WASTEWATER TREATMENT EVALUATION WAVERLY TOWNSHIP STP AMPHIDROME STUDY

LACKAWANNA COUNTY, PENNSYLVANIA

NPDES PA0061034

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DEPARTMENT OF ENVIRONMENTAL PROTECTION
WASTEWATER TECHNICAL ASSISTANCE PROGRAM

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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.

Executive Summary:

During the winter of 2020-2021, staff from Pennsylvania Department of Environmental Protection (DEP) conducted a limited evaluation of the Amphidrome *Cold*-Nite nitrification filter at the Waverly Township wastewater treatment facility located in Lackawanna County. The purpose of this study was to determine if the nitrification filter can treat to proposed ammonia-nitrogen limits that are part of the facility's most recent permit renewal under the National Pollutant Discharge Elimination System (NPDES # PA0061034). The findings of the study, conducted in February and March 2021, are that the Amphidrome can treat to the new requirements, provided that certain treatment issues are addressed by the facility owner.

Waverly Township owns and operates a 0.500 MGD serial lagoon treatment system serving a township comprised largely of single-family residences and some commercial properties. The lagoon system replaced two preexisting small package treatment systems in the township and has been in operation since late 1986. To enhance nitrification that meets the nutrient loading budget for the Chesapeake Bay tributaries, Waverly installed a triple-cell Amphidrome "Cold-Nite" nitrification filter at the effluent end of the lagoons. This is an automatic backwashing media filter with enhancements that encourage the growth of nitrifying biofilm to meet or surpass the nitrification reduction requirements of the NPDES Permit.

The facility normally operates well; however, it would operate optimally if the Township would address two serious factors affecting nitrification. They are:

1. High inflow and infiltration volumes entering the collection system cause hydraulic surges that interfere with detention time in both the lagoons and within the filter. Correcting I/I problems through a thorough program of pipeline and manhole repair and maintenance will reduce wet weather hydraulic volumes to the design capacity of the treatment facility. The township and their engineer should aggressively pursue funding of and repair and maintenance of its collection system and any tributaries in order to reign in the problem of excessive flows.
2. Despite the presence of Sodium bicarbonate alkalinity enhancement systems at the Amphidrome, there does not appear to be sufficient alkalinity addition during periods of high flows, and the alkalinity residual following normal flows also suggests that not enough alkalinity is being supplemented to maintain optimal performance. During one recent high flow day, the facility would have required 1,400 pounds of alkalinity as CaO3 be added; however, no changes in chemical addition rates were observed.

Recommendations:

Based on testing, monitoring, and observations conducted on site during February and March 2021, DEP staff suggests the following:

1. Address inflow and infiltration in the collection system. This includes;
    a. Televising smoke testing lines,
    b. Rehabilitating and grouting pipe runs and manholes,
    c. Checking laterals for excessive inflow from roof drains, broken or sub-grade cleanouts, or sump pumps,
    d. Assuring manhole inserts are available for all at-grade manholes, and
    e. Securing funding for annual collection system maintenance.
2. Provide for increased alkalinity and pH control when necessary, working with vendors to find optimal alkalinity chemicals to use.
3. Continue including Amphidrome influent and effluent in process monitoring tests, regularly checking nutrients in and out as well as the alkalinity using the calculation method shown in Attachment E.

4. Evaluate methods to increase ammonia loading to the Amphidrome, as discussed. The system was designed for a higher influent load than is currently available and may benefit from urea addition or from process adjustments to the lagoons.
5. Evaluate disinfection methods for the facility, given the pending changes to the pending total residual chlorine limits on the effluent.
6. Evaluate performance of the lagoons and consider removal of some of the sediments or sludges more frequently.
7. Employ 24-hour composite sampling for process monitoring and compliance testing. Use of composite sampling in process monitoring will provide more representative samples to characterize organic and nutrient loading at different parts of the process.
8. To improve energy efficiency, consider using some of the available land at this facility for renewable electricity generation that may help offset some of the energy costs.

Introduction

Waverly Township is part of a collection of small bedroom communities north of Scranton in Lackawanna County, Pennsylvania, locally known as “The Abingtons.” During the mid-to-late twentieth century, the community wastewater treatment needs were served by two small package treatment plants that were relatively unsophisticated. As the community grew and wastewater treatment standards improved, the township replaced these package plants with a half-million gallon per day (0.500 MGD) dual serial facultative lagoon treatment works. A schematic of this system follows as Attachment B.

The lagoon system consists of a modest headworks that includes a comminutor and a bypass bar screen. Wastewater flow passes through two 3.75-million-gallon lagoons operated in series and aerated using compressed air. Following this treatment to remove organic and some nitrogenous loading, lagoon effluent passes into a nitrification filter to enhance ammonium removal and thence to a conventional pair of disinfection contact tanks where halogen disinfection is used to kill pathogens. Effluent overflows from the contact tanks, cascading to a drain that leads to the final effluent outfall at an un-named tributary of Ackerly Creek. The creek has been listed as “impaired” due primarily to nutrients and is considered to be effluent-dominated.

The lagoon system had served the community well throughout the last thirty years; however, with the implementation of stricter nutrient reduction standards part of the Chesapeake Bay improvement strategy, point source permitees within the Susquehanna River basin have been required to treat to a higher standard or annually purchase nutrient pollution credits, all with an eye to reducing nitrogen and phosphorus emissions. Lagoon treatment systems are considered passive treatment technology, employing large land area and volumes of treatment capacity to allow for natural degradation of sewage and other wastes. Of and by themselves, though, most lagoons are not designed for biological nutrient reduction (BNR), and treatment efficiency for nutrient reduction falls off considerably during cold weather, owing to the slow reproduction rate of the principal nitrifying micro-organisms, *Nitrosomonas*, the ammonia-oxidizing bacteria (AOB) and *Nitrobacter*, the nitrite-oxidizing bacteria (NOB). Attachment I lists permit excursions at the facility prior to installation of the Amphidrome.

To solve this problem, in 2018, Waverly Township constructed a deep-bed biologically active filter (BAF) to treat ammonia. The principle of this technology is to concentrate a mass of nitrifying bacteria within a tertiary filter and build a prodigious biofilm during warm weather by supplementing the sewage ammonia with urea-nitrogen, so that when colder weather occurs, a highly concentrated population of nitrifiers is available to biologically treat ammonia despite colder water temperatures. A copy of the internal design review record is attached as Attachment F, and copy of a research paper on the pilot-study that preceded construction of the Waverly Amphidrome is appended to this report as Attachment G.

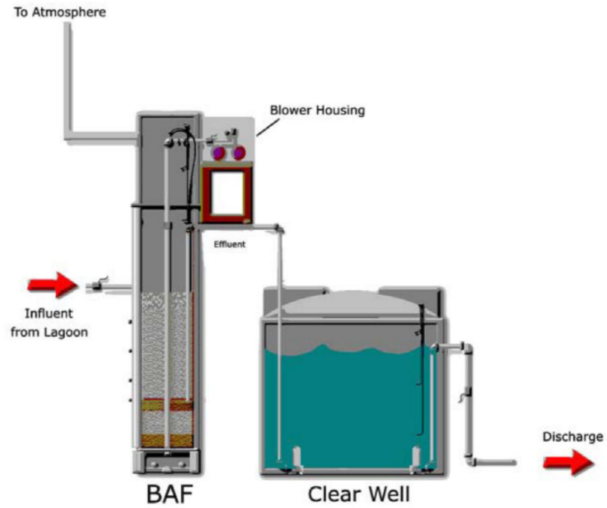

Figure 1: Deep-bed Biologically Active Filter (BAF)

Design Considerations:

When the Amphidrome was proposed, it was designed as three units each having a capacity of 36,000 gallons per day (gpd). Effluent flow from the second lagoon enters a wet well splitter box that divides the flow among the three filters. The lagoon system, though, had been re-rated to a hydraulic rating of 500,000 gpd that would, on first glance, seem to indicate that the filter is not designed for the permitted hydraulic flow. The application for the wastewater management permit noted that future expansion of the Amphidrome by addition of more self-contained filters is possible, but the designers also noted that peak hourly hydraulic flow through the lagoons would be attenuated by the volume of the lagoons and their freeboard, attenuating hydraulic surges through the filters. The filters themselves were designed for nitrification only, not for biological nutrient reduction (BNR) for either total nitrogen or total phosphorus control.
In 1999, the re-rate included no increase in maximum organic loading of 507 pounds of organic loading per day, due to wet weather flow issues cited in the record. The five-year annual average daily flow when the filter was designed had been 1.6 MGD during a year when record precipitation had been recorded in northeastern Pennsylvania. At the time, the construction permit documents noted that the Amphidrome is a continuous-flow system with provisions for bypass of any or all of the filter units by manual adjustment of valves and weir plates.

As a practical matter, were it not for the hydraulic surges due to inflow and infiltration, the Amphidrome as it exists is presently operated under its design ammonium loading. No additional units are needed at this time, if only the I/I could be regulated or eliminated. The system would probably operate more efficiently if, during the warm weather months, natural nitrification within the antecedent lagoons could be reduced, sending more ammonium to the filters for biological treatment.

Discharge Permit Renewal:

The National Pollutant Discharge Elimination System (NPDES) Permit for this facility expired in 2016, but it’s limitations continued to be in force until a succeeding Permit could be issued. A new draft Permit established new effluent limits for ammonia-nitrogen concentration and loading based upon the water quality of an un-named tributary to Ackerly Creek to which the Waverly Township STP discharges its effluent as a regulated point source. The old limits that have been in effect were seasonal, where the warm weather limit has been 4 mg/L as a monthly average, and 12 mg/L during colder weather, when nitrification typically becomes much less efficient due to the slow metabolism of nitrifying bacteria. The proposed new limits for Waverly are 1.5 mg/L as a monthly average between May 1 and October 31 and 4.5 mg/L between November 1 and April 30. The new permit also proposes an instantaneous maximum (grab) limit of 3 mg/L and 9 mg/L during the same period. There is no proposed weekly average limit. In terms of effluent loading, the mass limits for ammonia-nitrogen are proposed to be 6.2 lb./day and 18.7 lb./day within the same times of the year. Attachment H lists the old and the proposed new limits.

More importantly, the Chesapeake Bay nutrient limits (“cap loads”) remain unchanged, where the total nitrogen annual limit for the period beginning October 1 through September 30 is 9,132 lb./year.[1]

Nitrification of Aqueous Ammonia:

The oxidation of ammonia to nitrate is a two-step process where *Nitrosomonas* oxidizes ammonia to nitrite and *Nitrobacter* oxidizes nitrite to nitrate. Nitrite is a chemically reactive by product of this metabolism and is released in the form of nitric acid that lowers the pH of the

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[1] Nutrient cap loads are based on concentration limits of 6 mg/L for total nitrogen and 0.8 mg/L for total phosphorus, the design annual average daily flow in MG, and the mass of a gallon of water, 8.34 lb.

treated water. Because nitrifying bacteria are difficult to culture, the system requires careful attention to the balance of ammonium and inorganic carbon in the presence of slightly elevated pH in order to flourish. pH adjustment and inorganic carbon are provided through the addition of supplemental alkalinity, often in the form of sodium bicarbonate. Alkalinity buffers pH, protecting the nitrifying bacteria from acid-inhibition and lysis. Nitrifying bacteria are largely chemoautotrophic, meaning they utilize inorganic carbon for growth and reproduction.

The chemical reactions are depicted as follows:

$$NH_4^+ + \frac{3}{2}O_2 \rightarrow NO_2^- + 2\,H_2O + 2\,H^+$$ [2]

The chemical reaction that converts ammonium to nitrite is done by nitrosomonas bacteria. In aqueous solution, the resultant HNO_2 is nitric acid that depresses pH. This is also where insufficient dissolved oxygen in the nitrification process could cause the incomplete reaction from nitrite to nitrate, resulting in an excess of nitrite-nitrogen in the effluent that would consume chlorine in the disinfection process causing “nitrite lock,” a condition that reduces the availability of hypochlorous acid in the disinfection contact tank that could result in high fecal coliform counts during effluent testing.

$$NO_2^- + H_2O \rightarrow NO_3^- + 2\,H^+ + 2e^-$$ [3]

Biologically, the second reaction does not produce acidification. The nitrate ion is inert in aqueous solution, and the remaining protons and electrons are ultimately combined with oxygen to produce a water molecule. It is, however, a nutrient for algae and aquatic plant growth.

Wastewater Treatment Evaluation: The Amphidrome Study:

In 2020, as part of the Permit renewal cycle, new ammonia-nitrogen limits were proposed, dropping from a monthly average of 12 mg/L concentration to 1.5 mg/L during warm seasons and 4.5 mg/L during cold seasons. The owners contacted their engineer to appeal the stricter limits. Following discussion among the owners, their engineer, and the state regulatory agency, the parties agreed to a limited study of cold-weather Amphidrome performance to document its efficiency in treating ammonium-nitrogen at low temperatures. DEP staff from its wastewater technical assistance program (WWTAP), a federally funded instructional and process optimization program in its Bureau of Clean Water, arrived in late-January 2021, to deploy monitoring equipment and conduct limited-scope process monitoring tests. Results of this monitoring, in the form of trending graphs, are displayed in Attachment C, following.

DEP staff deployed a set of continuous immersion probes for pH, temperature, dissolved oxygen, ammonium-nitrogen, and nitrate, all at the distal end of the chlorine contact tank for the facility. Use of other locations had been limited by access and the need for continuous immersion. The four probes were connected to a controller set and data servers located in the Amphidrome control building. DEP had also placed an ammonium probe in a lagoon effluent wet well to measure the Amphidrome influent ammonium, but the probe seal failed, and the instrument was rendered out-of-service for the duration of the study. Instead, staff conducted

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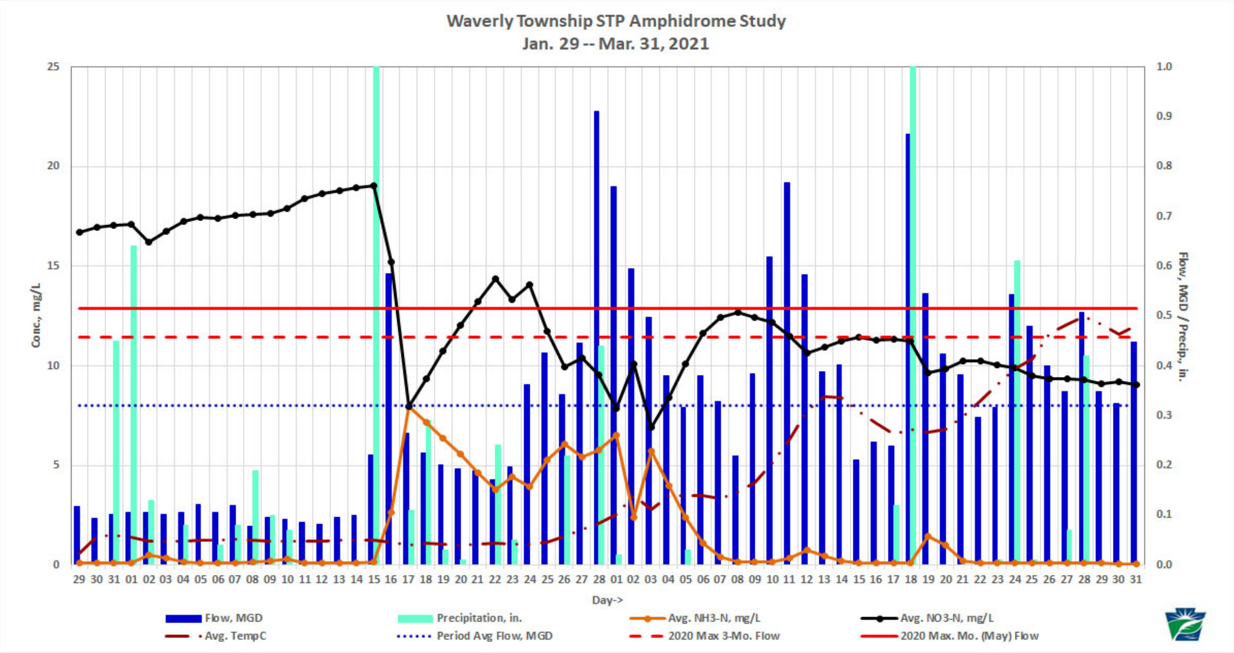
[2] This is the first reaction, converting ammonium to nitrite. The nitrite, in red, associates with the hydrogen, also in red, as nitrous acid, resulting in lower pH if alkalinity is inadequate.

[3] This is the second reaction, converting ammonium to nitrite. This reaction is less clearly understood, so the fate of the two protons produced cannot be shown. It is likely that these protons eventually associate with enzyme-attached oxygen to form water as a byproduct of a separate biochemical reaction.

weekly checks of the influent ammonia-nitrogen in combination with plant operators' routine process monitoring. Attachment D consists of photos recorded during the study.

The study continued through February until the end of March. Attachment A lists the personnel involved with the study. DEP staff visited the site weekly to check and clean monitoring probes, conduct wet chemistry monitoring and calibration checks, and to download data from its monitoring system. A small lab bench was set up in the Amphidrome control building near the effluent disinfection tanks at the northwest corner of the treatment plant. Data was graphed one or two times per week throughout and communicated with DEP technical partners, and any concerns were discussed with facility operators.

During late January and early February, cold, dry weather generally prevailed, with occasional snowfall and with ice developing at the surfaces of the lagoons and in the chlorine contact tanks. In late February, a mid-winter thaw occurred which increased flow into the treatment system. When flow through the Amphidrome exceeded 0.500 MGD, nitrification diminished rapidly and remained so for a few days afterward. The nitrifiers recuperated quickly, even in cold weather, and nitrification was restored. Following is a graph of the daily average ammonium and nitrate concentrations, combined with the daily average flow measured just prior to the facility outfall:



Graph 1: Waverly Effluent Nitrogen-species concentration, average daily flow, and precipitation.

This graph clearly shows that the ammonia-nitrogen normally is below 1.5 mg/L when flow averages 0.300 MGD. Nitrate concentration is virtually a mirror image of ammonium. When the capacity of the filters is overwhelmed with high flows due to inflow/infiltration in the facility's collection system, nitrification falls off rapidly, allowing ammonia-nitrogen concentration to increase but not necessarily exceed the current daily average permit limits.

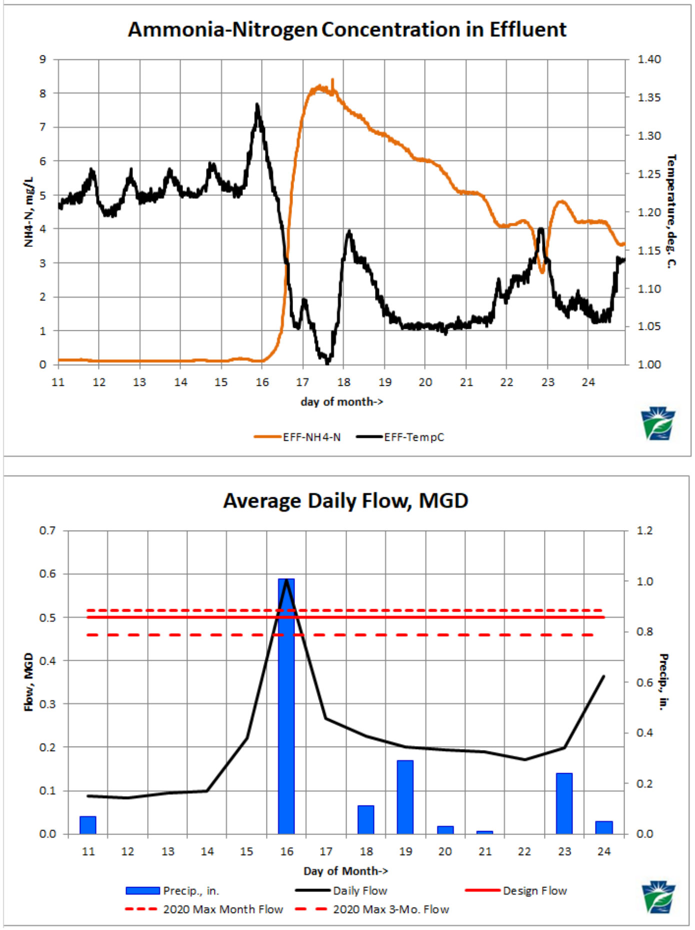
Clearly, rapid increases in flow through the Amphidrome inhibit its ability to nitrify. The problem isn't that the Amphidrome cannot treat to an exacting standard during cold weather; it is that excessive inflow and infiltration in the community's collection system overwhelm the filter's design capacity. Notice, following the "big thaw" near the end of February, how quickly the filters recovered from the hydraulic shock.

Observations:

From the data developed during the Amphidrome study, some things are very clear:

- The Amphidrome filter is designed to nitrify at very low water temperatures, generally.
- Rapid increases in hydraulic throughput at low water temperatures interrupted efficient nitrification.
- Biofilm recovery tends to be rapid and complete.
- Water alkalinity and pH are factors of concern.

In March, DEP staff were contacted by a former design engineer who worked for the company that built the filter. The observations were discussed broadly, and the consensus of opinion, backed by findings in the engineer's paper on the subject (Attachment F,) is that metabolic heat in the biofilm within the core of the filters plays the major role in treatment efficiency at cold temperatures. If this heat is displaced by large volumes of cold water, the bacteria metabolism slows to near-dormancy while its reproductive rate falls dramatically. Earlier studies by the manufacturer asserted that biofilm is not displaced from the media during high flows, that over 90% of the biofilm remains intact. But nitrifiers are notoriously slow-growth organisms and are highly subject to the effects of cold temperatures. Displacement of metabolic heat by high-volume slugs of cold water will rapidly degrade treatment efficiency. This appears to have happened as shown in graphs 2, after February 15 when the first high-flow occurred following a precipitation event, with low-temperature water (less than 1.3° Celsius), where nitrate production dropped off rapidly and untreated ammonia increased. The second slug of cold water occurred around February 24.



