems, but at a higher TN removal rate related to other municipal wastewater treatment SBRs. Additionally, all of the effluent sample TP concentrations were below the current permitted concentration level of 1.0 mg/L. For the examined SND process, the threshold limits for TN in the effluent were compared to those submitted to the USEPA for regional water bodies within the state of Florida. Of the 6 Florida regions evaluated, the explored SND process met the criteria for 5 of them. Therefore, based on the tested processed should be generally effective in meeting the proposed Florida Department of Environmental Protection's minimum Total Nitrogen annual geometric mean for streams throughout the state.

Though the results would be beneficial for many wastewater treatment plants, there are still potential areas for further study. First, research could be conducted to determine the minimum air requirements at which the Full Scale SBR Wastewater Treatment Facility would allow for nitrogen removal exclusively thru SND. Additionally, it would be important to consider the impact of the latter to CBOD and Total Phosphorus removal in addition to the overall energy cost to the facility.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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