# Utilizing Automatic Dissolved Oxygen and Internal Recycle Set-Point Control at Abington WWTP in Southeastern Pennsylvania

**Robert Leber[1], Steven Kestel[2*], Matthew Gray[2], Gregory Duffy[2]**

[1]) Abington WWTP
[2]) Biochem Technology, Inc
* To whom correspondence should be addressed. Email: skestel@biochemtech.com

## ABSTRACT

As permit requirements for effluent quality at wastewater treatment plants continue to become more stringent, intelligent control systems are needed to ensure optimal performance of the secondary treatment process. Such a control system was installed at Abington Wastewater Treatment Plant in southeastern Pennsylvania in 2005. Since that time, the control system has been optimizing dissolved oxygen set-points based on real-time loading with the goal of minimizing aeration requirements and maximizing process reliability. In 2009, after a plant upgrade, internal recycle optimization was added to the system. The benefits of this system have been a 5.5% reduction in aeration requirements, consistently meeting effluent ammonia goals, and optimal use of the anoxic volume for denitrification.

**KEYWORDS:** Energy Savings, Set-point Control, On-line Ammonia/Nitrate Analyzers, Plant Optimization, Instrumentation, Control and Automation

## INTRODUCTION

### Abington Wastewater Treatment Plant

The Abington Wastewater Treatment Plant (WWTP) provides sewage treatment for the Township of Abington and surrounding townships located in southeastern Montgomery County, Pennsylvania. The plant is required to achieve a secondary level of treatment which includes removal of organic wastes, suspended solids, nitrification and disinfection to prescribed levels. The facility's treated effluent is disposed of via surface water discharge to Sandy Run Creek, a tributary of the Wissahickon Creek. The Wissahickon Creek is itself a tributary of the Schuylkill River, a major water supply source for the City of Philadelphia.

The Abington WWTP was first commissioned in 1948 at which time it had a design capacity of 2.0 MGD. Over the years, the facility has undergone numerous upgrades and expansions to its present configuration as a biological nutrient removal, activated sludge process with a permitted capacity of 3.91 MGD. Sewer service is provided to nearly 45,000 residents in the surrounding area. The collection system consists of over 250 miles of gravity piping, 16 pumping stations and 8 metering stations that serve over 12,000 service connections.

### Original Configuration

The liquid treatment train at Abington WWTP consists of bar screens, grit removal, primary clarifiers, secondary treatment, secondary clarifiers, and UV disinfection prior to final effluent discharge. Prior to 2009, the secondary treatment process utilized a single stage activated sludge process for organics and ammonia removal. The process consisted of an anoxic selector and four parallel aeration zones. The anoxic selector was to improve sludge settling and provide some denitrification. Following the anoxic zone, the flow was split between four identical aeration zones. After the aeration zones, three secondary clarifiers completed the secondary treatment process. Figure 1 shows a diagram of this process.