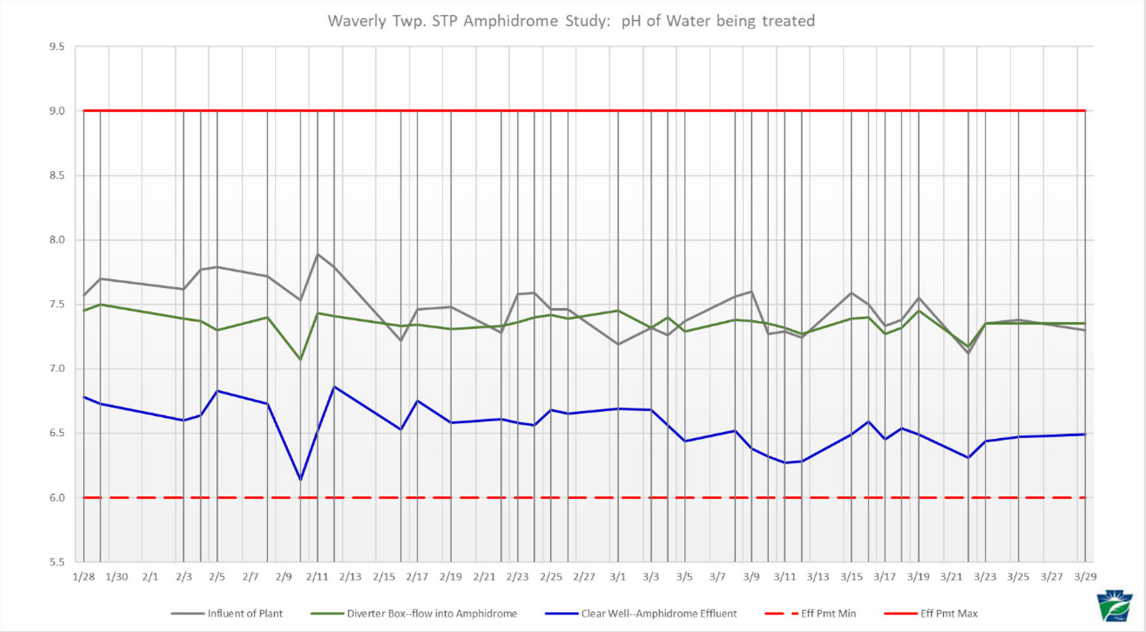
Graphs 2: Flow & Temperature effects on nitrification, February 16-24, 2021

As water temperature increased due to unseasonal warming in late February, the severity of nitrification loss diminished when flow increased. Graph 1 on the preceding page shows that, during high flows around March 10 and March 18, minimal loss of nitrification was observed.

These observations support the theory that displacement of metabolic enthalpy (heat) by large volumes of cold water is more responsible for the loss of nitrification than other contributing factors such as insufficient alkalinity, and the swift recovery of the biofilm in the filter shows that mechanical displacement of biofilm did not play a role.

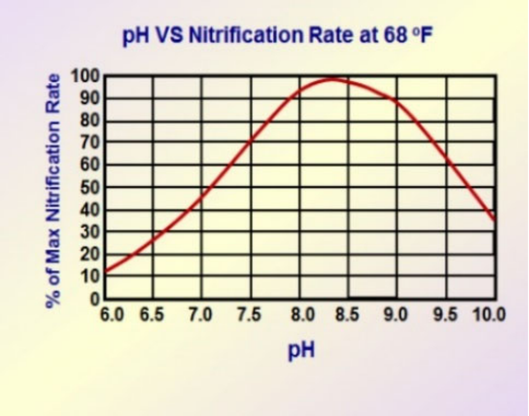
On the matter of pH and alkalinity, the study raised two additional concerns:

- pH of the water within the Amphidrome and in its effluent is below the optimum range for nitrification. During the study, it often remained below 6.4 s.u. when it should be at least 7.0 s.u. The desirable range for pH in nitrification is between 8.0 and 8.5 s.u.
- The pH graph shown below displays the reduction in pH of water as it flows from the plant headworks to the splitter box for the Amphidrome and in the clear well following the Amphidrome, based on grab samples and monitoring by facility staff. Clearly, there is an expected drop in pH through the filter media as a result of nitrification. Although the Amphidrome has admirably nitrified the influent ammonium load, the graph infers that the alkalinity provided has been insufficient to maintain pH in the optimal ranges for nitrification should ammonia loading increase.[4]



Graph 3: pH drop through successive processes, Amphidrome in blue

- An oft-used rule-of-thumb regarding alkalinity for nitrification is that the effluent alkalinity should be no less than 100 mg/L as calcium carbonate, $CaCO_3$. Experience has instructed, though, that it is more important to calculate the alkalinity demand of the influent wastewater in terms of its total Kjeldahl nitrogen (TKN) or, if that test isn't available, its ammonia-nitrogen and assure that a minimum 7.2:1 ratio of alkalinity to TKN exists in the bioreactor (in this case, the Amphidrome,) to assure that nitrification goes to completion while preserving excess alkalinity to buffer the effects of acidification by *nitrosomonas*.



Graph 4: pH ranges to elicit the Maximum nitrification rate

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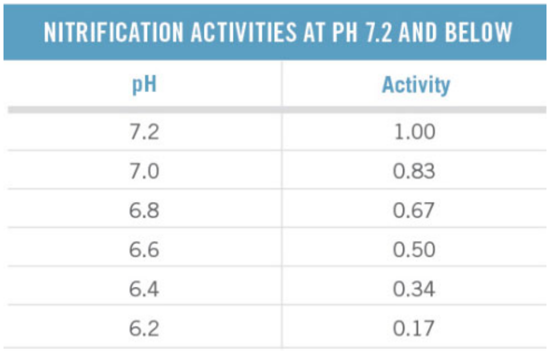
[4] The design documentation stated, though, that as hydraulic loading increases, there is an expected dilution of ammonium concentration, because flow increases over the dry-weather hydraulic loading are attributed solely to inflow/infiltration in the collection system.

- Despite the regular addition of supplemental alkalinity, the alkalinity within the filters and its effluent is too low and results in effluent pH that approaches a range where *nitrosomonas* and *nitrobacter* will go dormant. A discussion of how to calculate alkalinity demand follows as Attachment E.
- It may be beneficial to find alternative alkalinity chemicals to use in the Amphidrome to provide more available alkalinity per pound, in accessible form, to maintain effluent pH closer to neutral or higher in the final effluent. Different chemical formulations each have their pros and cons. It is important to choose an alkalinity that provides the best return on investment and is safe to work with.



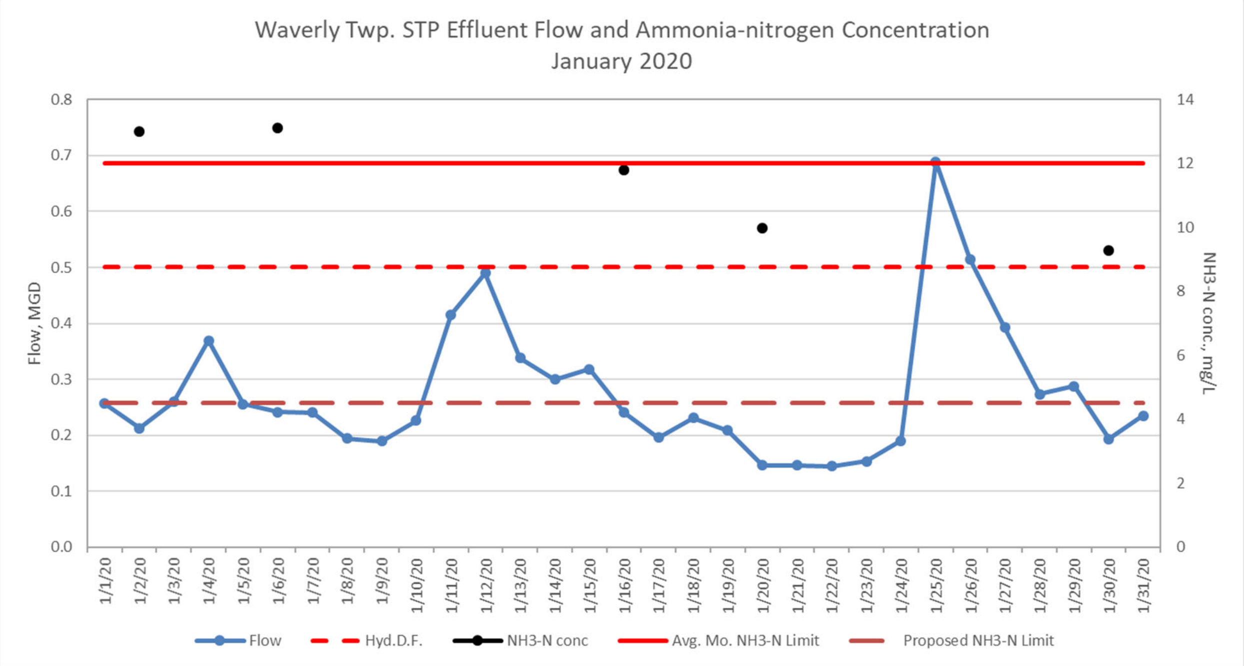
NITRIFICATION ACTIVITIES AT PH 7.2 AND BELOW

pH	Activity
7.2	1.00
7.0	0.83
6.8	0.67
6.6	0.50
6.4	0.34
6.2	0.17

FIGURE 2. Measurement of nitrification activity at a pH of 7.2 and lower
Source: EPA-625/4-73-004a Revised Nitrification and Denitrification Facilities Wastewater Treatment, U.S. Environmental Protection Agency Technology Transfer Seminar.

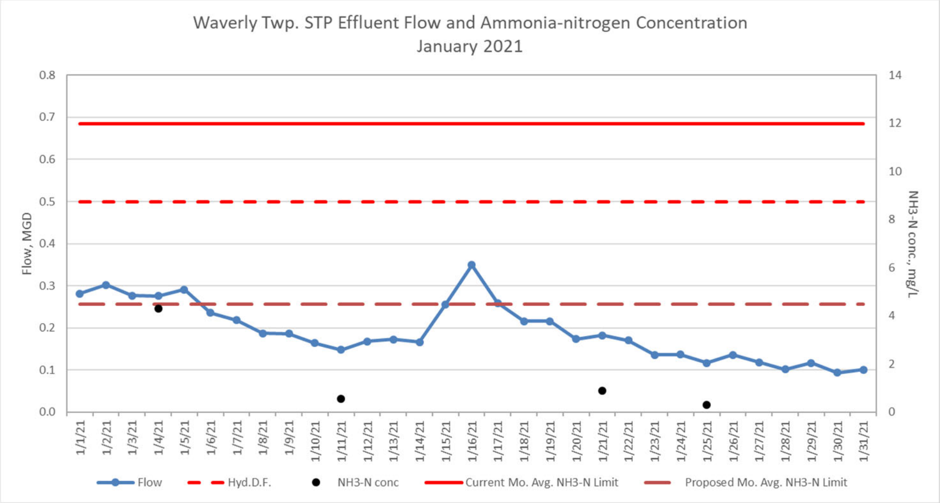
Ammonium Reductions at Waverly Township STP:

The January 2020 effluent ammonia limit was not exceeded during 2020, although two of five samples were high but not high enough to jeopardize the average monthly limit of 12 mg/L. If the proposed fifth year limit were applied to this data, 4.5 mg/L, all five sampling events would have exceeded the limit, indeed exceeding the imax grab sample limit of 9.0 by 27%.



Graph 5: January 2020 daily flow and ammonia-nitrogen concentration

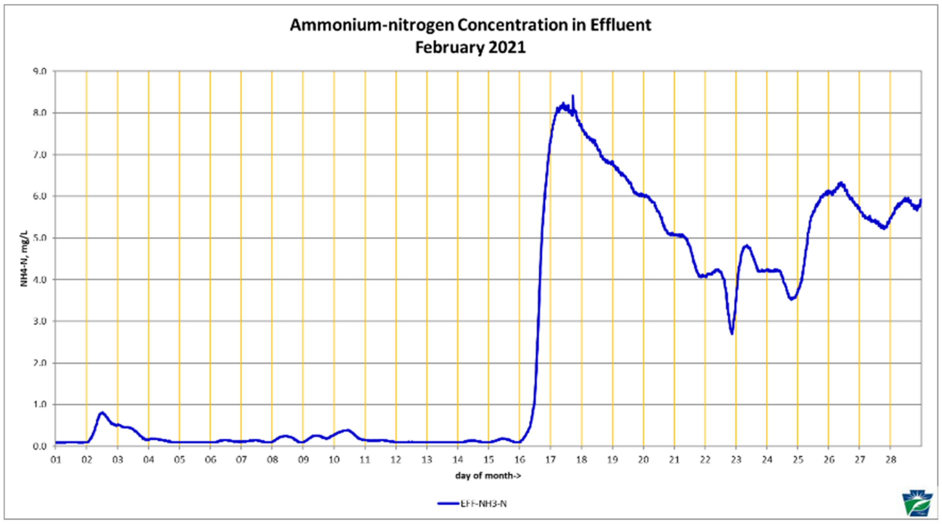
When these proposed ammonia limits are applied to the DMR data for January 2021, there is no exceedance. None of four 8-hr. composite samples exceeded 9.0 mg/L, and the monthly average, reported to the tenth of a milligram,[5] was still only 1.5 mg/L, well below the proposed average monthly limit for cold weather.



Graph 6: January 2021 Effluent flow and ammonia-nitrogen concentration

Looking at the first quarter of 2021, there were only two of thirteen sample events where the ammonia-nitrogen registered above a proposed cold weather average monthly limit of 4.5 mg/L. One of these occurred in February, when the average monthly ammonia nitrogen concentration had been 1.8 mg/L, still well below the proposed limit.

Moreover, the average monthly effluent ammonia-nitrogen for February 2021, measured in fifteen-minute intervals by DEP's ammonium probe, despite modest high concentrations during high flow periods, was only 2.56 mg/L, again, well below the proposed winter limit of 4.5 mg/L.



Graph 7: February 2021 Effluent ammonia-nitrogen concentration

Ammonium Loading to the Amphidrome

In a discussion of the Amphidrome performance with Philip Pedros, P.E., one of the engineers who worked on the pilot study prior to installing the filter at Waverly Township, he observed that the filters would work more efficiently at higher loading rates than presently observed. This makes sense when one considers the highly concentrated population of nitrifying bacteria in the biofilm attached top the filter media. During the evaluation, influent ammonium concentration averaged 29 mg/L. This average concentration was higher than the usual lagoon effluent

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[5] Note: a common error by treatment plant operators is to report insignificant digits on their Discharge Monitoring Reports. In this example, the Permit lists the limit to the tenth of a milligram; therefore, the average monthly NH3-N is rounded down from 1.52 mg/L to 1.5 mg/L. If the datum was calculated in summer, and the final proposed limit of 1.5 mg/L were in effect, there would be no violation of the monthly average.

values during the warm-weather months when nitrification is occurring in the lagoons. The filters likely can handle a higher influent loading value, but the question of inhibiting nitrification in the lagoons is a matter that the judicious operator would avoid: any chemical inhibition in the lagoons will damage the biofilm in the filters. Alternatively, decreasing the aeration of the lagoons may lead to malodors during warm-weather months without appreciably increasing the ammonium loading at the Amphidrome. Less efficient removal of BOD and TKN in the lagoons might engender some heterotrophic growth in the filters, providing more biomass as a hedge against cold-weather heat loss later in the year; however, lagoon effluent ammonia and nitrate test results during the winter months suggest that not much nitrification occurs there, so the filter influent ammonia-nitrogen values are probably as good as they will be without regularly adding a supplemental source such as urea-nitrogen.

Considerations for Lagoon Operation:

Mr. Pedros suggested that the lagoons might be operated in ways to enhance ammonium loading to the Amphidrome while reducing the effects of I/I hydraulic surges. This evaluation did not consider ways to modify the lagoons; however, the subject should be considered.

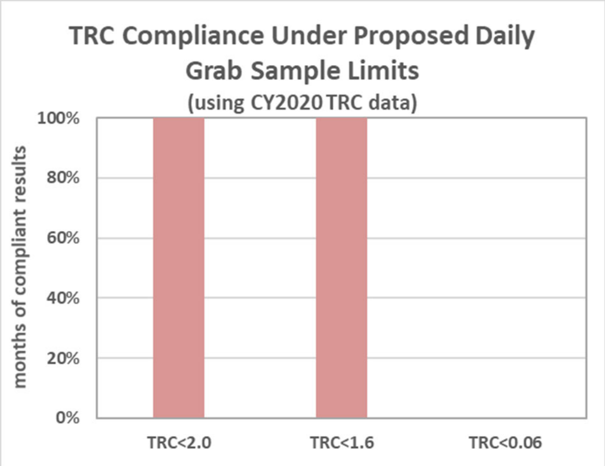
- Modifying the aeration of the lagoons during warm weather; that is, reducing aeration in the second lagoon, may deter natural nitrification and send more ammonium to the Amphidrome for processing. This could be tried experimentally but would require increased monitoring and testing to assure that it works and that it doesn't affect the efficiency of organic waste removal;
- Modifying the flow between the two lagoons may allow for some increased attenuation of hydraulic loads to the Amphidrome, reducing the negative effects of these surges on the filters' detention time; however, strict attention would be required to assure that the freeboard requirements be maintained. Obviously, the best solution here is to control the inflow and infiltration at its source than to risk problems with the lagoons.

Total Residual Chlorine (TRC), Proposed Limit:

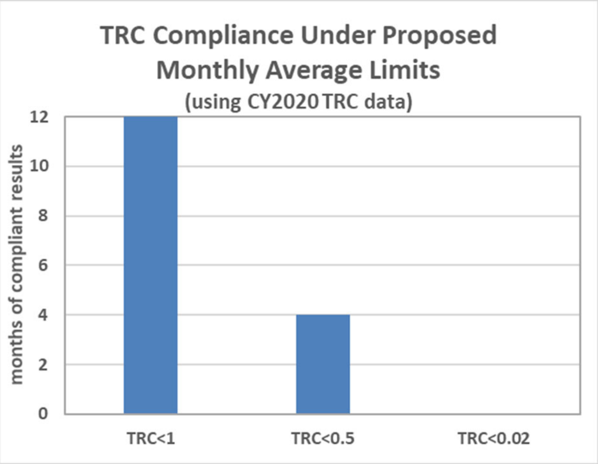
An issue that may have been overlooked during the evaluation deserves mention: It regards the impending TRC limits in the new NPDES Permit.

The facility presently enjoys a total residual chlorine limit of 1 mg/L as a monthly average and 2 mg/L as an instantaneous maximum ("imax" or grab sample). This limit will drop to 0.5 mg/L as a monthly average, and to 1.6 imax, following the first year of the new Permit limits. In the fifth and final year of the proposed Permit, the limit will drop to 0.02 mg/L monthly average and 0.06 mg/L imax.

During 2020, all 245 daily TRC compliance samples individually measured less than or equal to 1.6 mg/L; however, 8 of 12 monthly averages were above 0.5 mg/L. When the proposed fifth year imax concentration limit of 0.06 mg/L as imax is used, only 1 of 245 of TRC measurements are at or under the proposed imax concentration, and no monthly average TRC measurement is at or below 0.02 mg/L. Thus, it appears that



Graph 8: Percentage of TRC compliance if differing TRC limits are applied.


TRC Compliance Under Proposed Monthly Average Limits
(using CY2020 TRC data)

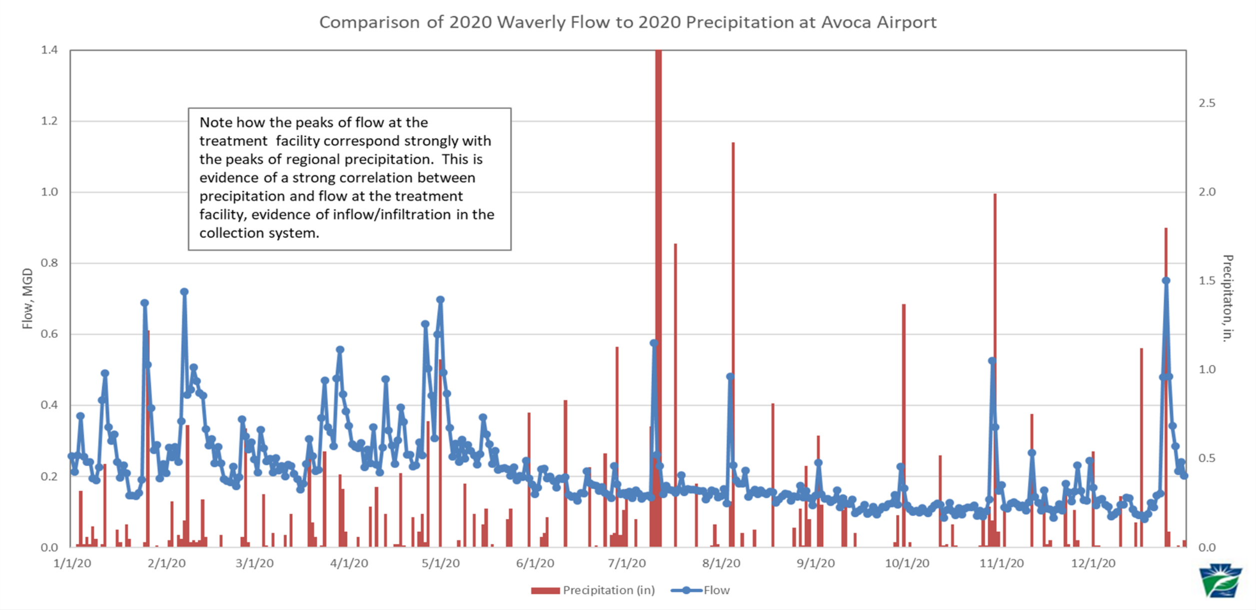
Graph 9: 2020 annual months of TRC compliance if differing TRC limits are applied.

adapting to the new TRC limit may be a more pressing matter than adapting to the new ammonia-nitrogen limit.

Waverly Township should ask its consulting engineer to consider modifications that will help the facility meet its impending TRC limits. Widely accepted solutions to more stringent TRC limits include post-disinfection treatment of the effluent with sulfur[6] compounds or replacing the use of chlorine-based disinfection with that of ultraviolet light (UV). Either method has advantages and disadvantages, the former being the introduction of another chemical process, and the latter being associated with increased electricity consumption and more attentive maintenance. At flow rates averaging 0.4 MGD rising to 0.7 MGD, use of liquid sulfur compounds may be safer than using sulfur dioxide gas.

The compliance testing method will have to be changed, also. There is a test for TRC in the "ultra-low range" (ULR) that employs colorimetric analysis, but the treated sample has to be mechanically pumped through a micro-cell adaptation to the standard spectrophotometer, although after sulfonation, the TRC result should almost always be less than the method detection limit for the test.[7] The operators will no longer be able to simply report the results obtained are less than the detection limit of the method or equipment presently used, nor may they simply assume that a non-detected result is equivalent to a "zero" or no TRC detected.

Inflow and Infiltration


Comparison of 2020 Waverly Flow to 2020 Precipitation at Avoca Airport

Note how the peaks of flow at the treatment facility correspond strongly with the peaks of regional precipitation. This is evidence of a strong correlation between precipitation and flow at the treatment facility, evidence of inflow/infiltration in the collection system.

Graph 10: Correlation of I/I to flow peaks at treatment facility

---

[6] "Dechlorination" or "Sulfonation"

[7] DEP assisted Clarks Summit State Hospital STP in employing the Hach Ultra-low Range Total Chorine DPD Test, Method 8370, with Pour-through Cell when they adopted newer ultra-low TRC limits.

As stated earlier, inflow and infiltration are an ongoing problem in the township's collection system. I/I can increase treatment costs for the customer base and may lead to connection bans and other limitations on the community. Inflow in a residential service area usually comes from banned connections to the collection system, such as broken or uncapped clean-outs, roof drains, basement sumps, perimeter "French" drains, and abandoned septic tanks that were improperly connected. Manholes without protective inserts, especially those located where rainwater is known to pool, are also a potential source. Infiltration happens when water finds its way into collection system pipes through cracks, damaged seals, shifted ground causing partial collapse, high water table, and damaged grout in manholes.

