COMMUNITY UTILITIES OF PA, INC.
PENN ESTATES WASTEWATER TREATMENT FACILITY
STROUD TOWNSHIP, MONROE COUNTY, PENNSYLVANIA

NPDES # PA0060283

DENITRIFICATION STUDY

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pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION
WASTEWATER TECHNICAL ASSISTANCE PROGRAM

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Disclaimers:
The mention or use of a brand of equipment is not an endorsement for any manufacturer or vendor. The Department urges the permittee to research available products and select those which are the most applicable for its situation and compatible with existing equipment.

The goal of the Department's Wastewater Optimization Program is to improve receiving water quality through training, troubleshooting, and monitoring. Permittees will be encouraged to achieve effluent quality above and beyond current permit requirements.

TABLE OF CONTENTS

ATTACHMENTS

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Executive Summary:

Pennsylvania Department of Environmental Protection (DEP) Bureau of Clean Water Wastewater Technical Assistance Program (WWTAP) staff worked with the operator and staff at Penn Estate's wastewater treatment facility, located in Stroud Township, Monroe County, to employ intermittent aeration in secondary activated sludge treatment to achieve natural denitrification of clarifier effluent. Continuous-monitoring submersible probes were deployed to monitor various activated sludge treatment qualities and conducted concurrent process monitoring tests on site from mid-April through June 2023. Prior to the start of the study, four chopper pumps were installed into the secondary aeration tanks to provide anoxic mixing during prescribed denitrification periods (aeration off). The clarifier return sludge air-lift pumps were modified by installing a separate, dedicated air compressor to return sludge from the clarifiers when the main blowers were off during anoxic mixing.

During this evaluation, facility staff consulted with DEP staff on a regular basis to adjust the process to achieve lower total nitrogen concentration in treated effluent. Probe data and laboratory testing confirmed that the facility would benefit from using intermittent aeration instead of its tertiary media filters with methanol addition as a means of meeting more stringent effluent quality standards required in the Penn Estates wastewater treatment facility's National Pollutant Discharge Elimination System (NPDES) Permit.

The study demonstrated that the use of intermittent aeration is highly successful when applied to conventional, flow-through secondary treatment systems, virtually negating the need for enhanced tertiary filtration that employs a supplemental carbon source. Effluent nitrate from the secondary clarifiers was reduced by over half, on average, below the NPDES Permit monthly average limit of thirteen (13) milligrams per liter (mg/L).

The principal benefits of employing intermittent aeration for process denitrification include:

- Removal of nitrite and nitrate in the finished effluent, reducing pollutants in downstream waters that are used for aquatic life, recreation, and for drinking water intakes;
- Reduction of electricity consumption because the aeration compressors do not have to be operated continuously;
- Reduction of chemical treatment costs related to satisfying alkalinity demand, because denitrification returns approximately half of the alkalinity consumed during nitrification of ammonia and organic nitrogen in the wastewater;
- Reduced potential for effluent permit violations that could result in civil penalties.

All these add up to winning outcomes from using intermittent aeration for denitrification. These are wins for the host community served by the treatment facility, for the facility owners and operators, for the regulatory community, and especially for the downstream users of the waters contributing to the Delaware River Watershed.

Recommendations:

Based on the outcome of the denitrification study and additional discussions with operations staff, the following recommendations are made for ongoing and future improvement:

1. Continue to use intermittent aeration as an alternative to capital investments into tertiary denitrification filter improvements, in order to meet and improve upon NPDES Permit requirements, by making permanent the practices and equipment demonstrated in this study.

2. Ensure all changes to the treatment facility are properly permitted and that any adjustments or changes are made to existing DEP issued Water Quality Management Part II NPDES Permits.
3. Following needed repair to the Rotomat headworks screening unit, inspect and maintain the device on a more frequent basis, initially within three months, then every six months, and keep spare replacement brushes and other critical parts in reserve.
4. Continue to improve upon the new blower system that operates the return sludge air-lift pumps. Work to more effectively balance the sludge blanket levels in the two clarifiers.
5. Install dissolved oxygen (D.O.) and oxidation/reduction potential (ORP) probes in the aeration tanks. D.O. probes would be most useful if used to regulate aeration blower output during oxidative processes, where the probe feedback through the controller can adjust motorized valves that control centrifugal blower air intake.[1] During the evaluation, the facility has been operating well; however, should denitrification become inhibited, the operator would benefit greatly from having ORP data available. At times of the year when it is favorable to control the intermittent aeration cycles using ORP-based control, the facility will see benefits of reduced energy consumption and costs for aeration. Control of D.O. through automated process and the use of D.O. probes will prevent over-aeration that will limit the effectiveness of denitrification during the anoxic phase.
6. If budget allows, other immersion probes that monitor effluent nitrate and ammonium and pH probes at the influent splitter box or in the secondary aeration tanks may prove useful, although they are not necessary if the operations staff is regularly sampling and testing throughout the facility. The organic carbon probe used to monitor influent wastewater organic carbon may be a high-end luxury; operators can easily monitor chemical oxygen demand using laboratory methods that require only two hours of sample digestion. Please see Attachment G for further information on probes.
7. Have the facility consulting engineer evaluate the condition of the aerators and aeration delivery to the secondary treatment process. Replace broken or inoperable diffusers and consider ways to drain, clean, inspect, and repair the aeration tanks and secondary clarifiers on an annual or biennial basis or at least once per permit cycle.
8. Also, have the facility engineer evaluate ways to better deliver alkalinity chemicals to the secondary process using metering pumps or add as slurry, preferably over the course of the day instead of simply emptying sacks of chemical powder into the facility. During the evaluation, the operator attempted to use a day tank to deliver the chemical as recommended, but a designed alternative may prove more efficient.
9. Automation of data management is useful, and trending of process monitoring data should be readily available to the operator to see what's happening when conditions are favorable or not. If installing monitoring probes, consider having readily accessible graphics included in your Supervisory Control and Data Acquisition (SCADA) system programming, giving the operator ability to call up graphs covering specified periods of time. (Overall, most aspects of the operations should be accessible as graphs for assisting the operator in making process control decisions.)
10. Continue to monitor nutrient levels at the facility on a frequent basis, using both grab and composite process samples, at least once per week until the operators have sufficient familiarity with their facility's nutrient load to both characterize their operation and to warn them when the process is trending toward process failures.

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[1] Centrifugal blowers operate at constant speed and cannot be regulated using variable frequency drives on their drive motors. Instead, the aeration output is regulated by adjusting the air intake valves to the centrifugal blower units. (This is how it is done at the Ligonier Township facility.) It is not possible to throttle the outlet valves of centrifugal blowers, as doing so would damage the compressors.

11. Consider connecting the final effluent residual chlorine analyzer ~~tied~~ into the SCADA system to provide continuous monitoring and recording, with the necessary alarm set points to notify operators if Total Residual Chlorine (TRC) concentrations exceed NPDES Permit limits.
12. Consider erecting catwalks around the secondary treatment tanks to give operators safe and efficient access to the new chopper pumps for maintenance and to properly maintain and clean the clarifier weirs and launders. Alternatives to manually cleaning the clarifiers may include installing brushes on the skimmer arm or covering the launders to reduce the effects of sunlight on algae growth.
13. Develop in-house monitoring and methods for effectively tracking sludge wasting to the digester, including regular total solids testing, and consider metering or measuring volume of sludge wasted, so that operators may better quantify sludge wasting and other standard operating parameters such as mean cell residence time (MCRT) or solids retention time (SRT).

Wastewater Treatment Evaluation:

Background:

During the Spring of 2023, the DEP Bureau of Clean Water's WWTAP staff deployed continuous-monitoring probes at the Penn Estates Wastewater Treatment Facility in Stroud Township, Monroe County, to assist facility operators in developing process control to meet effluent nitrate and ammonia limits mandated by its NPDES permit and in support of efforts by the Delaware River Basin Commission (DRBC) to reduce nitrate pollution in the Delaware River watershed. A listing of the evaluation team follows in Attachment A. Penn Estates is a privately managed, two-square-mile community of 1,500 houses in the Poconos, with a total population of approximately 4,500 people. The wastewater facility has a rated treatment capacity of up to 560,000 gallons per day (gpd), averaging 235,000 gpd during the study. The project included weekly process monitoring tests to verify nutrient removal efficiency of the activated sludge treatment process.

The wastewater treatment plant consists of a mechanical screen, influent flow equalization tanks, two aeration tanks in a circular configuration, two clarifiers, a sludge holding tank, five denitrification filters, a chlorine contact tank, and dechlorination tank. Support facilities include aeration centrifugal blowers, chemical metering equipment, chemical storage tanks, a process monitoring laboratory, automatic composite samplers, administrative office, workshop, and associated structures. Technical assistance was requested to improve compliance with ammonia and nitrate limits in the NPDES Permit. Continuous immersion probes were placed in the two aeration tanks to monitor D.O., pH, ORP, and total suspended solids (TSS). An organic carbon probe for measuring wastewater strength was placed in the influent splitter box upstream of the two aeration tanks, and probes to detect effluent ammonium- and nitrate-nitrogen were installed in the supernate column of one of the two clarifiers. A probe placement diagram may be found in Attachment B, and selected record photographs are found in Attachment D.

Nitrification is a biological process performed by bacteria that converts ammonia into nitrate. This process demands much oxygen for respiration and alkalinity as a source of inorganic carbon. For every pound of ammonia that is nitrified, 4.6 pounds of oxygen and 7.2 pounds of alkalinity are consumed.

Denitrification is a biological process performed by heterotrophic bacteria that reduces nitrate to nitrogen gas. This process requires anoxic conditions (absence of free oxygen) and food in the form of organic carbon.

The WWTAP program suggested converting the wastewater plant to intermittent or "on/off" aeration to utilize the aeration tank as the point where both nitrification and denitrification occur, an alternative to using the tertiary filters. When denitrification takes place in the aeration tank both alkalinity and oxygen are returned to the process reducing operational cost. In order to do this, mixers must be installed in the aeration tank to maintain bacterial contact with both influent carbon and a bound oxygen source, nitrate, mixing while the aeration blowers are off. Following depletion of dissolved oxygen in the tanks, bacteria begin to utilize nitrate for respiration.

The facility owner, Community Utilities of PA, Inc. (CUPA), a Corix Company, has been renovating Penn Estates' collection system and pumping stations to reduce inflow and infiltration to the treatment facility, where hydraulic surges during short periods of wet weather contributed to difficulty managing the treatment process. Inflow occurs when surface water enters the collection system through openings like drains or rain gutters. Infiltration is the entry of surface water through cracks or beaks in the collection system pipes and/or fittings.

Four 5-horsepower chopper pumps were installed along the outside walls of the aeration tank for anoxic cycle mixing pumps and an auxiliary blower was installed to operate the sludge return airlifts while the main aeration blowers were off during the anoxic cycle. The operators at Penn Estates then began alternating cycles of aeration using compressed air with periods of mixing without aeration, a process known as "intermittent" or "on/off" aeration. Timers were utilized to allow for two hours of aeration in the aeration tank, followed by one hour of anoxic mixing with no aeration in the aeration tank.

Optimizing biological nutrient removal in the activated sludge process will spare the expense of tens of thousands of dollars in improvements to effluent denitrification filters while achieving compliance with DRBC mandates. In addition to this, WWTAP staff also recommended that facility staff increase supplemental addition of alkalinity to the activated sludge process to improve reduction of ammonia-nitrogen. Using intermittent aeration has thus far been extremely successful, with post-implementation average nitrate-nitrogen concentration being 6.5 mg/L and as low as 3.3 mg/L, down from an average of 11.4 at the start of the project, where maximum concentration had reached 23.4 mg/L. Secondary effluent ammonia levels averaged 0.33 mg/L following hauling of excess settled material stirred up by first use of the chopper pumps, with a minimum of 0.7 mg/L during the period. This was down from a pre-project surveillance average concentration of 5.3 mg/L and a maximum of 19.4 mg/L. A graph shown below depicts the reduction of Nitrate-Nitrogen in clarifier effluent.

This has been a Win-Win-Win for all participants. It is a win for users of the watershed as better quality effluent is being discharged on a regular basis, a win for the Penn Estates community and its wastewater treatment facility as operational cost will be reduced (cost savings on alkalinity and electricity savings,) and a win for regulators, such as the EPA and DEP with improved permit compliance.

Scope of Work:

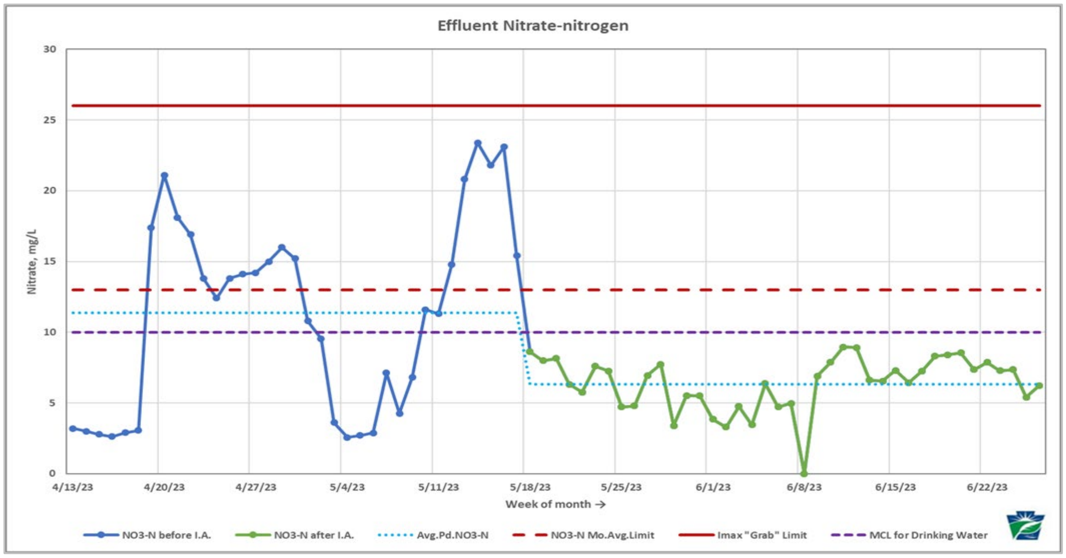
For the purposes of this study, the wastewater treatment evaluation (WTE) was limited to biological nitrogen removal in the secondary activated sludge treatment process. The WTE did not consider collection system with pumping stations, flow equalization, tertiary filtration, or disinfection processes. Where relevant to the secondary treatment, some examination of the plant headworks and chemical amendments was considered. Recommendations may include processes affecting efficiency of secondary treatment to improve performance.

Process Monitoring:

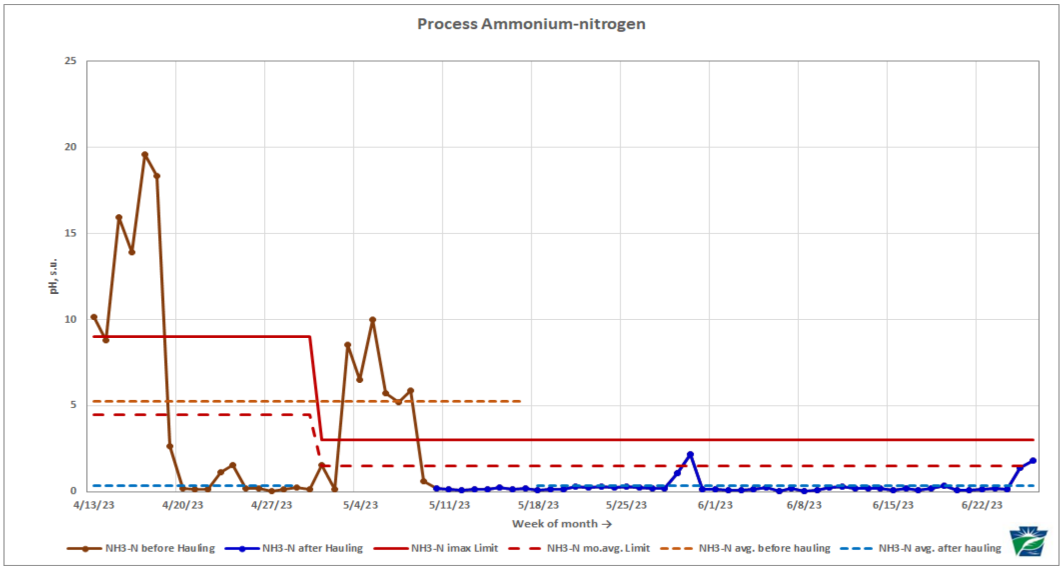
Facility staff conduct daily testing and analysis in their onsite process monitoring laboratory. The facility has electronic flow monitoring and video visualization of tertiary filtration. Compliance testing of influent and effluent samples is contracted to Suburban Testing Laboratories off-site.

DEP staff, as part of their routine monitoring of their probe network, regularly graphed data recorded by the probes and issued weekly updates. They also conducted weekly process monitoring tests including colorimetric analysis for nutrients and wastewater strength. Secondary treatment monitoring included routine wastewater lab tests such as suspended solids by volume, sludge settleability and clarifier core sampling, oxygen uptake and respiration rate tests, and checks of process pH and D.O. Early in the study, a limited dissolved oxygen profile was developed of the two aeration tanks. Graphs of probe and lab data are provided in Attachments C and H.