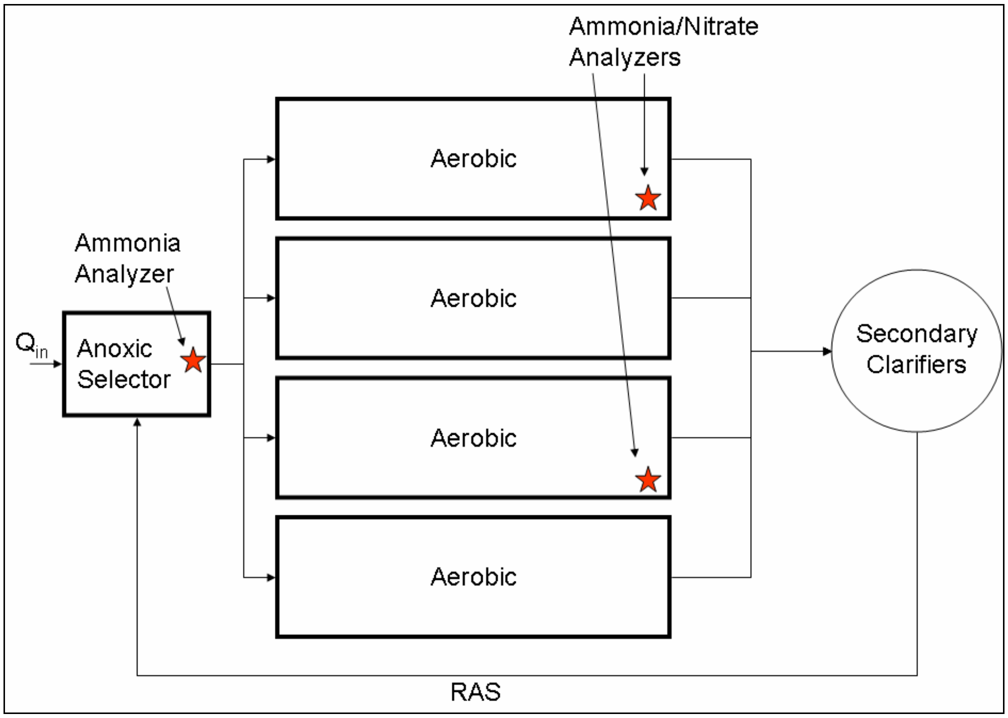


**Figure 1: Original Process Layout**

## Upgraded Configuration

Beginning in 2008, the plant underwent an upgrade to the $A^2/O$ process to improve biological nitrogen and phosphorus removal. The new process is designed to meet a total nitrogen of 6.0 mg/L and total phosphorus of 0.2 mg/L. As part of this upgrade, the anoxic selector was converted to an anaerobic zone. The four aerobic tanks were converted into two parallel trains, Train 1 and Train 2, and an anoxic zone was added before the aerobic zones. A third train, Train 3, consisting of anoxic and aerobic zones was added to the process. The third train has different dimensions from the first two trains due to site constraints. Each train has an internal recycle flow from the end of the aerobic zone to the front of the anoxic zone. The upgraded process is shown in Figure 2.

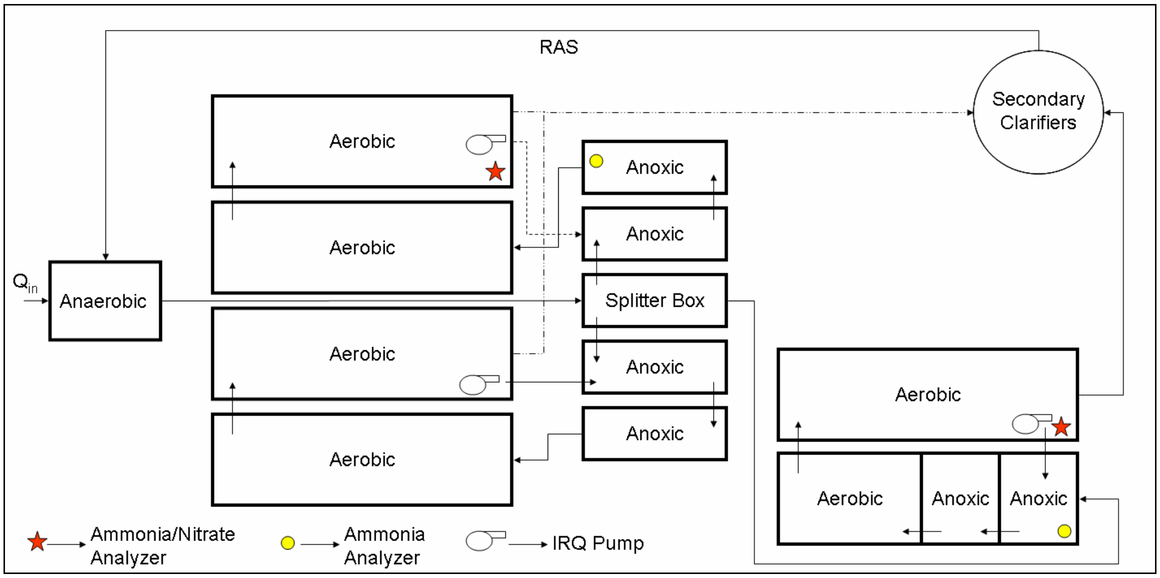

**Figure 2: Upgraded Process Layout** (IRQ = Internal Recycle Flow)

## Advanced Process Control System

In 2004, Abington WWTP received an Environmental Stewardship and Watershed Protection (Growing Greener) grant from the Pennsylvania Department of Environmental Protection (PA DEP) to install a Bioprocess Intelligent Optimization System (BIOS) from BioChem Technology, Inc., of King of Prussia, Pennsylvania. The BIOS is an advanced process control system that optimizes suspended growth biological treatment processes within a wastewater treatment plant. This optimization results in decreased effluent ammonia concentrations, less volatile effluent ammonia concentrations, and decreased aeration requirements.