Facility staff had reported receiving a grant one year to address I/I problems, but it appears that the system continues to experience increased hydraulic surges due to the continued presence of I/I in the system. The chart on the preceding page shows a comparison of the 2020 reported plant flow at Waverly with the precipitation measured at the Scranton International Airport at Avoca, nearby. With the caveat that some storm systems may vary widely in Pennsylvania's hilly and mountainous regions, the graph shows a strong correlation between peaks of plant flow and precipitation events, almost a one-to-one correspondence:

Until such time that I/I has been brought under control, it is strongly recommended that the operators track local precipitation amounts and compare it to hydraulic flow throughout the facility. The precipitation should also be reported as part of the facility's annual Wasteload Management "Chapter 94" Report in the table provided for precipitation on the DEP Chapter 94 Spreadsheet. Graphs from the 2020 Chapter 94 report, amended to show precipitation in the hydraulic loading chart, are reproduced in Attachment C. DEP observed a rain gauge at the facility but did not determine how often it has been used. Besides the weather station at the airport in Avoca, there is a Community Collaborative Rain, Hail and Snow Network weather observer in Clarks Green, Station PA-LC-28, with weather data that may be observed online at: https://www.cocorahs.org/ViewData/ViewDailyPrecipReport.aspx?DailyPrecipReportID=57cdb8c6-7aeb-4369-b2bb-101ab5399d0a

Process Monitoring Sampling and Testing:

During the data review and analysis, there were some inconsistencies among nutrient concentrations that rendered some test data incoherent, and it became quickly apparent that many process monitoring samples for nutrients in the historical record were based on analysis of grab samples. This method of sampling allows for snapshots-in-time of nutrient concentrations, but it doesn't always provide a coherent view of how nutrient concentrations change throughout the treatment process. Therefore, it is suggested that 24-hour composite sampling be employed more often. The NPDES permits have typically specified 8-hour composite sampling; however, such sampling is often incomplete in a society where activity is increasingly occurring at all times during the day. Typically, organic and nutrient loading declines overnight when most residential occupants are sleeping, so the 8-hour composite sample may cover the period when most wastewater is being generated in the collection system. But 8-hour composite sampling is based on worker schedules, not usually upon the period of time that best describes peak activity in the collection system, and it may not account for the time it takes for peak loading to arrive at the plant headworks. On the other hand, 24-hour composite sampling, ideally flow-proportioned to account for inflow and infiltration issues in addition to normal hydraulic loading (diurnal) cycles, will better characterize the total organic and nutrient loading over the course of the day. Occasionally using this composite sampling throughout the process monitoring sampling points will better demonstrate where the organic and nutrient loading is consumed, in comparable proportion to the material as it passes through the treatment system. Lastly, sometimes it may be useful to sample at different points in the collection system to characterize areas where raw wastewater loading is affected by localized inflow and infiltration or where slug or fugitive loading may be present. This type of sampling an testing will help the Township prioritize which parts of the collection system should be televised and to confirm problems and implement strategic remedies.

Energy Efficiency

Wastewater treatment presently uses about four percent (4%) of all electricity generated in the United States. However, lagoon treatment systems are somewhat passive and do not consume the same quantity of electricity as suspended solids treatment systems. Still, with the use of compressed air as a method for aerating the lagoons, there may be opportunities to take advantage of the large land area surrounding the treatment system to build on the natural energy efficiency of the lagoons.

Although energy consumption and efficiency of the Amphidrome had not been evaluated during this study, given recent innovations and developments in the use of renewable energy, the large land area used for the treatment system may be an exploitable asset should the Township consider installing solar energy arrays or small wind turbines that would almost certainly reduce monthly energy bills. Much of the surrounding land is parkland used for recreation. There may be opportunities to employ some of the undesignated space for renewable energy, including existing rooftops.

ATTACHMENT A: EVALUATION TEAM

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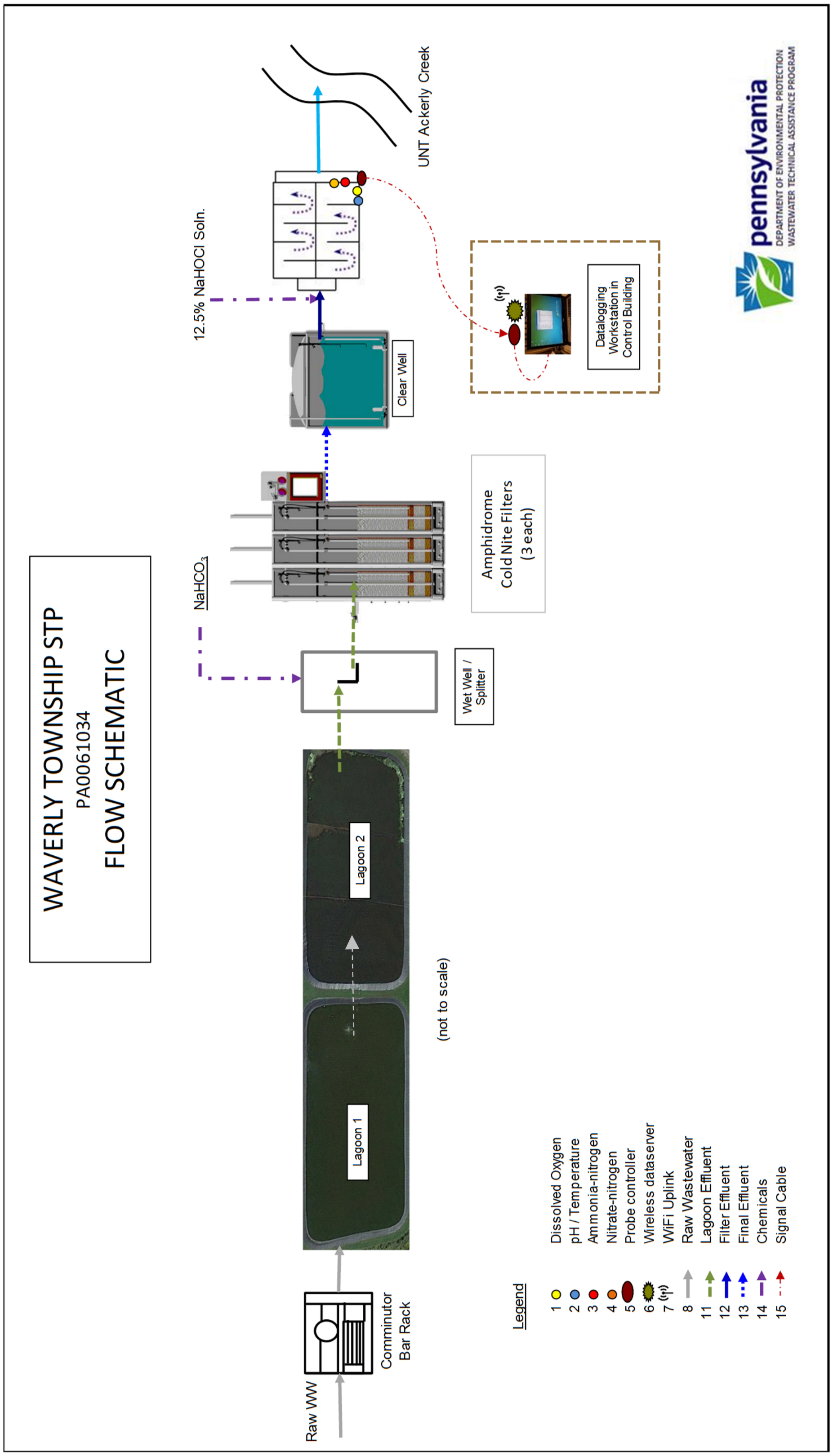
ATTACHMENT B: Facility Treatment Schematic:



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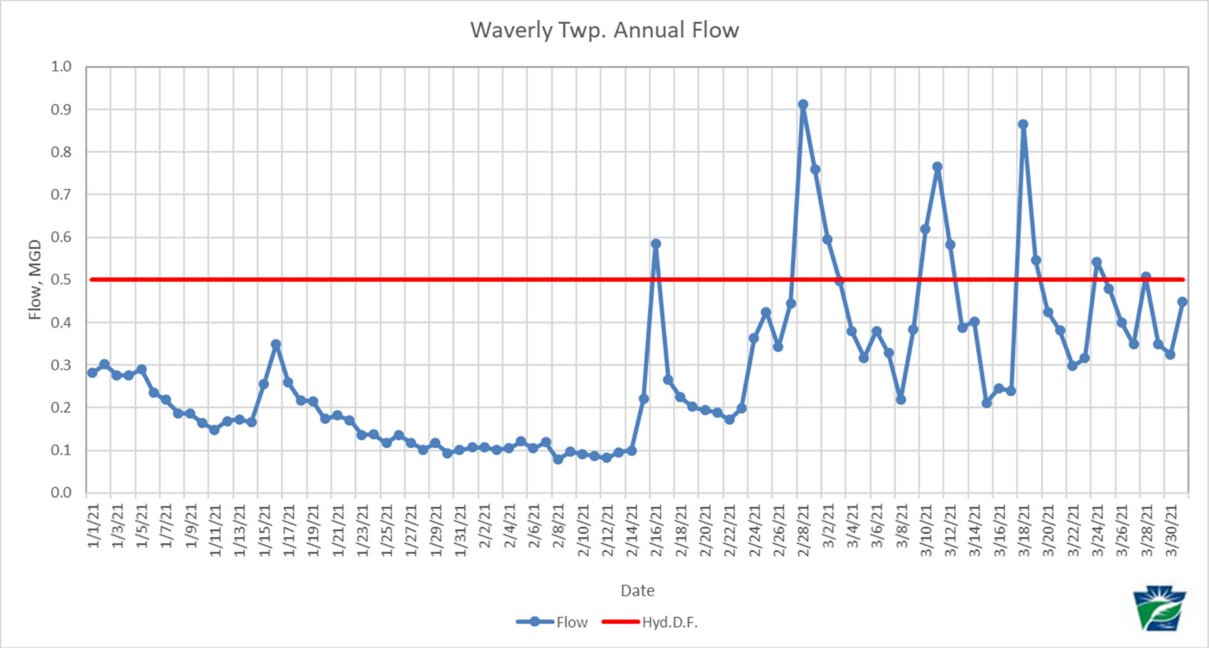
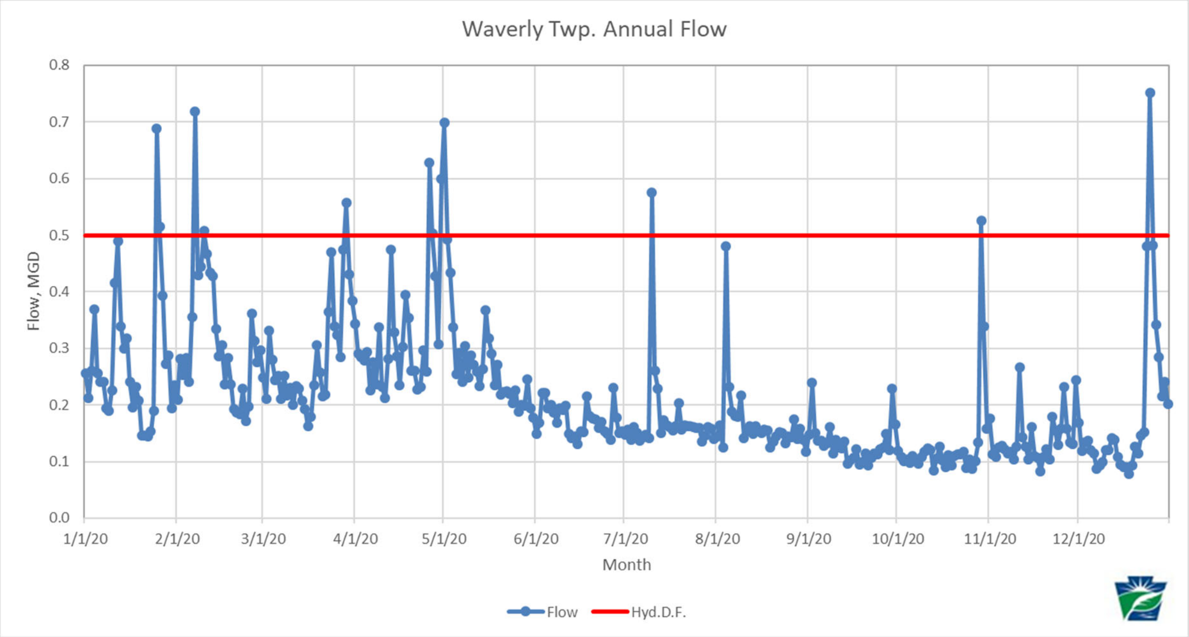
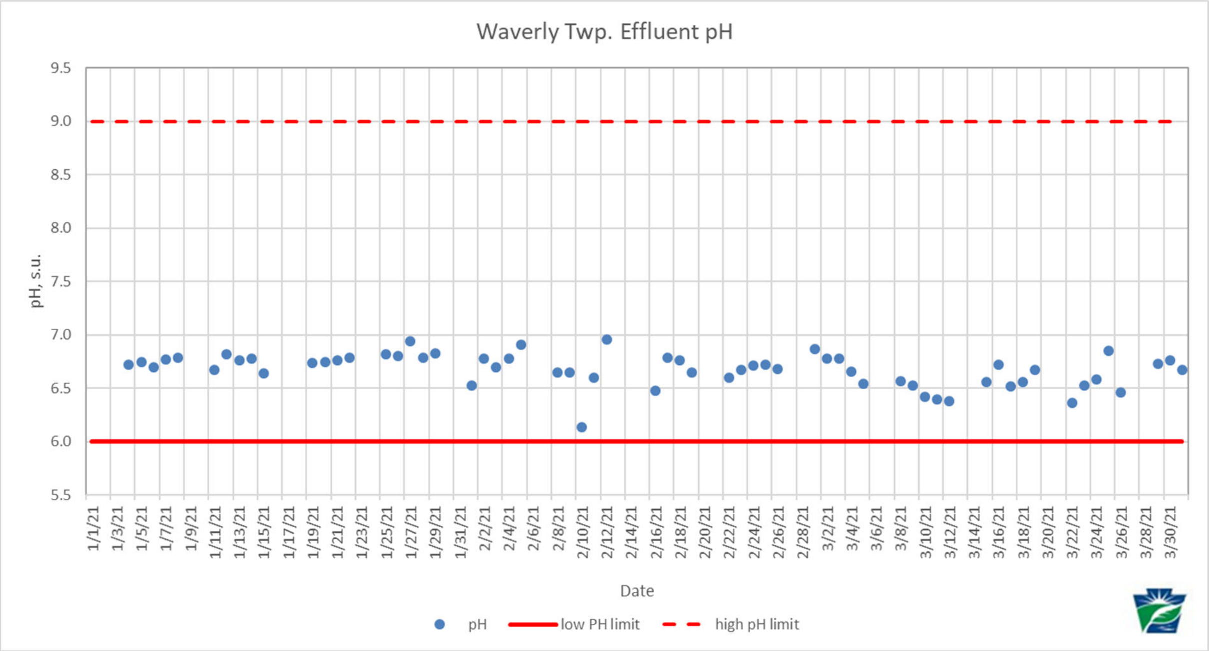
ATTACHMENT C: TREND CHARTS



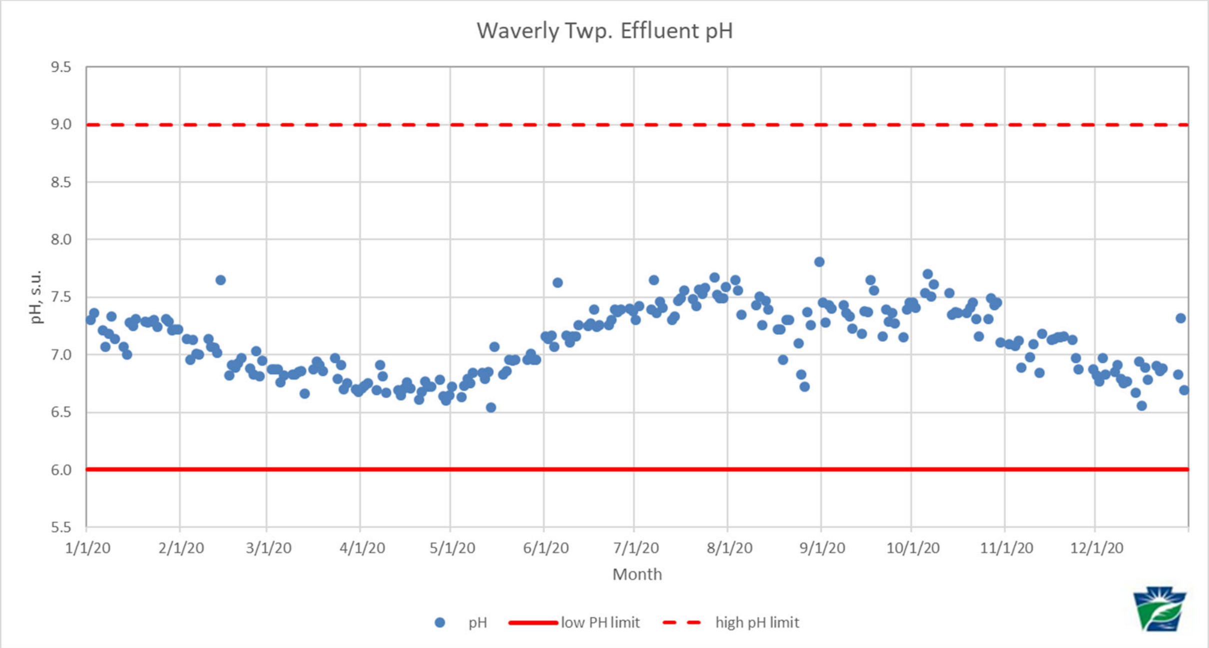
2021 Daily Flow: 11 times flow exceeded 0.5 MGD in 6 events.



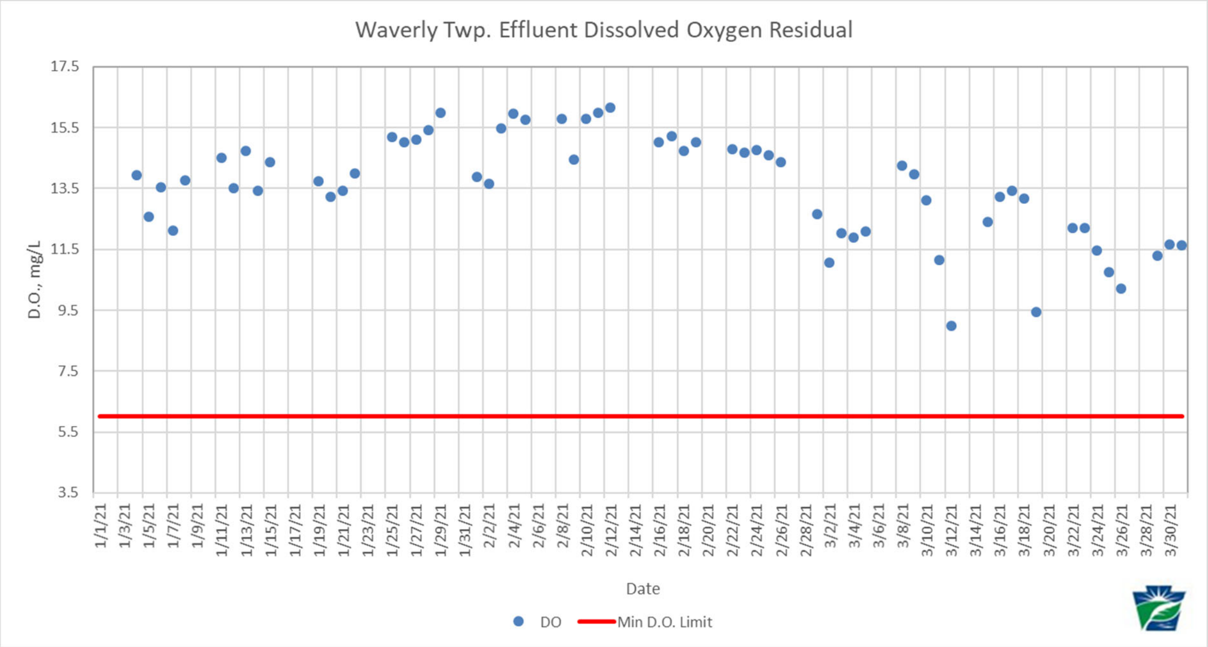
2020 Daily Flow: 11 times flow exceeded 0.5 MGD in 8 events.



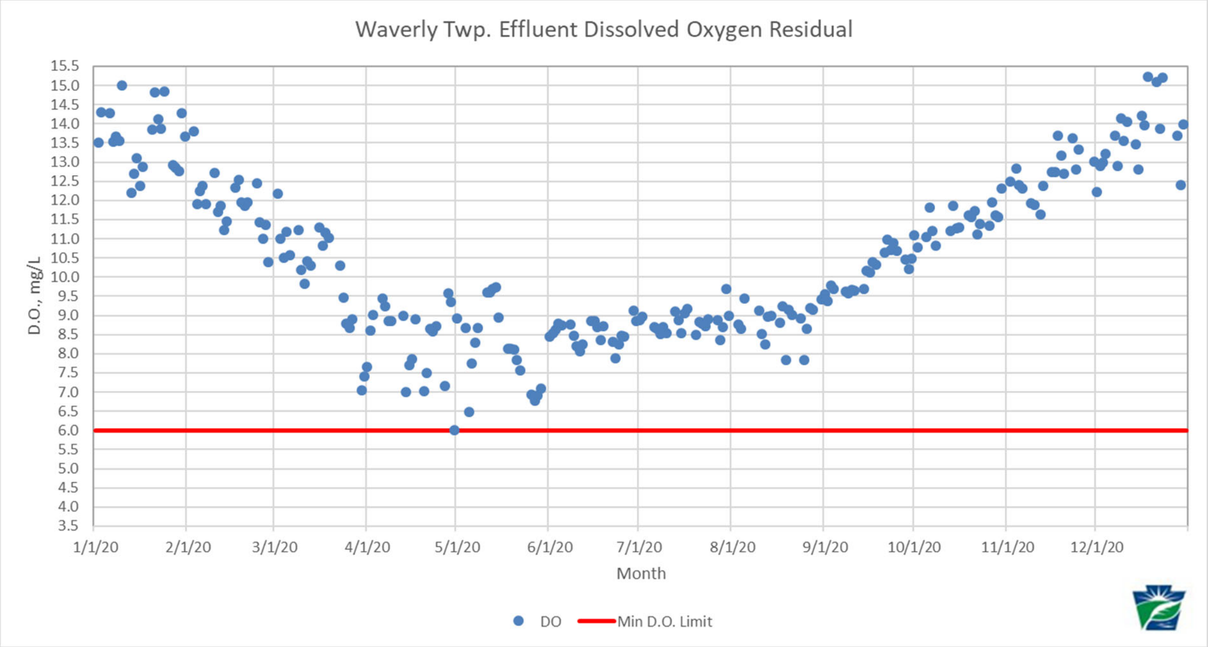
2021 pH: January through March: pH consistently below neutral, suggesting insufficient alkalinity.