Most significantly, use of intermittent aeration has resulted in marked reductions of effluent nitrate concentration, now often below the drinking water Maximum Contaminant Level (MCL) of ten (10) mg/L, which is a great improvement to downstream surface waters. This nitrate reduction is seen in the in this graph:



At the same time, operators preserved an exemplary level of nitrification of organic and ammonia wastes entering the facility:



It is important to understand that, with respect to nitrogen reduction, the processes of nitrification and denitrification work in tandem. A more detailed discussion of this is provided in Attachment E, following. Simply viewing denitrification without comparing ammonia oxidation with reduction of nitrate may lead an operator to think that denitrification is working well when in fact ammonia isn't being oxidized to nitrate in the first place. This showed up in the review of historical process monitoring data where sometimes effluent nitrate was lower than expected but when effluent ammonium was elevated. It is important to test the ammonia nitrogen entering in the raw wastewater. Effective nitrification, which requires controlled aeration in the presence of ample carbonate alkalinity, will yield almost as much nitrate-nitrogen when denitrification is not employed. Comparing effluent nitrate and ammonia in the graphs produces three conditions:

- high ammonia, low nitrate means insufficient nitrification;
- low ammonia, high nitrate means effective nitrification;
- Low ammonia, low nitrate means effective denitrification.

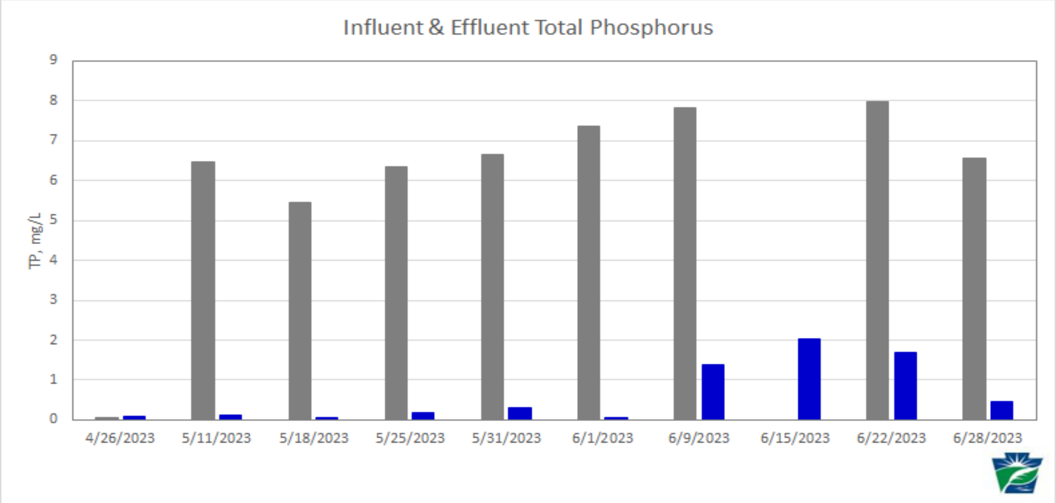
Achieving low concentrations of both effluent ammonia and effluent nitrate, as performed during this study, produces a triple win for all. Elimination of nitrate in the treated secondary effluent reduces the need for tertiary filter upgrades and the use of supplemental methanol there. It improves effluent quality and reduces chances of NPDES permit violations and civil fines. Reduced nitrogen in the effluent improves receiving stream quality and ultimately reduces nitrogen loading to the Delaware river and bay, an objective of the DRBC.

Energy and chemical cost savings are a benefit for all.[2] Reduced costs for electricity may prevent or slow customer rate increases. They provide for less wear and tear on the aeration blowers and infrastructure. Less electricity and chemical use lead to increased savings of carbon pollution from the atmosphere at power generation and chemical manufacturing plants, along with reduced carbon pollution from chemical transport and shipping. The environment shared by owners, operators, regulators, and customers is preserved and improved.

Other process monitoring demonstrated improvements to biomass health and quality. After the worst of the settled inert solids and detritus were removed from the aeration tanks, and after the clarifiers were drained and cleaned during Return Activated Sludge (RAS) pump improvements, the activated sludge appeared to be healthier and more robust. The charts and data presented below and, in the attachments, demonstrate that the facility is in a better place than before.

Phosphorus Removal:

Biological phosphorus removal was not part of the scope of work; however, phosphorus testing during process monitoring has shown that chemical reduction of phosphorus at this facility, using forms of poly-aluminum chloride (PAC) combined with tertiary filtration, effectively eliminate effluent phosphorus to below permit requirements. This graph compares the influent and effluent total phosphorus concentrations during the study:



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[2] Chemical cost savings, that is, if alkalinity addition has been reduced from actual initial alkalinity demand by denitrification's regeneration of half the alkalinity consumed during nitrification. Were alkalinity addition not closely monitored prior to employing intermittent aeration, there might be a net cost increase when the facility is now supplementing the recommended amount of alkalinity required for complete nitrification.

Disinfection:

Penn Estates wastewater treatment facility uses sodium hypochlorite solution for effluent disinfection in chlorine contact tanks, followed by elimination of chlorine residual using bisulfite solution prior to effluent discharge. The facility employs a continuous monitoring device for total residual chlorine, and TRC is typically near or at non-detect concentrations. Continuous monitoring data should be available to the facility operators for trending and diagnostic use, and it is recommended that the outputs from this device be incorporated into a SCADA system.

Records:

During the evaluation, DEP staff reviewed eighteen months of operating and laboratory records. Graphs of this data were constructed in Excel workbooks that are available to the operators should they wish to digitize their process monitoring records going forward. Graphing of operational data allows staff to develop and observe treatment trends, useful both in understanding baseline behavior of the process and in predicting potential adverse outcomes days in advance of process upsets. Many operations reference manuals include explanations of trends observed in process monitoring tests.

Based on the records review, DEP staff recommended some minor changes, such as increased nutrient monitoring if intermittent aeration is to be continued permanently. It was also recommended that sludge solids monitoring internally be more frequent to characterize the sludge density hauled off site for disposal.[3]

Process Improvements:

During the study, the owners and operators discovered that the air compressor installed for transferring RAS from the clarifiers to the aeration tanks had been partially insufficient. The air headers to the lift pumps were modified using larger bore pipe. There continues to be difficulty balancing the sludge blankets in the two secondary clarifiers. One clarifier blanket would be up to twelve feet thick while the other, only about a foot or two. The operators indicated that additional improvements were forthcoming.

Power and control wiring to the anoxic mixing pumps, originally installed as a temporary measure, were refastened to assure a longer duration. Plans to install conduit and bracing for this will assure more permanence. In addition, the anoxic mixing pumps had to be cleared of initial clogging caused by settled detritus in the aeration tanks. Staff is aware of the need for permanent scaffolding at the pump jacks to assure regular maintenance.

While starting the anoxic chopper pumps in early May, plant staff discovered that there were large amounts of settled inert solids and detritus stirred up in the aeration tanks. This material created problems downstream at the clarifiers, resulting in solids losses and loss of nitrification. Sludge wasting and hauling off-site was increased to remove as much of this as possible. In the weeks following, the pumps further macerated the remaining detritus so that the quality of the suspended biosolids improved.

Alkalinity addition in the form of soda ash was increased to meet the alkalinity demand of the raw wastewater organic and ammonia nitrogen load. Initially, alkalinity demand was on the order of approximately three hundred pounds per day, but as denitrification proceeded, this demand was reduced because biological denitrification returns approximately half of the alkalinity consumed during nitrification of ammonia. By the end of the study, operators were adding approximately

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[3] Total Solids Test on digester contents, done on samples taken the day that solids are hauled from the facility. The percentage is reported on the Biosolids Supplemental Worksheet.

one hundred to one hundred fifty pounds per day of soda ash.[4] Early in May, an attempt had been made to wet the soda ash used and deliver it as a solution to the aeration tanks through chemical metering pumps. This trial proved ineffective in the short term; however, DEP staff suggested that wetting the chemical and delivering it over the course of the day is a more effective method of adding alkalinity than simply adding dry powder or pellets to the influent wastewater. Over the course of May and June, alkalinity concentration in the aeration tanks improved according to dosage recommendations made based on influent ammonia-nitrogen concentration. As denitrification improved, where up to fifty percent of alkalinity consumed in nitrification is biologically returned to the activated sludge, the operators were able to reduce the quantity of soda ash required to meet daily alkalinity demand. A further discussion of alkalinity demand follows in Attachment F.

During the study, DEP staff suspected that some of the aeration branch lines for secondary treatment may be damaged or in disrepair. An unfortunate quality of the existing tankage is that the operators are unable to temporarily bypass and drain either of the two aeration tanks for inspection and maintenance, so it is conceivable that repair of the aeration system has been wanting for several years. Nevertheless, sufficient aeration exists to fully nitrify ammonia on a consistent basis. It is recommended that the facility engineer consider ways to temporarily remove aeration tanks from service for inspection, maintenance, and repair. One of the potential concerns about doing this one tank at a time is whether either of the existing above-ground tanks may be fully drained without risking bulkhead failure at its intersection with the other tank when full. It may be necessary to acquire temporary aeration and treatment vessels for use during such planned maintenance, while it may also be possible to employ much of the existing flow equalization and sludge holding tankage for this purpose, with ample temporary modification to provide sufficient air diffusion.

One of the principal recommendations for facilities planning Biological Nutrient Removal (BNR) improvements is that continuous monitoring probes be employed to control aeration and to monitor denitrification and process pH. DEP employed several different probes during this study, but the most important ones for BNR would be dissolved oxygen, ORP, and pH probes in both aeration tanks. Probe controllers would be useful in regulating blower output and chemical addition, chiefly using variable frequency drives, motorized valves, and chemical feed pumps, all tied into a SCADA facility. DEP staff noted that the centrifugal blowers used as the main aeration source cannot be connected to Variable Frequency Drives (VFDs), because these blowers require constant motor speed to operate. However, it is possible to regulate dissolved oxygen supplied from centrifugal blowers by regulating the air intake valves for the blowers, using motorized valves in a control feedback with the D.O. probes to assure that dissolved oxygen concentration in the activated sludge remain between one and three ppm for successful nitrification.

Aeration improvement recommendations also consider replacing coarse bubble diffusers with fine or ultra-fine diffusion, if it is possible to do so. Coarse bubble diffusion relies on creating a “roll” of the activated sludge mass in the aeration tanks, in this case from the inside walls to the outside walls. Replacing this by covering the floor of the tanks with a grid of fine bubble diffusers may change the quality of the complete mixing, and this would require further engineering to plan for an effective substitution.

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[4] Here, it is recommended that alkalinity addition be based on influent TKN loading, at a rate of 7.2 lb. as $CaCO_3$ for every pound of influent TKN. The chemical addition should be metered as a liquid slurry over the course of the day instead of being delivered in bulk once per day at the plant headworks. Attachment F provides further details.

For most of the study period, the screening facility at the plant headworks was improperly functioning. This allowed the introduction of considerable amounts of detritus and trash into the secondary treatment process, interfering with the performance of the chopper pumps used for anoxic mixing and, likely, with the aeration system. Operators had the brushes in the screen replaced, and screening and removal of untreatable material has improved significantly. In addition, while CUPA's website includes much-needed advice to sewer users to prevent flushing of trash and debris into the collection system, further and more direct customer outreach may be necessary to encourage them to reduce or eliminate the flushing on non-degradable material that should be disposed on in the household trash. Since most utility billing has moved on-line, using bill inserts may not reach all the desired audience. The operators and engineers for CUPA may want to consider training homeowners at public meetings in the community space or hosting small groups of homeowners for education and insight.

Results:

The study at Penn Estates has effectively demonstrated that using intermittent aeration for denitrification works well with conventional activated sludge systems without resorting to tertiary filtration or other designs, such as sequential batch reactors or Bardenpho.

Acknowledgements:

DEP gratefully acknowledges the contributions of CUPA employees and their contractors for inviting participation in this study and for providing equipment and service upgrades necessary to make it successful.

LIST OF ATTACHMENTS

Attachment A lists the study team members and summarizes the wastewater technical assistance program.

Attachment B is a schematic of probe and pump locations

Attachment C shows selected graphs of probe and process monitoring data

Attachment D contains record photographs

Attachment E has additional information on biological nutrient removal

Attachment F discusses calculating alkalinity demand to improve nitrification of influent ammonia wastes

Attachment G discusses purchase and maintenance costs for selected monitoring probes

Attachment H is a graphic of dissolved oxygen profile of the two aeration tanks

ATTACHMENT A: EVALUATION TEAM

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The DEP Wastewater Technical Assistance Program:

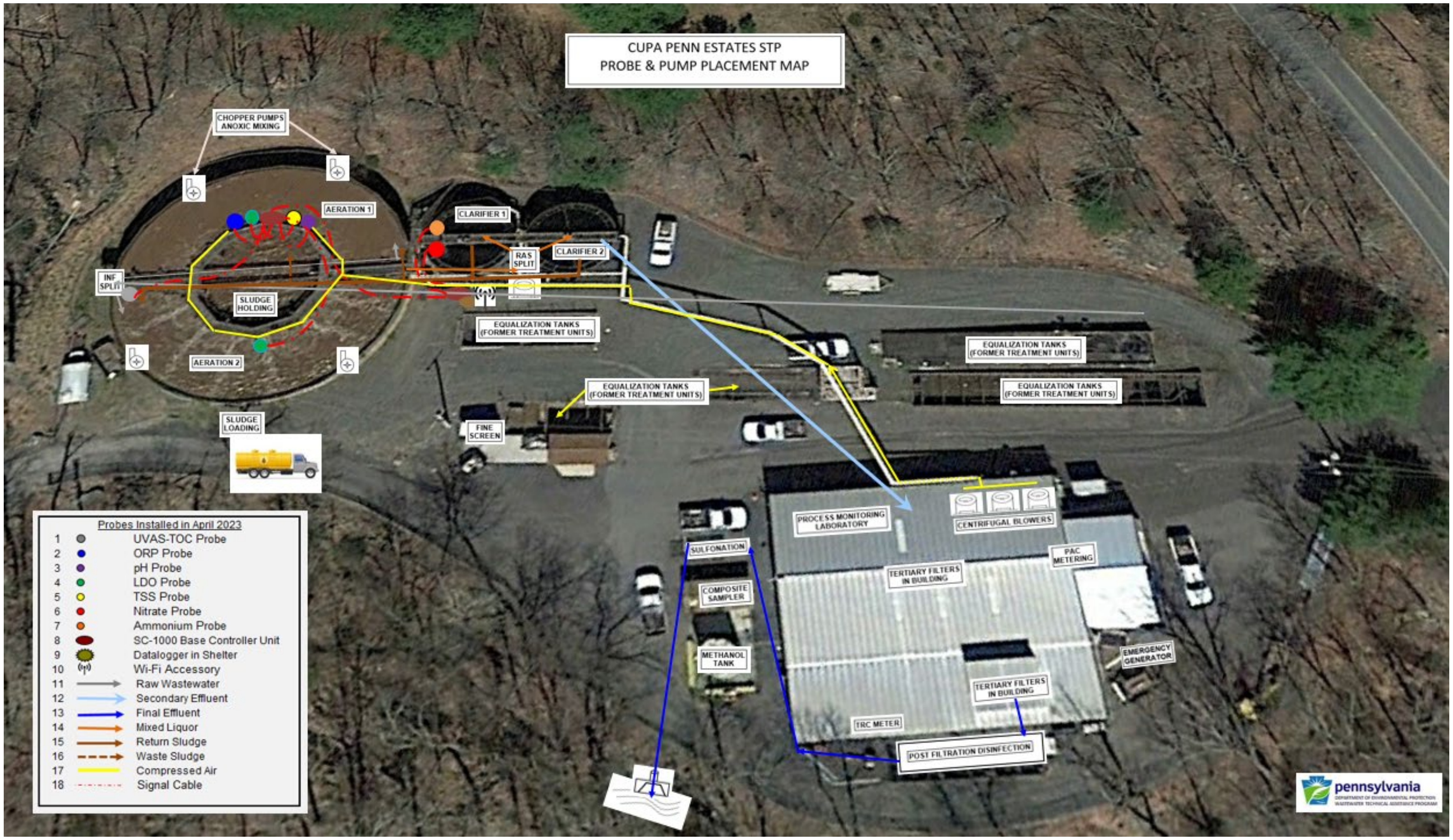
PADEP Bureau of Clean Water WWTAP offers a broad range of services including compliance assistance and on-site training in basic operational practices. An element of the program, the Wastewater Treatment Evaluation (WTE) employs instrument-based monitoring and analysis as an option for diagnosing problems and monitoring performance. This service, as originally constituted, seeks to improve effluent water quality at wastewater treatment facilities through establishment of sound process monitoring and control practices, and it is done with an emphasis on low-cost, easily practicable process adjustments rather than capital improvements and expenditures, although the latter is sometimes the only alternative to improving effluent compliance. Other aspects of WWTAP provide compliance assistance to facility owners and operators, but the instrument-based analysis seeks to build on existing compliance by promoting best practices, including laboratory-based monitoring, to achieve improvements in effluent quality that go beyond the basic requirements of a facility's NPDES permit.

Sometimes, it is not possible to enact low-cost improvements to a wastewater treatment process, and recommendations are made to investigate alternative treatment technologies that will incur significant capital investment to achieve improved effluent quality and more efficient operational practices. When this becomes evident, the data produced using instrumentation in a WTE may provide the basis for such recommendations. DEP strongly recommends that facility owners and operators work with their preferred consulting engineers to properly evaluate and implement any of a wide array of process improvements that ensure high-quality treated effluent and beneficial reuse of appropriately treated biosolids.