The dual advantages of energy savings and lower effluent concentrations were the primary driver for the installation of the advanced control system at Abington WWTP. Nutrient levels in the Wissahickon Creek are being targeted for reduction by PA DEP. According to PA DEP, high concentrations of nutrients in the Wissahickon Creek are responsible for 93% of the stream miles being impaired with large algae blooms. The blooms release chemicals that are expensive and difficult to remove via water treatment at the Queen Lane Water Treatment Plant (WTP), which supplies potable water to the region. While required ammonia nutrient permit levels at Abington WWTP are based on monthly averages, the advanced control system enables Abington WWTP to provide advanced wastewater treatment and discharge ammonia nutrient levels that are consistently below required permit levels. The advanced control system greatly reduces the likelihood of high ammonia loads being discharged, even for short periods of time.

## METHODOLOGY

The advanced control system installed at Abington WWTP is a state-of-the-art control system that automatically adjusts the dissolved oxygen (DO) and the internal recycle flow rate (IRQ) set-points of the treatment process based on real time process requirements as described in Liu, 2003. The purpose of the BIOS system is to optimize the treatment efficiency and power usage while producing a consistent effluent quality that meets discharge standards. It achieves its objectives by using real time monitoring of nutrient concentrations in the process, communication with the plant SCADA system, and a feed-forward computer control system. The customized feed-forward model used for control is based on the Activated Sludge Model #1 (ASM1) developed by the International Association on Water Quality (IWA).

BIOS uses information provided by Abington WWTP's Supervisory Control and Data Acquisition (SCADA) System along with real-time influent and effluent nutrient concentrations measured by in-situ BioChem Technology ammonia/nitrate analyzers. This information is utilized in a feed-forward control algorithm by BIOS to determine the optimum DO and, after the process was upgraded, IRQ set-points for the treatment process. Due to the feed-forward nature of the control, a customized model of the secondary treatment process at Abington WWTP is an integral part of the control system. Because inputs to the control system are in real time, the optimum set-points change as conditions within the treatment process change. The traditional control system at Abington WWTP did not vary the set-points as treatment conditions changed.

**DO Optimization**

The use of the advanced control system for the monitoring and control of activated sludge treatment processes represents a departure from the traditional methods of process control. At Abington WWTP, the traditional DO control system operated by using a constant DO set-point which was input by operators. This set-point was aimed to provide sufficient treatment under daily peak loading conditions. Typically at Abington WWTP, the DO set-point remained constant throughout the day regardless of the load to the process. In contrast, the advanced control system uses a dynamic DO set-point that is calculated based on the real time load to the process. This strategy provides two advantages. First, the set-point is decreased under low loading conditions, requiring less air flow to the process and thus saving energy. Second, under high loading conditions, the DO set-point can increase to match the demand, preventing deterioration of effluent quality and lowering the overall effluent concentrations from the process. In previous testing, the utilization of the advanced control system led to a 19% decrease in the energy usage (Liu, 2005).

**IRQ Optimization**

The advanced control system also contributes to reducing nitrate levels in the Wissahickon Creek. According to the PA DEP, the influence of the Wissahickon Creek is causing nitrate levels at the intake of Queen Lane WTP to exceed 3 mg/L on average, putting the water supply at risk. The advanced control system measures real time nitrate concentrations in the treatment process so it can determine the extent of nitrate removal. The IRQ set-point is adjusted to optimize performance of the anoxic zones by reducing either under-loading or overloading of the anoxic zones, minimizing effluent nitrate concentrations. In previous testing, use of the advanced control system has led to a decrease of 32% in Total Inorganic Nitrogen (TIN) effluent concentration (Liu, 2005).