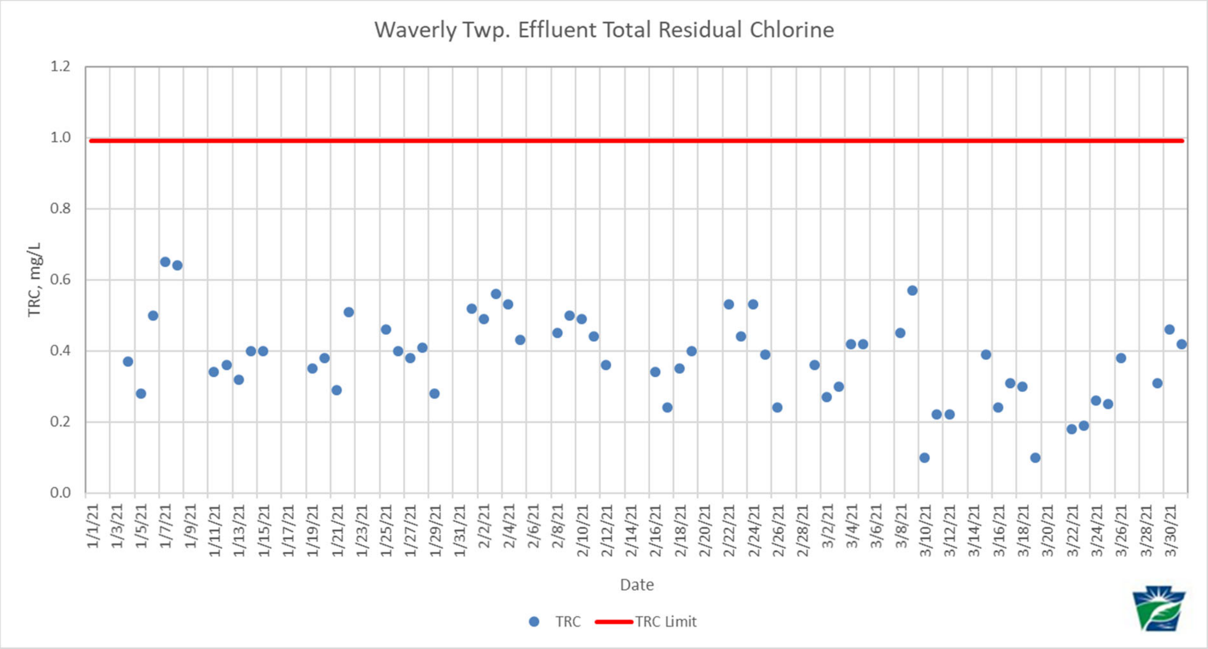
2020 Effluent pH: 5 months where pH was less than the ideal neutral condition for nitrification.



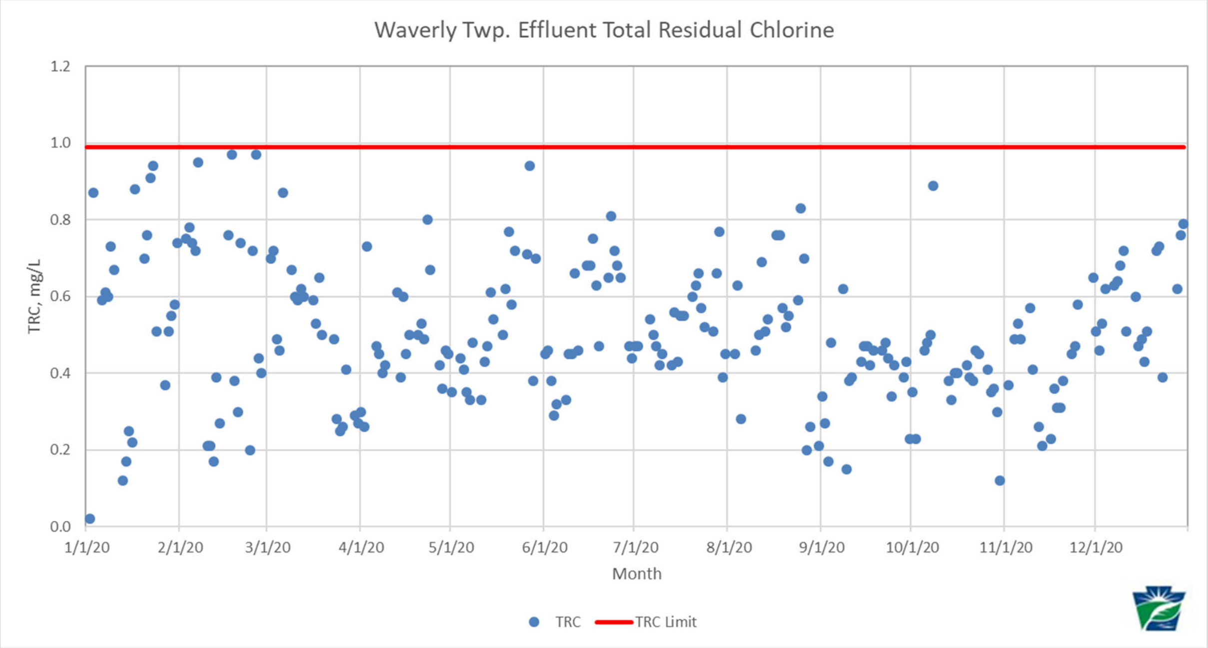
2021 Effluent DO Residual: Jan-Mar: Effluent is well-aerated.



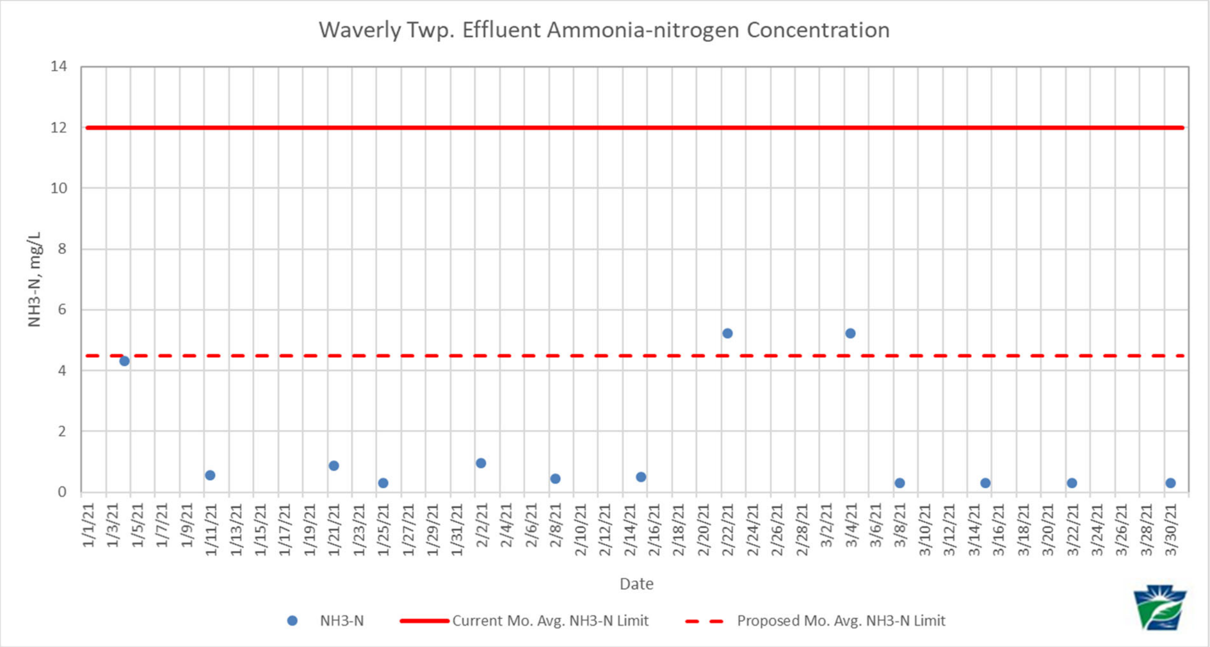
2020 Effluent Dissolved Oxygen Residual: typical seasonal profile



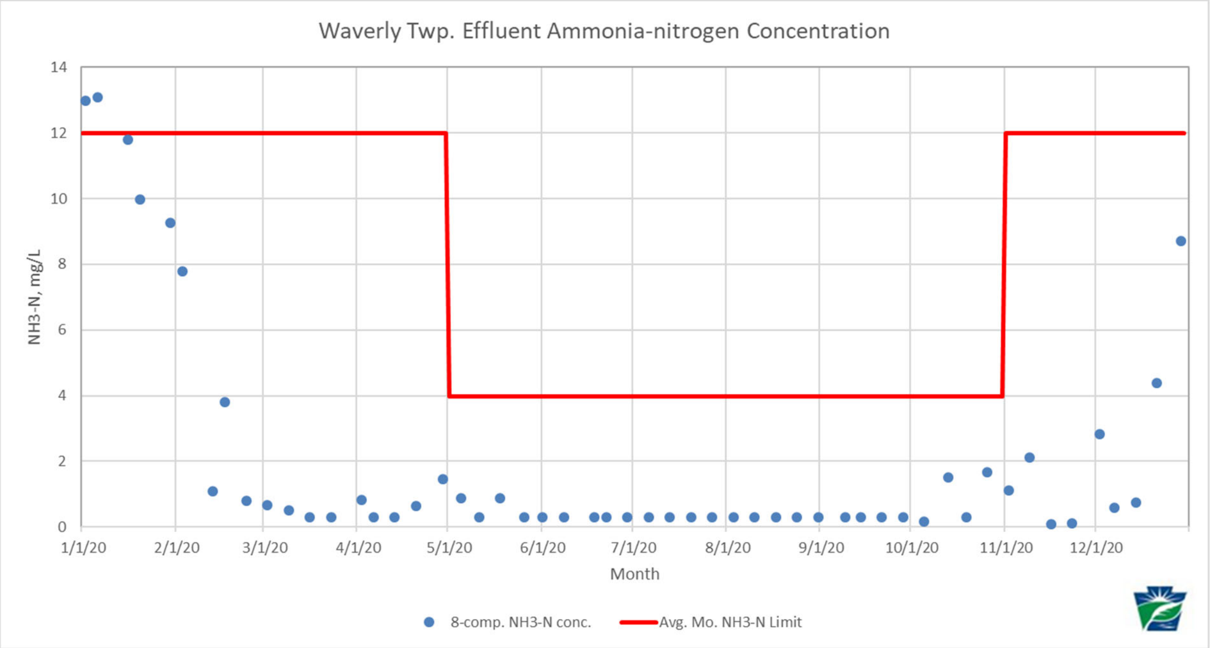
2021 Total Residual Chorine (TRC) concentration, Jan-Mar: 82% of 1st Qtr. TRC at or below pending
new NPDES Permit TRC limit of 0.5 mg/L in the fifth year of the Permit.



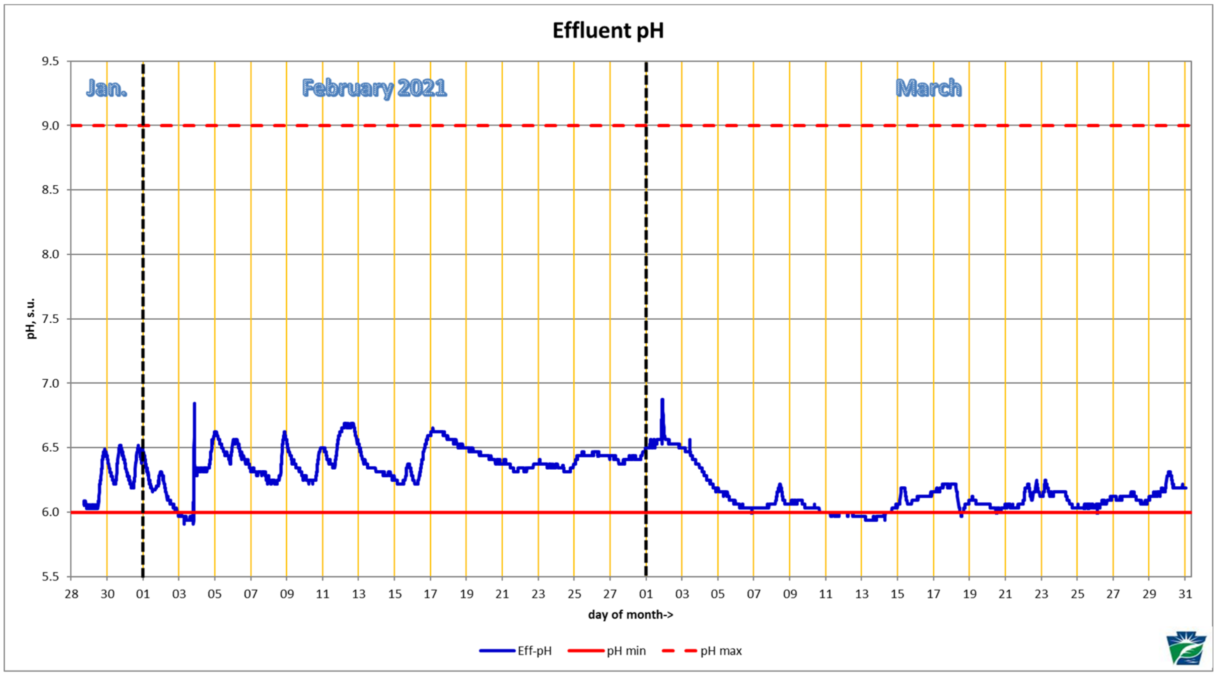
2020 TRC Concentration: 53% of TRC results are at or below 0.5 mg/L, the new TRC Limit.



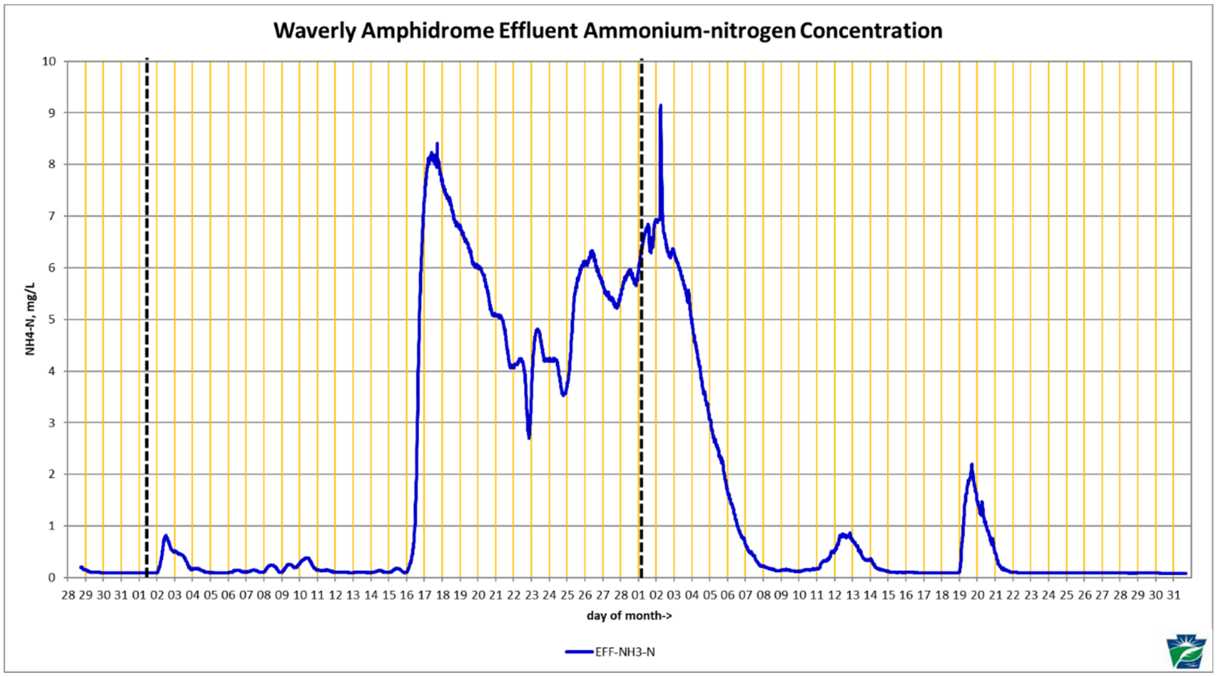
2021 Ammonia-nitrogen concentration: Jan—Mar: No DMR samples exceeded proposed year 5 limit.



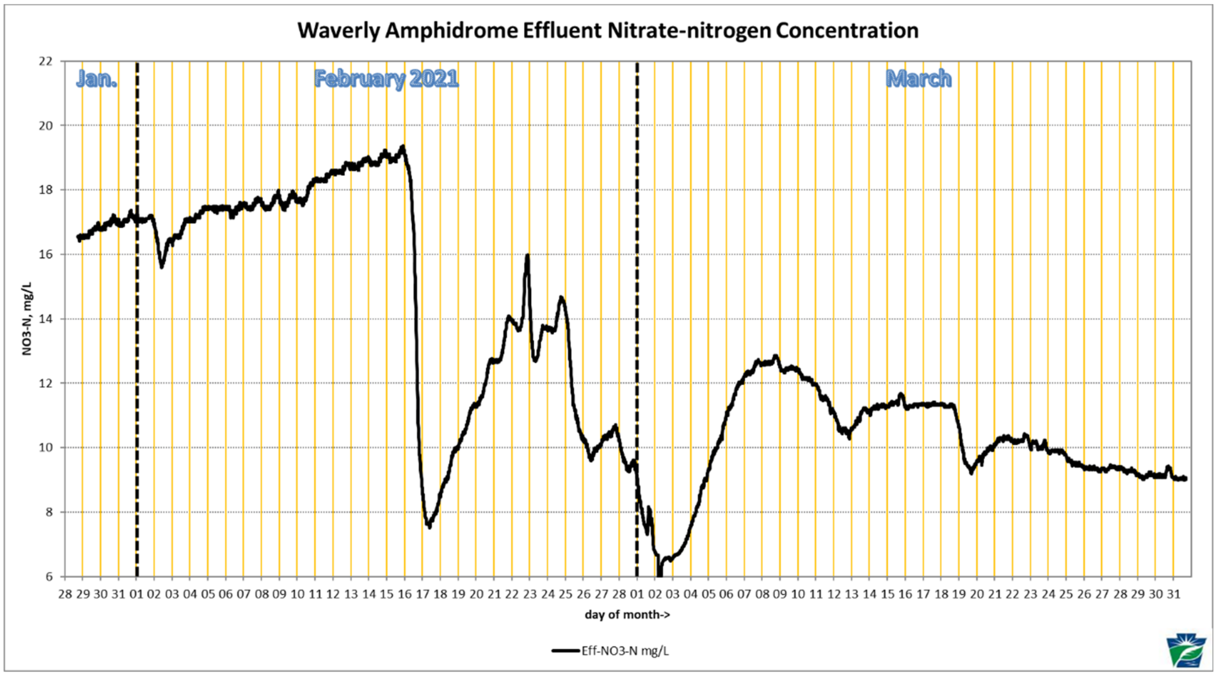
2020 Effluent NH3-N conc.: 2 exceedances in Jan.; proposed Permit limit would have been exceeded only in January on a monthly average;



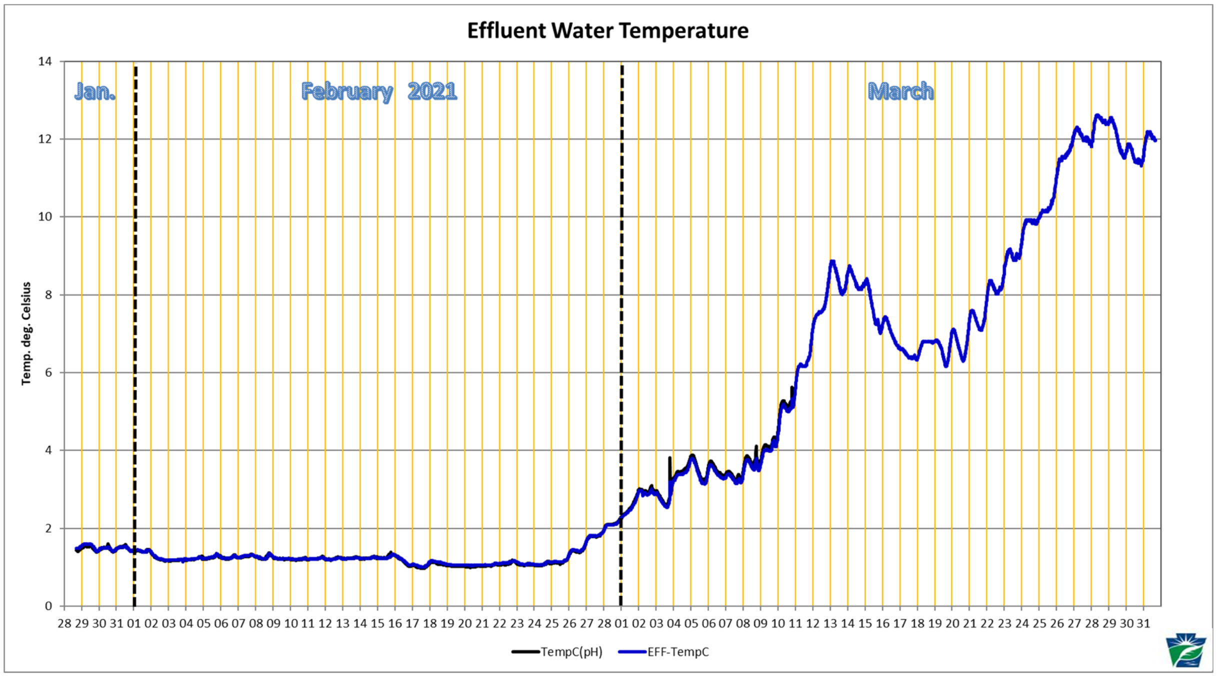
Effluent pH, , continuous monitoring graph



