UNDERWOOD engineers
99 North State Street
Concord, New Hampshire 03301
Tel: 603-230-9898 Fax: 603-230-9899

DRAFT Technical Memorandum

To: Thomas Lambert, Water & Sewer Superintendent

From: David J. Mercier, P.E., Jordan R. Provencher

Date: December 20, 2022

Subject: Troy, NH Lagoon Treatment Optimization Study

Background

The Town of Troy, New Hampshire owns and operates a 0.265 MGD aerated facultative lagoon wastewater treatment facility (WWTF). The facility was originally constructed in the 1980s and underwent a significant upgrade in 2006 after the facility received ammonia limits which they were not able to meet. The upgrade employed in 2006 involved abandoning the largest Lagoon #1 and providing new aeration systems, new baffles, and new floating covers to Lagoons 2 and 3 which were then renamed as Lagoons 1 and 2. Each of the operating lagoons was divided into two cells with the baffles named Cell 1A, 1B, 2A, and 2B.

In 2013, in addition to ammonia limits, the facility also received low total phosphorous and copper limits. To address these limits, the facility began adding poly aluminum chloride (PAC) at the end of Cell 1B, and both PAC and sodium aluminate at the beginning of Cell 2A.

Until fairly recently, the facility is reported to have been able to meet its ammonia effluent limits. Despite the chemical addition, the facility has struggled to meet the total phosphorus and copper limits, and in recent years, the facility has not been meeting ammonia limits either. The New Hampshire Department of Environmental Services (NHDES) and the Environmental Protection Agency (EPA) have been pressuring the Town to perform upgrades to bring the facility into compliance and on September 29, 2022, EPA issued an Administrative Order (AO) to Troy. The AO established interim (relaxed) limits for the facility to provide time (24 months) for the Town to study the problem, identify solutions, and develop cost estimates and schedules for implementation.

Understanding that a major upgrade to the facility will take time to then design and construct, the Town retained Underwood Engineers (UE) to perform a Lagoon Treatment Optimization Study to determine what, if any, changes could be implemented in the near term to bring the facility closer to compliance with its effluent discharge limitations in an economical fashion. The following technical memo presents the findings of the treatment optimization study.

UNDERWOOD engineers

Lagoon Performance Analysis

The following **Table 1** presents the historical limits provided to Troy in their National Pollutant Discharge Elimination System (NPDES) permit for ammonia, total phosphorus, and copper.

Table 1 – Historical NPDES Limits

Parameter	2002 Permit	2013 Permit	2021 Permit	Temp per AO
Ammonia Nitrogen (Oct 1 – Apr 30)	10.9 mg/L	13.2 mg/L	13.2 mg/L	40.0 mg/L
Ammonia Nitrogen (May 1 – Sept 30)	7.2 mg/L	8.7 mg/L	4.2 mg/L	34.5 mg/L
Total Phosphorus (Apr 1 – Oct 31)	Report	0.34 lbs/d	0.34 lbs/d	1.63 lbs/d
Total Recoverable Copper	N/A	3.1 ug/L	3.1 ug/L	7.0 ug/L

UE analyzed Troy's last three calendars years-worth of effluent data from January 2018 through December 2021. Multiple charts were generated from the data and those can be found in **Appendix A**. The three effluent limitations which the Troy WWTF struggled to meet and which all aerated facultative lagoons would struggle to meet were ammonia, total phosphorous, and copper.

From the charts in **Appendix A** it can be seen that the plant met its ammonia limit from August to January each of the last three years and exceeded it January to August. For total phosphorus, the plant has a seasonal limit from April 1 – October 31 each year and over the last three years met the limit approximately 50% of the time. The copper limit is year round and this limit was also met approximately 50% of the time over the last three years.

Note: Based on the interim limits issued to Troy in the EPA AO (See **Table 1** and **Appendix A**), over the last three years the plant would have met the interim limits most of the time but not all of the time. This suggests some short-term improvements should be implemented just to meet the interim limits.

Ammonia Removal

Ammonia is removed through biological treatment by specialized bacteria which convert the ammonia to nitrite first and nitrate second, dubbed "nitrification." The bacteria that perform these operations require the BOD level to be 30 mg/L or less, adequate dissolved oxygen and alkalinity, and a wastewater temperature greater than 5ºC. Nitrifying bacteria prefer to grow/attach to a fixed surface, and they are sensitive to shock loadings which can cause toxicity issues for them. Nitrifying bacteria have an extremely slow growth rate such that if they die off due to non-optimal conditions, it takes weeks to months to build back sufficient populations to fully nitrify and if this occurs during colder wastewater temperatures the system will not recover until the wastewater is warm again.