**Advanced Control System Description**

The advanced control system consists of two major components, the first of which is the in-situ nutrient analyzers. An analyzer is located at the end of the anoxic zone to measure the influent ammonia concentration. Additionally, one analyzer is located at the end of the aeration basin to measure the effluent ammonia and nitrate concentrations. The measured nitrate concentration is equivalent to the concentration in the internal recycle flow which is used to calculate the optimal

IRQ . The primary purpose of these instruments is to provide measurements that are used in the feed forward model of the BIOS control system to calculate the optimum DO set point. Secondarily, the data collected by the instruments is recorded by both the instruments themselves and in the BIOS control computer. This data can then be used to gain a greater understanding of the treatment process and its performance.

**Ammonia/Nitrate Analyzers**

The analyzers are composed of four main components: the in-process sampler (IPS), a lifter, electronics enclosure, and a reagent/pump enclosure. A diagram of an analyzer is shown in Figure 3. A 25 ft. length of flexible conduit connects the IPS to the enclosures and contains reagent delivery tubing and cables/wiring. The IPS is the actual wastewater sampling chamber and is physically immersed in the wastewater. A lifter enables the IPS to be mounted to a typical walkway railing and allows easy retrieval of the IPS unit for servicing. The electronics enclosure houses all electronics components including a data storage device (flash card) and a user interface (keypad and display screen). The reagent enclosure is heated and holds calibration solution and Ionic Strength Adjuster (ISA) bags and the delivery pump. The electronics and reagent enclosures are attached so they appear and mount as a single unit.

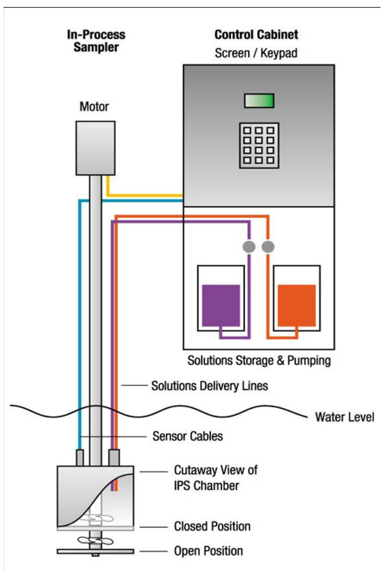


**Figure 3: Diagram of the In-situ Nutrient Analyzer**

## Controller

The second major component of the advanced control system is the controller. A picture of the controller is shown in Figure 4; it contains a programmable logic controller (PLC) and a microprocessor with embedded software containing a control algorithm programmed to match the layout and operating conditions of Abington WWTP. The controller utilizes data from the analyzers as well as other operational data from the Abington WWTP SCADA system to determine the optimal DO and IRQ set-points required to meet treatment goals while minimizing energy costs. Before the plant upgrade the same DO set-points were used for all four process trains. After the upgrade, the same DO and IRQ set-points were used for Trains 1 and 2. The DO and IRQ set-points for Train 3 were calculated independently due to the different tank sizes from Trains 1 and 2. These optimal set-points are communicated back to the plant SCADA system and utilized to control the process. The control panel also contains a computer touch screen, which allows user inputs to the BIOS system through graphical user interfaces (GUI) as well as displaying key parameters from the treatment process. These parameters include plant flow rates, DO concentrations, nutrient concentrations, and air flow rates.


**Figure 4: Control Panel**

## RESULTS AND DISCUSSION

The advanced control system has been installed at Abington WWTP for more than four years. Initially, the advanced control system only optimized the DO set-point; IRQ set-point control was added to the system in 2009 after the plant upgrade was complete. The system was shut down from March 2008 to June 2009 while the plant was upgraded and the new process was started-up.

### Original Process Control

The typical performance of the advanced control system under the original process is shown in Figure 5. During this time period, the system had a goal of maintaining the effluent ammonia concentration below 1.5 mg/L. During the early morning hours when the loading was low, the DO set-point was at its minimum allowable value, 1.0 mg/L. As the advanced control system detected the increased loading entering the secondary treatment process, the set-point was automatically raised, eventually reaching the maximum allowable value, 2.0 mg/L. After the loading decreased, the DO set-point was decreased back to 1.0 mg/L. This action results in a reduction in aeration requirements of 7.6% if the set-point had been fixed at 2.0 mg/L for the entire day. Additionally, the effluent ammonia was maintained below the target value of 1.5 mg/L.