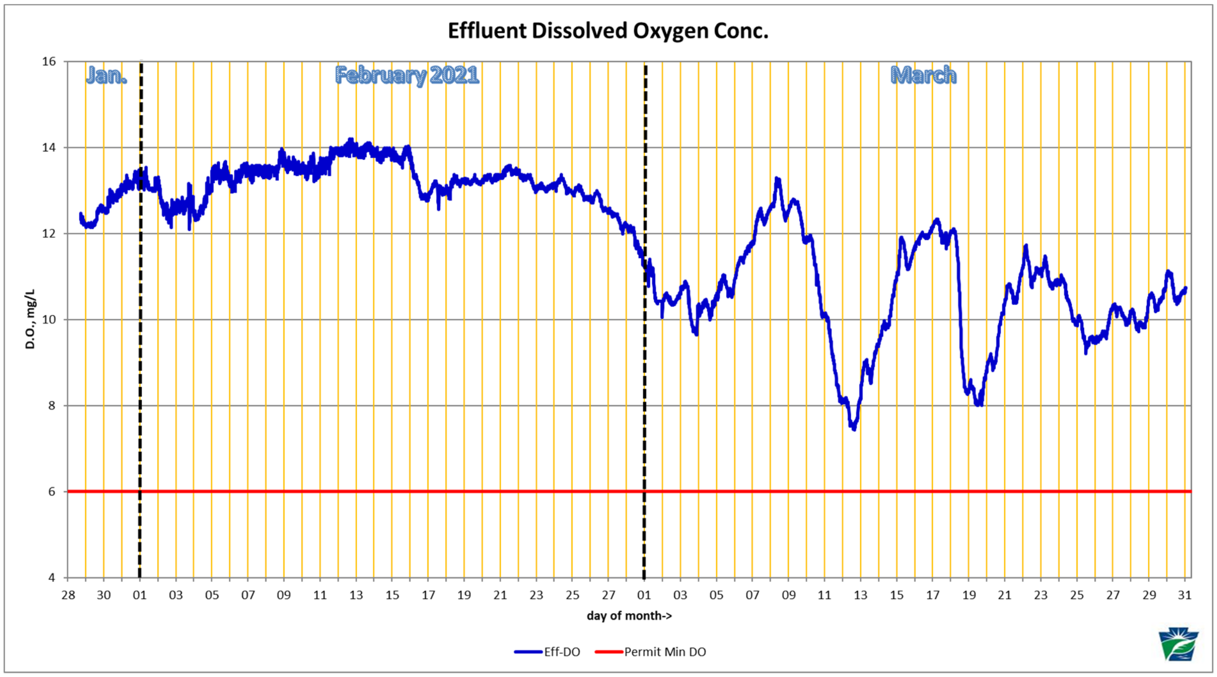
Effuent Ammonium-nitrogen concentration, continuous monitoring graph



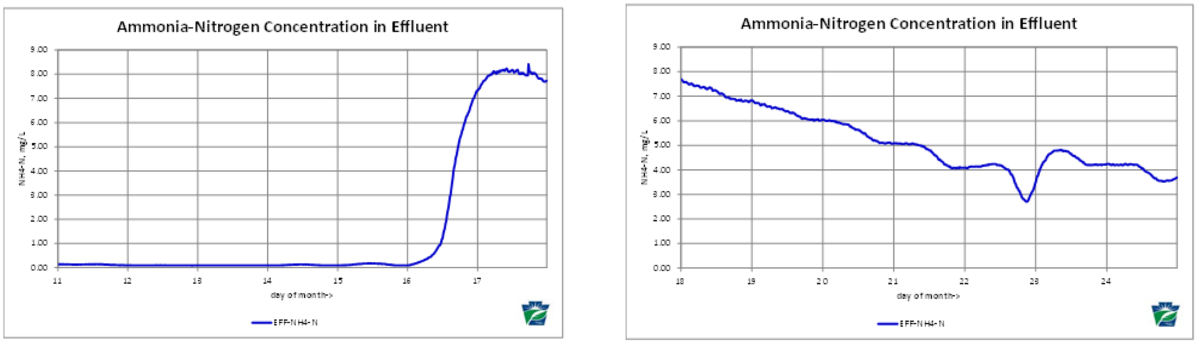
Effluent Nitrate-nitrogen concentration, continuous monitoring graph



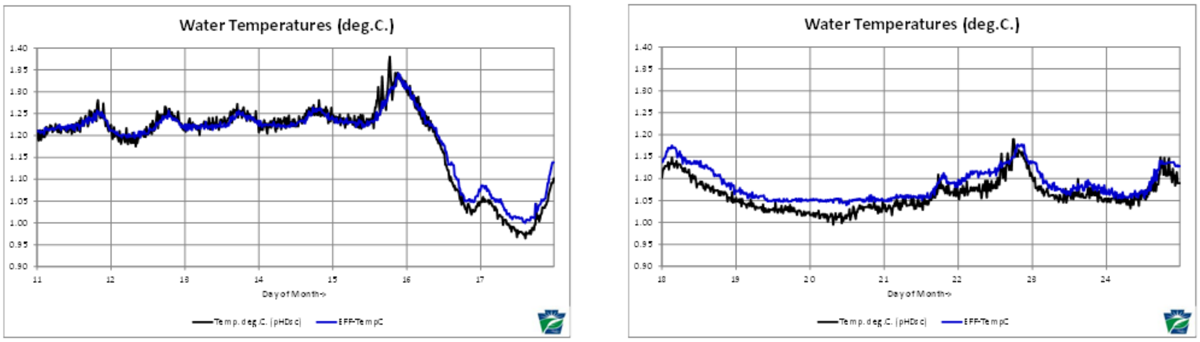
Effluent Water Temperature, continuous monitoring graph



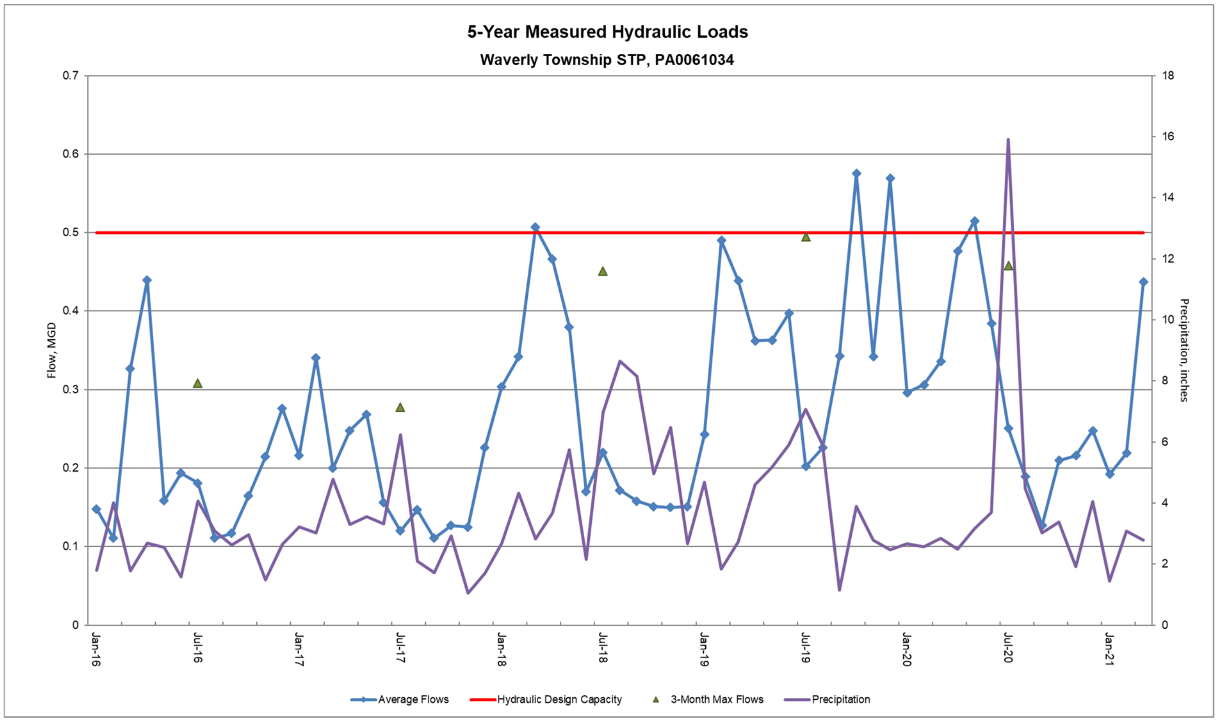
Dissolved Oxygen Residual, continuous monitoring graph



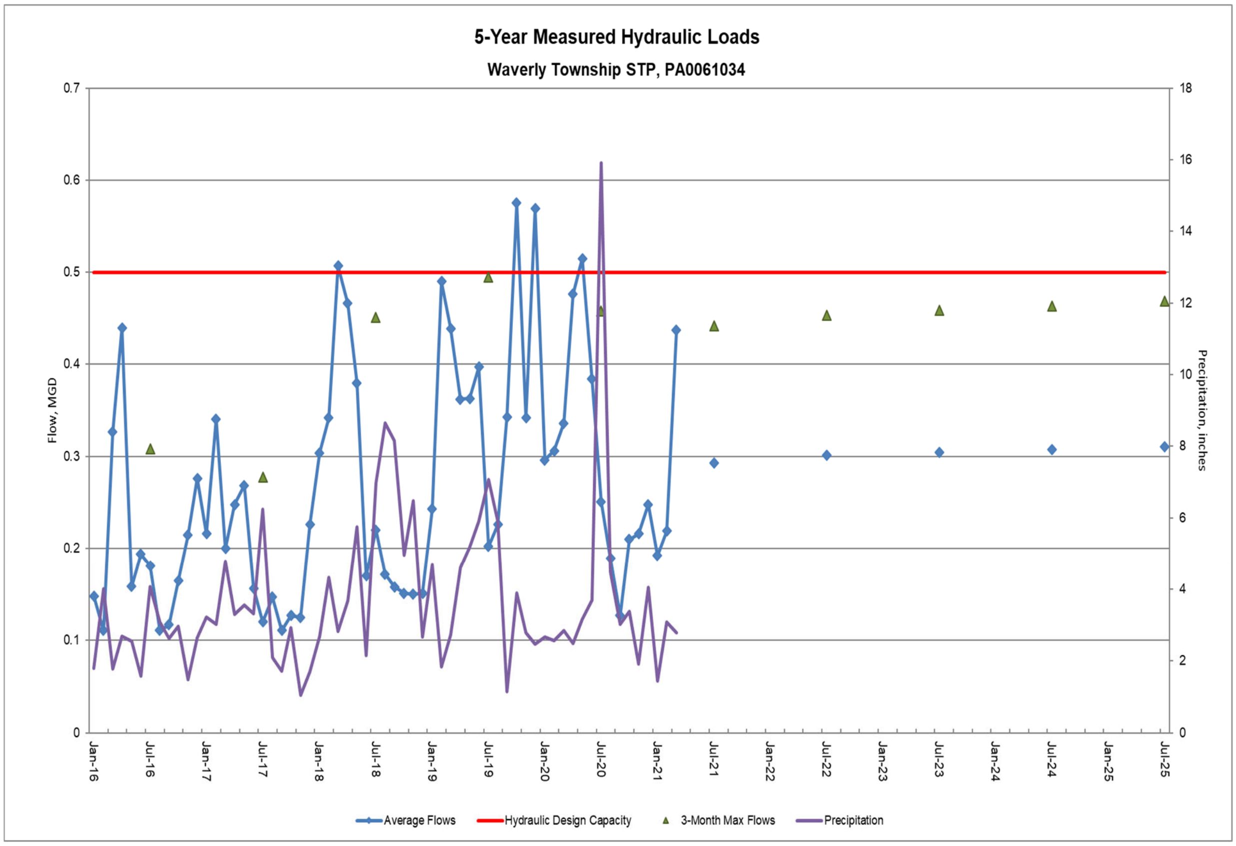
Weeks 3 and 4 Ammonium-nitrogen: first temperature upset in filter core



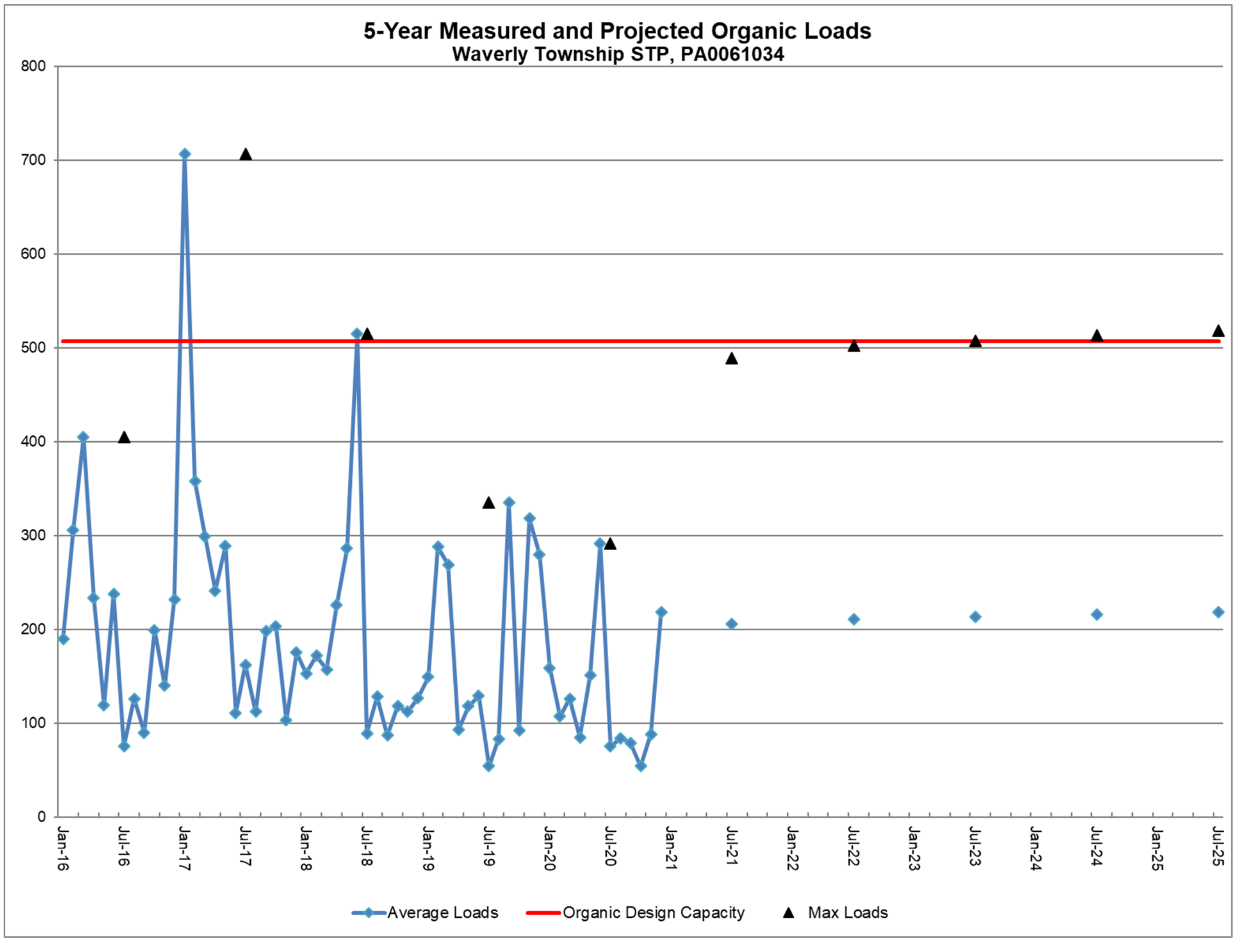
Weeks 3 and 4 Effluent Water Temperature: slight dip preceeds loss of nitrification above



5-year hydraulic loading graph, with precipitation tracking, from 2020 Chapter 94 Report



Projected Hydraulic Loading, from 2020 Chapter 94 Report



2020 Chapter 94 Report predicts maximum month organic loads may exceed design limit, potentially overloading the treatment facility.

ATTACHMENT D: RECORD PHOTOGRAPHS

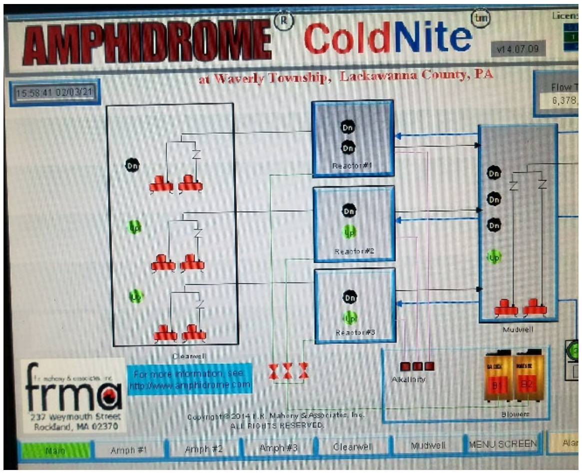

Aerial Overview of Treatment Facility


View of Control Building & Headworks


View of second lagoon


View of Amphidrome filter and building


View of installed monitoring probes at effluent



For more information, see http://www.amphidrome.com

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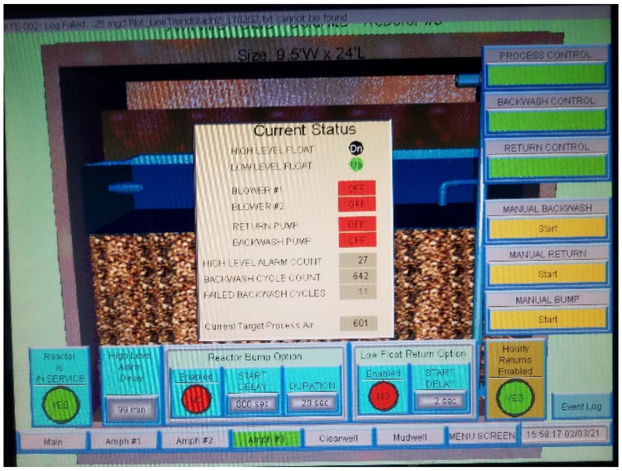
ALL RIGHTS RESERVED.

Schematic for Amphidrome Filter



RTE-002: Log Failed. .25 mgd Plot_LineTrendGraph2_170202.txt cannot be found

Size: 9.5'W x 24'L

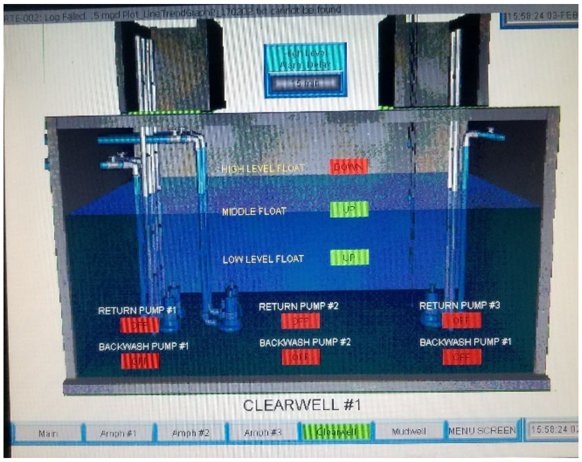
Current Status

HIGH LEVEL FLOAT Dn
LOW LEVEL FLOAT Up
BLOWER #1 OFF
BLOWER #2 OFF
RETURN PUMP OFF
BACKWASH PUMP OFF
HIGH LEVEL ALARM COUNT 27
BACKWASH CYCLE COUNT 642
FAILED BACKWASH CYCLES 11
Current Target Process Air 601

Reactor is IN SERVICE YES
High Level Alarm Delay 99 min
Reactor Bump Option: Enabled NO; START DELAY 800 sec; DURATION 20 sec
Low Float Return Option: Enabled NO; START DELAY 2 sec
Hourly Returns Enabled YES

15:58:17 02/03/21

Schematic for filter cell



RTE-002: Log Failed. .5 mgd Plot_LineTrendGraph2_170202.txt cannot be found

15:58:24 03-FEB

High Level Alarm Delay 15 min

HIGH LEVEL FLOAT DOWN
MIDDLE FLOAT UP
LOW LEVEL FLOAT UP
RETURN PUMP #1 OFF
RETURN PUMP #2 OFF
RETURN PUMP #3 OFF
BACKWASH PUMP #1 OFF
BACKWASH PUMP #2 OFF
BACKWASH PUMP #1 OFF

Schematic for Clearwell

RTE-002: Log Failed. Alarm_160226.txt cannot be found

High Level Alarm Delay 5 min

HIGH LEVEL FLOAT DOWN
LAG FLOAT DOWN
LEAD FLOAT DOWN
LOW LEVEL FLOAT UP
MUDWELL PUMP #2 OFF
MUDWELL PUMP #1 OFF

15:58:32 02/03/21

Schematic for Mudwell

DEP probe controller and data collector

Sodium bicarbonate day tank & pump

Urea supplement station

Monitoring probes during installation

Monitoring probes near effluent pit

Foaming in Filter Influent Splitter Box

Surface ice forming around effluent probes

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ATTACHMENT E: ALKALINITY DEMAND

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 $CaCO_3$[8], multiply the influent (or raw) TKN (total Kjeldahl nitrogen, which is organic nitrogen and ammonium nitrogen, combined)[9] 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:
32 mg/L Influent TKN x 7.14 mg/L alkalinity per 1 mg/L TKN = 228 mg/L alkalinity required

If the secondary influent already has 56 mg/L of alkalinity, then the net alkalinity demand is:

228 mg/L alkalinity needed to treat – 56 mg/L alkalinity in Influent = 172 mg/L alkalinity demand

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 <u>0.035 MGD</u>, then the amount of alkalinity required would be

172 mg/L x 0.035 MGD x 8.34 lb./gal = 50 lb./day.

To convert this to a chemical dose, you will have to determine the available alkalinity in the chemical. For example, 1 lb. hydrated lime has 0.74 lb. alkalinity[10]. This means that to provide 50 lb./day alkalinity as $CaCO_3$, you need to divide this by the ratio of chemical to alkalinity:

50 ÷ 0.74 = 68 lb./day of hydrated lime

Figure adding 1-½ fifty-pound bags added over 24 hours, not all at once. Using the 100-gallon day tank, the feed rate would be

75 lb./day ÷ 24 hours = 3-1/8 lb./hr. (100 gal. per day = c. 4.2 gal./hr.)

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.

---

[8] 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.

[9] 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.

[10] See the table on the next page.

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 F: AMPHIDROME DESIGN REVIEW RECORD

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

NORTHEAST REGIONAL OFFICE
CLEAN WATER PROGRAM

WATER QUALITY MANAGEMENT INTERNAL REVIEW AND RECOMMENDATIONS

Application Type **New**
Facility Type **Sewage**
WQM Type **WQ2TP**

Application No. **3513401**
APS ID **800176**
Authorization ID **957515**

Applicant and Facility Information

Applicant Name	**Waverly Township (Lackawanna County)**	Facility Name	**Waverly Township WWTP**
Applicant Address	Lake Henry Drive, PO Box 8 Waverly, PA 18471-0008	Facility Address	Lake Henry Drive Waverly, PA 18471-0008
Applicant Contact	Ronald Whitaker (Chairman)	Facility Contact	Tom James (Maintenance Superintendent)
Applicant Phone	(570) 586-0111	Facility Phone	(570) 586-9579
Client ID	87532	Site ID	250886
SIC Code	4952	Municipality	Waverly Township
SIC Description	Trans. & Utilities - Sewerage Systems	County	Lackawanna

Purpose of Application Upgrade of WWTP via installation of Amphidrome filter(s) for reduction of Ammonia-N in effluent.