Based on the last three years of effluent ammonia data (refer to **Appendix A**) it can be seen that the plant fully nitrifies from approximately August each year until January each year. What is most likely occurring is that despite having the insulated covers, the coldest temperatures and the limited liquid volume available in Cell 2A creates a condition under which the free-swimming nitrifying bacteria die off and wash out of the system and the remaining nitrifiers are not able to reproduce in great enough numbers to achieve nitrification. In the spring once the wastewater begins to heat up, it still takes 3-4 months to rebuild an adequate population to fully nitrify and begin meeting permit.

One of the benefits of having multiple cells for treatment in series is that it allows a different population of bacteria to thrive in each cell as the available food and oxygen sources vary. To assess current operational conditions, UE collected samples from each of the four cells on November 15, 2022 and ran testing on them. The results of those tests can be seen in **Table 2** below.

Table 2 – Troy WWTF Sample Data

Parameter	Influent	Lagoon 1		Lagoon 2		Effluent
		Cell A	Cell B	Cell A	Cell B	
Alkalinity (CaCO3), mg/L	310	69	64	60	66	63
Ammonia-N, mg/L	-	1.4	0.23	0.063	2.0	2.0
Nitrate-N, mg/L	-	15	16	15	13.0	13
Total Phosphorus-P, lbs/d	-	2.11	1.84	0.87	0.76	1.41
Ortho Phosphate-P, lbs/d	-	1.46	1.36	0.54	0.60	-
Copper, ug/L	72	23	11	7.8	2.6	2.5

Notes:

1. Samples were grabs collected on 11/15/22
2. Total phosphorus and ortho phosphate have been converted to lbs/d assuming the plant ADF of 65,000 gpd.

From **Table 2** above it can be seen that on 11/15/22, significant nitrification was already occurring within Cell 1A and full nitrification by the end of Cell 1B as evidenced by the low ammonia numbers and high nitrate numbers. This tells us that at warm wastewater temperatures and an established nitrifier population that the retention time in Cells 1A and 1B are adequate to drive the BOD of the influent wastewater to a low value which then allows the nitrifiers to take over and perform nitrification. However, at cold wastewater temperatures, the kinetic rate at which BOD (or carbon) is broken down and utilized by the bacteria is typically reduced by half. This means that the detention time or volume required for BOD treatment during cold weather is essentially doubled. To confirm the volume required for cold weather BOD removal at the Troy lagoons, UE performed kinetic calculations utilizing the Marais & Shaw equation. The results predict that at today's maximum month influent flow of 87,000 gallons per day and average BOD concentration of 216 mg/L that the BOD would be reduced to just above 30 mg/L at the end of Cell 1B, leaving Cell 2A for nitrification and Cell 2B for polishing.

According to the NHDES design standards for aerated facultative lagoons, lagoons must be sized assuming a 20% loss of volume due to sludge accumulation and ice accumulation. Since the Troy lagoons are covered, loss to ice is not a concern, however, this would suggest that once the sludge accumulation approaches 2-3 feet deep in a given 10-foot deep cell, that it should be removed. Troy WWTF staff recently sampled the sludge depth at various points throughout the two lagoons and four cells. This data was provided to UE and can be found in **Appendix B**.

Based on the October 2022 sludge depth measurements by town staff, the average sludge depths in Cells 1A, 1B and 2B are 2.0, 0.8 and 1.2 feet, respectively. Cell 2A however is reported to have an average sludge depth of 5.6 feet which takes up significant capacity in this cell making it unavailable for nitrification. The excess accumulation of sludge in Cell 2A makes sense as the first chemical addition point is at the tail end of Cell 1B close to the transfer pipe between Cells 1B and 2A, and Cell 2A itself is the location of the second chemical addition point. Based on the lack of vigorous mixing and the baffle between Cells 2A and 2B, it is not surprising that Cell 2A has the highest sludge accumulation. The current lack of nitrification treatment space available in Cell 2A explains why the plant was able to nitrify year round after the 2006 upgrade, but not anymore.

Cell 2B does not have any aeration equipment installed in it and is intended to be a quiescent settling zone for polishing of the effluent. UE agrees this is a good arrangement for algae removal and settling. However, when sludge levels become high it can result in releases from the degrading sludge that yield higher final effluent values so this cell should also be cleaned of sludge when it reaches 2-3 feet.

In order for full nitrification to occur, the bacteria must have adequate alkalinity available in the wastewater to counter the effects of the nitrification process which utilizes alkalinity and depresses the pH. The optimal pH for nitrification is right around pH neutral of 7 and if the pH is allowed to drop to 6.5 or lower, nitrification is inhibited. As a rule of thumb, it is recommended that the alkalinity within the treatment process be maintained at a minimum of 70 mg/L as calcium carbonate (CaCO3). This amount of residual alkalinity will ensure that the pH does not drop too low. On November 15, UE gathered samples throughout the Troy WWTF process and analyzed the samples for alkalinity. While the influent alkalinity was measured as 310 mg/L, all four of the lagoon cells and the final effluent had marginal values of 60 to 70 mg/L of alkalinity. This suggests that a greater of amount of alkalinity should be added but more importantly, UE recommends that alkalinity addition at the Headworks Building be fully automated and paced with influent flow rather than dumped into the influent channel in powdered form and allowed to dissolve in an uncontrolled fashion. This will be more efficient, reliable, and accurate.