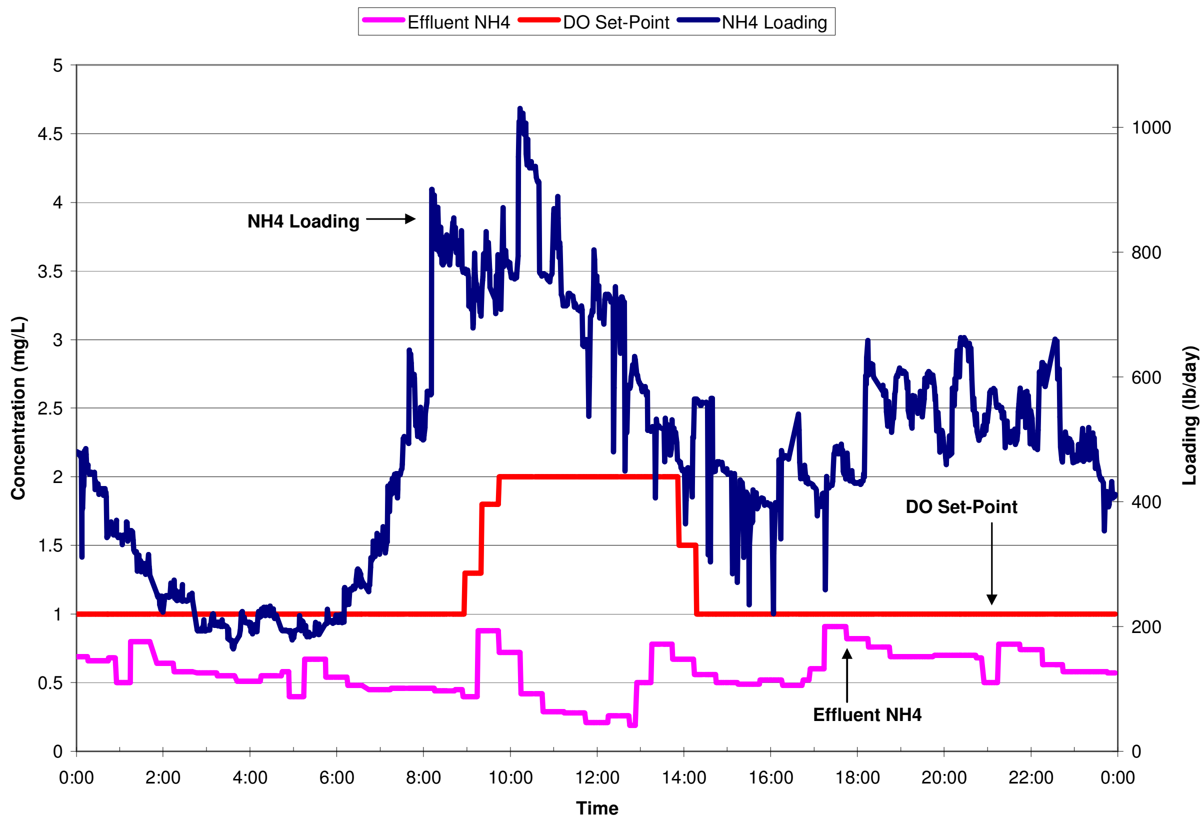


**Figure 5: Typical DO Set-point Control, Original Plant Configuration**

The average monthly influent ammonia, effluent ammonia, and DO set-point values for the entire period of control of the original process are shown in . The average DO set-point was 1.47 mg/L, for an estimated aeration savings of 5.5% if the DO set-point had been fixed at 2.0 mg/L. This value is below the previously reported savings of 19% (Liu 2005). Two factors are responsible for this difference. First, the baseline DO set-points reported by Liu were higher than the DO set-point used at Abington WWTP. For example, if the DO set-point calculated by the advanced control system was compared against a fixed DO set-point of 3.0 mg/L, the savings would have increased to 15.7%. Secondly, savings reported by Liu include savings from optimizing the IRQ set-point. Optimizing the IRQ maximizes COD removal in the anoxic zones hence minimizing COD removal in the aeration basins, leading to a drop in aeration requirements. Because Abington WWTP did not have an internal recycle flow during this time period, no savings were generated from IRQ optimization. The effluent ammonia concentration has been consistently below the target of 1.5 mg/L, except at the start of 2008 when tanks were taken off-line as the plant upgrade began.

