

*ChemScan<sup>®</sup> Process Analyzer*

Reprint

Orlando's Nitrogen Profile Program

...A New Approach to Activated Sludge Process Control

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## Introduction

The City of Orlando, FL has been operating a ChemScan Process Analyzer System at their Conserv II Water Reclamation Facility since January 1997. A previous ASA publication (#74) focused on the evaluation by the City of Orlando of the ChemScan system in use at this plant for analysis of nitrate, nitrite, ammonia and transmittance at multiple sample points in the nitrification and denitrification tanks.

The attached publication is from a technical presentation made by the City of Orlando at the 72<sup>nd</sup> Annual Water Environment Federation Conference & Exposition in New Orleans, LA during October 1999. This publication explains several methods for use of nitrogen profile data to achieve better nitrification and denitrification results. The automated blower control system developed for this plant is also explained. This control system uses on-line nitrogen profile measurements from the ChemScan analyzer system to pace air delivery within the process to nitrification demand.

Additional process analyzer and control software information can be obtained from Applied Spectrometry Associates, Inc.



# CITY OF ORLANDO

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## **Orlando's Nitrogen Profile Program** *... A New Approach To Activated Sludge Process Control*

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### **KEYWORDS**

Nitrification, Denitrification, Nitrite, Nitrate, Ammonia, Micro-Filtration, Ultra-Violet Analyzer, Nitrogen Breakthrough, PLC-Based Process Control, Automated Blower Control, On-Line Nitrogen Control

### **ABSTRACT**

This paper presents concepts and protocol associated with the design, start-up and operation of an activated sludge process control system utilizing ammonia and nitrate for control of aeration rates in a conventional activated sludge process. The heart of this system is a UV analyzer which identifies and displays the nitrogen profile in each aeration tank; the nitrogen profile consists of nitrite, nitrate, and ammonia.

Based on target (setpoint) levels of ammonia and nitrate in various aeration tanks, the motorized air valves in each tank and the process blowers are appropriately modulated to maintain the selected nitrogen levels. As the ammonia level rises above setpoint, the air valves automatically adjust (open) to increase the air supply rate which furthers nitrification. Conversely, as nitrate concentrations rise above target levels, the air valves automatically throttle (close) to decrease the air supply rate which furthers denitrification.

If ammonia setpoints cannot be achieved by opening the aeration tank air valve, then the on-line process blower(s) will automatically increase their air output volume. When the on-line blower(s) is/are running at 100%, and the ammonia level in the selected aeration tanks is above setpoint, the next blower in the sequence will automatically start and all on-line blowers automatically equally adjust to provide the required volume of air to achieve ammonia setpoint.

Conversely, when the on-line blowers are supplying more air than required, as determined by ammonia levels below the target setpoint, blower inlet valves will be automatically throttled to decrease air output. If all on-line blowers are running at the selected minimum valve position, then the last lag blower will automatically shutdown. At that point, the remaining on-line blower inlet valves will be equally adjusted to provide the required air rates to maintain the selected ammonia setpoint.

This paper details annual cost savings realized since implementation of this unique activated sludge process control system due to optimized process performance and reduced direct operator involvement.

## **THE CONCEPTUAL APPROACH • WHAT ARE WE TRYING TO DO**

### **Conserv II Water Reclamation Facility Overview**

The City of Orlando's Conserv II Water Reclamation Facility is operating in a process control regime that was not intended by design. The facility design, prior to 1986, was based on an average daily flow of 12 mgd to achieve effluent permit standards of 20 mg/l BOD<sub>5</sub> and 20 mg/l TSS. The facility was expanded in 1986, increasing the permit capacity to 25 mgd and decreasing the effluent TSS limit to 5 mg/l, but still without any regulatory requirements addressing nitrate levels in the plant effluent. However, in 1992, a nitrate limitation of 10 mg/l as a monthly average was included in the facility's Florida DEP operating permit. Since that time, the City has successfully met all nitrate permit limits by altering the design mode of operation within the plug flow conventional activated sludge process. Operational protocol of the plug flow conventional activated sludge system has been modified to allow nitrification and partial denitrification to take place simultaneously within the same aeration zone. This facility was not designed or constructed specifically to accomplish nitrification or denitrification, but under the present operational protocol the City is confident it can achieve a Total Nitrogen (TN) concentration of less than 10 mg/l to comply with anticipated future permit standards