Internal Review and Recommendations

The project consists of a WWTP upgrade via installation of an additional tertiary nitrification stage/system consisting of three (3) parallel “Amphidrome^{TM}” Biologically Active Filters (BAF) units (a.k.a. Submerged Attached Growth Bioreactor (SAGB) units) with “clearwell” & “mudwell”, configured for nitrification only (not oxidation of carbonaceous material nor reduction of TN/TP annual mass loading) in order to achieve Ammonia-N limits set forth in the 7/1/2011 NPDES Permit ID# PA0061034 Part C.I.B (Compliance Schedule). The System will further treat effluent already treated by the existing site lagoon treatment system (prior to chlorination & discharge). No proposed increase in WWTP hydraulic capacity (0.50 MGD) or organic capacity (507 lbs. BOD_5/day).

Background:

- PDG Status: The application is no longer covered by the DEP Permit Decision Guarantee Program time-frames due to a required Technical Deficiency Letter.
- General History:
  - The 7/31/2012 Pilot Study Report (discussed below) indicated that the existing WWTP process (two (2) 3.75 million gallon aerated facultative lagoons in series) was not designed for nitrification, and has not shown an ability to nitrify during periods of colder weather. In 1999, the WWTP was rerated from 0.36 MGD to 0.50 MGD (no increase in maximum organic loading of 507 lbs. BOD5/day) due to wet weather flow issues.
  - The WWTP has had ammonia-N issues for years per the DEP files, with a 1/18/2011 DEP NOV letter citing Ammonia-N violations during all seasons over a period of several years. A 2/11/2011 Milnes Engineering Letter (consultant) indicated that the existing WWTP begins to lose nitrification capacity when temperatures fall below 50 °F.
  - The NPDES and WQM Part II Permit ID# 3584403-T1 permits were transferred to Waverly Township on 7/1/2011. Here is an excerpt from the 7/1/2011 NPDES Fact Sheet/IRR: “After the draft permit was sent, the Department was advised that the municipal authority had been dissolved and the Township has changed its name from Abington to Waverly (effective 1/1/11). The applicant submitted an application for transfer to

Approve	Return	Deny	Signatures	Date
X			James D. Berger, P.E. / Environmental Engineer	April 30, 2013
X			Brian F. Busher, P.E./ Environmental Engineer Manager	
X			Michael J. Brunamonti P.E./ Program Manager	

Internal Review and Recommendations

reflect the new permittee and facility names, which are reflected in the final permit. Along with the NPDES renewal, the associated Water Quality Management Part II Permit (3584403) is being transferred."

- 7/1/2011 NPDES Permit ID# PA0061034: This is a 0.50 MGD "significant" Phase 3 Chesapeake Bay POTW with annual mass caps for TN and TP (no concentration limits) effective in 2015. Per the 7/11/2011 NPDES IRR, the 2/11/11 Permittee Letter indicated WWTP upgrades would be done in order to address ongoing compliance issues (ammonia-nitrogen violations); nitrification; and possibly equipment for denitrification and/or phosphorus removal. The Permit Part A required weekly (8-hour composite) Ammonia-N sampling with limits (4.0 mg/l average monthly/8 mg/l IMAX Summer; 12 mg/l average monthly/24 mg/l IMAX Winter). The NPDES Permit Part C.I.B (Compliance Schedule) included the following dates:
  - 12/31/2012: "Submit Water Quality Management Part II Permit Application for WWTP modifications"
  - 6/30/2013: "Award contract for construction"
  - 3/31/2014: "Complete construction (plant fully operational)"
  - 6/30/2014: "Establish nitrification (compliance with Ammonia-Nitrogen effluent limitations)"
  - 9/30/2014: "Establish denitrification and phosphorus removal or obtain nutrient credits as needed for Chesapeake Bay compliance year beginning 10/1/2014"
  - 9/30/2015: "Compliance with Chesapeake Bay effluent limitations".
- Receiving Stream Condition: The receiving stream (Unnamed Tributary #28835 To Ackerly Creek (CWF)) is impaired for aquatic life due to "Municipal Point Source - Organic Enrichment/Low D.O.; Municipal Point Source - Suspended Solids; Urban Runoff/Storm Sewers – Metals". Tentative TMDL scheduled for 2015. NOTE: The permittee was informed of the potential for future Watershed TMDL Waste Load Allocations (WLAs) due to ongoing stream impairment (not subject to Chesapeake Bay nutrient trading options, with 2015 NPDES TN/TP caps tied strictly to Chesapeake Bay requirements) via the 1/30/2013 Technical Deficiencies Letter. Nutrient-caused impairments are a potential cause for low Dissolved Oxygen (DO) conditions.
- Amphidrome System: The manufacturer/supplier (FRMA) website had the following general information on the technology:
  - "The system is a fixed film sequencing batch biological filter." "In a fixed film reactor the biomass attaches itself to a fixed media in the reactor and the wastewater flows over it." "The Amphidrome™ system is a submerged attached growth bioreactor process, designed around a deep-bed sand filter. It is specifically designed for the simultaneous removal of soluble organic matter, nitrogen and suspended solids within a single reactor. Since it removes nitrogen, it may also be considered a biological nutrient removal (BNR) process." NOTE: The onsite demonstration project & project design are basically the nitrification part of a stand-alone Amphidrome sewage treatment system.
  - "This Amphidrome™ reactor consists of the following four items: underdrain, support gravel, filter media, and backwash trough. The underdrain, constructed of stainless steel, is located at the bottom of the reactor. It provides support for the media and even distribution of air and water into the reactor. The underdrain has a manifold and laterals to distribute the air evenly over the entire filter bottom. The design allows for both the air and water to be delivered simultaneously--or separately--via individual pathways to the bottom of the reactor. As the air flows up through the media, the bubbles are sheared by the sand, producing finer bubbles as they rise through the filter. On top of the underdrain is 18" (five layers) of four different sizes of gravel. Above the gravel is a deep bed of coarse, round silica sand media. The media functions as filter, significantly reducing suspended solids and provides the surface area for which an attached growth biomass can be maintained." NOTE: Other states have approved small Amphidrome filters for use as SFTFs/SRSTPs, including Delaware, Maryland, Minnesota, etc. The technology source (Severn Trent Services) has a website indicating that its systems can handle up to 25,000 GPD. One FRMA internet document indicated that the Amphidrome System has been utilized in 0.20 MGD sized facilities, but did not identify specific examples.
- Pilot Project: The 7/31/2012 "Nitrification Pilot Study using Amphidrome Biologically Active Filter for Waverly Township Wastewater Treatment Facility" Report (Milnes Engineering, Inc.) included the following information.
  - Demonstration Unit: The pilot study involved use of a "F.R. Mahony & Associates, Inc." (FRMA) Amphidrome™ process demonstration unit" (over a Fall/Winter period) in regard to nitrification (to achieve ammonia-N reduction for compliance with NPDES permit). The pilot unit was designed to treat 1,000 GPD, and an influent Ammonia-N concentration of 40 mg/l (i.e. 0.34 lbs-N/day). It consisted of a 2.5-foot diameter by 13-foot high reactor chamber (with multiple layers), a 1,650 gallon clear well, blowers, ($CaCO_3$) chemical feed system, and pumps. The average flow through the unit was 1,678 GPD per the Report.

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  - Pilot Project Time-frame & Cold Weather: The demonstration unit operated between 9/7/2011 – 4/25/2012. The mild winter did not include a sustained cold period of 33 °F – 34 °F, with the lowest daily water temperature of 35.4 °F (1/23/2012).
  - Pilot Study Results: The pilot study showed that the Amphidrome system can nitrify Ammonia-N to Nitrate-Nitrite-N (no current permit limit) during the experienced cold weather conditions (high 30s °F and above). The Report indicated that the effect of colder temperatures could not be simulated due to the comparative mildness of the 2011-2012 Winter. (Attempts to use dry ice to cool the influent were unsuccessful). Preliminary design basis recommendations were made for the future Amphridome system nitrification system.
    - Summarized Data: Tables 1 & 2 summarize WWTP influent and effluent composition from Pilot Study Report. Table 3 summarizes data regarding nitrification efficiency during the sustained cold weather period (all grab samples at influent sample tap or effluent Amphidrome clearwell). Table 4 summarizes eDMR data for comparison from 9/2011 through 12/2012 for background. Table 5 summarizes available lab testing data during pilot study (all grab samples from influent sample tap or clearwell).
    - Nitrification/Denitrification Effectiveness: The Amphidrome filter units achieved nitrification, but did not achieve significant denitrification (i.e. Ammonia-N was converted to Nitrate-Nitrite-N, not nitrogen gas), The lowest sustained temperature period was <41 °F influent temperature, between 12/30/2011 and 3/2/2012, when the influent Ammonia-N concentration of 9.8 mg/l (average over 15 tests) was reduced to an average 1.5 mg/l per the Report. This equates to a reduction of 84.69% by direct calculation. The Report indicated an average nitrification rate of 93.7%, ranging from 44.6% - 99.9% for the overall project (with typical start-up problems noted). See Tables 3 & 5 for details. NOTE: It is expected that biological nitrification activity will be reduced as temperatures approach freezing (because biological activity decreases with temperature).
    - Other Constituents: Table 5 shows that the Lagoon effluent concentrations were somewhat reduced in terms of DO, TSS, and BOD_5 influent/$CBOD_5$ effluent (with some uncertainty due to non-identical test methods; use of grab samples). The high BOD_5 levels might also be coming from deeper levels of lagoon rather than from what the lagoon actually discharges. The Pilot Study did not monitor phosphorus, and made no claims of phosphorus treatment capability.
    - Follow-up Denitrification Study: The Report's Appendix 1 (Denitrification Study) addressed a follow-up pilot test to see if a modified Amphidrome configuration/operation could achieve denitrification. The additional 6-week denitrification test run (5/7/2012 – 6/3/2012) was conducted (replacing alkalinity feed with 20% solution methanol feed system; disconnecting the aeration blower; operating at an average 1,290 GPD and 6.0 mg/l DO) at an influent temperature range between 55.8 °F - 76.6 °F. Actual influent was the treated lagoon wastewater (without tertiary nitrification). The Report indicated that Nitrate-Nitrite-N was reduced from 4.89 mg/l to 0.97 mg/l (TKN was not measured) based on in-house WWTP sampling and analysis. It was noted denitrification would probably have been greater if the DO level had been reduced. The Report claimed that denitrification can be achieved (for an influent of consisting of 10 mg/l BOD_5, 10 mg/l TSS, 1 mg/l Ammonia-N, and 30 mg/l Nitrate-Nitrite-N) to reach a goal of 1 mg/l nitrate, but operational costs should be considered and compared to the option of purchasing nitrogen credits. Also, the basis for the claimed effectiveness was somewhat unclear because the hypothetical influent differs substantially from the actually treated influent. No tertiary denitrification stage is proposed as part of this WQM Permit Application.
- Scope of Project:
  - Design Intent: Installation of modified (i.e. simplified) Amphidrome System to reduce ammonia-N in the (treated) Lagoon No. 2 effluent (year-round), prior to chlorination & discharge. The project is not designed to reduce TN, TP or other constituents (except incidentally). The DE Report & Amphidrome Specification Section 9.0 (Process Guarantee) assumes a minimum 3.3 °C (38 °F) operating temperature (presumably to be met by wastewater biological activity and residual heat during the cold weather months). NOTE: The permittee plans to purchase TN and TP credits to address future Chesapeake Bay annual mass cap limits, and believes that existing lagoons adequately treat $CBOD_5$ and TSS.
  - Unit Sizing: The Amphidrome System design was based on 0.36 MGD dry weather flow for organic loadings (at lagoon effluent concentrations), and hydraulic flow of 0.516 MGD (maximum monthly average flow for 2011, the Record Year of Precipitation whereas 0.50 MGD is the NPDES permit basis wet weather flows), and 1.6 MGD peak daily flow from 2011 (record year of precipitation in NE PA). This is a continuous flow system, with provisions to bypass the Amphidrome System or specific Amphidrome reactor units (as needed

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for daily backflows -10 minutes long) by shutting/opening valves or plates in the V-notch flow splitter box. NOTE: The Design Engineer indicates that the Amphidrome System can be expanded if increased flows ever become an issue.

- Financing: The upgrade is being financed by a “H_2O Grant” (not PennVest) and a local lender.
- Permit Coordination: Not needed. The Application indicates that no construction will occur within the 100-year floodplain (E-maps does not define the 100-year floodplain at the WWTP location), and that no Earth Disturbance Permit is needed because only 0.35 acres of earth disturbance is proposed (within the existing WWTP).

Project Description: The Amphidrome System consists of the following:

- New Pipelines and Valves:
    - Pipeline 2: One (1) 16-inch DI/CL Class 50 (~ 70 LF) Pipeline (from Amphidrome Clearwell to Pipe No. 1/Lagoon Effluent Pipe to Chlorine Contact Tank)
    - Pipeline 4: One (1) 1½-inch PE Schedule 40 Pipe No. 3 (from Pipe No. 3/(existing fire hydrant to existing wastewater treatment building) to Amphidrome Building) for water supply
    - Pipeline 5: One (1) 4-inch PVC SDR-21 (~80 linear feet) pipeline (from Mudwell to Existing Headworks)
    - Pipeline 7: Three (3) 8-inch DI/CL Class 50 (~38 LF; ~50 LF; ~63 LF) pipelines (from Proposed Splitter Box to Amphidrome Reactors)
    - Pipeline 8: One (1) 16-inch DI/CL Class 50 (~127 LF) pipeline (from Pipe No. 6/Lagoon No. 2 Effluent pipeline to Flow Splitter) with new Gate Valve.
    - New Gate Valves (V-41 & V-25): On Pipeline 6 (Lagoon No. 2 effluent pipeline) to allow flow to be directed to the Amphidrome Flow Splitter Box or to go directly to Chlorine Contact Tank.
- One (1) Flow Splitter Box: Inlet baffle (for surge control) with three V-notch weirs & ultrasonic flow-meter (for process control purposes only, not accurately measuring influent due to backwash flows).
- Amphidrome Building & Underlying Concrete Structure (40.5-foot by 34-foot) including Mudwell, Amphidrome Filter/Reactors, and Clearwell (embedded in an engineered fill plateau area):
    - New Building: 34-foot by 16.667-foot structure with concrete pad (overlying amphidrome system) with associated equipment and construction:
        - Blowers: Two (2) 50-horsepower, 570 cfm @ 9 psig, Kaiser Model DB236 Compac blowers (positive displacement) or equivalent
        - Chemical Feed Systems ($CaCO3/NaHCO3$ for Alkalinity Control): With three (3) LMI Model AA161 Metering Pumps or equivalent, each capable of delivering 2.0 gal/hr @ 50 psig.
        - Fence extending around new Building/Amphidrome System.
        - Driveway extending to new Building.
    - Mudwell: One (1) 0.5 MGD, 13,688 gallon capacity, Mudwell: This 5-foot wide by 31-foot long by 21.375-foot high tank contains pumps to discharge to the plant headworks (and is meant to hold two backwash volumes of wastewater within working capacity of chamber for potential recycling during cold weather conditions):
        - Discharge Pumps P-7 & P-8: Two (2) 7.5-horsepower, 200 GPM @ 50 Foot TDH, Homa Model AMX 334-206 Submersible Pumps.
    - Three (3) Amphidrome Biologically Active Filter/Reactor in parallel (0.12 MGD each, total capacity of 0.36 MGD): 9.5-foot wide by 24-foot long by ~22-foot high (minimum 11-foot media depth) each (228 square foot filter area, with five 18-inch thick gravel layers base and 11-foot silica sand layer), with two (2) 570 cfm @ 9 psig Kaiser Model DB236 (Compac package units) with Omega Model 43P positive displacement blowers or equivalent per Amphidrome unit. The Specification does not allow for any alternative to the Amphidrome filter/reactor. Module 21 indicated a 3.75-hour “total react cycle time”.
    - Clearwell: One (1) 0.5 MGD, 13,800 gallon capacity Clearwell (a.k.a. Backwash Liquid Storage Chamber a.k.a. Backwash Return Pump Chamber): This 6-foot wide by 31-foot wide by 21.375-foot high tank provides storage of treatment batches, and includes assorted pumps (and is meant to hold two backwash volumes of wastewater within working capacity of chamber for potential recycling during cold weather conditions).
        - Backwash Pumps P-2, P-4, and P-6: 7.5-horsepower (684 GPM @ 20 feet TDH) HDMA Model AMX 334-206 Submersible Pumps or equivalent
        - Return Flow Pumps P-1, P-3, and P-5: 7.5-horsepower (684 GPM @ 20 feet TDH) Homa Model AMX 334-206 Submersible Pumps or equivalent

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The project appears to conform to the regulations and the applicable general requirements set forth in the DEP "Domestic Wastewater Facilities Manual" (ID# 362-0300-001). Manufacturer Guidance, site-specific 2012 Pilot Study Report. The DEP "WQM Permits for Sewage Treatment Facilities" Section IV.D (page 6-7) guidance regarding SBR design standards (applicable to complete treatment systems using SBR technology) was not used because this modified Amphidrome System is not functioning as an overall STP sequence batch reactor. Special Condition A will require a permittee report on cold weather operations for the first two (2) years after Amphidrome System start-up in order to help evaluate whether the technology remains effective during colder time-frames than achieved during the previous Pilot Study. In addition, the Design Engineer has assured the Department on the following points:

- Cold Weather Operation: The Amphidrome System can adequately treat Ammonia-N under cold weather conditions because:
    - Gravity piping to and from new system eliminates pump freezing concerns.
    - Underground system unit tanks/overlying building/slab construction & additional tank insulation will retain biological and underground heat.
    - The Amphidrome system incorporated Manufacturer recommendations about cold weather operation. 80 thermocouples per reactor will measure system temperatures, and they will have the capability to adjust recycling rates to introduce warm water back from the doubled-size clearwell back into the media)
    - The WWTP anticipates the usage of existing lagoon storage capacity and use of portable generators in event of a power outage during cold weather to prevent any exceedences of Ammonia-N IMAX limits in event of a power outage during cold weather conditions.
- High Flow Conditions: The Amphidrome system has the flexibility and capacity to treat higher (wet weather) flows rates to meet NPDES permit limits because the wet weather flows tend to be more diluted and ability of lagoons to "dampen" peak instantaneous flows. The facility does not expect any increases in wet weather flows due to previous and ongoing I&I corrective work. The Amphidrome system can be upgraded or expanded in event of need (to include another reactor unit to handle increased flows.
- Potential Future TMDL Requirements: The WWTP retains the ability to upgrade or expand the Amphidrome System in event that the future TMDL for the impaired receiving stream requires denitrification (above and beyond Chesapeake Bay TN/TP requirements).
- Operational Considerations:
    - The site O&M Manual (including Amphidrome System O&M) and site PPC Plan will be updated by the Design Engineer prior to system start-up.
    - There are adequate provisions for access into the reactor chambers for maintenance/repairs.
- Construction Impacts: Construction fencing & monitoring will ensure that construction does not negatively impacting neighboring walking path & stream;

NOTE: The permittee is separately looking at disinfection options. (The existing chlorine system's hydraulic design capacity of 0.36 MGD was lower than annual average 0.50 MGD NPDES permit basis flow per Module 1.)

Compliance History: The 4/12/2013 NMS Query (Open Violations for Client by Permit number), using the WWTP's NPDES Permit number, indicated no open violations.

Public Notice: The public notice for this application was published on February 16, 2013. No comments were received.

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Telephone Log: 3/21/2013 Telephone call to Mark Catalano (Design Engineer):

- **Overall System Operation: They have implemented received Manufacturer recommendations for this variation of the regular Amphidrome System.**
- **Discharge Flow Measurement Point: They measure discharge flow at the discharge point, so the System will have not negative impacts on flow measurements.**
- **Ammonia-N Concentration Design Assumption (13 mg/l): They based the Ammonia-N levels based on historic average information. They will evaluate whether a power outage during cold weather might result in Ammonia-N IMAX exceedences, and how they would prevent exceedences. NOTE: The NPDES permit has IMAX limits for Ammonia-N (8.0 Summer/24.0 Winter).**
- **Module 1: Module 1 will be updated to eliminate discrepancies between Design Loading Data and Facilities Design data for the new tertiary nitrification system (number mismatches implying loading greater than design assumption, etc.).**
- **Specification 11300 Part 1.1.0 Scope and Design Criteria (p. 11300-1) & Part 5.0 Process Performance (page 11300-12): Missing updated Specification (referenced in narrative) will be supplied.**
    - **Specification 11300 Part 8.0 Warranty (p. 11300-12): UPDATED SPEC NOT PROVIDED. The only manufacturer/supplier Warranty is an 18-month equipment warranty, with no guarantee of minimum performance. The Design Engineer must therefore evaluate whether any "typical" design plans or details from the manufacturer/supplier are adequate for this particular project.**
- **Drawing M-5: This "typical" design detail drawing was checked to be adequate for this specific project by the Design Engineer.**

NPDES Permit Fact Sheet **NPDES Permit No. 3513401**
Waverly Township

Internal Review and Recommendations

Table 1 (Summary of WWTP Effluent Data From Pilot Study)

Effluent Parameter	Ammonia-N (mg/l)	TKN (mg/l)	Nitrate-Nitrite-N (mg/l)	Total N (mg/l)
Permit Limits	**4.0/8.0 Summer; 12/24 Winter**	**-**	**-**	**Future annual mass cap ~ 6.0**
2010 Annual Average	10.2 Summer (0.1 – 22.4 range) 8.1 mg/l Winter (4.1 – 11.8 range)	12.4 (2.1 – 24.5 range)	4.3 (0.7 – 17.4)	16.7
2011 Annual Average*	3.6 mg/l Summer (0.1 – 14 range) 7,1 mg/l Winter (0.5 – 17 range)	9.6 (1.05 – 47 range)	2.48 (0.16 – 8.52)	12.08

* Future 9,132 lbs annual mass cap for 0.50 MGD flow.

**2011 was the record year of precipitation in NEPA. The Pilot Study involved a small diverted flow of ~1,600 GPD from September 7, 2011 through April 25, 2012 (not enough to change overall effluent quality).

Table 2 (2011 WWTP Influent Operating Ranges from Pilot Study)

Parameter	Average During Project	Min	Max
Flow	-	0.165269 MGD (January)	0.585840 MGD (March)
Temperature of Influent	-	40 °F (March)[3]	67 °F (August)
Temperature of WWTP Effluent	-	30 °F (December)[4]	82 °F (July 9, 2011)
Organic Loading	310 lbs. BOD_5/day	112 lbs. BOD_5/day (August)	589 lbs. BOD_5/day (May)[1]
WWTP Influent BOD_5 (monthly average)	103 mg/l	47 mg/l	219 mg/l
WWTP Influent TSS (monthly average)	83 mg/l	18 mg/l	213 mg/l
WWTP Influent TKN[2] (monthly average)	-	-	-
WWTP Influent N-N-N[2]	-	-	-

[1] The WWTP organic load capacity was identified as 507 lbs. BOD_5/day

[2] Not composite sampled. (BOD_5 and TSS were composite sampled weekly).

[3] Colder temperatures in reported 2012 data (Pilot Study).

[4] Possible typo or mismeasurement (below freezing point of clean water).