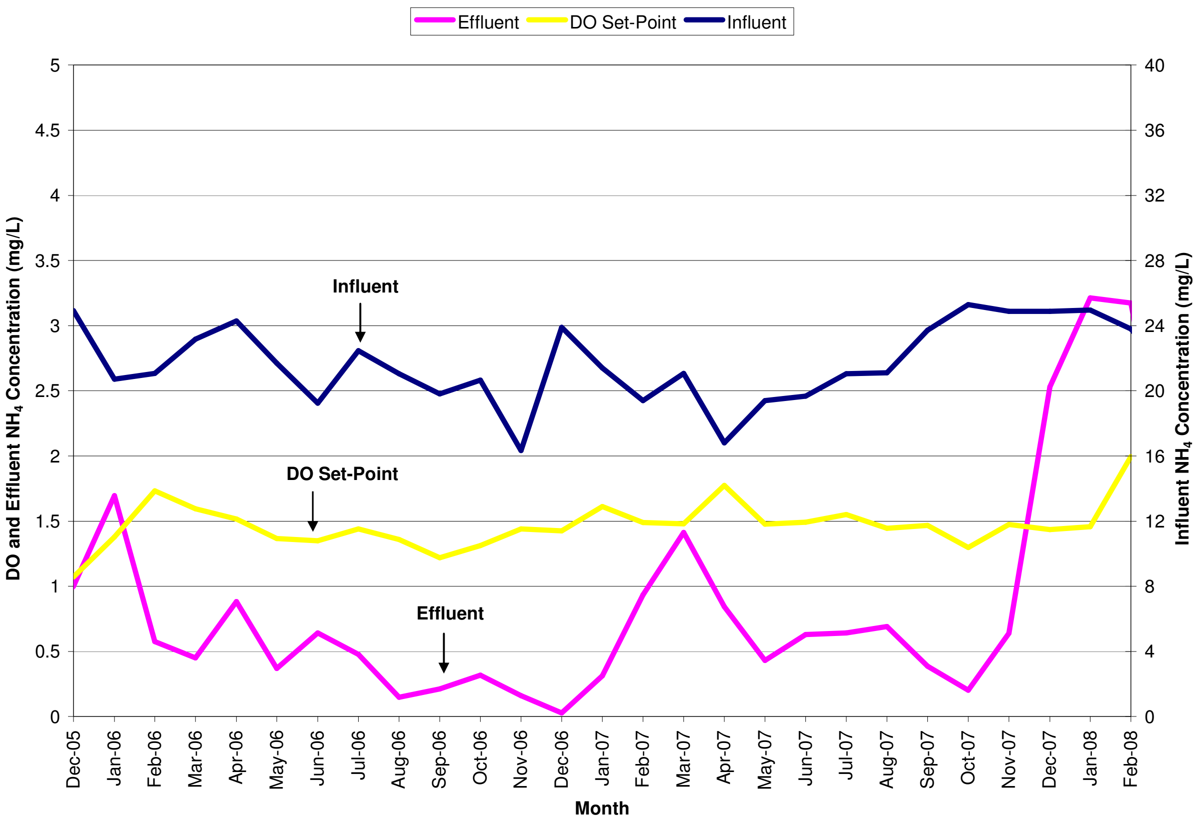


**Figure 6: Monthly Average Influent Ammonia, Effluent Ammonia, and DO Set-point**

## Upgraded Process Control

After the plant upgrade was completed, the advanced control system was updated to take the new process layout into account. This included adding IRQ set-point control to the system. The performance of the advanced control system over a three day period in Train 1 is shown in . The total aerobic volume of the secondary treatment process was increased by 54% as part of the upgrade. This has resulted in excess nitrification capacity and so the advanced control system has maintained the DO set-point at its minimum allowable value, 1.0 mg/L. The IRQ set-point has varied with the effluent nitrate and anoxic ammonia concentrations. As the effluent nitrate concentration increases, the amount of nitrate returned to the anoxic zone by the internal recycle flow increases. The advanced control system decreases the IRQ set-point to compensate for the increased nitrate loading to prevent oversaturation of nitrate in the anoxic zone. As nitrate concentration in the internal recycle flow decreases, the IRQ set-point is raised to fully utilize the anoxic zone for denitrification. The IRQ set-point is also adjusted based on estimated BOD loading to the anoxic zones. BOD is estimated by assuming a fixed BOD to ammonia ratio. If denitrification becomes BOD limited due to insufficient influent BOD, the IRQ set-point is lowered to prevent build up of nitrate in the anoxic zone.

In , the anoxic ammonia levels are equivalent to the influent ammonia concentration after dilution by RAS and IRQ, plus any return ammonia in the IRQ. The relatively high effluent nitrate levels shown in Figure 7 are an indication of limited denitrification capacity at Abington

WWTP. While this does not impact permit compliance, weak influent BOD loading is insufficient for full denitrification, leading to higher effluent nitrate.