### **Operational Difficulties**

In attempting to optimize existing equipment and tankage, the most significant difficulty staff faced in achieving nitrification and denitrification was manual control of the process blowers due to fluctuating ammonia levels during various flow periods of the day. Influent ammonia levels fluctuate significantly throughout the day due to a large percentage of the facility's loading originating from industrial contributors. Because of the extreme fluctuation of influent ammonia, monitoring changes and making manual control adjustments of the process aeration blowers presented a problem. With manual aeration, at times, too much air would be delivered to the aeration system resulting in complete nitrification but reduced denitrification resulting in high nitrates in the effluent. At other times, insufficient air would be supplied to the aeration tanks resulting in extremely low nitrates but elevated ammonia levels, and, often, elevated nitrites. The elevated nitrites caused instability in the effluent chlorination process making it difficult to maintain a chlorine residual. As nitrites increase, additional chlorine feed is required to satisfy the high chlorine demand before adequate chlorine residuals can be achieved; however, as ammonia increases, reduced chlorine demand requires a lower dose to maintain a combined chlorine residual. Staff faced challenges not only with the biological systems (activated sludge process), but also with the chemical systems (effluent chlorination process) due to the changes in the degree of nitrification achieved.

## **THE SYSTEM • HARDWARE AND CONTROL METHODOLOGY DEVELOPED**

### **Lots of Aeration Profile Experiments**

Before we arrived at our current air flow profile, we experimented with several different profiles of air placement throughout the aeration system. In 1992, the facility was issued an FDEP effluent permit limit of 10 mg/l nitrate (NO<sub>3</sub>). At that time, staff's objective was to devise a method of complying with the new permit limitation by altering the profile of air delivery throughout the aeration system without expensive capital modifications. Since 1992, staff has experimented with the operational protocol of the activated sludge process, and have never exceeded the average weekly or monthly NO<sub>3</sub> permit limit. Staff's internal target was to produce effluent nitrate levels of 6 to 8 mg/l, leaving 2 mg/l for a margin of error.

Various air flow delivery experiments included: 1) Cycling air On and OFF in the 1st stage aeration system, 2) No air in the 1st half of the 1st stage aeration system, high air in the 2nd half of the 1st stage aeration system, and medium air throughout the 2nd stage aeration system, 3) No air in the entire 1st stage aeration system and high air in the 2nd stage aeration system, 4) High air in the 1st stage aeration system and low air in the 2nd stage aeration system.

All scenarios produced positive and negative responses; a brief explanation of each air flow profile follows:

*1) Cycling air On and OFF in the 1st stage aeration system*

This was staff's first attempt at turning off air to any portion of the aeration system. This method provided mixed results; however, it did allow partial denitrification to take place during the OFF air cycles. Staff's experiments included several different cycling time frames, including 15 minutes air OFF and 45 minutes air ON; 30 minutes air OFF and 30 minutes air ON; and 60 minutes air OFF and 60 minutes air ON. It was estimated that the 60/60 cycle produced the best results in which 2 to 4 ppm of nitrates were reduced to nitrogen gas using this method. However, ammonia levels fluctuated and nitrate levels were unpredictable. The other problem experienced with this method was the potential long-term damage to the numerous aeration tank motorized air valves caused by cycling open and closed on a routine basis. At best, this method produced nitrate levels dangerously close to the new 10 mg/l nitrate permit standards.