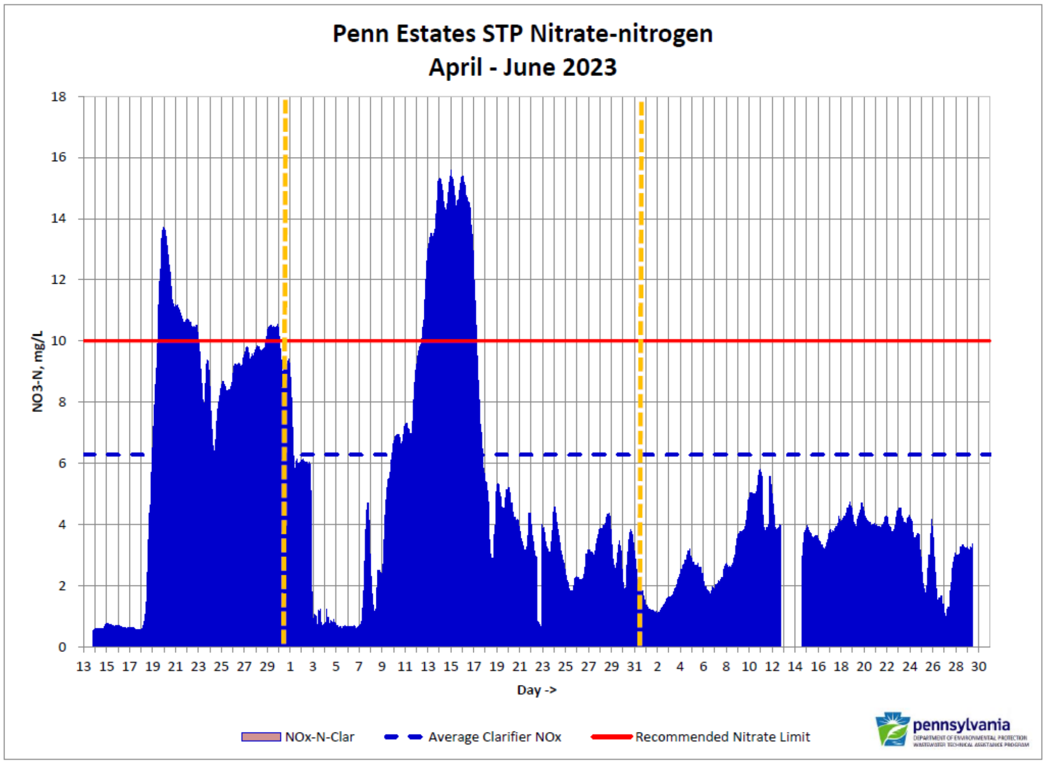
ATTACHMENT B: PROCESS SCHEMATIC & PROBE PLACEMENT

Community Utilities of Pennsylvania, Inc. Penn Estates
Wastewater Treatment Facility
Stroud Township, Monroe County, Pennsylvania

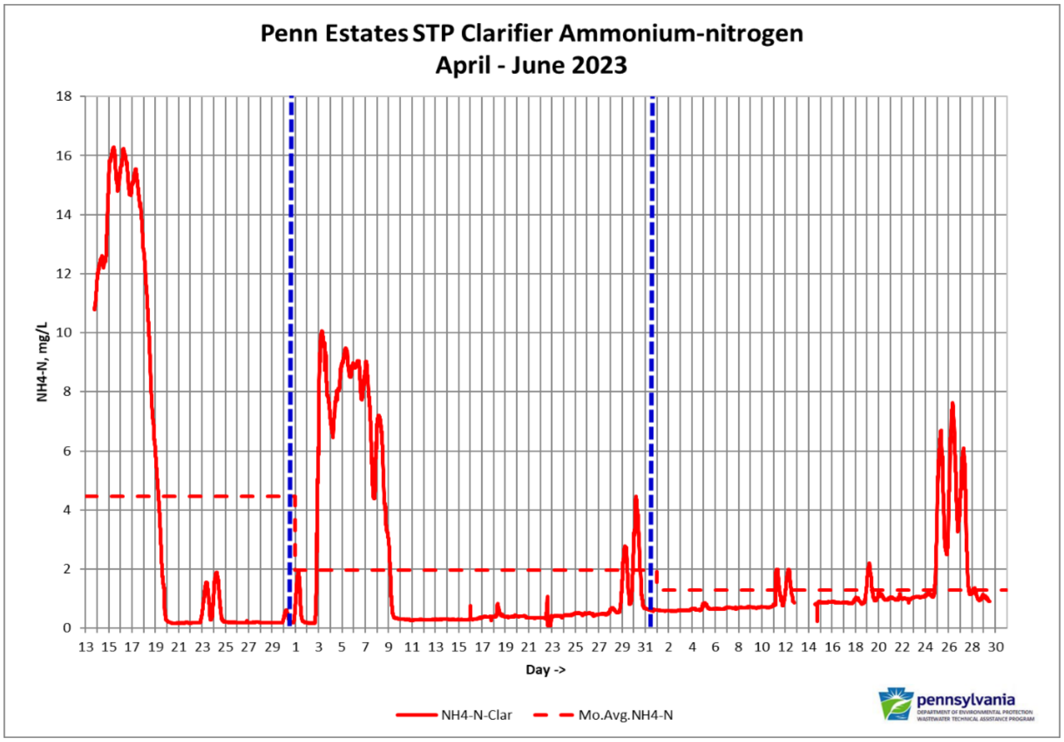
Probe Placement Diagram



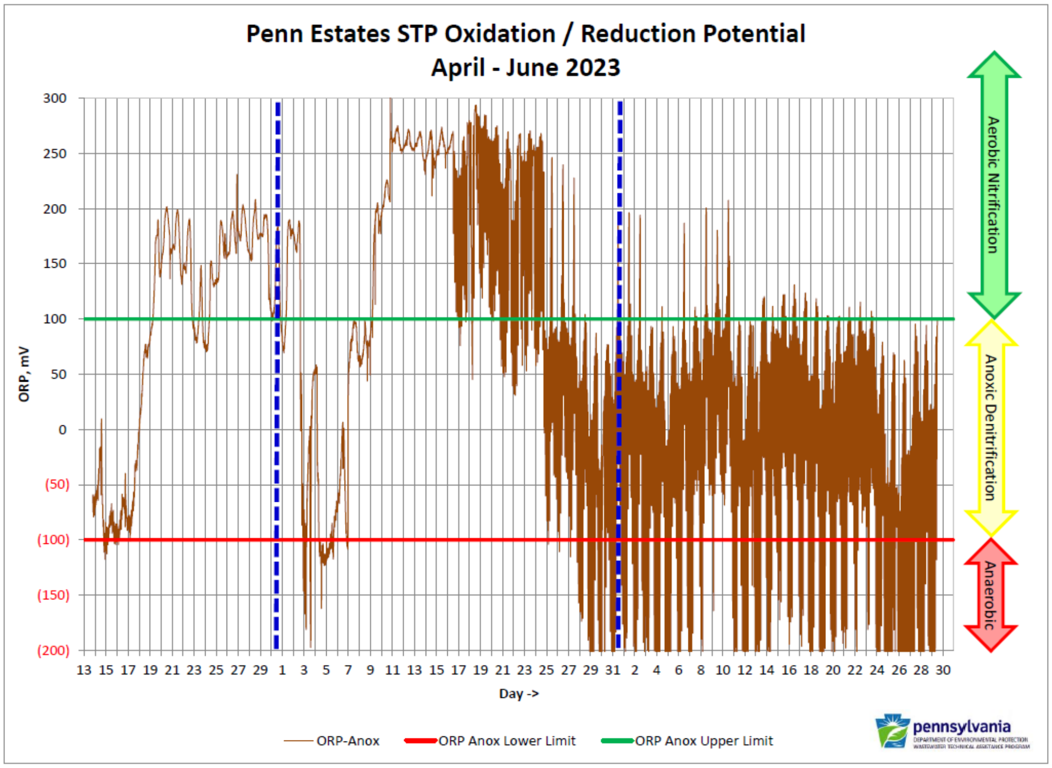
ATTACHMENT C: DATA GRAPHS



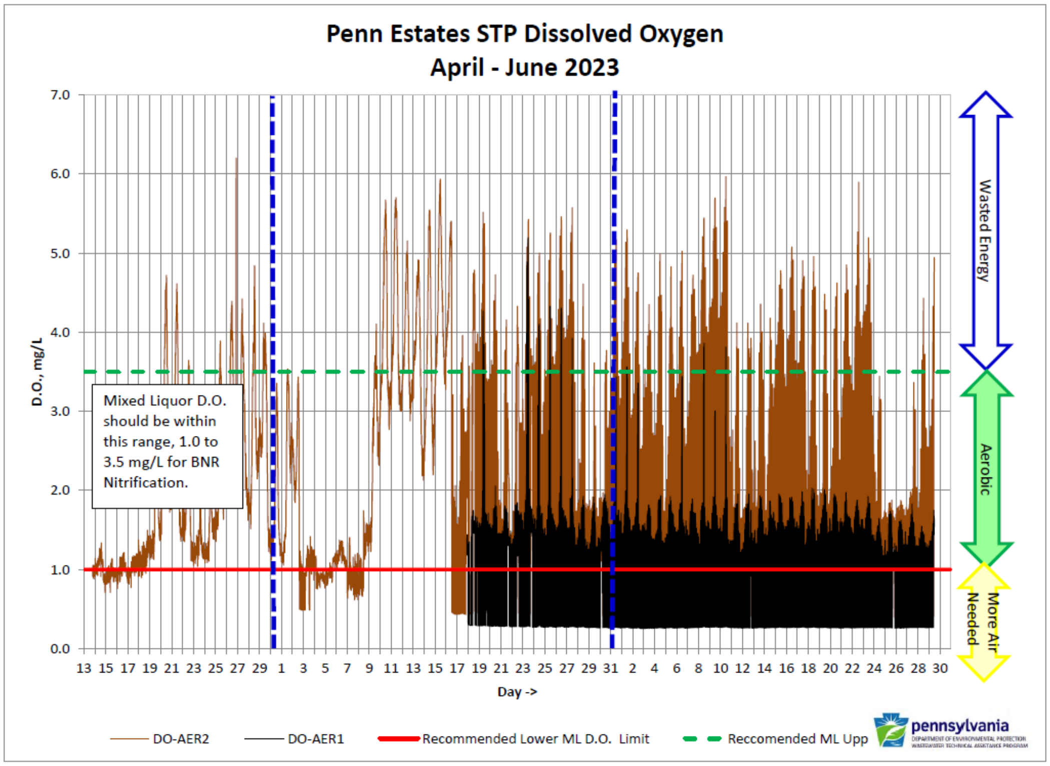
Nitrate-nitrogen Concentration, Secondary Clarifier Supernatant, full period: effective denitrification began in mid-May.



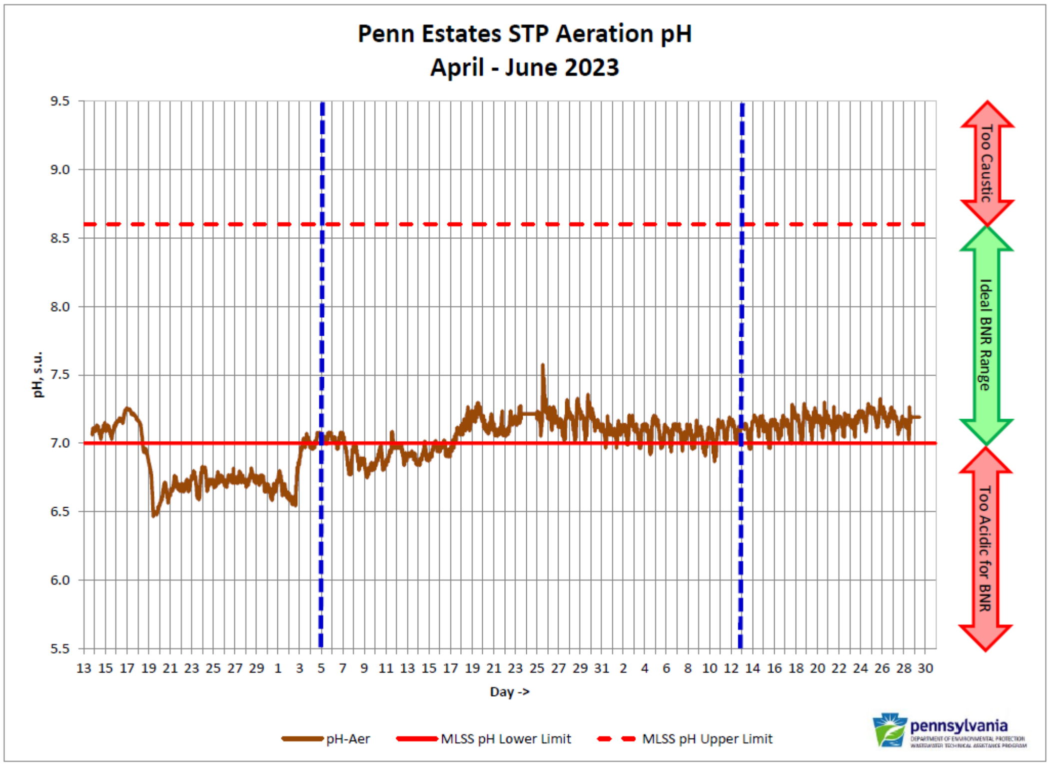
Ammonium-nitrogen, Secondary Clarifier Supernatant, full period



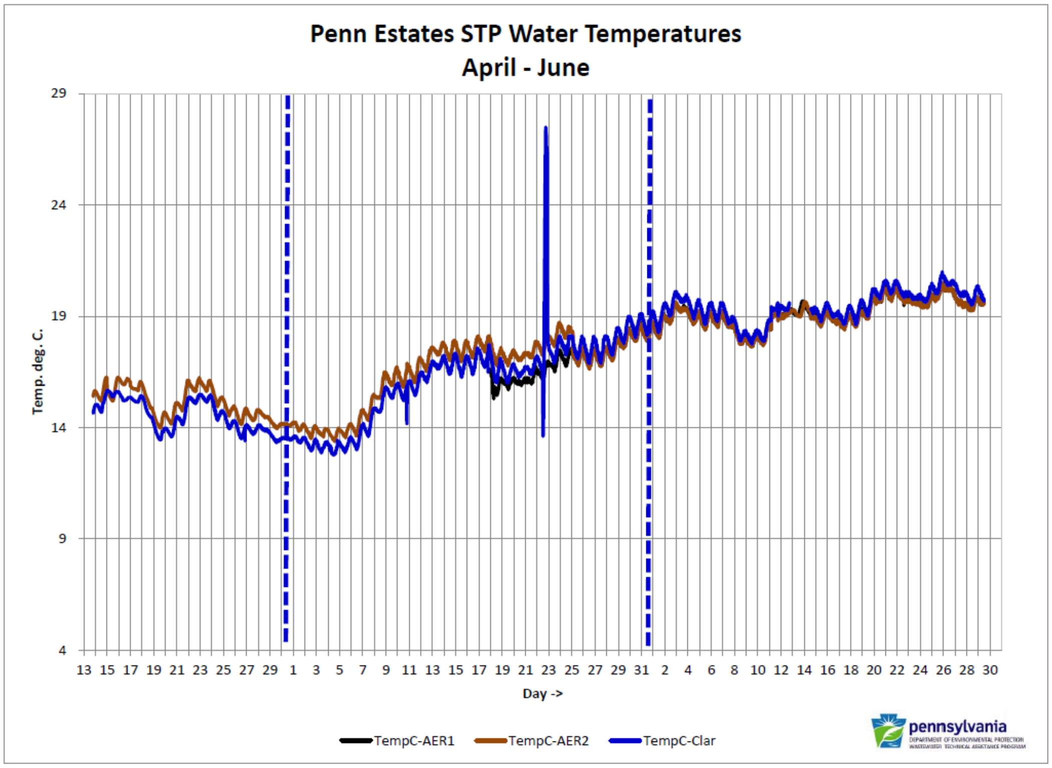
Oxidation / Reduction Potential, Secondary Aeration Tanks, full period



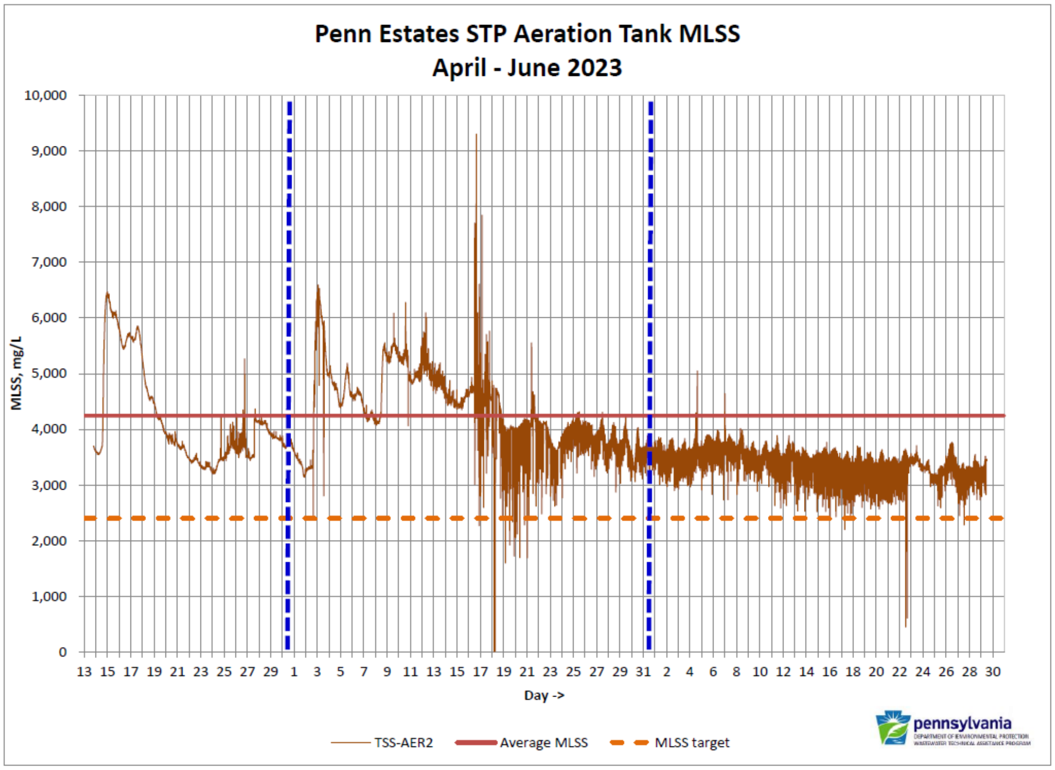
Dissolved Oxygen Residual, Secondary Aeration Tanks, full period