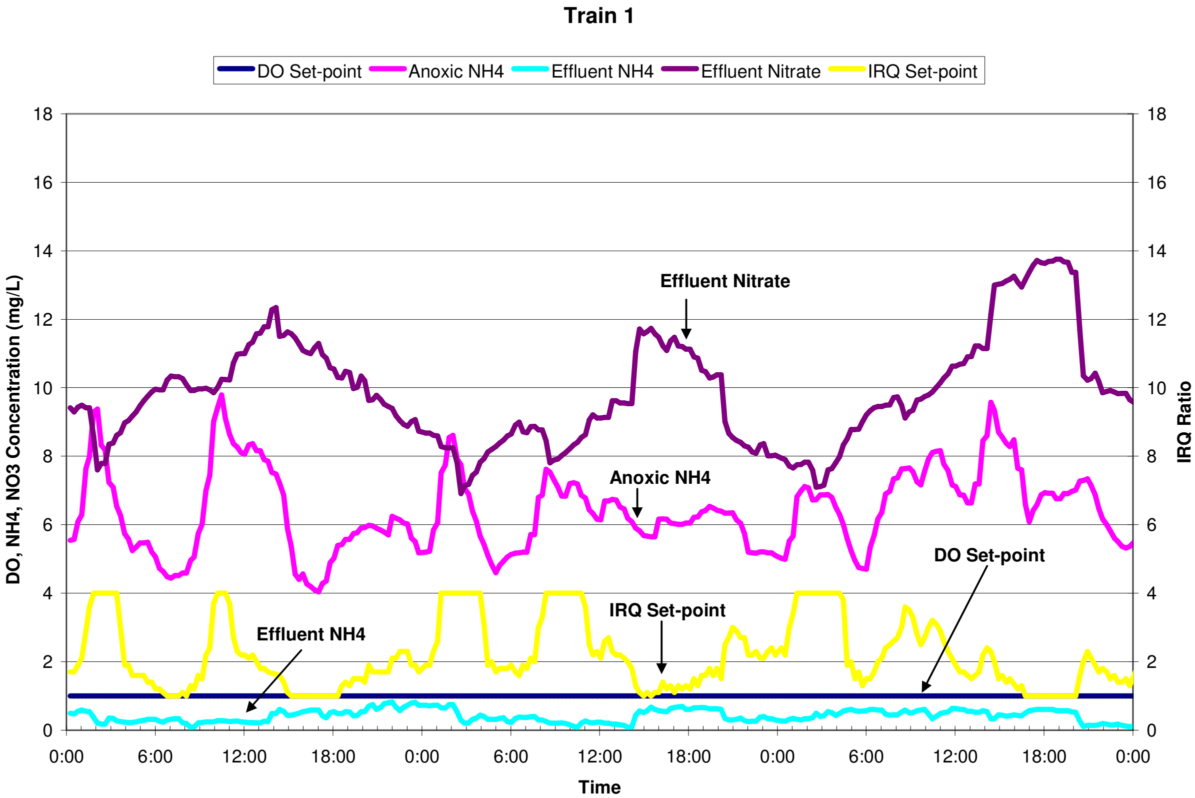


**Figure 7: Train 1 Typical DO and IRQ Set-point Control, Upgraded Process**

The advanced control system performs similarly in Train 3, shown in Figure 8, with the primary difference being a lower average IRQ set-point. The average IRQ ratio for Train 1 is 2.03 compared to 1.72 for Train 3. This difference is due to the anoxic zones of Train 3 being 18% smaller than the anoxic zones of Train 1 or 2 and hence lower denitrification capacity. Like Train 1, the DO set-point is held at its minimum allowable value of 1.0 mg/L due to excess nitrification capacity. Long term data on the performance of the upgraded process is not available due to the recent start-up of the process.