*2) No air in the 1st half of the 1st stage aeration system, high air in the 2nd half of the 1st stage aeration system, and medium air in the 2nd stage aeration system*

Once staff overcame concerns with air off in a portion of the aeration system (and leaving it off) experiments began with shutting off the 1st half of the 1st stage of aeration. The first portion of the aeration tanks have the highest availability of carbon (primary effluent BOD) and the highest demand for oxygen. The concept was to use  $\text{NO}_3$  in the RAS stream as a source of oxygen as the microorganisms use the carbon in the raw wastewater as food. This method worked very well and was much more predictable than cycling air on and off, however, achieving 10 mg/l of effluent nitrates was still difficult to meet on a consistent basis. Due to delayed nitrification, effluent nitrate levels were low but ammonia was high. This method produced effluent nitrate levels between 7 to 9 mg/l ... still somewhat higher than we were comfortable with and TN levels were a concern although not a permit issue at present.

*3) No air in the entire 1st stage aeration system and high air in the 2nd stage aeration system*

Staff reasoned that if no air in the 1st half of the 1st stage aeration system was partially successful, then no air in the entire 1st stage aeration system might be even better. Staff was right ... effluent nitrate levels were consistently in the 4 to 7 mg/l range. Staff achieved compliance with permit standards with this method of operation, and followed the protocol for 5 years. It was not an uneventful 5 years. Staff had acquired a trade-off given the highly unstable effluent chlorine residuals and chlorination control methods. In 1992/1993, staff was saying what does activated sludge process operations have to do with effluent chlorine residual stability? The answer is a great deal!

By limiting nitrification under this operating protocol, the system was allowing ammonia to "bleed through" aeration during peak flow and/or peak loading periods. The system would achieve complete nitrification during the average to low flow and loading periods. When the operating protocol achieved complete nitrification, zero ammonia in the effluent, the chlorination system operated in breakpoint and the chlorine residual was stable. However, as ammonia bled through the aeration system and reached the chlorine contact chamber, even though the dose rate and flow rate would remain constant, the chlorine residual would drop. In response to the lower residual, operators would rush to increase the chlorine feed rate. The residual would then drop even lower ... as they continued to incrementally increase the chlorine feed. Plant staff suffered through a learning curve until discovering relationships between ORP readings in the effluent as an indicator of ammonia presence. Bottom line was staff had to be conditioned to accept that sometimes the chlorine feed rate had to be decreased in order to increase the effluent chlorine residual.

Briefly, as chlorine reacts with ammonia, chloramines are formed. Chloramines provide combined residual as long as the chloramines are not destroyed through over-chlorination. However, if the chlorine feed rate is increased in response to falling TRC, as what occurs on the back side of the breakpoint hump, then the higher levels of chlorine dosage react with the generated chloramines and begin to destroy them. As the chloramines are destroyed, the chlorine residual drops. If more chlorine is fed, the combined residual will drop even more, until breakpoint is achieved. At that point (which could take a great deal of chlorine to achieve), every 1 ppm of chlorine feed becomes 1 ppm of free chlorine residual.

So, for 5 years staff achieved consistent levels of effluent nitrates (almost always below 8 mg/l), but suffered with fluctuating chlorine residuals due to incomplete nitrification and varying concentrations of ammonia in the plant effluent. Staff went back to the experimental drawing board.

#### *4) High air in the 1st stage aeration system and low air in the 2nd stage aeration system*

In this method, staff was hoping to find a way to produce a higher level of nitrification consistently while, of course, being able to maintain a comfortable level of effluent nitrates. Staff rearranged the air flow profile to provide high air volume to the 1st stage aeration system, and low air volume throughout the 2nd stage aeration system. The goal was to accomplish near complete nitrification in the 1st stage aeration system, and then to accomplish denitrification in the 2nd stage aeration system. Staff was able to accomplish this fairly well, with some ammonia break-through happening during peak flow and/or loading periods. However, even during these 1st stage ammonia bleed through periods, nitrification was completed in the 2nd stage aeration system. The effluent nitrate values still remained at acceptable levels between 6 to 8 mg/l, and the effluent chlorine residual stability condition improved significantly.