Table 3 (Pilot Study Results: Influent versus Effluent from Lab Testing for Sustained Low Temperature[1])

Date	Temp.[2] Infl. & Effl. (°F)	NH_3-N Infl. & Effl. (mg/l)	NH_3-N Δ[3] (decrease)	TKN Infl. & Effl. (mg/l)	TKN Δ[3] (decrease)	N-N-N[2] Infl. & Effl. (mg/l)	N-N-N Δ[3] (decrease)	TN Infl. & Effl. (mg/l)	TN Δ[3] (decrease)
12/19/11	*39.7* *41,7*	8.47 0.7	99.17%	7,95 2.42	69.55%	8.56 0.25	97.07%	16.51 2.67	83.82%
1/3/12	*39.7* *44.4*	8.56 2.95	65.53%	12 5.19	56.75%	0.912 6.18	-577.63%	12.912 11.28	12.63%
1/16/12	*36.8* *40.4*	11.3 6.26	44.60%	14.3 9.29	35.03%	0.809 5.18	-540.29%	15.109 14.47	4.22%
1/30/12	*38.8* *43.2*	9.26 10.9	-17.77%	- 13.8	-	- 0.57	-	- 14.37	-
2/6/12	*40.8* *45,8*	12.1 0.544	95.50%	13.1 4.44	66.10%	0.644 8.84	-1,272.67%	13.744 13.28	3.37%
2/8/12	*39.9* *44.2*	11.5 0.393	96.58%	-	-	*1.412* *11.962*	-747.16%	-	-
2/10/12	*40.7* *45.4*	11.28 0.119	98.94%	-	-	*1.654* *11.157*	-574,54%	-	-
2/13/12	-	7.74 0.072	99.06%	-	-	*3.89* *10.125*	-160.28%	-	-
2/15/12	*39* *44.2*	8.201 0.059	99.28%	-	-	*1.677* *10.606*	-532.43%	-	-
2/17/12	*39* *45.1*	8.414 0.157	98.13%	-	-	*1.466* *10.011*	-582.87%	-	-
2/20/12	*39.7* *42.9*	10.54 0.203	98.07%	-	-	*1.26* *10.51*	-734.12%	-	-
2/24/12	*40* *44.5*	10.24 0.092	99.10%	-	-	*1.667* *11.299*	-577.80%	-	-
2/27/12	*38* *42.8*	10.74 0.114	98.93%	-	-	*2.079* *11.961*	-475.32%	-	-
2/29/12	*40* *47.8*	9.28 0.243	97.38%	-	-	*1.881* *12.331*	-555.55%	-	-
3/2/12	*40* *45.5*	10.75 0.217	97.98%	-	-	*1.395* *8.511*	-510.10%	-	-

[1] The lowest sustained temperature period was <41 °F influent temperature, between 12/30/2011 and 3/2/2012.
[2] In-house WWTP test data is italicized. (In-house data on T, NH_3-N, NO_2-N and NO_3-N available for other dates.)
[3] Delta (Δ) plus is decrease; Delta (Δ) minus is <u>increase</u> in constituent concentration.

ATTACHMENT G: INFLUENCE OF TEMPERATURE ON BIOFILTER

Cold Temperature Nitrification of Lagoon Wastewater using a Biologically Active Filter (BAF)

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Abstract
The paper describes the results of a pilot test of a biologically active filter (BAF) for cold temperature nitrification of lagoon wastewater. Consistent nitrification to fractional levels was achieved due to the heat transfer characteristics of BAF. The performance results are discussed and the convection heat transfer characteristics of the reactor are discussed to explain the effectiveness of the reactor as a heat exchanger.

Keywords
Cold temperature nitrification; BAF; convection heat transfer in a porous medium

INTRODUCTION

Lagoons or stabilization ponds are terms for a group of suspended growth systems that do not have downstream clarification and no solids recycle. Lagoons have been used to stabilize biodegradable organic matter; although nitrification has also been observed in some systems. The first recorded installation of a lagoon, in the United States, was at San Antonio, Texas in 1901, (EPA 1983). Prior to the widespread emergence of nutrient removal over 7000 lagoons were installed in the United States; however, as nitrogen requirements have become more prevalent many of these systems are facing either ammonia or total nitrogen limits. For lagoons located in areas that experience cold temperatures, meeting ammonia or total nitrogen limits during the winter may be problematic.

In the Township of Waverly, Lackawanna County, Pennsylvania, which has been operating two lagoons in series since September 1986, a pilot study was conducted to augment the lagoons with a biologically active filter (BAF) in order to maintain nitrification throughout the summer and winter months. Each facultative lagoon is 91 m x 37 m. by 3 m. with a 3:1 slope. The permitted wet weather flow is 1,893 m^3/d with a normal permitted flow of 1,363 m^3/d. The average flow is approximately 1,136 m^3/d. Currently, the plant has seasonal ammonia limits. From May through October the average monthly effluent ammonia-nitrogen limit is less than 4 mg/l with an instantaneous maximum limit of 8 mg/l. From November through April the average monthly effluent ammonia-nitrogen limit is 12 mg/l with an instantaneous maximum limit of 24 mg/l. Although the plant generally meets the permit requirements many of the winter violations are likely attributable to water temperatures as low as 0°C. In addition, the plant discharges into the Susquehanna River Basin and hence into the Chesapeake Bay, which means that more stringent nutrient requirements, including total nitrogen limits, are scheduled to be imposed. For this reason, the Township chose to investigate a process that may be used in conjunction with the existing lagoons that will achieve low ammonia levels throughout the coldest months.

METHODS

The pilot unit was a deep-bed sand biologically active filter (BAF), consisting of an underdrain, support gravel, and filter media as illustrated in Figure 1. The stainless steel underdrain located at the bottom of the reactor and provides support for the gravel and media, and for even distribution of air and water into the reactor. The underdrain has a manifold and laterals that distribute the air evenly over the entire filter bottom. The design allows for both air and water to be delivered simultaneously or separately, via individual pathways, to the bottom of the reactor. On top of the underdrain was 0.46 m of gravel, in four different sizes laid down in five layers. The gravel was placed in order of descending size, (i.e. the largest at the bottom layer). Its' purpose was to keep the smaller sand media from penetrating down into the plenum below the underdrain. Above the gravel was 1.22 m of coarse round, silica sand media. The sand media has a 3.2 mm nominal diameter producing a media porosity of approximately 35%. The media specific surface area was 850 m^2/m^3.

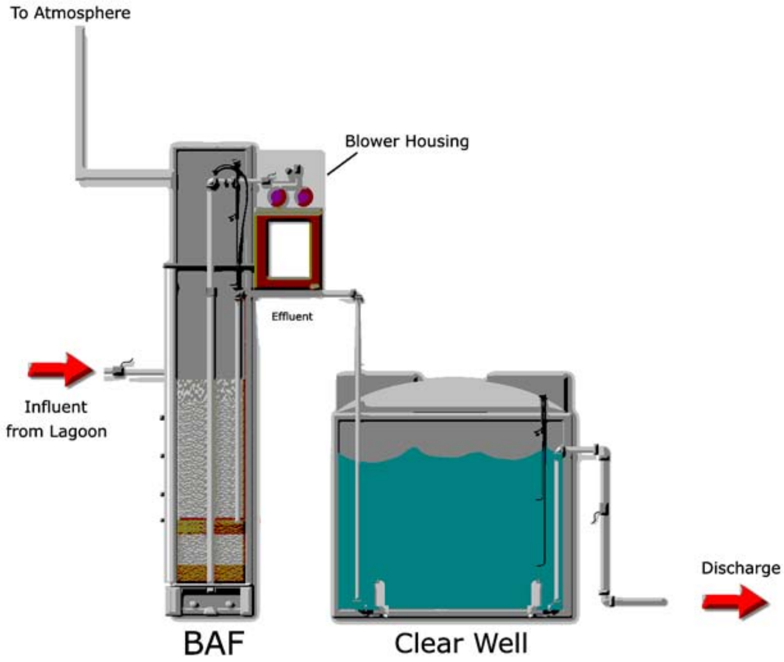

Figure 1. Pilot Plant Operated at the Waverly Township Facility

The reactor was 0.762 m in diameter, with 1.22 m of media, with an overall height of 3.81 m. The process air was supplied to the reactor intermittently by a 93-watt rotary vane air compressor, at a rate of 0.012 m^3/min. Four sampling ports were located at various depths within the media from which samples were collected and the temperature recorded. Due to this method the temperatures represent a bulk cross sectional average.

There was periodic internal recycle from the clear well back to the filter. Sludge was wasted from the filter by a backwash of both air and water and return to the lagoon. The backwash air was supplied by the process air compressor and by a 1.1 KW rotary lobe backwash air compressor. The design volumetric flow for the backwash air was 0.708 m^3/min. Backwash water was provided by one pump, located in the clear well and connected to the filter effluent line. The backwash water flow rate was 0.095 m^3/min.

The pilot test was conducted from September 2011 to April 2012 with the objective of demonstrating the ability of the system to receive relatively cold wastewater while maintain nitrification to fractional levels of ammonia.

RESULTS

The maximum influent ammonia concentration was 12.1 mg/l with a median value of 8.41 mg/l. The average effluent concentration was 0.59 mg/l and the median was 0.10 mg/l. The average flow rate to the reactor was 6.383 m^3/d, above the design flow of 3.785 m^3/d. The average nitrification rate throughout the test was 93.6% with a median of 97.6%. For a loading of 0.132 kg-NH_3-N/m^3-day and temperature of 3.3°C an effluent ammonia concentration of 0.1 mg/l was achieved, as shown in Figure 2. Figure 2 also indicates that during the test the effluent ammonia concentration exceeded 1.0 mg/l on six occasions; however, only two of these were at a temperature below 5°C. The plot of ammonia removal rate versus temperature, (Figure 3) indicates that as the temperature went up the removal rate went down. This is due to increased nitrification in the lagoon at these temperatures. As expected the higher influent ammonia concentration to the BAF occurred during the coldest period of the test.

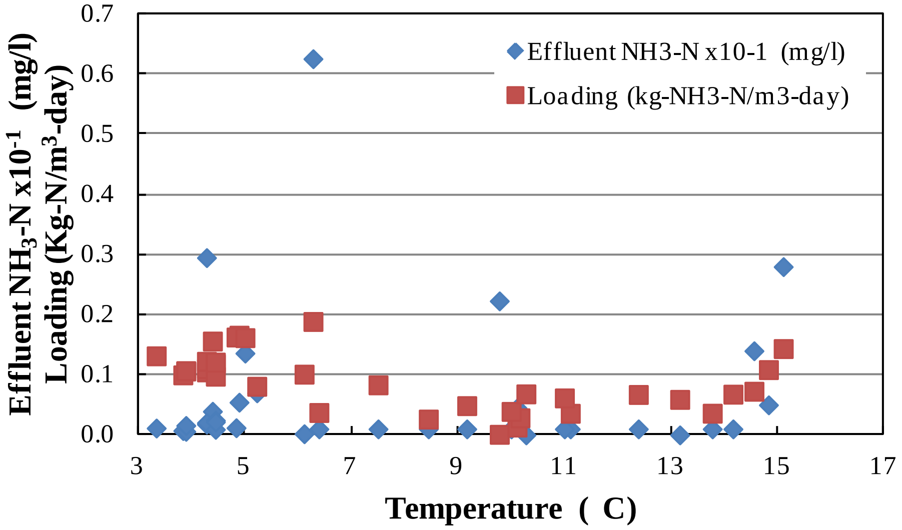

Figure 2. Ammonia Loading and Effluent Concentration versus Temperature

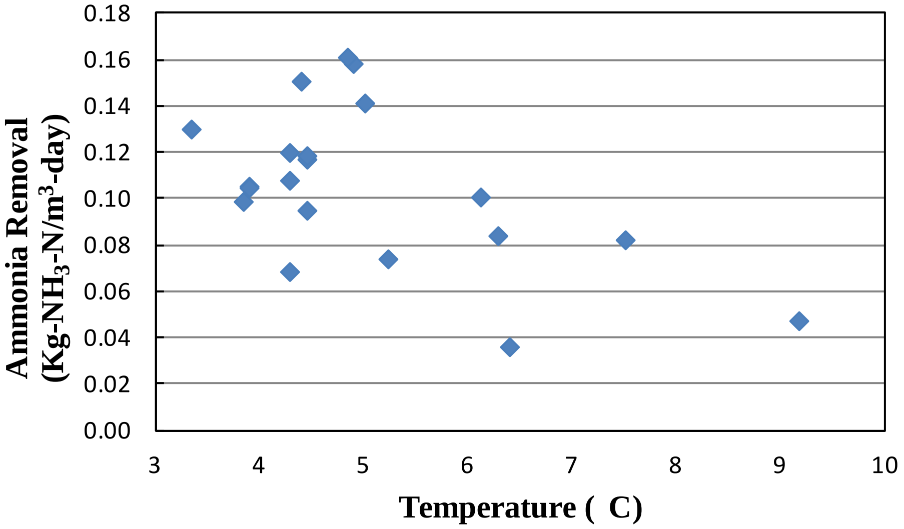

Figure 3. Ammonia Removal versus Temperature

The influent wastewater temperature ranged from 3.3ºC to 15.1ºC on days that samples for the laboratory were collected. However, the minimum recorded influent temperature from the lagoon was 1.9 and the corresponding wastewater temperature within the filter was 4.5 ºC. In Figure 4 the temperature of both the influent wastewater and wastewater within the filter are plotted against the flow rate. The graph indicates in all cases the wastewater temperature increased within the filter.

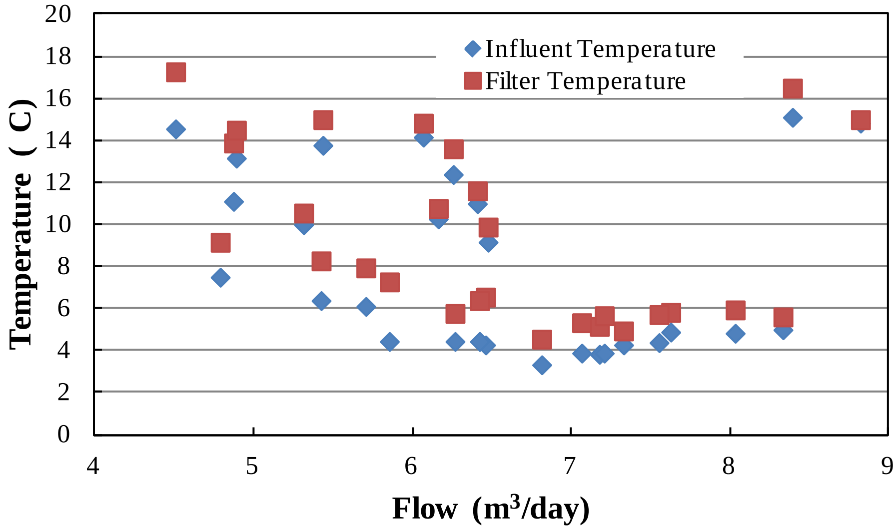

Figure 4. Influent and Filter Wastewater Temperature versus Flow

DISCUSSION

All submerged attached growth bioreactors (SAGBs) or BAFs, utilized in the water and wastewater industry, are essentially tubes packed with a porous media that are designed to treat wastewater. However, examination of the transport properties through porous media indicates that with the selection of certain material as the media the reactors may also function as a heat exchanger augmenting the desired treatment. Two reasons may explain the reason for the increase the first is the heat released from the biochemical reactions and the second is the physical design of the reactor.

Experimental Analysis:

Application of the first law of thermodynamics to a control volume around the reactor shown in Figure 5, gives the following:

$$\frac{d(E_{CV})}{dt} = \dot{Q}_{CV} - \dot{W}_{CV} + \sum_i \dot{m}_i \left(h_i + \frac{V_i^2}{2} + gz_i\right) - \sum_e \dot{m}_e \left(h_e + \frac{V_e^2}{2} + gz_e\right)$$

neglecting: kinetic and potential energy, that the work is zero and noting that

$\dot{m} = \dot{m}_i = \dot{m}_e$ yields:

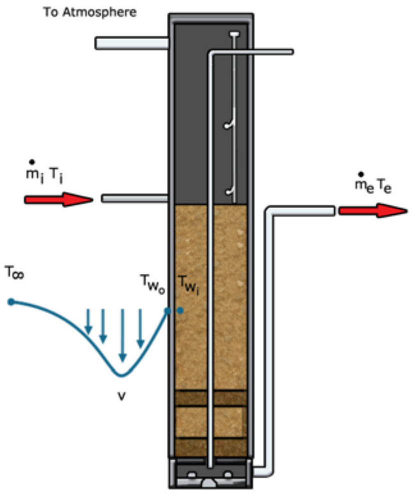

Figure 5. Reactor Control Volume

$$\frac{d(E_{CV})}{dt} = \dot{Q}_{CV} + \dot{m}(h_i - h_e)$$

$$\dot{Q}_{CV} = \frac{d(E_{CV})}{dt} - \dot{m}\,c_p \Delta T$$

Once the energy generated in the reactor, by the biochemical reactions, is calculated, and using the temperature increase measured during the pilot test, this equation can be used to determine the energy required to raise the temperature of the wastewater.

To determine the heat generated from the biological activity, it was assumed that the only reaction occurring in the reactor was nitrification. Therefore, the energy is obtained from the oxidation-reduction reaction:

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

$$G_f^{\circ'} = G_{f\,(products)}^{\circ'} - G_{f\,(reactants)}^{\circ'}$$

$$G_f^{\circ'} = -349.01\frac{\mathrm{KJ}}{\mathrm{mole}} \qquad \text{(Brock et al.)}$$

The results of applying both equations are plotted in Figure 6 and indicate that the heat generated from the nitrification of the relative low concentration of ammonia in the lagoon effluent are an order of magnitude lower than the energy required to raise the temperature of the water to level recorded. This values appear to be on the same order of magnitude as the heat generated from nitrification reported by Daverio et al. (2003).

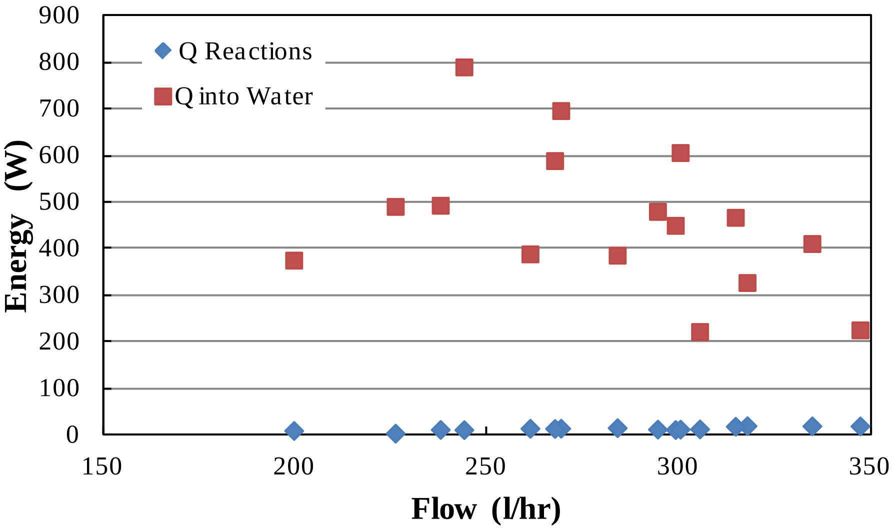

Figure 6. Energy from Reactions and Energy Required to Heat the Water versus Flow

Theoretical Analysis:

Returning to the control volume in Figure 5 the energy balance around the system must include natural convection around the reactor and clear and forced convection through the porous medium (i.e. media & fluid) within the reactor.

For natural convection:

$$Q = hA(T_{wo} - T_{\infty})$$

$$h = 1.42\left(\frac{\Delta T}{L}\right)^{\frac{1}{4}}$$ (Holman, 1981)

In order to consider the natural convection conduction through reactor wall needs to be considered and is determined from assuming steady state, one dimensional conduction and given by:

$$Q = -kA\frac{dT}{dx}$$

Setting Q equal to one another and solving by iteration we get T_{wi} and T_{wo}

$$-kA\frac{dT}{dx} = 1.42\left(\frac{\Delta T}{L}\right)^{\frac{1}{4}} A(T_{wo} - T_{\infty})$$

Having obtained T_{wo} the heat transfer coefficient for natural convection (h) may be determined and therefore $Q_{(\text{natural convection})}$ can also be obtained.

The next step is to determine the heat transfer within the filter. Again, application of the first law of thermodynamics to the porous media zone results in

$$\left[\phi\rho_f c_{p_f} + (1-\phi)\rho_s c_s\right]\frac{\partial T}{\partial t} + \rho_f c_{p_f} u\frac{\partial T}{\partial x} = \left[\phi k_f + (1-\phi)k_s\right]\frac{\partial^2 T}{\partial x^2} + (1-\phi)q_s''' + u\left(-\frac{\partial P}{\partial x} + \rho_f g_x\right)$$

Before proceeding to an empirical solution; several points may be deduced from this equation. Assuming a one dimensional model with parallel conduction, the thermal conductivity of the porous medium becomes a combination of the thermal conductivity of the fluid and of the media:

$$k_m = \phi k_f + (1-\phi)k_s$$ (Bejan, 2004)

The thermal inertia of the medium is a function of the individual inertia of both the fluid and the media (i.e. solid) and is expressed as:

$$\sigma = \frac{\phi\rho_f c_{p_f} + (1-\phi)\rho_s c_s}{\phi\rho_f c_{p_f}}$$ (Bejan, 2004)

As the porosity of the medium increases, the rate of internal heat generation per volume of the porous medium decreases as the porosity increases.

$$q''' = (1-\phi)q_s'''$$ (Bejan, 2004)

The solution for the energy equation for a tube with a porous media with fully developed heat transfer is expressed as a constant Nusselt number (Rohsenow and Choi, 1961, Nield and Bejan, 1999 and Bejan, 2004).

Assuming a constant heat flux:

$$Nu_D = \frac{q''}{T_{w(x)} - T_{m(x)}}\left(\frac{D}{k_m}\right) = 8$$

Solving the above equation for *q”* and multiplying it by the surface area of the porous media section of the filter will give the energy input to the fluid with the filter. In Figure 7 the heat transfer measured from the temperature raise of the water is plotted against the calculated temperature of the water. The agreement of the measure versus calculated values are in agreement given the experimental accuracy and the assumptions made. For example, in order to simplify the analysis the process air supplied to the reactor was not accounted for. Although it has been stated that heat energy in the liquid may be removed by the aeration process in an activated sludge reactor, (Jördening and Winter, 2005), the effect of aeration on this reactor is not clear and was neglected in the analysis. The reason for this is that the reactor was intermittently aerated for approximately 45 to 60 minutes per day. Additionally, the Reynolds number for the forward (downward) flow of was approximately 8 indicating the equations for porous media are valid. However, the Reynolds number of 170 for the return flow is indicative of turbulence within the porous medium. The equations used are applicable in the laminar region only.