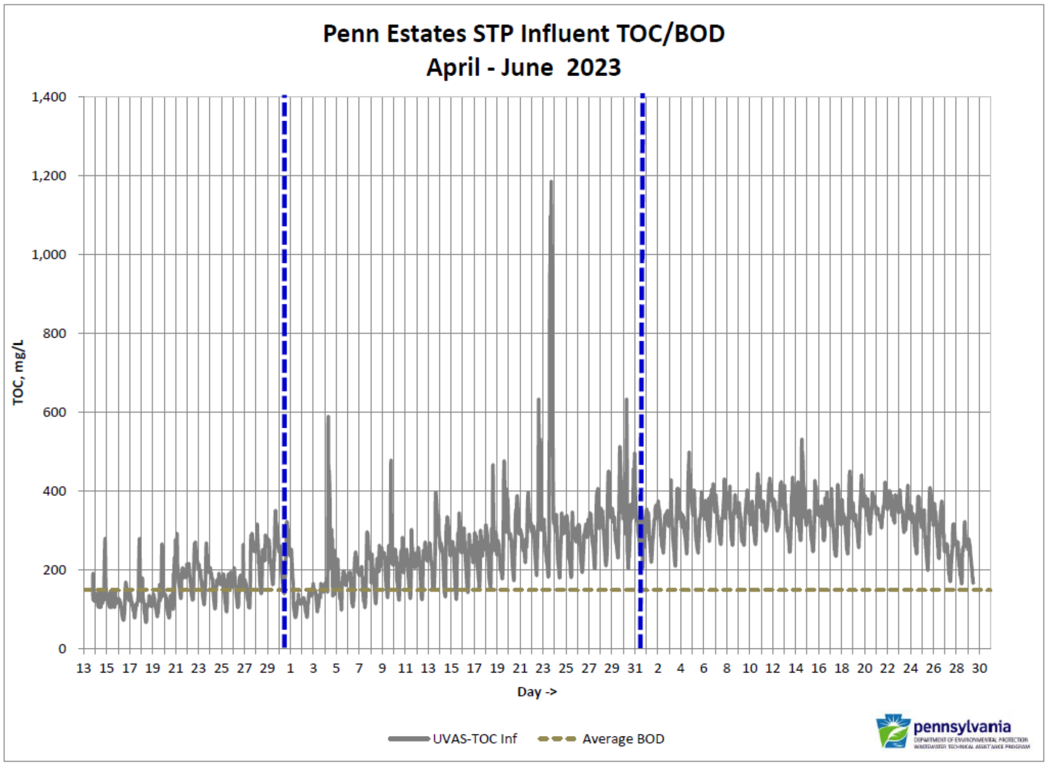
Mixed Liquor pH, Secondary Aeration Tanks, full period



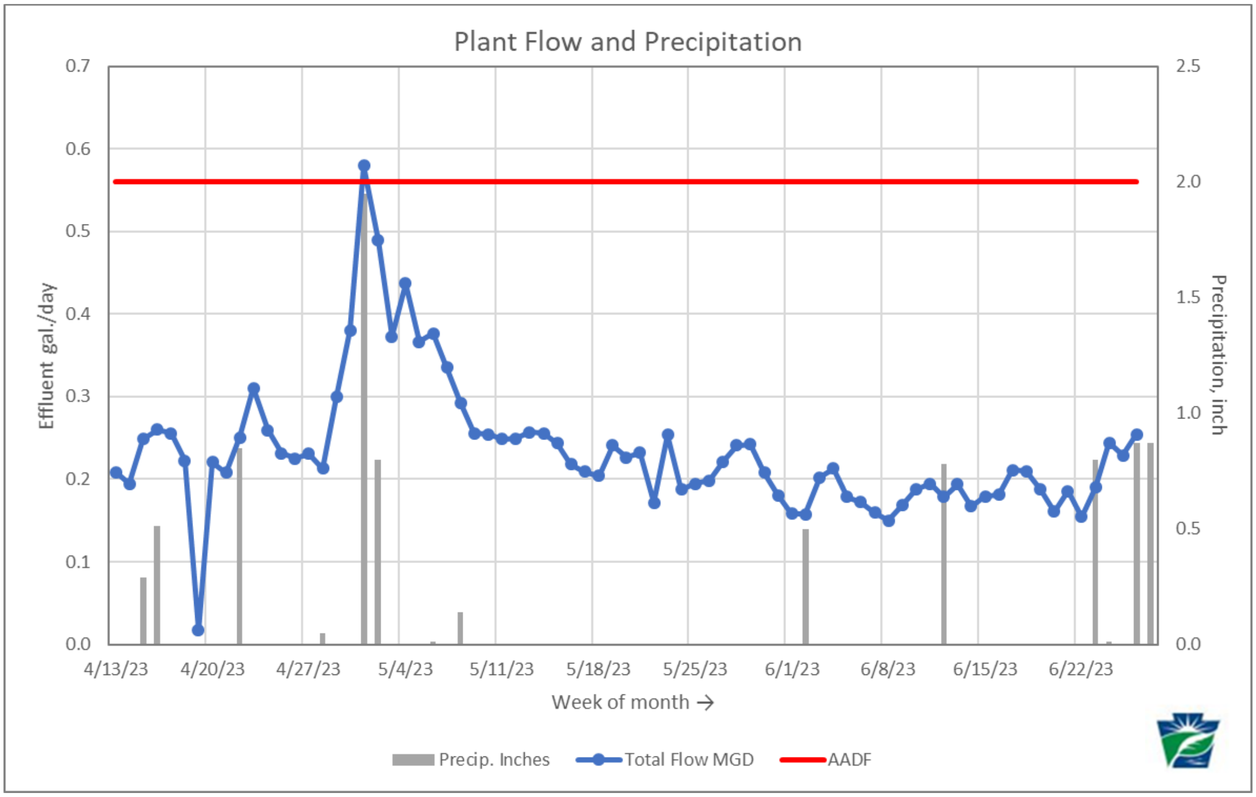
Secondary Process Water Temperatures, full period



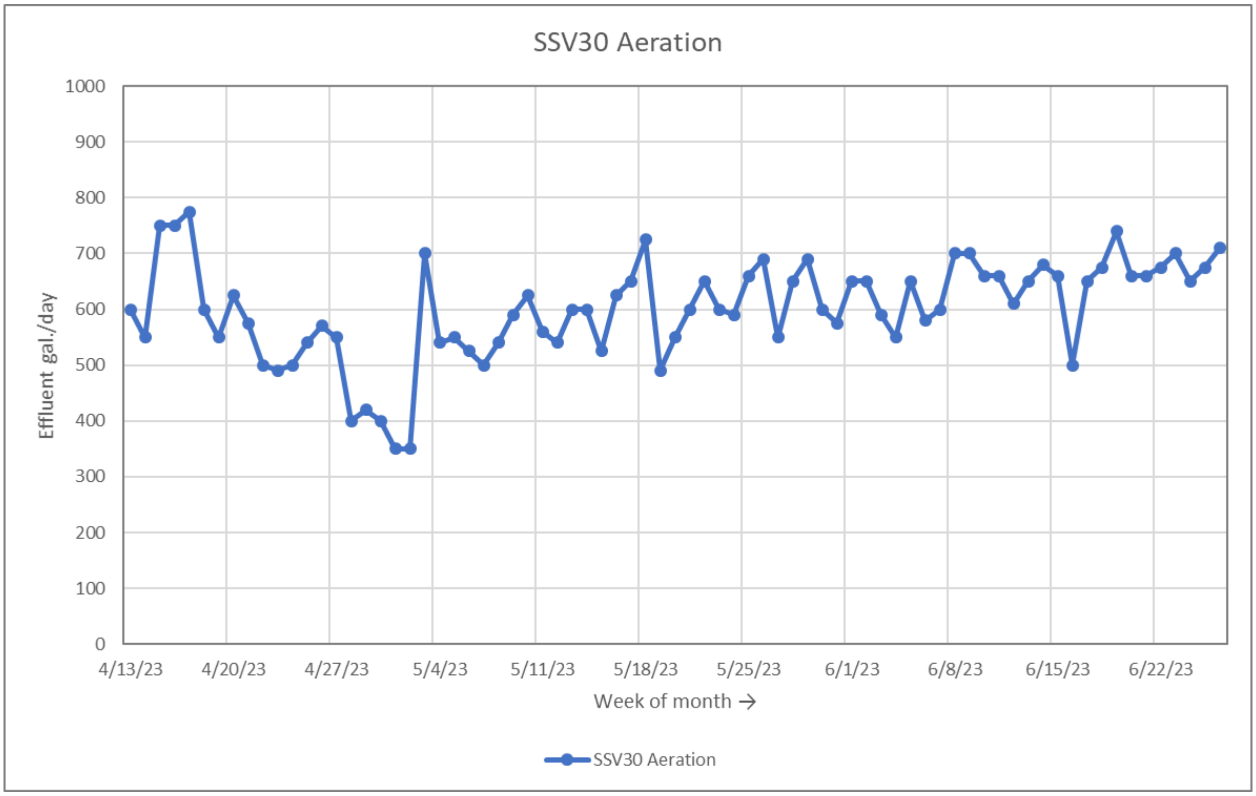
Mixed Liquor Suspended Solids Concentration, Secondary Aeration Tanks, full period



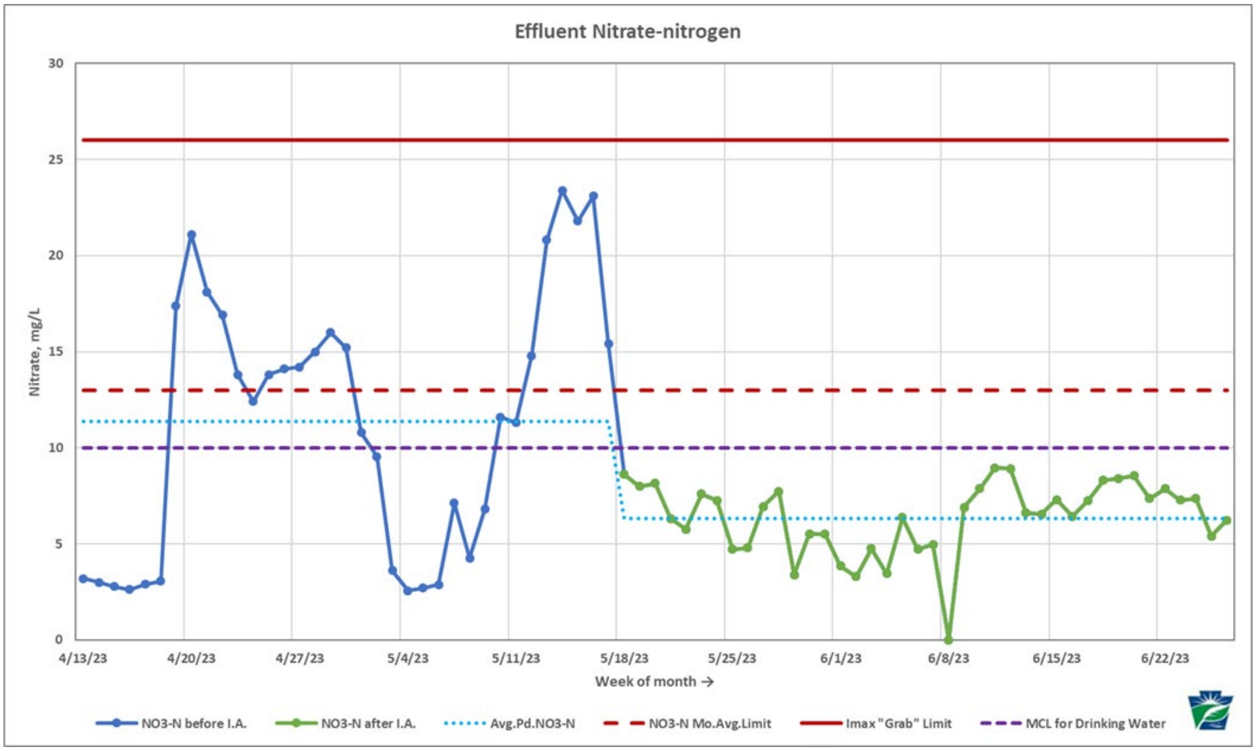
Influent Wastewater, Influent Splitter Box, full period



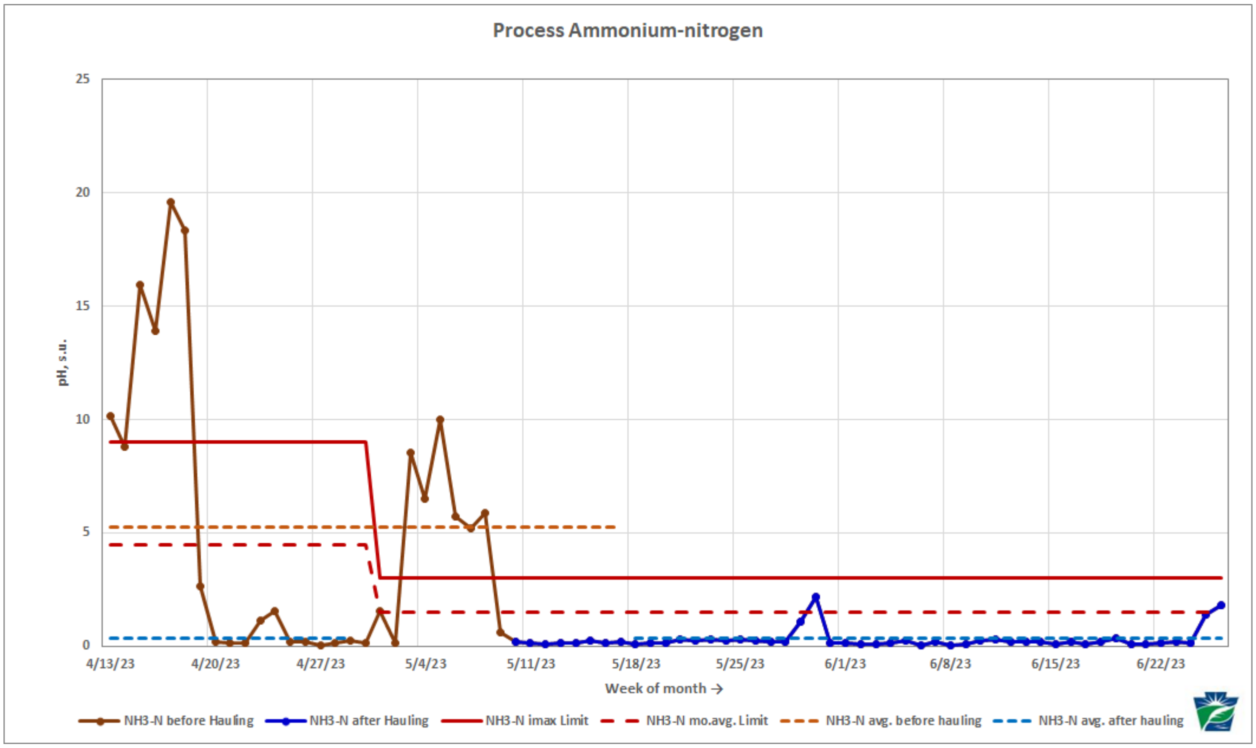
Facility Daily Flow and Local Precipitation: Heavy rain event at start of May saw concurrent increase in flow into the facility, which did cause a plant upset in the first days of the month.