The operating protocol is to regulate air in the 1st stage aeration system to maintain about 1 to 1.5 mg/l ammonia in the outlet. This appears to allow enough CBOD<sub>5</sub> to remain in the 2nd stage aeration system to accomplish adequate denitrification. Even though the D.O. value in 1st stage aeration is normally between 2 to 3 mg/l, initial investigation shows that partial denitrification is being achieved. Figure 2 reveals that on June 21, 1999, nearly 25% denitrification occurred in a high D.O. environment. In order to encourage maximum denitrification, staff uses just enough air in the 2nd stage aeration system to prevent settling of the MLSS and provide polishing of the nitrification process should small amounts of ammonia breakthrough 1st stage aeration. D.O. levels in the 2nd stage are normally less than 1.0 mg/l.

High air in the 1st stage aeration system and low air in the 2nd stage aeration system presented a few down-sides: 1) settleability of MLSS is fairly slow -- producing higher than normal clarifier sludge blankets, and, 2) filamentous bacteria growth rate and dominance is much higher as compared with low air in the 1st stage. Staff overcame these problems through implementation of RAS stream chlorination which provides for an acceptable sludge blanket depth and control of filamentous organisms.

Staff has selected the high air in the 1st stage aeration system and low air in the 2nd stage aeration system, based on several years of experience, as the optimal operating protocol at Conserv II to achieve nitrification and denitrification as well as chlorine residual stability.

#### **Nitrogen Profile Analyzer**

Staff could not have refined the aeration system operating protocol without the on-line nitrogen profile analyzers. The nitrogen profile analyzers were selected after completing a 30-day demonstration (performed for 9 months). The analyzers receive filtered MLSS samples sequentially drawn from each aeration tank in service and perform UV spectrum analysis to identify the nitrite, nitrate, and ammonia concentrations in about 4 to 5 minutes per tank.

Two (2) complete and self-contained continuous sequencing nitrogen profile analyzer systems are in service to test for nitrite, nitrate, and ammonia concentrations in the 1st stage and 2nd stage aeration tanks. Each aeration tank is a plug flow reactor with modulating in-line air valve upstream of the fine bubble air diffusers. The detention time at 12.5 mgd is 4.0 hrs in the 1st stage aeration system, 8.3 hrs in the 2nd stage aeration, for a total of 12.3 hrs under various aeration conditions. Sequential samples of MLSS are withdrawn from each aeration tank, either from the middle or the end of the tank, and supplied to the ultra-filtration units to remove a clean water source from the mixed liquor. The clean water sample is then supplied to the UV analyzer for the nitrogen profile analysis.

#### **OPERATIONAL CONTROL**

After two years of process evaluation, an automated control system was selected for the aeration blowers utilizing the on-line UV analyzers. In the manual control mode, facility operators monitor the analyzer data and make corresponding process air supply adjustments to either the appropriate aeration tank inlet air valves, the blower inlet

air valves, and/or the number of blowers in service. Process air adjustments are made when: 1) nitrate levels rise above a target value, signaling the operators to close air valves and/or turn-down blowers, 2) ammonia levels rise above a target value, signaling the operators to open air valves and/or increase blower output. The manual control system operates well, but requires constant operator attention and frequent adjustments to maintain target nitrogen levels throughout the aeration process.

## **AUTOMATED AERATION & BLOWER CONTROL SYSTEM**

Facility staff has developed a PLC-based process control system to allow automatic adjustment of aeration tank air supply valves, blower inlet valves, and the number of blowers in service based on target ammonia and nitrate values at various points within the aeration tanks. The automated control system reduces operator involvement while achieving near complete nitrification on a more consistent basis. The enhanced consistency prevents swings of ammonia in the activated sludge process from adversely affecting the stability of the effluent chlorine residual, while increasing confidence in compliance with permit nitrate standards.