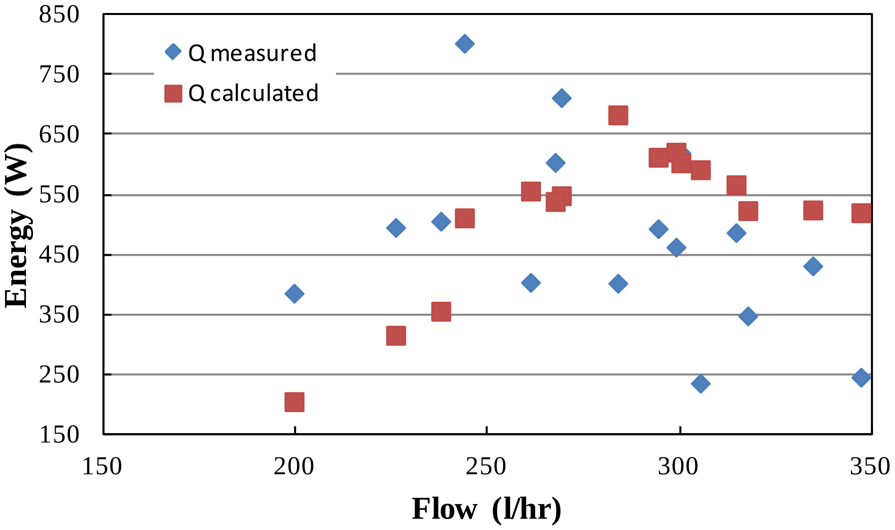

Figure 7. Energy Input to Wastewater, Measured and Calculated versus the Flow

Despite these assumptions the calculated values are within the range of the measured values to support the premise that the temperature increase of the wastewater was due to the physical design of the reactor (i.e. the porous medium). These results are explained by the heat transfer augmentation (Nield and Bejan, 2006). Comparing the Nusselt number for full developed flow in a pipe without porous media is similar to the expression given above, except that the combine conductivity k_m is replaced by k_f of the fluid. The augmentation is approximately ratio of the convection heat transfer coefficients:

$$\frac{h_{x(porousmedia)}}{h_{x(nonporousmedia)}} \approx \frac{k_m}{k_f}$$ (Nield and Bejan, 2006)

which for this reactor is equal to 3.675. Considering the augmentation effect and the effect of porosity on the internal heat generation, assuming the biofilm around the media causes it to act as heat source, then proper choice of both media and porosity could result in a more effective reactor for cold weather applications.

CONCLUSIONS

The results of the pilot indicate that consistent nitrification was achieved at low temperatures. Although the data reported here was only that which was sampled at an outside lab and the lowest temperature for this data was 3.3 °C. Additional, data sampled with Hach kits indicated fractional ammonia levels with an influent water temperature of 1.9 °C and a corresponding temperature within the filter of 4.5 °C.

The loading rates achieved in this test were modest and any additional test should include an ammonia feed system to increase the loading in the event that effluent from the lagoon has a lower than desired ammonia concentration.

The physical design of this BAF provided a heat transfer augmentation of approximately 3.6 due to the choice of silica sand (i.e. quartz) as the media. The result was a stable temperature, within the porous medium, throughout the winter.

The pilot plant was constructed within a building that was maintained at approximately 10°C, the full scale system will be below grade. In addition the section f the reactor with the media will be below the frost line will be surrounded by earth. Therefore, the mode of heat transfer will be by conduction and not natural/free convection, which will likely be more effective with respect to energy transfer.

The full scale design for the Waverly, Pennsylvania treatment plant is estimated to cost 1.5 million dollars as opposed to 5 to 6 million dollars for a completely new treatment plant (i.e. scraping the lagoons. The pilot test demonstrated that this particular biofilm reactor, in conjunction with the existing lagoons, would reduce the overall cost of the upgrade and achieve the current effluent limits as well as the more stringent effluent limits scheduled to be imposed.

NOMENCLATURE

$\frac{d(E_{CV})}{dt}$	Change of energy within the control volume (cv)
$\dot{Q}_{CV}$	Rate of heat transfer across the control volume (cv)
$\dot{W}_{CV}$	Rate of work done on or by the control volume (cv)
$\dot{m}_i$	mass flow rate into control volume (cv)
$\dot{m}_e$	mass flow rate out of control volume (cv)
h_i	enthalpy into control volume (cv)
h_e	enthalpy out of control volume (cv)
$\frac{d(E_{CV})}{dt} = \dot{Q}_{CV} + \dot{m}(h_i - h_e)$	
$\frac{V_i^2}{2}$	kinetic energy into control volume (cv)
$\frac{V_e^2}{2}$	kinetic energy out of control volume (cv)
gz_i	potential energy into control volume (cv)
gz_e	potential energy out of control volume (cv)
c_p	constant-pressure specific heat, (*c* for a solid)
$G_f^{\circ'}$	Gibb free energy of formation
$Q_{convection}$	heat transfer by convection
$Q_{conduction}$	heat transfer by conduction
h	convection heat transfer coefficient
A	surface area

D	diameter
T_{wi}	temperature of inner wall
T_{wo}	temperature of outer wall
T_{∞}	free stream temperature
T_m	bulk temperature
$T_{w(x)}$	wall temperature at x along axis of flow
$T_{m(x)}$	bulk temperature at x along axis of flow
k	thermal conductivity
k_m	thermal conductivity of the porous medium (fluid & solid)
k_f	thermal conductivity of the fluid
k_s	thermal conductivity of the solid
ϕ	porosity
ρ_s	density of the solid
ρ_f	density of the liquid
q_s''	heat transfer per unit area (flux)
q'''	heat transfer per unit volume
u	velocity
$\frac{\partial P}{\partial x}$	pressure gradient
σ	thermal inertia of the porous medium
Nu_D	Nusselt number

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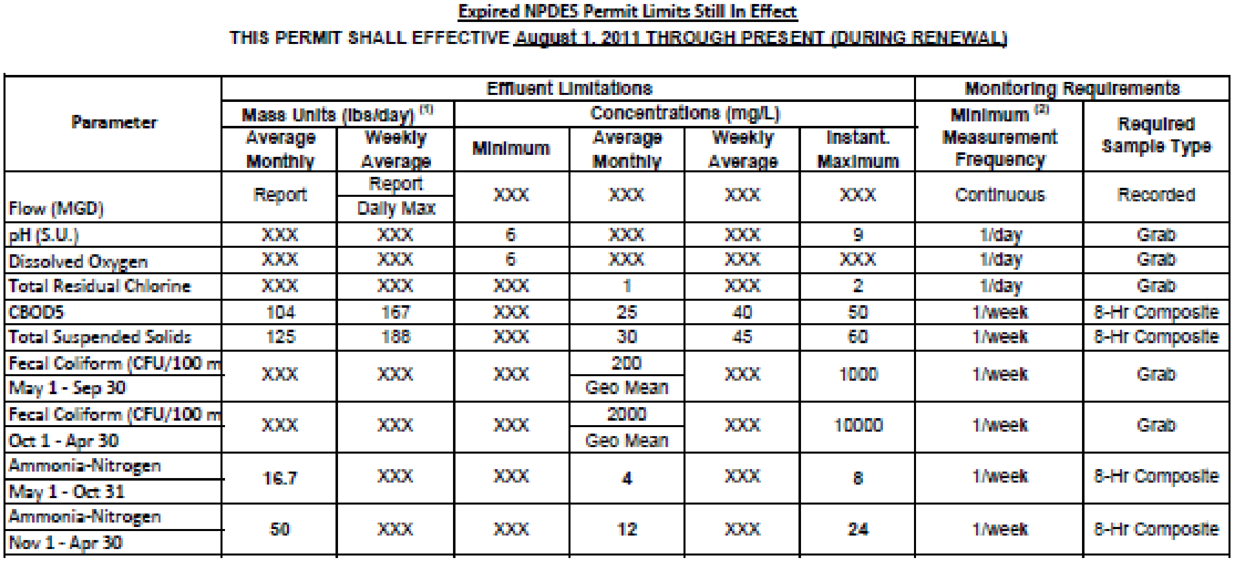
ATTACHMENT H: NPDES Permit Limits

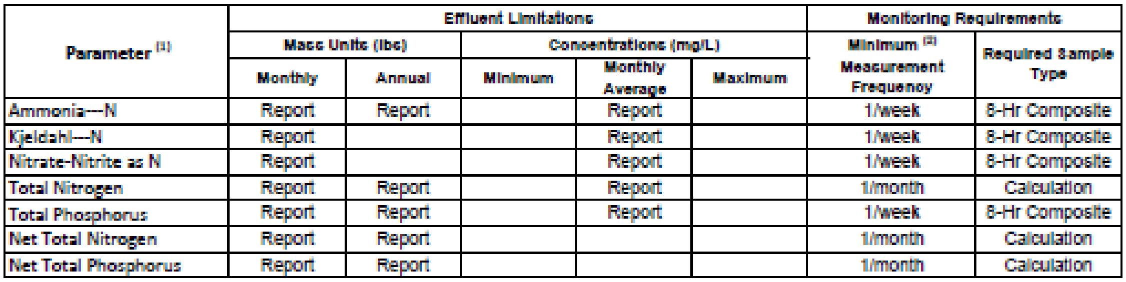
Current but Expired NPDES Permit Limits remaining in effect:



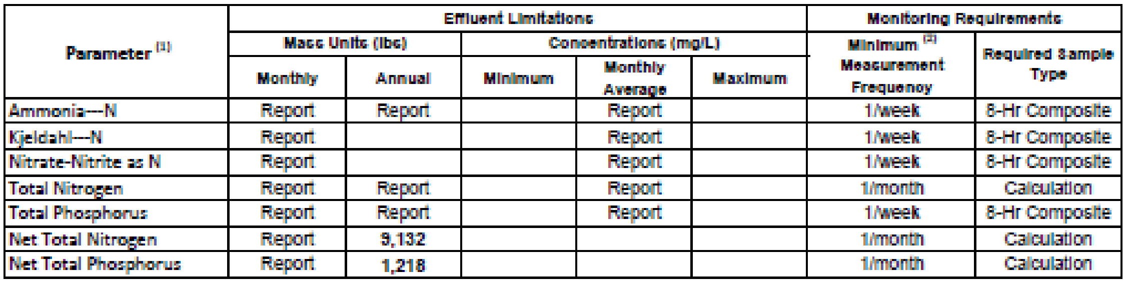
Expired NPDES Permit Limits Still In Effect

THIS PERMIT SHALL EFFECTIVE August 1, 2011 THROUGH PRESENT (DURING RENEWAL)

Parameter	Effluent Limitations						Monitoring Requirements	
	Mass Units (lbs/day) [1]		Concentrations (mg/L)				Minimum [2] Measurement Frequency	Required Sample Type
	Average Monthly	Weekly Average	Minimum	Average Monthly	Weekly Average	Instant. Maximum		
Flow (MGD)	Report	Report Daily Max	XXX	XXX	XXX	XXX	Continuous	Recorded
pH (S.U.)	XXX	XXX	6	XXX	XXX	9	1/day	Grab
Dissolved Oxygen	XXX	XXX	6	XXX	XXX	XXX	1/day	Grab
Total Residual Chlorine	XXX	XXX	XXX	1	XXX	2	1/day	Grab
CBOD5	104	167	XXX	25	40	50	1/week	8-Hr Composite
Total Suspended Solids	125	188	XXX	30	45	60	1/week	8-Hr Composite
Fecal Coliform (CFU/100 m May 1 - Sep 30	XXX	XXX	XXX	200 Geo Mean	XXX	1000	1/week	Grab
Fecal Coliform (CFU/100 m Oct 1 - Apr 30	XXX	XXX	XXX	2000 Geo Mean	XXX	10000	1/week	Grab
Ammonia-Nitrogen May 1 - Oct 31	16.7	XXX	XXX	4	XXX	8	1/week	8-Hr Composite
Ammonia-Nitrogen Nov 1 - Apr 30	50	XXX	XXX	12	XXX	24	1/week	8-Hr Composite



Parameter [1]	Effluent Limitations					Monitoring Requirements	
	Mass Units (lbs)		Concentrations (mg/L)			Minimum [2] Measurement Frequency	Required Sample Type
	Monthly	Annual	Minimum	Monthly Average	Maximum		
Ammonia---N	Report	Report		Report		1/week	8-Hr Composite
Kjeldahl---N	Report			Report		1/week	8-Hr Composite
Nitrate-Nitrite as N	Report			Report		1/week	8-Hr Composite
Total Nitrogen	Report	Report		Report		1/month	Calculation
Total Phosphorus	Report	Report		Report		1/week	8-Hr Composite
Net Total Nitrogen	Report	Report				1/month	Calculation
Net Total Phosphorus	Report	Report				1/month	Calculation



Parameter [1]	Effluent Limitations					Monitoring Requirements	
	Mass Units (lbs)		Concentrations (mg/L)			Minimum [2] Measurement Frequency	Required Sample Type
	Monthly	Annual	Minimum	Monthly Average	Maximum		
Ammonia---N	Report	Report		Report		1/week	8-Hr Composite
Kjeldahl---N	Report			Report		1/week	8-Hr Composite
Nitrate-Nitrite as N	Report			Report		1/week	8-Hr Composite
Total Nitrogen	Report	Report		Report		1/month	Calculation
Total Phosphorus	Report	Report		Report		1/week	8-Hr Composite
Net Total Nitrogen	Report	9,132				1/month	Calculation
Net Total Phosphorus	Report	1,218				1/month	Calculation

Proposed Permit Limits Over 5 Years of New Permit:

New NPDES Permit Limits when Issued:

For the duration of the Permit, 5 years:

Parameter	Effluent Limitations						Monitoring Requirements	
	Mass Units (lbs/day) (1)		Concentrations (mg/L)				Minimum (2) Measurement Frequency	Required Sample Type
	Average Monthly	Daily Maximum	Instant. Minimum	Average Monthly	Maximum	Instant. Maximum		
Flow (MGD)	Report	Report	XXX	XXX	XXX	XXX	Continuous	Recorded
pH (S.U.)	XXX	XXX	6	XXX	XXX	9	1/day	Grab
Dissolved Oxygen	XXX	XXX	6	XXX	XXX	XXX	1/day	Grab
Fecal Coliform (No./100 ml) May 1 - Sep 30	XXX	XXX	XXX	200 Geo Mean	XXX	1,000	1/week	Grab
Fecal Coliform (No./100 ml) Oct 1 - Apr 30	XXX	XXX	XXX	2,000 Geo Mean	XXX	10,000	1/week	Grab
Influent Biochemical Oxygen Demand (BOD5)	Report	Report	XXX	Report	XXX	XXX	1/month	8-Hr Composite
Influent Total Suspended Solids	Report	Report	XXX	Report	XXX	XXX	1/month	8-Hr Composite

The following Permit Limits change throughout the five-year duration of the Permit:

Interim, year 1 of Permit

Parameter	Effluent Limitations						Monitoring Requirements	
	Mass Units (lbs/day) (1)		Concentrations (mg/L)				Minimum (2) Measurement Frequency	Required Sample Type
	Average Monthly	Average Weekly	Minimum	Average Monthly	Maximum	Instant. Maximum		
Total Residual Chlorine (TRC)	XXX	XXX	XXX	1	XXX	2	1/day	Grab

Interim, years 2 through 4 of Permit

Parameter	Effluent Limitations						Monitoring Requirements	
	Mass Units (lbs/day) (1)		Concentrations (mg/L)				Minimum (2) Measurement Frequency	Required Sample Type
	Average Monthly	Average Weekly	Minimum	Average Monthly	Maximum	Instant. Maximum		
Total Residual Chlorine (TRC)	XXX	XXX	XXX	0.5	XXX	1.6	1/day	Grab

Interim, years 1 through 4

Parameter	Effluent Limitations						Monitoring Requirements	
	Mass Units (lbs/day) (1)		Concentrations (mg/L)				Minimum (2) Measurement Frequency	Required Sample Type
	Average Monthly	Weekly Average	Minimum	Average Monthly	Weekly Average	Instant. Maximum		
Carbonaceous Biochemical Oxygen Demand (CBOD5)	104	167	XXX	25	40	50	1/week	8-Hr Composite
Total Suspended Solids	125	188	XXX	30	45	60	1/week	8-Hr Composite
Ammonia-Nitrogen Nov 1 - Apr 30	**50**	XXX	XXX	**12**	XXX	**24**	1/week	8-Hr Composite
Ammonia-Nitrogen May 1 - Oct 31	**16.7**	XXX	XXX	**4**	XXX	**8**	1/week	8-Hr Composite

Year 5 of Permit

Parameter	Effluent Limitations						Monitoring Requirements	
	Mass Units (lbs/day) (1)		Concentrations (mg/L)				Minimum (2) Measurement Frequency	Required Sample Type
	Average Monthly	Weekly Average	Minimum	Average Monthly	Weekly Average	Instant. Maximum		
Total Residual Chlorine (TRC)	XXX	XXX	XXX	0.02	XXX	0.06	1/day	Grab
Carbonaceous Biochemical Oxygen Demand (CBOD5)	41.7	62.5	XXX	10	15	20	1/week	8-Hr Composite
Total Suspended Solids	41.7	62.5	XXX	10	15	20	1/week	8-Hr Composite
Ammonia-Nitrogen Nov 1 - Apr 30	**18.7**	XXX	XXX	**4.5**	XXX	**9**	1/week	8-Hr Composite
Ammonia-Nitrogen May 1 - Oct 31	**6.2**	XXX	XXX	**1.5**	XXX	**3**	1/week	8-Hr Composite

ATTACHMENT I: Permit Excursions, 2010-2018

Waverly Twp. STP
NPDES Reported Excursions based on Test Results

NC ID	Start Date Event	End Date Event	Parameter	Type Limit	Value Reported		Limit Permit	Unit	Point Sampling	Frequency Sampling	Type Sampling
75399	9/1/2018	9/30/2018	Ammonia-Nitrogen	Average Monthly	6.3	>	4	mg/L	Final Effluent (001)	1/week	8-Hr Composite
75398	9/1/2018	9/30/2018	Ammonia-Nitrogen	Average Monthly	42.1	>	16.7	lbs/day	Final Effluent (001)	1/week	8-Hr Composite
72138	8/1/2018	8/31/2018	Ammonia-Nitrogen	Average Monthly	11.5	>	4	mg/L	Final Effluent (001)	1/week	8-Hr Composite
72137	8/1/2018	8/31/2018	Ammonia-Nitrogen	Average Monthly	56.2	>	16.7	lbs/day	Final Effluent (001)	1/week	8-Hr Composite
70451	7/1/2018	7/31/2018	Fecal Coliform	Instantaneous Maximum	1,300	>	1,000	CFU/100 ml	Final Effluent (001)	1/week	Grab
54551	2/1/2018	2/28/2018	Total Suspended Solids	Weekly Average	68	>	45	mg/L	Final Effluent (001)	1/week	8-Hr Composite
52608	1/1/2018	1/31/2018	Ammonia-Nitrogen	Average Monthly	13.5	>	12	mg/L	Final Effluent (001)	1/week	8-Hr Composite
77521	10/1/2017	9/30/2018	Total Nitrogen (Total Load, lbs)	Total Annual	9,133	>	9,132	lbs	Effluent Net (001)	1/year	Calculation
36727	10/1/2015	9/30/2016	Total Phosphorus (Total Load, lbs)	Total Annual	1,284	>	1,218	lbs	Effluent Net (001)	1/year	Calculation
3597	3/1/2015	3/31/2015	Ammonia-Nitrogen	Average Monthly	14	>	12	mg/L	Final Effluent (001)	1/week	8-Hr Composite
3596	2/1/2015	2/28/2015	Ammonia-Nitrogen	Average Monthly	14	>	12	mg/L	Final Effluent (001)	1/week	8-Hr Composite
3595	5/1/2014	5/31/2014	Ammonia-Nitrogen	Average Monthly	5.9	>	4	mg/L	Final Effluent (001)	1/week	8-Hr Composite
3594	3/1/2014	3/31/2014	Total Suspended Solids	Weekly Average	210	>	188	lbs/day	Final Effluent (001)	1/week	8-Hr Composite
3593	2/1/2014	2/28/2014	Ammonia-Nitrogen	Average Monthly	13	>	12	mg/L	Final Effluent (001)	1/week	8-Hr Composite
3592	8/1/2013	8/31/2013	Fecal Coliform	Instantaneous Maximum	2,200	>	1,000	CFU/100 ml	Final Effluent (001)	1/week	Grab
3591	6/1/2013	6/30/2013	Ammonia-Nitrogen	Average Monthly	4.2	>	4	mg/L	Final Effluent (001)	1/week	8-Hr Composite
3590	5/1/2013	5/31/2013	Ammonia-Nitrogen	Average Monthly	15.5	>	4	mg/L	Final Effluent (001)	1/week	8-Hr Composite
3589	5/1/2013	5/31/2013	Ammonia-Nitrogen	Average Monthly	26.4	>	16.7	lbs/day	Final Effluent (001)	1/week	8-Hr Composite
3588	12/1/2012	12/31/2012	Fecal Coliform	Instantaneous Maximum	20,000	>	10,000	CFU/100 ml	Final Effluent (001)	1/week	Grab
3587	4/1/2012	4/30/2012	Total Suspended Solids	Weekly Average	56	>	45	mg/L	Final Effluent (001)	1/week	8-Hr Composite
3586	6/1/2011	6/30/2011	Ammonia-Nitrogen	Average Monthly	13.3	>	4	mg/L	Final Effluent (001)	1/week	8-Hr Composite
3585	5/1/2011	5/31/2011	Ammonia-Nitrogen	Average Monthly	5.6	>	4	mg/L	Final Effluent (001)	1/week	8-Hr Composite
3584	5/1/2011	5/31/2011	Ammonia-Nitrogen	Average Monthly	5.6	>	4	mg/L	Final Effluent (001)	1/week	8-Hr Composite
3583	2/1/2011	2/28/2011	Ammonia-Nitrogen	Average Monthly	14.7	>	12	mg/L	Final Effluent (001)	1/week	8-Hr Composite
3582	10/1/2010	10/31/2010	Ammonia-Nitrogen	Average Monthly	8.2	>	4	mg/L	Final Effluent (001)	1/week	8-Hr Composite
4310	8/1/2010	8/31/2010	Ammonia-Nitrogen	Average Monthly	5.3	>	4	mg/L	Final Effluent (001)	1/week	8-Hr Composite
4309	7/1/2010	7/31/2010	Ammonia-Nitrogen	Average Monthly	22.4	>	4	mg/L	Final Effluent (001)	1/week	8-Hr Composite
4308	6/1/2010	6/30/2010	Ammonia-Nitrogen	Average Monthly	15.6	>	4	mg/L	Final Effluent (001)	1/week	8-Hr Composite
4307	5/1/2010	5/31/2010	Ammonia-Nitrogen	Average Monthly	9.6	>	4	mg/L	Final Effluent (001)	1/week	8-Hr Composite

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pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION
WASTEWATER TECHNICAL ASSISTANCE PROGRAM