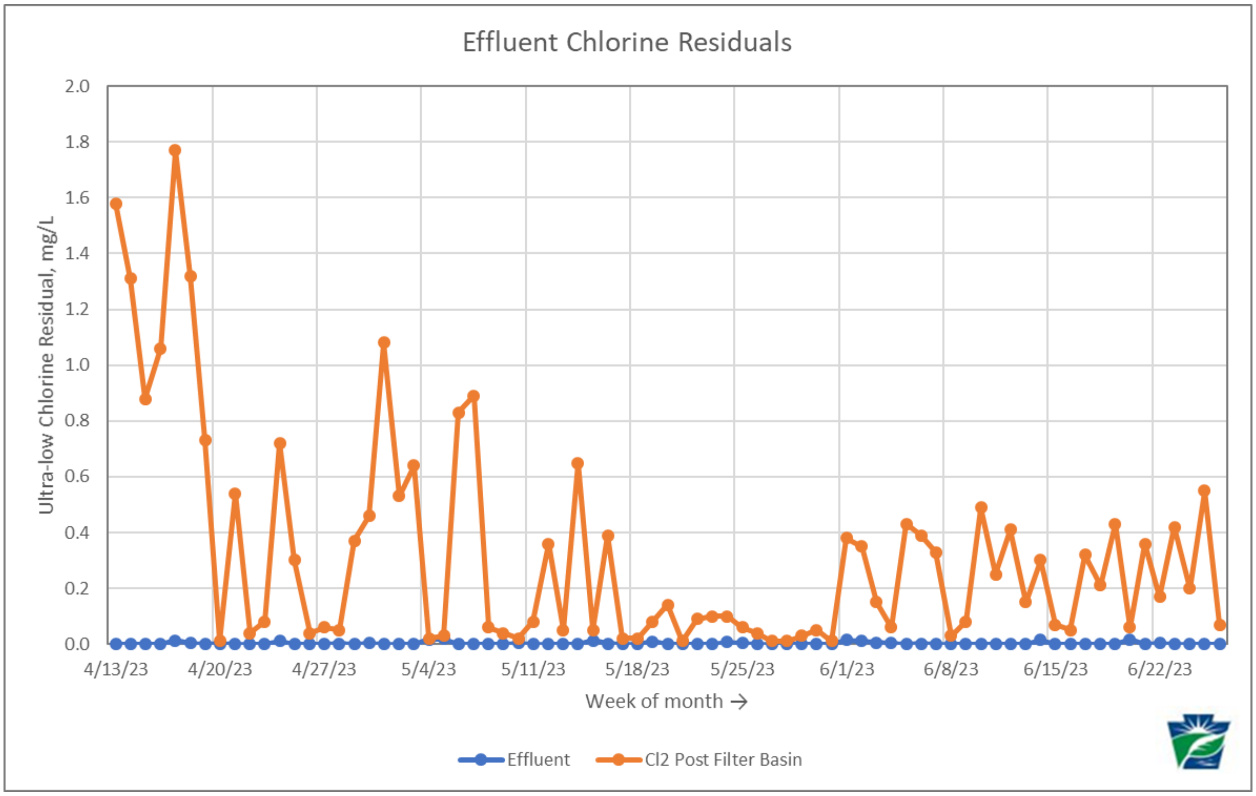
Mixed Liquor Settled Sludge Volume at 30 minutes, Penn Estates STP Process Monitoring



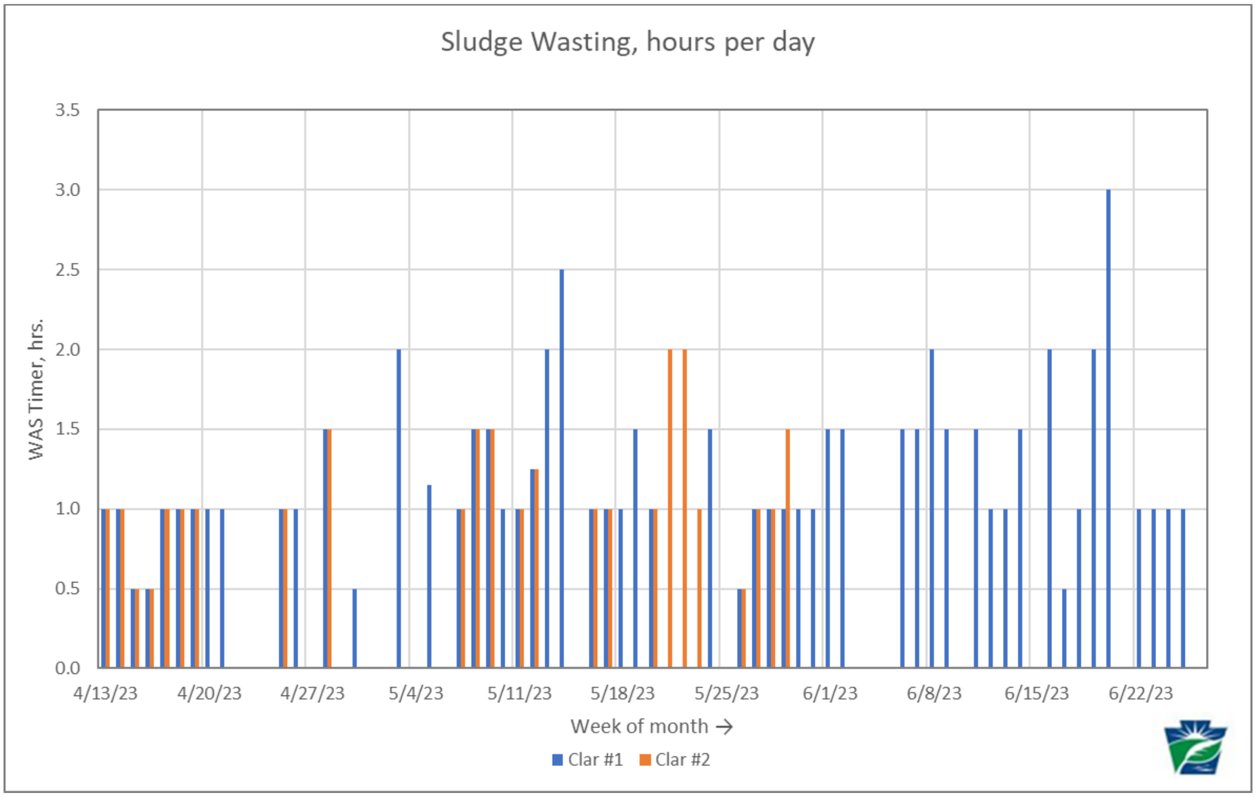
Effluent Nitrate-nitrogen Concentration, Penn Estates STP Process Monitoring



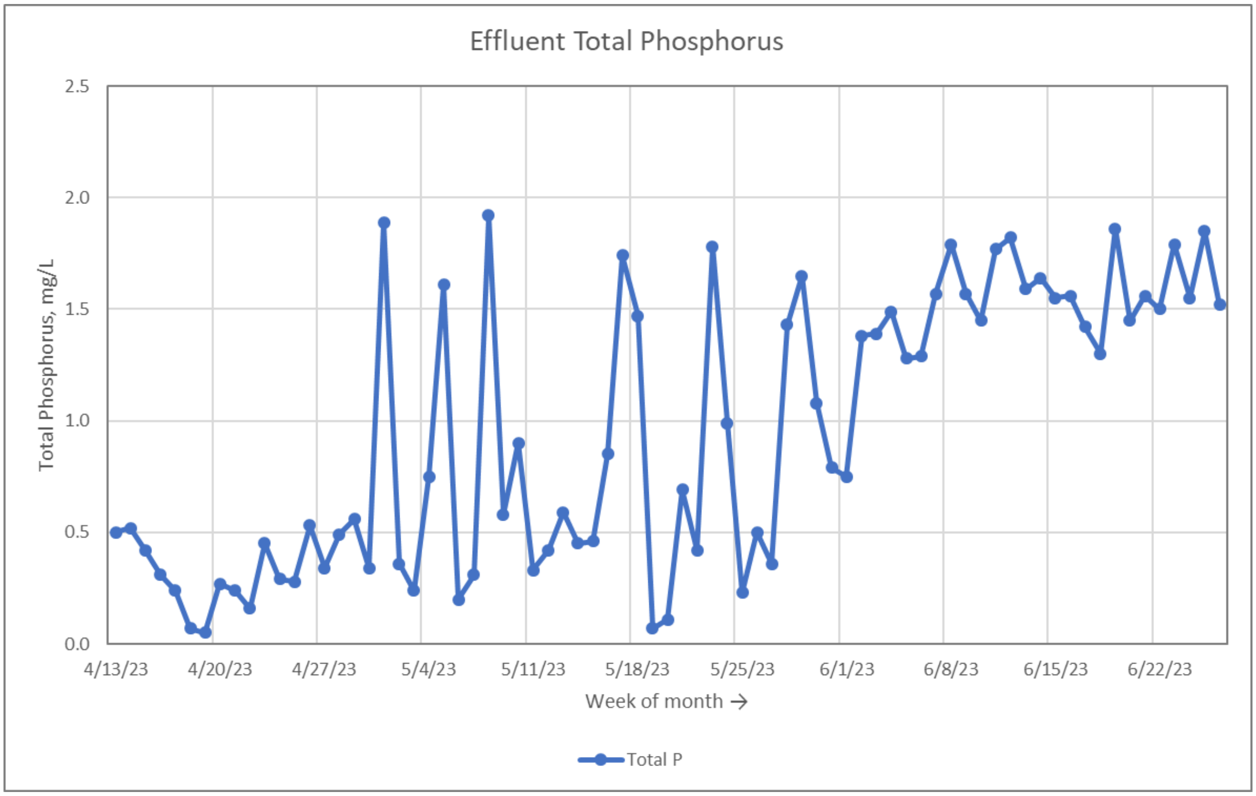
Effluent Ammonium-nitrogen Concentration, Penn Estates STP Process Monitoring



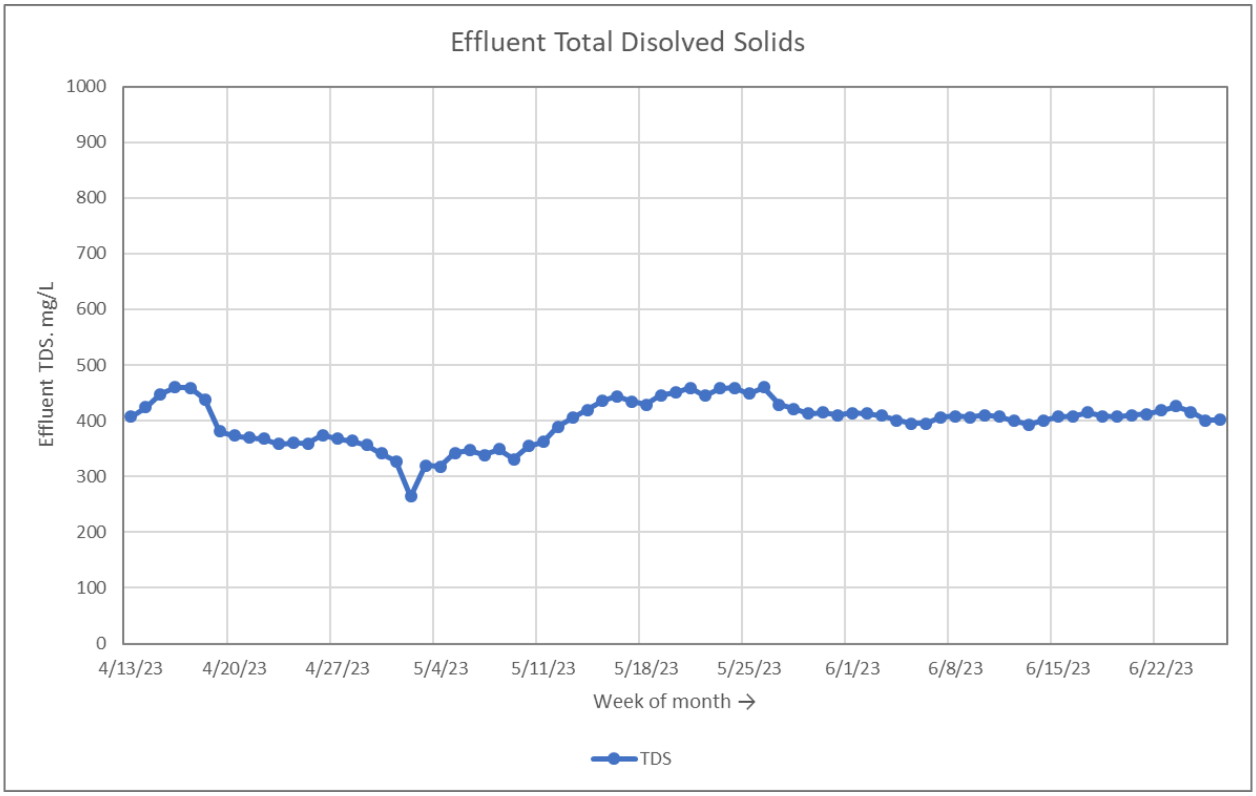
Effluent TRC concentrations, post filtration & final effluent, for the study period



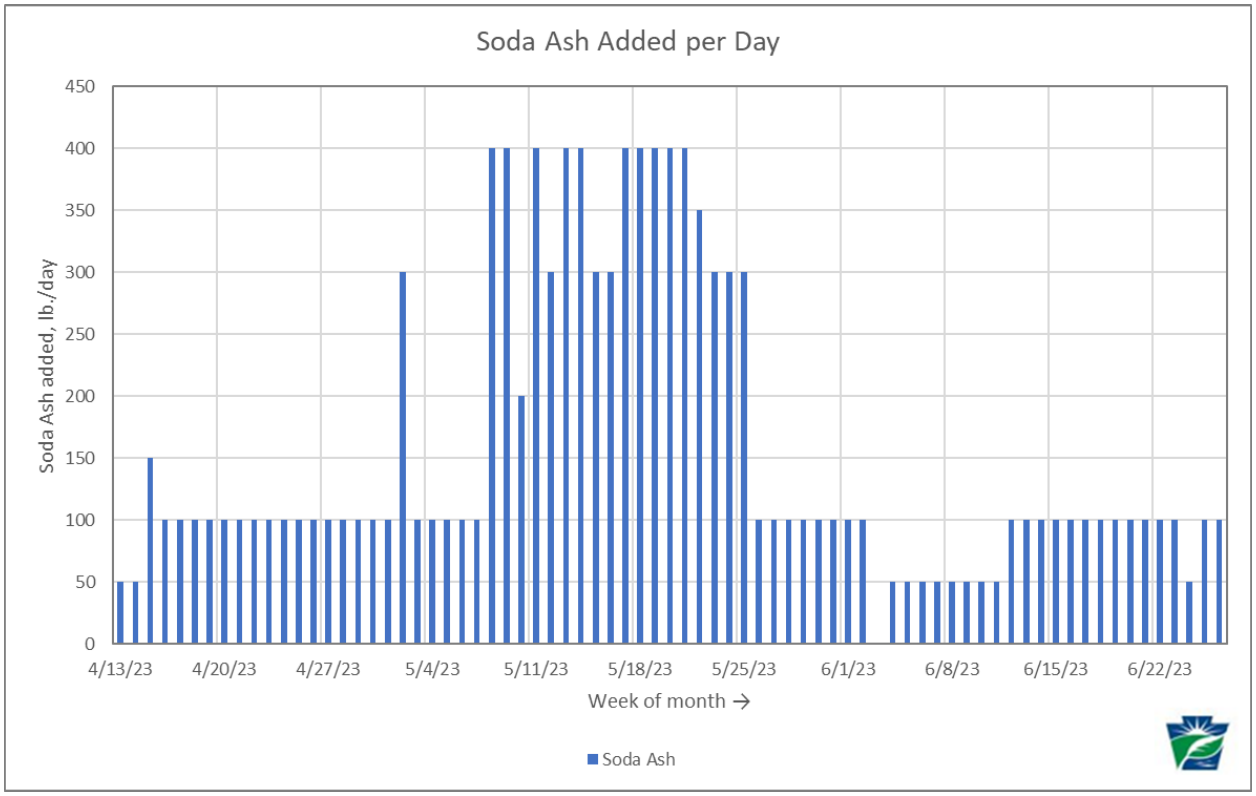
Sludge wasting pump run time, daily hours during study period



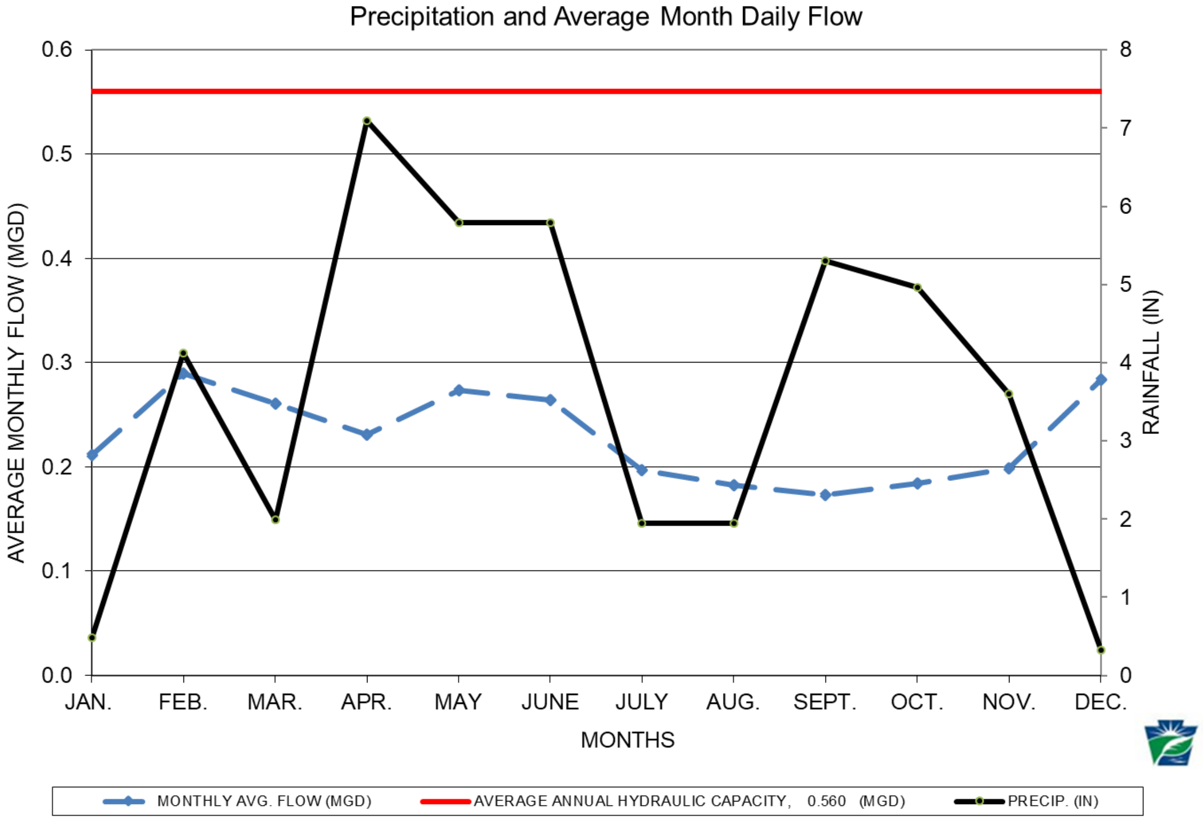
Final Effluent Total Phosphorus, Process Monitoring Lab, for the study period