### **AERATION VALVES CONTROL MODE**

Each aeration tank has a motorized air valve on the main air line. The motorized air valves can be controlled using either ammonia or nitrate as the base setpoint signal. In the portion of the aeration system selected for NH<sub>3</sub> control mode, as the on-line analyzer sequentially updates the results for each tank, the actual NH<sub>3</sub> value is monitored, and if it rises above the NH<sub>3</sub> setpoint value, an OPEN adjustment signal is sent to the air valve for that tank increasing the valve opening a certain percentage. Also, in the NH<sub>3</sub> control mode, if the actual NH<sub>3</sub> reading falls below the NH<sub>3</sub> setpoint value, a CLOSED adjustment signal is sent to the air valve for that tank decreasing the valve opening a certain percentage. In the portion of the aeration system selected for NO<sub>3</sub> control mode, if the actual NO<sub>3</sub> value rises above the NO<sub>3</sub> setpoint value, a CLOSED adjustment signal is sent to the air valve for that tank. The amount of adjustment, either OPEN or CLOSED, of an aeration tank air valve depends on the degree of deviation between the setpoint and actual values. When the deviation is at a minimum value, the percent adjustment to the air valve is a minimum adjustment. However, as the deviation increases, the percent adjustment of the air valve also increases proportionately.

### **BLOWER CONTROL MODE**

#### ***The First Method***

Automatic blower control uses the difference between the ammonia setpoint vs. actual ammonia readings in the selected aeration tanks. The operational staff can select whether the ammonia setpoint for blower control is derived from the 1st stage or 2nd stage aeration tanks. In either selected control location, the concept for blower control is the same. The typical location for blower control will be the bank of aeration tanks where the majority of nitrification is intended to be accomplished. When high air is supplied to the 1st stage aeration tanks, nitrification will be at its highest, and this location would be selected for the ammonia-based blower control system. However, if low air is supplied to the 1st stage aeration tanks and high air is supplied to the 2nd stage aeration tanks, then the 2nd stage aeration tanks will be performing the majority of the nitrification and this location would be selected for ammonia-based blower control.

With either location, the SCADA program compares the actual ammonia level to a setpoint ammonia target and automatically performs the following blower-related tasks based on changing process conditions:

- Event #1 • Add more air by OPENING the on-line blower inlet valves
- Event #2 • Add more air by STARTING the next lag blower
- Event #3 • Reduce process air by CLOSING the on-line blower inlet valves
- Event #4 • Reduce process air by STOPPING the lag blower

As identified in Event #1, when the actual ammonia level exceeds the target level, the control system opens the inlet valves of all on-line blowers equally. The system is designed to perform a calculation to determine how much to open the blower valves according to the percentage difference between the actual and target ammonia levels ... the deviation.

Event #2 will automatically start another blower when the inlet valves for the on-line blowers are wide open and the actual ammonia level still exceeds the target value. As the next lag blower is being started, all on-line blowers automatically reduce their output (turned down) to an operator-definable position. Then, all blower inlet valves are opened simultaneously, to a system calculated percent opening, to achieve the required air flow rate and match the ammonia setpoint.

Event #3 will be activated when the actual ammonia level is lower than the target value. As the ammonia value begins to fall lower than target, the control system will make a system calculated closed adjustment on all of the on-line blower inlet valves. The degree of valve closure will be determined based on the deviation between the actual ammonia level and the target value. All on-line blower valves will be adjusted equally.

As identified in Event #4, when all on-line blower inlet valves reach their pre-selected lowest position, the control system, after an appropriate time delay, will automatically shut off the lag blower. As this blower is being stopped, the inlet valves on the remaining blowers are automatically regulated to the optimal position based on system calculations in order to match the actual ammonia value to the ammonia setpoint value.

#### ***The Back-up Method***

A back-up blower control mode utilizes a pressure sensing device mounted on the blower discharge line providing pressure readings utilized for the automated back-up blower control mode. As aeration tank valves are OPENED, in response to elevated NH<sub>3</sub> levels, the blower outlet pressure will drop. The signal to increase the blower output air flow rate is based on detection of a falling pressure signal from the pressure transducer mounted on the blower common discharge pipeline. As the blower outlet pressure falls to a setpoint low pressure, between 7.5 to 8.0 psi, the signal is sent to increase the output of all active blowers. The percent OPENING of the blower inlet valves is automatically calculated based upon on the deviation between the actual pressure vs. the setpoint pressure value. As aeration tank valves are CLOSED, to reduce the NO<sub>3</sub> levels, the blower outlet pressure would begin to increase. The signal to decrease the blower output air flow rate is based on a rising pressure signal received from the pressure transducer mounted on the blower common discharge pipeline. As the blower outlet pressure rises to a setpoint high pressure, between 9.5 to 10.0 psi, the signal is sent to decrease the output of all active blowers. The percent CLOSING of the blower inlet valves depends on the deviation between the actual pressure vs. the setpoint pressure value.