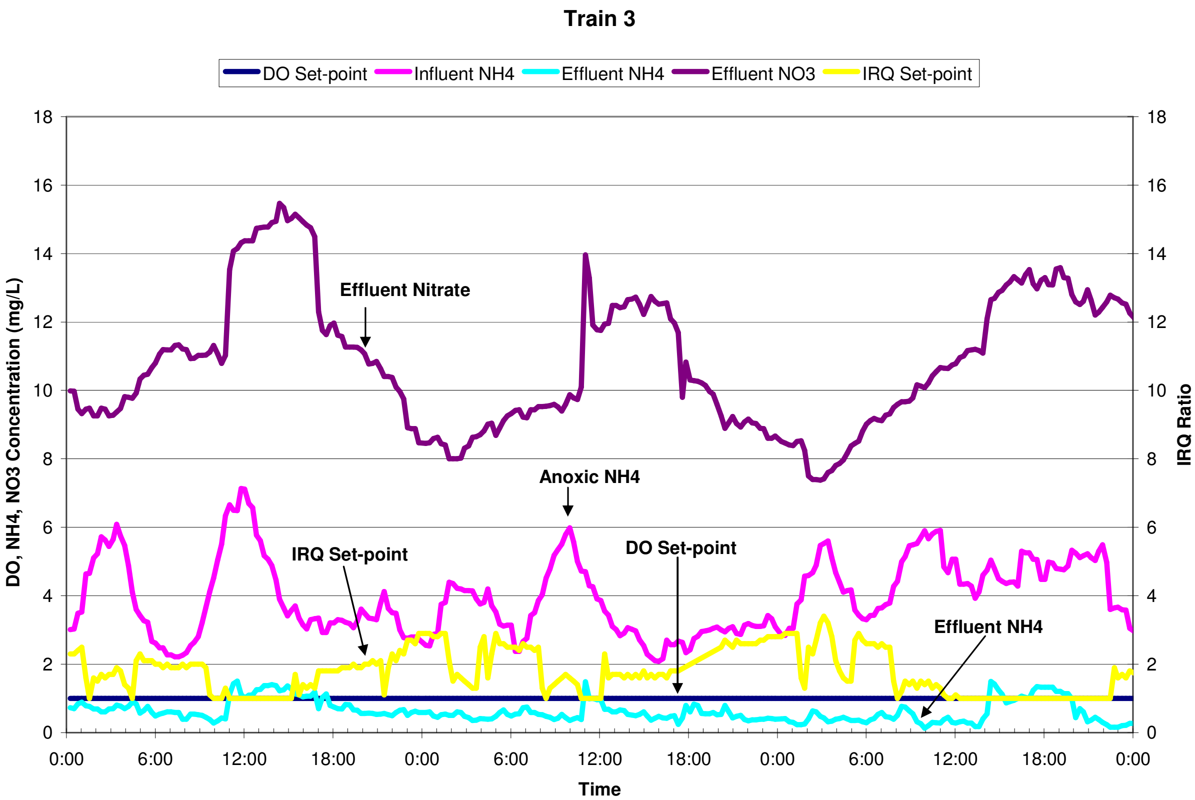


**Figure 8: Train 3 Typical DO and IRQ Set-point Control, Upgraded Process**

## CONCLUSIONS

Since 2005, the BIOS advanced control system has been successfully operating at Abington WWTP. The benefits of this system have been decreased aeration requirements leading to energy savings, reliable effluent ammonia values, and optimized anoxic zone usage. Long term performance data of the upgraded system will be available once sufficient time has passed to fully evaluate the system.

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