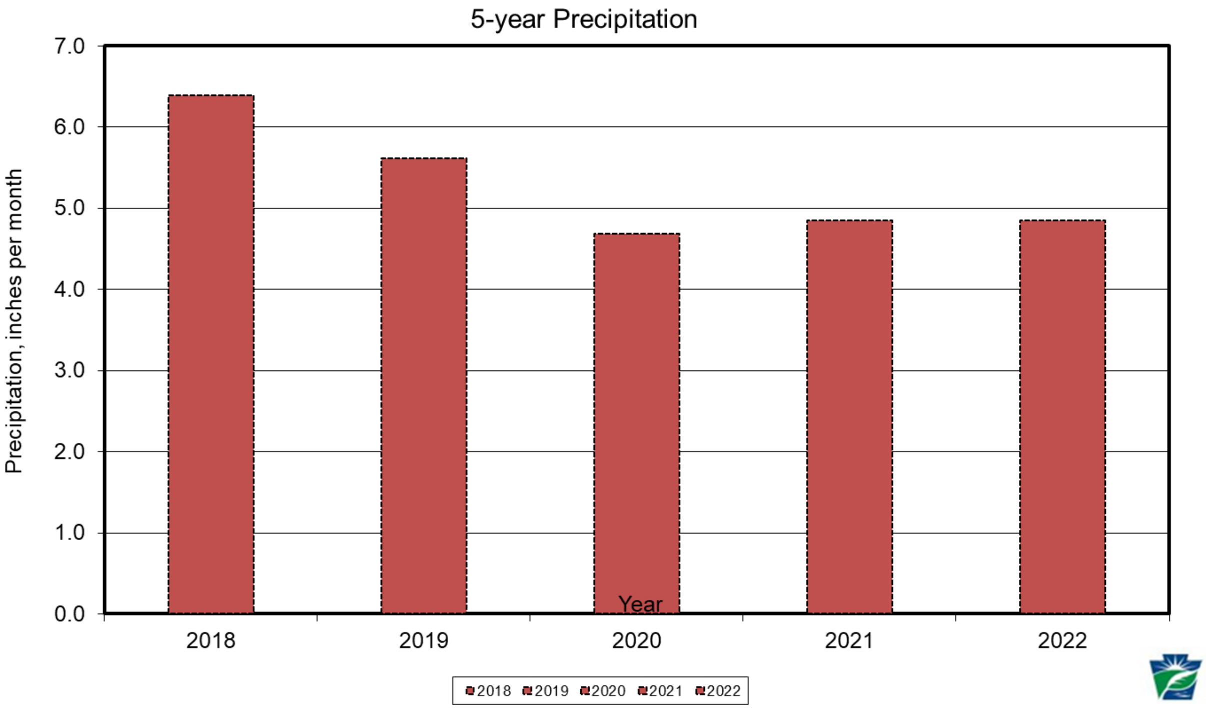
Effluent Total Dissolved Solids (TDS), for the study period



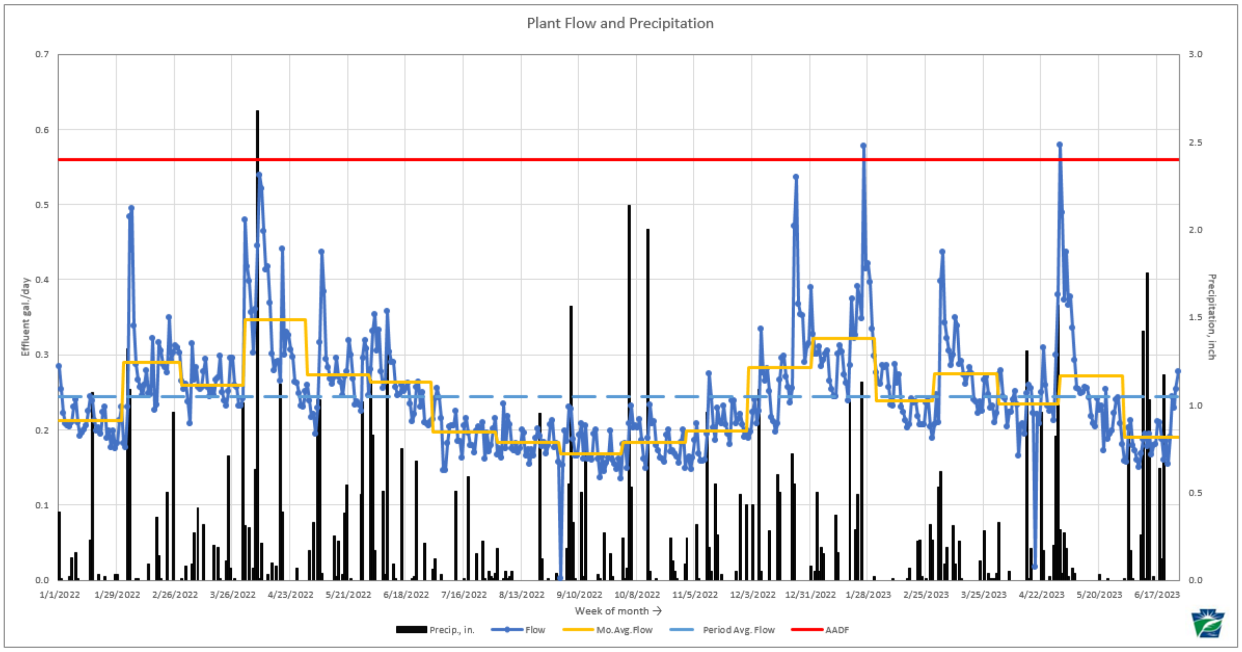
Soda ash added for alkalinity enhancement, lb./day, for study period



2022 Precipitation and Average Month Daily Flow, from Ch. 94 worksheet

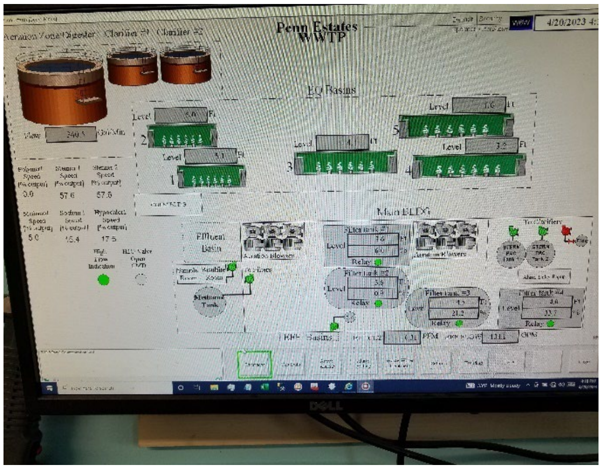


5-year Annual Precipitation, East Stroudsburg, from Chapter 94 Worsheet



Flow & Precipitation Comparison for period from 1/1/22 through 6/27/23

ATTACHMENT D: PROJECT PHOTOGRAPHS



Overview of Facility (SCADA screen)

Five Equalization Tanks, Headworks, & Control / Filter Building

View across Aeration & Digester Tanks

View of Secondary Clarifiers

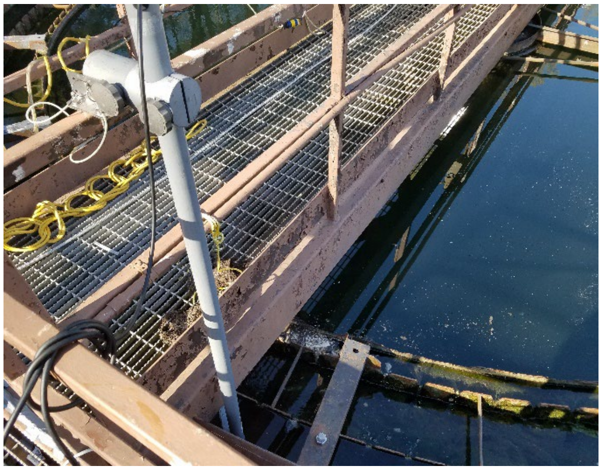
Influent Distribution Box w/ Flow Detection

Sludge Distribution Box at Clarifiers


Probes in AER#1 (pH, D.O., ORP, TSS)


D.O. Probe in AER #2


Ammonium Probe with Air-Blast Cleaning


Nitrate Probe between tank wall and weir


Probe Controller & Data Processor


Telemetry Devices (Data Server & Wi-Fi)

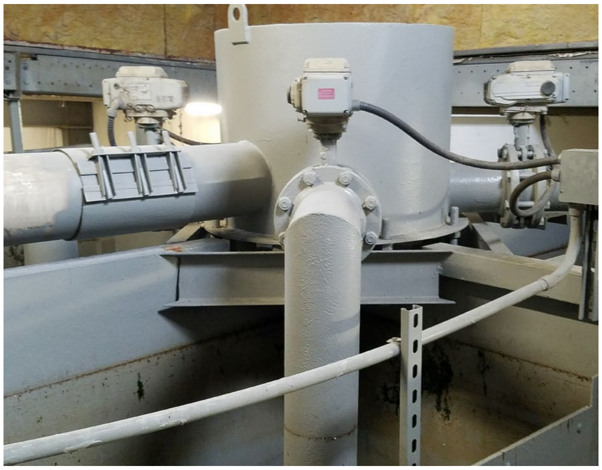
Jack Stand for Chopper Pump (1 of 4), with temporary platform for maintenance

Rotary Lobe Blower installed to independently operate air-lift pumps

Timer installed to regulate intermittent cycles

Temporary Soda Ash Day Tank

Soda Ash in 50 lb. Sacks



Filter #4 Distribution Box

Inside Filter Building (Filters 1 – 3, Water Storage Tank)

View into a filter unit

Centrifugal Blowers for Aeration Needs

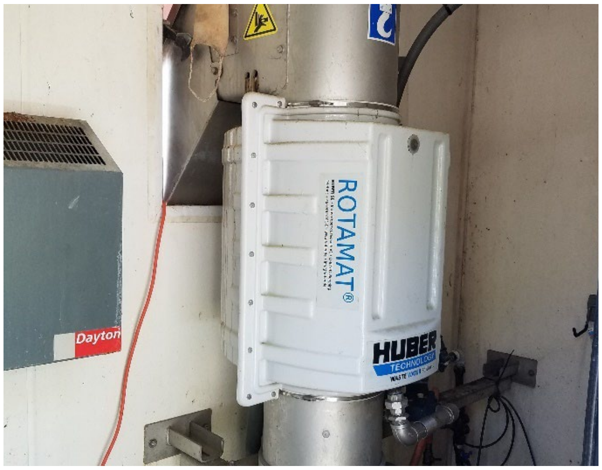
Sludge Holding / Aerobic Digester

Tank Drain Valves at Grade

Hypochlorite Contact Tank


Methanol Tank, Effluent Sampler, Sulfonator


Sulfite Contact Tank in Ground



Headworks Screening Device


Rotary Screen Occlusions


Algae in Clarifier Weirs


Cleaning Weirs while Clarifier emptied for air-lift pump modifications

Clarifer Rake during down time

Broken air distribtion line at digester

High Clarifier Blanket, pending increase in compressor size for air lift pumps

Siphoning of mixed liquor during OFF cycle

AER #1 high level due to small oriface between two aeration tanks

Final effluent outfall to UNT Brodhead Creek

ATTACHMENT E: DISCUSSION OF BIOLOGICAL NUTRIENT REMOVAL (BNR)

Why Nutrients in the Effluent are a Concern:

Dissolved nutrients such as nitrate-nitrite and phosphorus in treated wastewater effluents create both environmental and health concerns. Nitrate and phosphorus cause over-fertilization of algae and plant growth that sets up a cycle of excessive growth followed by eutrophication and decay. The excessive growth robs the natural environment of its capacity to support local biota that are the source of food for aquatic organisms and displaces native plant species. Once eutrophication has been established, large algal die-offs result in decay that robs the aquatic environment of D.O., causing entire aquatic populations to suffer and die. This degrades water quality for higher uses, as well, including withdrawals for drinking water filtration, swimming and recreation, angling, and other activities.

DEP has an operator training manual covering this topic, found here .

Nitrate and nitrite are pollutants of concern in surface waters filtered for human consumption and in groundwater sources for drinking water wells. EPA has set an enforceable standard called a MCL in potable drinking water for nitrates at 10 parts per million (ppm) (10 mg/L) and for nitrites at 1 ppm (1 mg/L). Many regulators are calling for similar limits for point-source and ground water discharges. Within the Delaware River watershed, the DRBC is currently seeking to regulate nitrate to the drinking water maximum concentration limit (MCL) of 10 mg/L in both surface and groundwater discharges, while the Susquehanna River Basin Commission (SRBC) has adopted a more stringent average concentration limit of 6.2 mg/L for discharges into the Susquehanna River basin, which is the largest contributor of nutrient pollution to the Chesapeake Bay.[5]

Human health concerns are a major factor in regulatory efforts to reduce nitrate in wastewater discharges. Exposure to nitrate also increases the risk of thyroid disease[6] and may lead to certain types of cancers of the colon and bladder[7], as well as a very specific birth defect called neural tube disorders caused early in pregnancies.[8] Nitrate acts on hemoglobin in red blood cells to form methemoglobin, reducing the oxygenation of organs and tissues.[9] Acquired methemoglobinemia in infants may occur when they consume nitrate in water used to mix infant formula or in nitrate-rich foods, medications such as benzocaine or dapsone, or through household exposure to naphthalene found in mothballs, toilet deodorants, plastics, and chemicals.[10] Nitrate may also be implicated in diabetes, miscarriages, and acute respiratory infections. The medical science on the effects of nitrates continues to develop.

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[5] The SRBC recommended concentration-based limit for total phosphorus is 0.8 mg/L

[6] Epidemiology: May 2010 - Volume 21 - Issue 3 - p 389-395 (Nitrate converts to nitrite in vitro which becomes nitrosamines, leading to a host of health issues.)

[7] Schullehner J, Hansen B, Thygesen M, Pedersen CB, Sigsgaard T. Nitrate in drinking water and colorectal cancer risk: A nationwide population-based cohort study. Int J Cancer. 2018 Jul 1;143(1):73-79. doi: 10.1002/ijc.31306. Epub 2018 Feb 23. PMID: 29435982.

[8] Epidemiology: July 2004 - Volume 15 - Issue 4 - p S184; The Lancet, Volume 14, 100286, March 1, 2022

[9] Kross BC, Ayebo AD, Fuortes LJ. Methemoglobinemia: nitrate toxicity in rural America. Am Fam Physician. 1992 Jul;46(1):183-8. PMID: 1621630

[10] Wisconsin Dept. of Health Services website, Infant Methemoglobinemia (Blue Baby Syndrome) , (rev. 04/15/2021)

Nitrification and Denitrification:

During the 1970s, treatment facilities were required to nitrify ammonia wastes to eliminate this pollutant that was killing aquatic life in receiving waters. Nitrification employs autotrophic bacteria in highly aerated conditions to convert ammonia to nitrate. The bacteria, normally found in topsoil, are found in activated sludge. During the past thirty years, microbiologists have discovered that there exist many genera of nitrifying bacteria, some of which are capable of completely nitrifying inorganic ammonia to nitrate.[11] *Nitrospira* and *nitrococcus* come to mind. Traditional explanation of nitrification, prior to these discoveries, focused on a two-step process performed by two different genera of bacteria. These two genera of nitrifiers work in tandem: *nitrosomonas*, an ammonia-oxidizing bacteria (AOB), converts ammonium to nitrite, after which *nitrobacter*, a nitrite-oxidizing bacteria (NOB) converts nitrite to nitrate. The net reaction is shown below:

$$\mathrm{NH3 + O2 + H2O \;\rightarrow\; NO3- + 5H+ +4e} \qquad (1)$$

The first step reaction by *nitrosomonas* is shown here:

$$NH_4^+ + 3/2\ O_2 \rightarrow NO_2^- + 2\ H_2O + 2\ H^+ \text{[12]} \qquad (2)$$

Additional oxygen and detention time are necessary to allow *nitrobacter* to oxidize the biologically active nitrite ion to chemically inert nitrate ion.[13]

$$NO_2^- + \tfrac{1}{2}\ O_2 \rightarrow NO_3^- \qquad (3)$$

Nitrification requires several factors to complete the process. These include

- Sufficient detention time, 10 to 14 days: most of the Carbonaceous Biochemical Oxygen Demand (cBOD) must first be consumed by heterotrophic and facultative bacteria in the activated sludge.
- Dissolved oxygen residual between 1.5 mg/L and 3.5 mg/L in the bioreactor.
- 4.6 lb. of oxygen consumed per pound of ammonia converted to nitrate: this can double the amount of oxygen required, compared to only treating for cBOD.
- pH generally above 7.0 S.U., ideally between 7.3 and 8.6, but no lower than 6.5 S.U.
- 7.14 pounds of alkalinity is needed to convert every 1 lb. of ammonia.
- Alkalinity in the raw wastewater should be over 200 mg/L as $CaCO_3$ or be supplemented to assure effluent alkalinity remains between 50 mg/L and 100 mg/L after treatment.
- Water temperature above 5 degrees Celsius (41 deg. Fahrenheit).

Nitrosomonas and nitrobacter are very sensitive to toxicity, as well, and one or the other can easily be suppressed by the presence of many household and commercial cleaners, excessive metals, and other contaminants.

Considering these factors, it is important for wastewater operators to regularly perform process control testing to determine whether the conditions are favorable for nitrification. If nitrification breaks down, these tests may help to determine what conditions are affecting the bacteria and

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[11] van Kessel, M., Speth, D., Albertsen, M. et al. Complete nitrification by a single microorganism. Nature 528, 555–559 (2015). https://doi.org/10.1038/nature16459

[12] This is the first half of the reaction, converting ammonium to nitrite. The nitrite, in red, associates with the hydrogen, also in red, as nitrous acid, resulting in lower pH if alkalinity is inadequate.