#### **PROJECT CONCLUSIONS**

Staff estimates annual operational savings of approximately \$125,000 per year at Water Conserv II facility attributed to implementation of the nitrogen-profile based automated aeration control system. Estimated annual operational savings consist of \$70,000 per year in reduced aeration blower horsepower due to optimization of the air delivery system, \$20,000 per year associated with the reduction of previously required staff response and adjustment time of aeration tank air valves and blowers, and \$35,000 per year in reduced chlorine consumption by minimizing ammonia and nitrite swings and breakthroughs allowing consistency in the selection and setting of chlorine dosage rates.

The greatest savings, however, is the ability to utilize the existing conventional activated sludge plug flow tankage, originally designed only for BOD removal, to accomplish nitrification and significant denitrification saving the City millions of dollars in averted capital expenditures. Estimates to design and construct traditional tankage for nitrification and denitrification, as an add-on to a 25 mgd conventional activated sludge facility, were received from nationally recognized design firms in the range of \$20 million dollars.

The facility's staff have worked hard to find ways to maximize utilization of existing equipment and structures through experimentation, observation and optimization assuring the community served professional operation of the

investment in infrastructure previously made. Management in Orlando is very proud of the professionalism displayed throughout the organization.

**City of Orlando, Florida**  
**Water Conserv II • Water Reclamation Facility**

**Table 1**

*Typical Process Data*

<b>Parameter</b>	<b>Units</b>	<b>Result</b>
Average Daily Flow	mgd	12.5
Daily Peak Flow	mgd	20
Influent CBOD <sub>5</sub>	mg/l	215
Influent NH <sub>3</sub>	mg/l	25
Influent TKN	mg/l	39
Influent NO <sub>x</sub>	mg/l	0.37
Primary Effluent CBOD <sub>5</sub>	mg/l	155
Primary Effluent NH <sub>3</sub>	mg/l	22
Primary Effluent TKN	mg/l	32
Primary Effluent NO <sub>x</sub>	mg/l	1.63
Aeration MLSS	mg/l	2500
Aeration MLVSS	mg/l	2170
Average RAS Q	mgd	9.0
RAS TSS	mg/l	5000
Average RAS NO <sub>x</sub>	mg/l	1.5
Average WAS Q	Kgpd	145

**City of Orlando, Florida**  
**Water Conserv II • Water Reclamation Facility**

**Table 2**

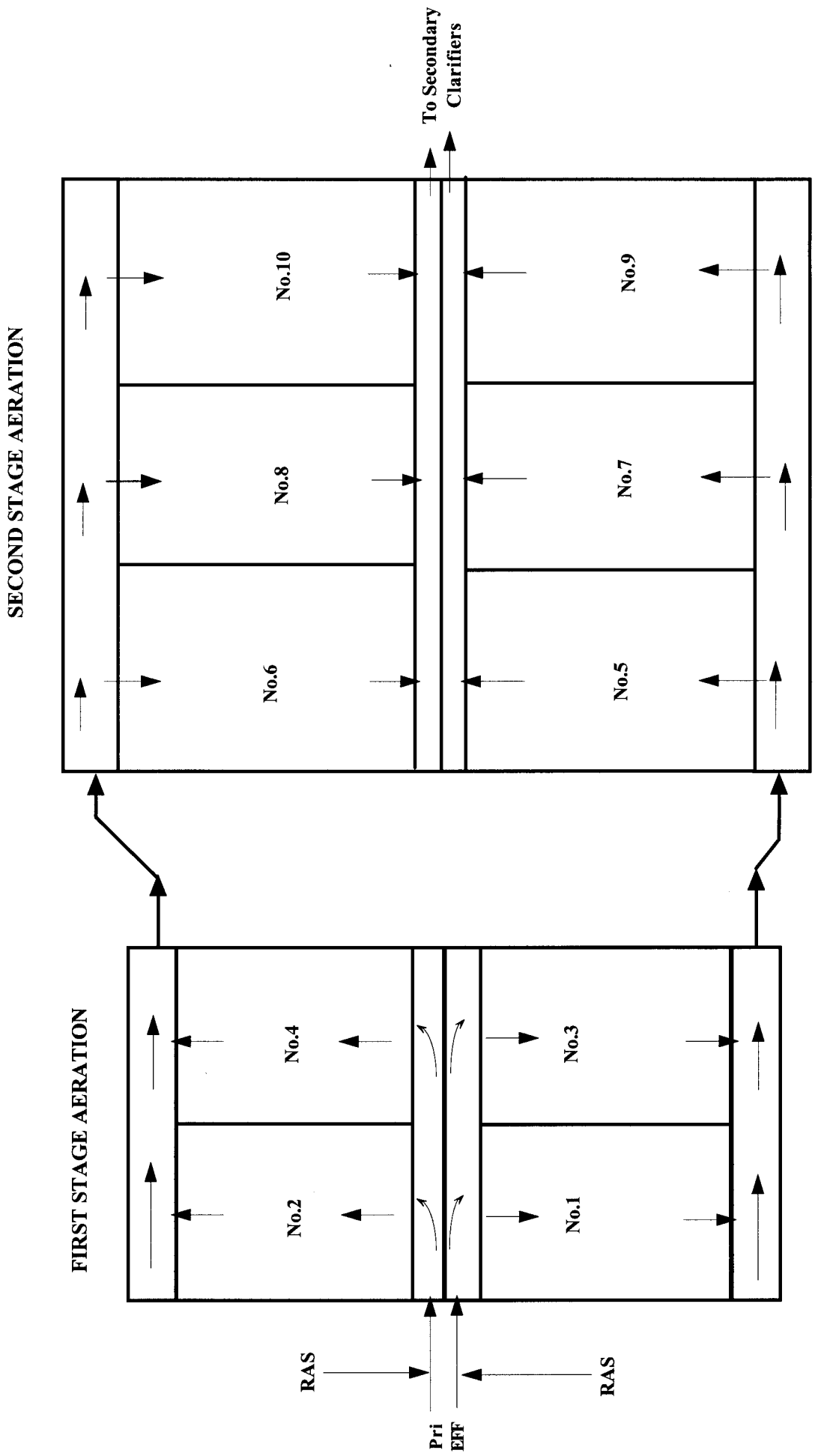
*Aeration System Information*

<b>Parameter</b>	<b>Units</b>	<b>Results</b>
Number of Aeration Tanks		10
Air Diffusion		Fine Bubble Ceramic Stones
Tank Depth	feet	15½
1st Stage Tanks Capacity (4)	gallons, each	520,000
1st Stage Tanks Detention Time	hours @ 12.5 mgd ADF	4.0
	hours @ 20 mgd peak	2.5
	hours @ 25 mgd design	2.0
Typical D.O. 1st Stage Aeration Tanks	mg/l	3.3
2nd Stage Tanks Capacity (6)	gallons, each	720,000
2nd Stage Tanks Detention Time	hours @ 12.5 mgd ADF	8.3
	hours @ 20 mgd peak	5.2
	hours @ 25 mgd design	4.1
Typical D.O. 2nd Stage Aeration Tanks	mg/l	<1.0
Total Aeration System Volume	gallons	6,400,000
Total Aeration System D.T.	hours @ 12.5 mgd ADF	12.3
	hours @ 20 mgd peak	7.7
	hours @ 25 mgd design	6.1