[13] The chemical oxidation state of nitrate ion is such that it does not necessarily associate with hydronium to produce more acid. It more typically associates with metal ions and is inert.

which, *nitrosomonas* or *nitrobacter*, are most affected. Testing for pH, alkalinity, are dissolved oxygen residual are critical to maintaining effective nitrification.

Many wastewater treatment facilities built or upgraded in recent times have been equipped for BNR. Denitrification is a process by which facultative, heterotrophic bacteria in the activated sludge will reduce nitrate to nitrogen gas that leaves the water and returns to the atmosphere. The balanced chemical equations are shown below:

$$6\ NO_3^- + 2\ H_3COH \rightarrow 6\ NO_2^- + 2\ CO_2 + 4\ H_2O$$ [14]

$$6\ NO_2^- + 3\ H_3COH \rightarrow 3\ N_2\uparrow + 3\ CO_2 + 3\ H_2O + 6\ OH^-$$ [15]

For successful denitrification, the following conditions are necessary:

- anoxic treatment conditions, where no dissolved oxygen is present. Generally, dissolved oxygen should be below 0.3 mg/L for denitrification.
- nitrate-rich environment: nitrification should be complete to the best extent possible. Nitrate dissolved in the water will provide the oxygen needed by the bacteria for metabolism.
- Presence of organic carbon as a food-source for the bacteria: usually, this comes from the raw wastewater but sometimes is required as supplemental cBOD in for form of simple chemicals like methanol, citrate, or glycerol, or as food manufacturing wastes such as molasses sugar, fruit juice waste, or whey powder.

Denitrification is a rapid reaction under the right conditions. If a treatment facility can successfully nitrify, there should be little or no problems denitrifying. In fact, in conventional and extended aeration facilities, denitrification is sometimes observed occurring in secondary clarifiers when the sludge blanket there has been retained too long: fine bubbles form in the floc causing clumps of sludge to rise to the surface. This "lava lamp" effect, called "rising sludge," can cause effluent violations when solids are carried over the clarifier weirs to the outfall. Excessive solids carryover will also inhibit downstream disinfection processes by consuming available chlorine or by occluding the penetration of ultraviolet light.

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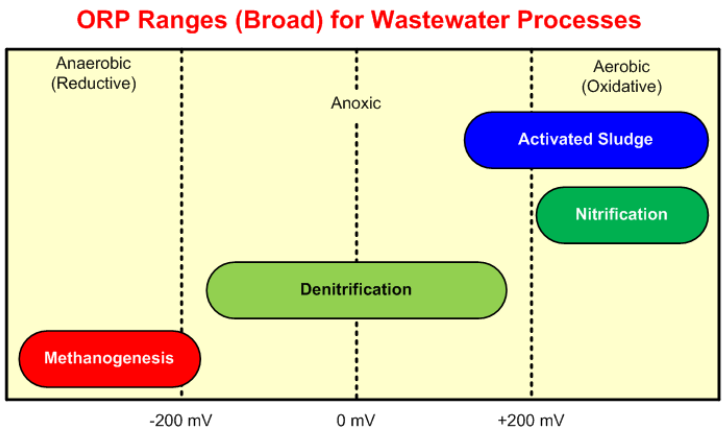
[14] In this equation, H_3COH represents methyl alcohol, a simple organic carbon most often used in denitrification filters.

[15] The carbon dioxide and hydroxyl ion combine in water to produce carbonate alkalinity. Almost half of the alkalinity consumed by nitrification is returned to the treatment process by denitrification, resulting in reductions of alkalinity needed up front as well as energy consumed in oxygenating the water.

The illustration to the right shows that it is possible to use Oxidation / Reduction Potential (ORP) to monitor nitrification and denitrification in activated sludge treatment. The bacteria that provide these necessary steps are highly efficient within specified ranges of ORP. This is measured in millivolts using portable or continuous monitoring, submersible probes. The favored range for denitrification is between +150 and -150 millivolts (mV), with ideal treatment "sweet spots" usually in the range from 0 mV to -50 mV. Nitrification, being strictly aerobic, requires ORP ranges from approximately 200 mV to 400 mV. Using ORP probes to monitor denitrification is more favorable than using D.O. probes, because D.O. probes cannot reliably demonstrate ideal anoxic conditions.



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Alkalinity is Critical

During nitrification, the nitrifying bacteria consume inorganic carbon in the form of dissolved carbonate / bicarbonate in the water. Alkalinity provides buffering against rapid and drastic pH changes, but it also provides a source of inorganic carbon. For every pound of ammonia oxidized, 7.14 pounds of alkalinity are consumed. (Given water chemistry and cellular metabolism, this amount is often rounded up to 7.2-to-7.5 lb. alkalinity per 1 lb. ammonia oxidized.)

If the biomass is deficient of alkalinity, the AOB conversion of ammonia to nitrite will lower the pH. This is because the nitrite released from the bacteria, as a waste product, is the anionic half of nitrous acid. The metabolism of ammonia produces hydronium ion that acidifies the water. To counteract this, supplemental alkalinity is often required in many parts of Pennsylvania where, excepting the limestone-rich geology of the Great Valley and similar areas, most of the geography is naturally deficient in alkalinity. Acid-mine drainage also contributes to lowering the pH of surface and ground waters.

While the rule-of-thumb holds that a facility is in good stead if effluent alkalinity is 100 mg/L and influent alkalinity is over 200 mg/L, experience has demonstrated that facility operators should calculate alkalinity demand in the course of their routine process monitoring and control tests. DEP has developed alkalinity calculator spreadsheet tools to aid in this, found at this website .

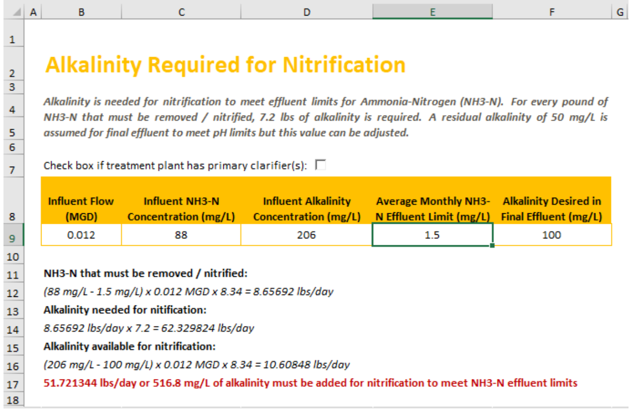
Using the calculator, operators enter test value for influent ammonia concentration and for influent alkalinity. Entering the estimated flow in million-gallons-per-day (MGD) calculates the ammonia and alkalinity loads present, the alkalinity required to oxidize the ammonia, and the equation produces a net result of how much additional alkalinity to add to the process.

It should be noted that conversion factors should be applied, based on the type of alkalinity chemical being deployed. These are found in a table on the following page. To use this table, select the ratio for the chemical being used and divide this into the estimated amount required to treat the ammonia to meet the ammonia effluent limit.

E.G., from the calculator and table:

51.7 lb./day as $CaCO_3$ ÷ 1.06 = 48.8 lb./day as Soda Ash

For practical purposes, the operator could round this example result up to 50 lb./day, since the Soda Ash is provided in 50 lb. sacks.



Alkalinity Required for Nitrification

Alkalinity is needed for nitrification to meet effluent limits for Ammonia-Nitrogen (NH3-N). For every pound of NH3-N that must be removed / nitrified, 7.2 lbs of alkalinity is required. A residual alkalinity of 50 mg/L is assumed for final effluent to meet pH limits but this value can be adjusted.

Check box if treatment plant has primary clarifier(s): ☐

Influent Flow (MGD)	Influent NH3-N Concentration (mg/L)	Influent Alkalinity Concentration (mg/L)	Average Monthly NH3-N Effluent Limit (mg/L)	Alkalinity Desired in Final Effluent (mg/L)
0.012	88	206	1.5	100

NH3-N that must be removed / nitrified:

(88 mg/L - 1.5 mg/L) x 0.012 MGD x 8.34 = 8.65692 lbs/day

Alkalinity needed for nitification:

8.65692 lbs/day x 7.2 = 62.329824 lbs/day

Alkalinity available for nitrification:

(206 mg/L - 100 mg/L) x 0.012 MGD x 8.34 = 10.60848 lbs/day

51.721344 lbs/day or 516.8 mg/L of alkalinity must be added for nitrification to meet NH3-N effluent limits

Example alkalinity calculator

Compounds	Alkalinity-Ratio, ppm/ppm $CaCO_3$
Soda Ash	1.06
Acetate	0.82
Hydrated Lime	0.74
Quick Lime	0.56
Bicarbonate	1.68
Caustic soda	0.8
Magnesium hydroxide	0.5

Alkalinity ratios to use in converting alkalinity doses

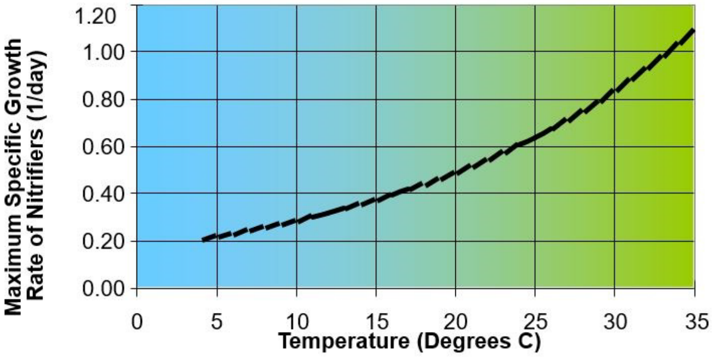
When adding any chemical to a biological treatment process, it helps if the chemical is dosed over the course of the day rather than dumped as a bulk or slug load. Therefore, it is beneficial to mix powders with water as a diluted solution and use metering pumps to deliver the chemical dose in a twenty-four-hour period. For example, if a 50 lb. sack of Calcium carbonate is dissolved into 100 gallons of water in a day tank, the metering pump should be set to deliver 4.2 gallons per hour.

PA DEP has a training manual for chemical feed systems, found here .

Inhibition of Nitrification

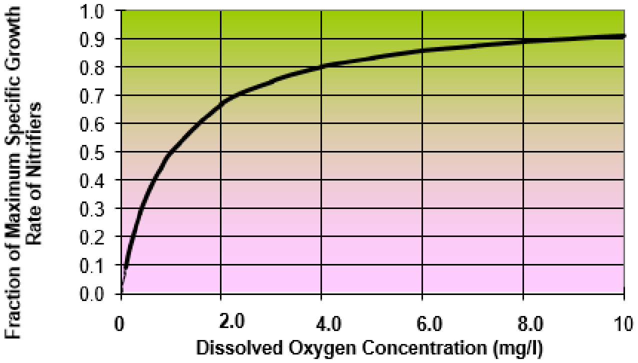
Many factors may lead to inhibition of nitrification. These include:

- pH out of range for the biomass, causing nitrifiers to stop reproducing and get washed out of the system.
- Low water temperature: Below 5 degrees Celsius, the biological reaction slows considerably, as see in this graph:



  Growth of nitrifiers is dependent on temperature, and at colder temperatures, they do not replicate quickly enough to be effective

- Dissolved oxygen:



- Mean Cell Residence Time:
- Alkalinity concentration should be sufficient to maintain pH within a range from 7.0 S.U. to 8.6 S.U., and the effluent alkalinity residual should remain between 50 and 100 mg/L.
- cBOD removal:
- Toxic compounds in the wastewater will inhibit the metabolism and reproduction of nitrifying bacteria that are more sensitive to environmental changes than are the facultative heterotrophs that consume cBOD and denitrify nitrate.
- Facility design affects nitrification because of detention time, limits on hydraulic loading, quality of aeration and mixing, removal of trash and detritus, and capacity of waste sludge holding.
- Wet weather operation and inflow/infiltration affects nitrifiers because they reproduce slowly and are easily washed out of the system by hydraulic surges and overloads.

Effect of Partial Nitrification on Chlorine Disinfection

If conditions are unfavorable for complete nitrification, nitrite level will rise and exert a chlorine demand by reacting with both free chlorine and chloramines. This is called “nitrite lock.” Low D.O., insufficient alkalinity, or acidic pH; high temperature or pH; and toxic or inhibitory substances will inhibit the final oxidation step from nitrite to nitrate. Nitrite lock also may occur during facility startup or during seasonal transitions, because *nitrobacter* grow more slowly than *nitrosomonas*. For example, in the seasonal temperature transition range from 10° C to 17° C, the rate of nitrite formation is slower than the rate of nitrite disappearance. 1 mg/L of nitrite will consume 5 mg/L of chlorine as Cl_2. When the nitrite concentration in the clarified effluent exceeds 1 mg/L, nitrite lock makes it seem like operators cannot add enough chlorine to their disinfection process; TRC becomes non-detectable even at high chlorine doses, and fecal coliform counts exceed permit limits.

Since nitrite lock has many potential causes, the remedies for it are also variable. Maintaining desirable pH and alkalinity in the mixed liquor is important. Eliminating toxic or inhibitory substances in the waste stream will help, too. Sometimes these substances may be generated internally, too. For example, using small doses of liquid bleach to control filamentous growth in the biomass will likely inhibit *nitrobacter* before it affects *nitrosomonas*, resulting in higher nitrite concentrations. While water temperature cannot be easily controlled, low water temperatures generally call for longer MCRT, and this may be achieved by building up the concentration of biomass through reducing the sludge wasting rate.

For more immediate remedies to nitrite lock, if a treatment process has more than one treatment train and both are independent of one another, it may be possible to blend low-nitrite effluent with the problematic high-nitrite effluent to dilute the nitrite. Also, if the facility permit allows it, increasing the concentration of ammonia in the effluent above that of the nitrite concentration may solve the problem, because chloramines forming in the disinfection process appear to be less prone to nitrite lock than free chlorine.

Most treatment facilities test for nitrite and nitrate together. From a process control standpoint, though, it may be better to test the two separately to ensure the operator(s) can be alerted to rising nitrite concentration in time to avert problems.

Nitrogen Removal Without Major Process Changes

In modern treatment facility design, BNR has become common. Many process designs exist to support both nitrification and denitrification. However, it is not necessary for older treatment facilities to be radically redesigned to achieve nitrogen removal. The simplest method is called “intermittent” or “on / off” aeration, where the aeration blowers are cycled to provide either full-on aeration for oxidation of organic and ammonia waste, or turned off to provide periods of anoxic treatment where denitrification reduces nitrate to nitrogen gas in the bioreactor, preventing rising sludge from occurring in the clarifier.

Intermittent aeration requires some minor modifications to make it work successfully:

- Dissolved oxygen control: Ideally, D.O. during oxidative periods should range from 1.5 mg/L to 3.5 mg/L to achieve complete nitrification.
- Anoxic, subsurface mixing: During air “off” period, denitrification will be optimal if mechanical mixing is present in the bioreactor to maintain the bacteria, cBOD, and dissolved nitrate all in contact with one another. Without anoxic mixing, the denitrification reaction will occur mostly at the top of the sludge blanket that forms, although rising sludge (as in a clarifier) does occur, showing that denitrification will occur, albeit inefficiently, throughout the sludge blanket.
- Organic carbon: Facultative, heterotrophic bacteria that denitrify require a carbon source for cellular metabolism and reproduction. Usually, this organic carbon comes from raw wastewater continuing to enter the bioreactor while it is in the “off” period. If necessary, supplemental carbon in the form of commercially prepared additives or otherwise as simple food processing wastes, sugar, rabbit or fish food, may be substituted.

Operational Benefits of Biological Nitrogen Removal

It is said that if a facility is required to nitrify ammonia wastes as part of its NPDES permit, it should denitrify the nitrate, as well, because of the economic benefit of doing so. Nitrification is energy intensive, and there are costs associated with power consumption, maintenance costs for aeration systems, chemical expenses associated with alkalinity addition, and use of polymer for sludge settling aids that counteract rising sludge in clarifiers.

Denitrification reduces the overall amount of power and chemicals consumed. These may be quantified as follows:

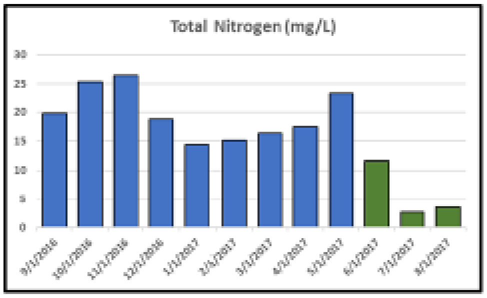
- 3.57 lb. of alkalinity as $CaCO_3$ is recovered for every 1 lb. NO_3-N reduced to nitrogen gas, N_2. Remember, 7.14 lb. of alkalinity are consumed by nitrification of ammonia, so roughly 50% of alkalinity is returned.
- 2.86 lb. O_2 is recovered for every 1 lb. NO_3-N reduced. This means the work required of motor-driven air compressors brush rotors, or surface aerators is reduced.
- Electricity conservation is observed in the use of intermittent aeration in conventional activated sludge treatment, where aeration run times may be reduced by as much as sixty percent. Activated sludge aeration need not be constant.

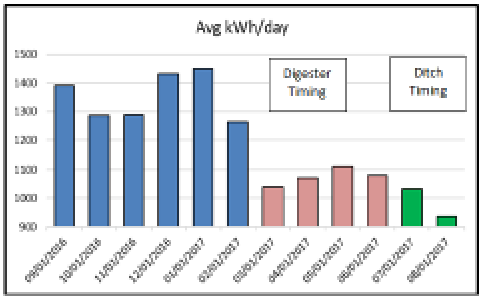
Case History

Intermittent aeration was tried at the Adamstown, Lancaster County, wastewater treatment facility to reduce effluent total nitrogen—mostly nitrate—so that the facility operators could save money by avoiding annual purchase of nitrogen credits to meet their Chesapeake Bay nutrient reduction goals. The facility includes two secondary bioreactors as oxidation ditches, aerated through surface mechanical aerators.

Using instrumentation to monitor dissolved oxygen, pH, and ORP, and installing simple timers on the aerators' motor controls, the operators were able to reduce aeration time from 24/7/365 to 2 hours "on" and 3 hours "off" for every five-hour cycle.

Based on feedback from the instrumentation, the operator manipulated the timing regime from 24hr/day ON to 9.6 hours/day ON to optimize denitrification (TN removal). At the close of the project, effluent Total Nitrogen (TN) and energy consumption were reduced by 74% and 30%, respectively.



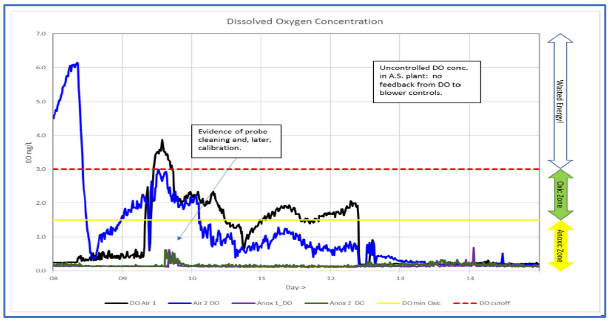


Figures: Effluent Nitrogen Reduction

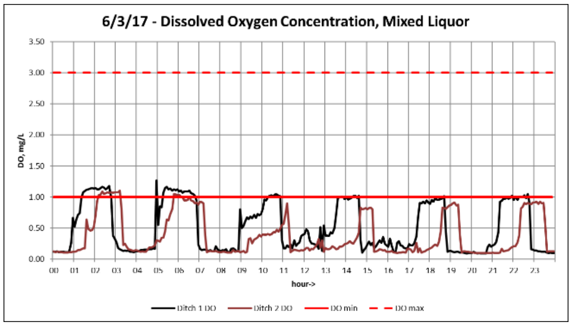
Electrical Consumption

Instrumentation and Automation

Excessive dissolved oxygen residual in bioreactors could be controlled by using variable frequency motor drives (VFD) to regulate the motors driving aeration blowers. The principle is to install continuous monitoring dissolved oxygen probes in the bioreactors and using a 4-to-20 milliamp signal from the probe controller to signal the VFD to maintain blower speed that maintains D.O. residual between 1.5 mg/L and 3.5 mg/L. The graphs below compare unregulated D.O. residual to controlled residual within aeration tanks:



Unregulated D.O. residual in bioreactor



Controlled D.O. residual via VFD feedback loop

The technology of the D.O. probes is limited at the lower end of the scale, where any reading below 0.3 mg/L may be considered to be zero. To better understand the effective ranges for denitrification, ORP probes are used, where anoxic process is favorable between 150 mV and -150 mV. In practice, the denitrification "sweet spot" occurs between 0 mV and -50 mV, although experience may be different among differing treatment technologies. ORP probes are installed in the same bioreactor in the cases of intermittent aeration, sequencing batch reactors (SBR), oxidation ditches, Orbals, Schreiber process tanks, membrane bioreactors (MBR), and the like. Where anoxic processes occur in separate tanks, the ORP probes are placed in anoxic (denitrification) tanks or in anaerobic selectors. Process automation may use ORP probes to regulate the addition of supplemental carbon or to control the nitrate recycle rate as ways to optimize denitrification.

Because nitrifier bacteria are very sensitive to pH changes, and because the action of AOB to oxidize ammonia to nitrite produces acidification of the biomass, it is important to monitor pH in the aeration tank. Automation may use pH set points to regulate the addition of alkalinity to control pH. Nitrosomonas has an optimal pH between approximately 7.0 and 8.0 S.U., and the optimum pH range for Nitrobacter is approximately 7.5 to 8.0 S.U.

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ATTACHMENT F: METHOD FOR ALKALINITY DOSING CALCULATION

Typically, alkalinity in effluent should be 50 mg/L or match that of the receiving stream; however, because of bioavailability of alkalinity at the pH range needed by nitrifying bacteria, this concentration should be higher in the Aeration Tanks, 100 mg/L up to 220 mg/L.

Alkalinity demand should be calculated. Since each 1 mg/L of ammonium in the secondary influent requires 7.14 mg/L alkalinity as $CaCO_3$[16], multiply the influent (or raw) TKN (total Kjeldahl nitrogen, which is organic nitrogen and ammonium nitrogen, combined)[17] concentration in mg/L X 7.14 mg/L alkalinity to determine a minimum amount of alkalinity needed for ammonia removal through nitrification. Then determine the influent alkalinity concentration already present and subtract this from the alkalinity demand you just calculated for your influent ammonium.

Example:

- **36 mg/L Influent Ammonia-nitrogen in Raw Wastewater**
  (Estimated that Ammonia-nitrogen is 70% of TKN in domestic wastewater)
  (88 x 100%) ÷ 70% = 126 mg/L TKN estimated
- **51 mg/L Influent TKN x 7.2 mg/L alkalinity per 1 mg/L TKN = 368 mg/L alkalinity required**

If the secondary influent already has 100 mg/L of alkalinity, then the net alkalinity demand is:

368 mg/L alkalinity needed to treat - 100 mg/L alkalinity in Influent = 268 mg/L alkalinity demand exists

To convert this to an actual chemical dose, you will have to multiply the net demand concentration by the Influent flow rate:

If the average flow is 0.229 MGD, then the amount of alkalinity required would be

268 mg/L x 0.229 MGD x 8.34 lb./gal = 512 lb./day.

To convert this to a chemical dose, you will have to determine the available alkalinity in the chemical. For example, 1 lb. Soda Ash has 1.06 lb. alkalinity[18]. This means that to provide 52 lb./day alkalinity as $CaCO_3$, you need to divide this by the ratio of chemical to alkalinity:

512 lb./day ÷ 1.06 = 483 lb./day of Soda Ash (round up to 500 lb.)

Figure adding 5 one hundred-pound bags over 24 hours, not all at once. Using a 225-gallon tote drum as a day tank, the feed rate would be

500 lb./day ÷ 24 hours = 20 lb., 13 oz. per hour (225 gal. per day = c. 9.4 gal./hr.)

The tank would require constant stirring, and it may be necessary to use a slurry pump.

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[16] To account for bioavailability of alkalinity at the desired MLSS pH of 7.2 to 7.5, substitute 8 mg/L for 7.14 mg/L. This increased the alkalinity required but is also more realistic, since 7.14 mg/L is the **minimum** required.

[17] If you can't test for TKN, substitute a test for ammonia-nitrogen and multiply the result by 1.25 to approximate the combination of organic nitrogen and ammonium nitrogen, together.

[18] See the table on the next page.

Keeping track of the alkalinity demand over time should help when determining the size and capacity of the chemical feed pump and the size of the line needed. When using this dosing method, it doesn't hurt to round up or down to easier quantities to work with; for example, 483 pounds of chemical rounds up to 500 pounds.

Remember: Successful denitrification returns 50% of alkalinity consumed during nitrification. This means that, after equilibrium has been established, the alkalinity demand should drop by half, reducing overall chemical consumption.

Supplemental Alkalinity Buffering Compounds

Compounds	**Alkalinity-Ratio, ppm/ppm $CaCO_3$**
Soda Ash	1.06
Acetate	0.82
Hydrated Lime	0.74
Quick Lime	0.56
Bicarbonate	1.68
Caustic soda	0.80
Magnesium hydroxide	0.50

ATTACHMENT G: IMMERSION PROBE ESTIMATED COSTS

The equipment deployed at Penn Estates wastewater treatment facility for this study was chiefly comprised of Hach products. In this attachment, the estimated cost for purchasing this equipment and maintaining it is listed, excluding installation costs. Modifications to the SCADA system to incorporate these probes would have to be contracted with the SCADA provider at additional programming cost. Engineering costs for design and for regulatory approvals are not included.

Following is a table listing equipment needed for probe installation into two aeration tanks:[19]

No.	Item	Hach Cat.	Unit Price	Qty.	VWR Line Cost
10	Hach LDO sc Model 2 , DO Probe	9020000	$ 2,996.00	2	$ 5,992.00
20	Hach General Purpose Digital ORP Sensor, Conve	DRD1P5	$ 1,595.00	2	$ 3,190.00
30	Digital pH sensor with glass differential electrod	DPD1P1	$ 1,546.00	2	$ 3,092.00
40	Solitax ts-line sc Turbidity (0.001-4000 NTU) and	LXV423.99.00100	$ 6,779.00	1	$ 6,779.00
50	Ammonium-ISE Probe, Immersion, w/RFID	LXV440.99.10002	$ 10,856.00	1	$ 10,856.00
60	NT3200sc UV Nitrate Sensor, 2 mm path length	LXV448.99.22001	$ 18,793.00	1	$ 18,793.00
70	UVAS sc Total Organic Carbon Probe, 2 mm path	LXV418.99.20001	$ 25,383.00	1	$ 25,383.00
80	Pole Mount Set for 1" NPT Sensors	9253000	$ 754.00	7	$ 5,278.00
90	PVC rail mount kit for ISE sensors	6184900	$ 648.00	1	$ 648.00
100	UVAS Pole mounting hardware, 10 cm bracket, S	LZY714.99.53520	$ 694.00	1	$ 694.00
110	Stainless steel pole mounting hardware, 10 cm b	LZY714.99.53220	$ 735.00	1	$ 735.00
120	SC1000 8-sc inputs, 120 vac, for conduit mount	LXV400.99.1G092	$ 3,360.00	1	$ 3,360.00
130	SC1000 Multi-parameter Universal Controller Display Module (without GSM/GPRS)	LXV402.99.00002	$ 4,569.00	1	$ 4,569.00
140	Air Blast Cleaning System, 115 Vac	5795100	$ 2,937.00	1	$ 2,937.00
150	Cleaning unit for AN-ISE sc	LZY706	$ 515.05	1	$ 515.05
160	Cartrical sensor cartridge for AISE sc, LZY694, 2 pe	LZY694	$ 1,755.64	2	$ 3,511.28
			Total Hach Pricing:		$ 96,332.33

The costs listed here may not be current and do not include installation costs for physical and electrical work, nor for modifications to a SCADA system to incorporate the data and controls.

An annual budget for maintenance costs should be included for renewal parts, standard solutions, and wiper blades for some of the probes, plus professional service costs for replacement of seals, desiccant, and worn or broken parts. During professional service, the technician also updates any firmware and recalibrates the probes. Some of these costs are listed below:

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[19] Costs are estimated based on current catalog pricing and are presented only for estimating purposes. Facility owners and operators should check and compare with equipment vendors as to the most appropriate equipment and pricing before drafting budgets. DEP makes no endorsement of any particular brand of equipment.

No.	Item	Hach Cat.	Unit Price	Qty.	VWR Line Cost
10	Salt bridge PEEK, PVDF junctions	SB-P1SV	$ 124.00	4	$ 496.00
20	Standard Cell Solution, Concentrated pH 7.0 Buffer (Equi-Transferrant), 500 mL	25M1A1025-115	$ 113.00	1	$ 113.00
30	ORP Buffer Solution, 200 mV, 500 ml.L, or	25M3A1001-115	$ 101.00	1	$ 81.39
	Zobell's ORP Buffer Solution, 500 ml. (alternative)	2316949	$ 81.39	1	$ 81.39
50	LDO Replacement Sensor Cap Kit for LDO2sc	9021100	$ 350.00	2	$ 700.00
60	Nitrate Standard, 25 mg/L NO3, 500 ml.	LCW828	$ 86.09	1	$ 86.09
70	NT3200 Spare wiper blades, pk 5	LXZ448.99.00003	$ 133.00	1	$ 133.00
80	Wiper blades for Solitax probe, pk 5	LZX050	$ 118.00	1	$ 118.00
			Total Hach Pricing:		$ 1,808.87

Service plans are available for these probes, but the costs are not listed. Hach offers differing levels of service:

- Bench Service Preventative Maintenance Partnership, one or two services per year;
- Bench Service Partnership, one or two services per year;
- Field Service Partnership, one or two services per year;
- Warranty Service Partnership, one or two services per year.

Service plan costs may be obtained from the manufacturer or vendor. DEP staff estimates that its costs for sending the four premium probes employed during this study to Hach for bench service (UVAS, Nitratax, Solitax, A-ISE) are approximately $4,600. The more expensive service plans, where a technician maintains the probes at the treatment plant site, reduces the probe maintenance turn-around time from approximately eighteen days to one or two. This is an important consideration when a facility does not have back-up equipment in reserve.

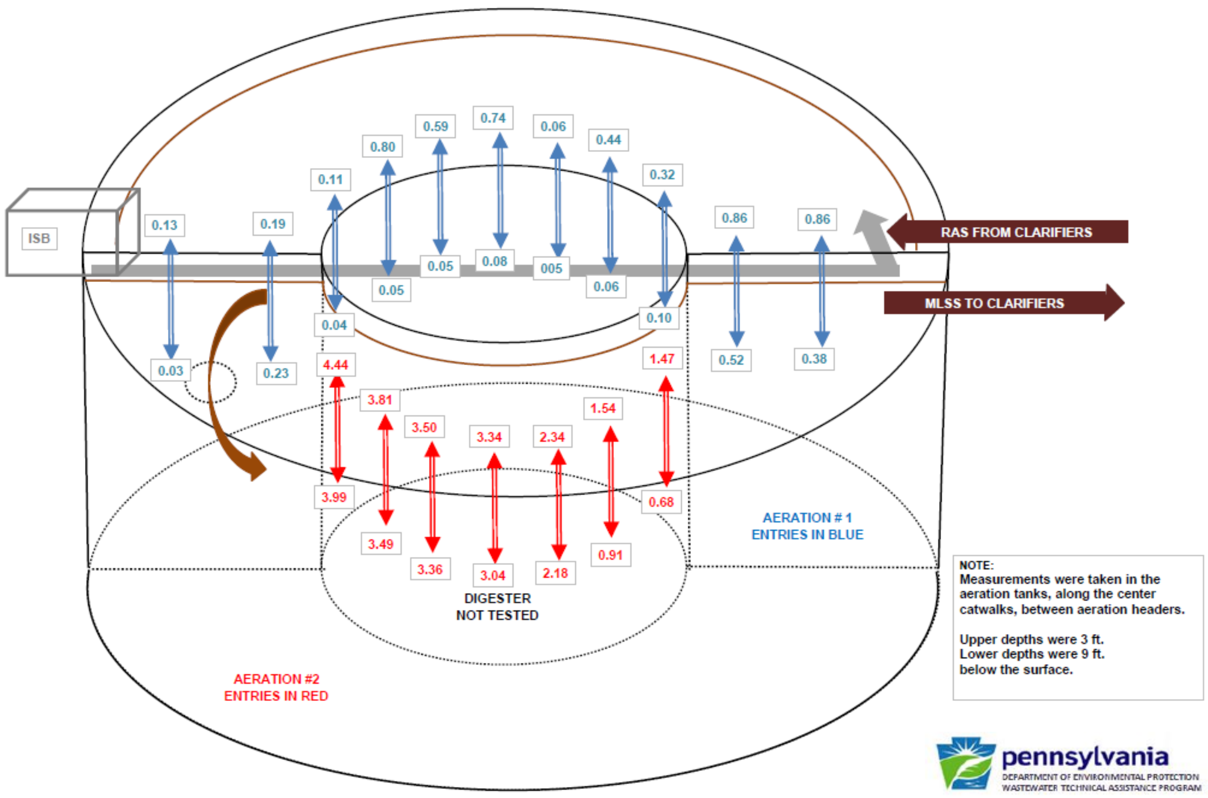
For the ammonium ISE probe, the service typically includes the cost for replacing the sensor cartridges twice per year, and this is reflected in its higher cost.

ATTACHMENT H: DISSOLVED OXYGEN PROFILE

DEP staff conducted a dissolved oxygen profile of the aeration tanks at Penn Estates STP on May 10, 2023. The purpose was to verify the recordings of the dissolved oxygen probe located at the midpoint along the catwalk for Aeration Tank # 2. The readings for that tank, seen in red in the diagram, confirmed the readings of the D.O. probe; however, based on the variation in dissolved oxygen residuals between the two aeration tanks, staff decided to relocate the other diagnostic probes (pH, ORP, TSS) to Aeration Tank # 1, where it appears most of the biological activity was occurring.

Both the raw wastewater rich in organic carbon and the nitrate-rich return activated sludge enter the process at similar places in Aeration Tank # 1. Thus, the bulk of the denitrification occurs in this tank during the anoxic mixing period.

DISSOLVED OXYGEN PROFILE FOR AERATION TANKS 1 AND 2
PENN ESTATES STP, STROUD TOWNSHIP, MONROE COUNTY, PENNSYLVANIA



NOTE:
Measurements were taken in the aeration tanks, along the center catwalks, between aeration headers.

Upper depths were 3 ft.
Lower depths were 9 ft.
below the surface.

Flow between the two tanks is limited by the size of the orifice in the wall between the tanks, maintaining a difference in biological and loading characteristics. Later during the evaluation, the facility operator diverted some of the raw wastewater flow into Aeration Tank # 2, near the influent splitter box (ISB). This did provide organic carbon to the bacteria in that tank, probably creating a polishing effect that allowed for additional denitrification in this tank, resulting in even lower nitrate residuals in the clarifier supernate. This diversion should be maintained going forward, as it helps maintain stability of the biomass.

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WASTEWATER TECHNICAL ASSISTANCE PROGRAM