# City of Orlando, Florida Water Conserv II • Water Reclamation Facility

## Aeration System Flow Pattern

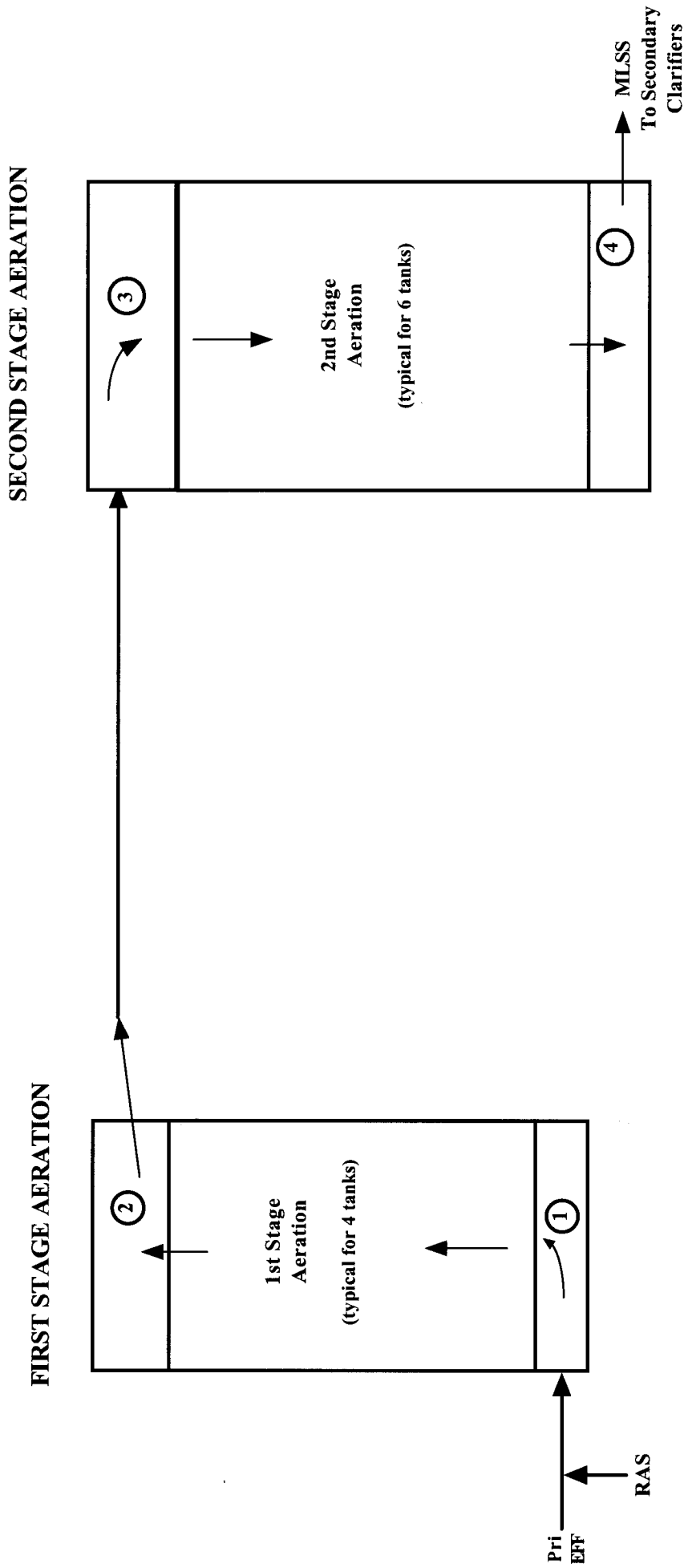
Figure 1



# City of Orlando, Florida Water Conserv II • Water Reclamation Facility

## Aeration System Nitrogen Profile

Figure 2



Sample	TKN	NH <sub>3</sub>	NO <sub>2</sub>	NO <sub>3</sub>	NO <sub>x</sub>	TN	Sample	TKN	NH <sub>3</sub>	NO <sub>2</sub>	NO <sub>3</sub>	NO <sub>x</sub>	TN
1	15.0	11.7	0.04	<0.01	0.04	15.04	3	4.74	0.07	0.11	9.07	9.18	13.92
2	2.26	0.21	0.23	8.89	9.12	11.38	4	3.66	0.04	0.02	6.26	6.28	9.94