Phosphorus and Copper Removal

While it is possible to remove phosphorous and copper biologically, when effluent limits become very low as they are in Troy, it is necessary to add chemicals in order to bind the phosphorus and copper to the biological solids and then either settle the solids or filter the solids from the final effluent to achieve very low values. Keys to achieving efficient chemical removal of phosphorous and copper include selecting the optimal coagulant and/or coagulant/polymer combination, making sure that the coagulant/polymer is fully activated before being deployed, making sure the coagulant/polymer is fresh and not separated due to extensive hold times or extreme hot or cold temperatures, making sure that the chemical is flash mixed and fully dispersed throughout the flow stream so that it can be as effective as possible, and providing adequate quiescent time for the formulated solids to fully settle out of solution.

On November 15, UE and Clean Waters conducted coagulant and polymer testing on various samples at the Troy WWTF. Through the various trials we verified that the PAC product being utilized is a good choice when the sample total suspended solids (TSS) is still high such as in the raw influent or in Cell 1A. However, by the time the TSS had become low in the sample such as from the end of Cell 1B and on, the PAC was not overly effective at sequestering and settling additional solids and instead a polymer product was found to be more effective. This likely mimics the Town’s decision to use sodium aluminate in Cell 2A.

While the current choice of chemicals is believed to be appropriate, UE noticed several issues with how the chemicals are being deployed that are likely resulting in less than optimal performance. In particular, these include dosing the chemicals into the middle of a lagoon cell without vigorous mixing and the potential for short circuiting of the dosed flow through the cell without fully mixing with the entire contents of the cell, and dosing the chemicals through long runs of delivery tubing laid across the lagoon covers which exposes the chemicals to extreme temperatures in the summer and winter that likely degrade their potency before delivery.

One other note on copper is that the source of the copper in the wastewater influent could be coming mostly from the water distribution system if corrosion control is not optimized. The one influent copper sample we took on 11/15/22 was 72 ug/L which is in line with typical nonindustrial wastewater which suggests there may not be a lot of room for improvement but it is still worth investigating further.

Existing Lagoon System Capacity

The Troy Sewer Department has expressed that there is some interest in taking on additional users and flow via developable lots along the existing collection system (infill). In order to assess the potential for this, UE ran traditional lagoon kinetic calculations on the existing aerated lagoon Cells 1A, 1B, and 2A. In order for the existing system to achieve removal of ammonia the BOD concentration must be reduced to low levels in Cells 1A and 1B so that by the time the wastewater reaches Cell 2A it is possible for a nitrifying bacteria population to thrive and multiply to achieve full nitrification in Cell 2A. Cell 2B needs to be a quiescent settling zone to polish the final effluent.

Utilizing the Marais & Shaw equation and the maximum month flow, average BOD concentration and volume of each of the three aerated cells less 20% loss to sludge accumulation yields a treatable design flow of 90,000 gpd under winter conditions and 180,000 gpd under summer conditions.

Current maximum month flows are 87,000 gpd which suggests that the existing four-cell lagoon system, even with the optimization recommendations from this report implemented, would have no capacity for growth. If the Troy Sewer Department wishes to add sewer connections and flow, it will be necessary to upgrade the abandoned Lagoon #1 in a similar fashion as Cells 1A and 1B if lagoons are kept.

Existing System Optimization Strategies

Ammonia Removal

With regard to ammonia removal, UE believes that there are several optimization strategies that could be implemented in a short duration and piloted to assess their effectiveness. These would include the following:

- Automated and flow-paced alkalinity addition in the Headworks Building utilizing magnesium hydroxide.
- Sludge removal from Cell 2A (as a minimum).
- Construction of separate reactor tankage with fixed media for nitrification outside the lagoons in between Cells 1B and 2B.

Total Phosphorous and Copper Removal

Underwood recommends the following optimization measures be implemented and piloted in the near term to confirm their effectiveness for improving total phosphorous and copper removal as follows:

- Change the chemical addition point from dual point addition in Cells 1B and 2A to single-point automated and flow-paced PAC addition at the Headworks Building.
- If needed and in conjunction with the above bullet, polymer addition within the transfer piping between Cells 2A and 2B.

Costs for Improvements to be Piloted

With regard to a new automated alkalinity feed system, UE recommends that Troy transition from powdered sodium bicarbonate to liquid magnesium hydroxide for alkalinity addition. The reasons for this are that magnesium hydroxide is a more efficient chemical for adding alkalinity on a pound per pound basis and therefore will be less costly to utilize long term, and magnesium hydroxide comes in liquid form such that it can be direct fed to the influent channel without first having to be batch mixed from powder form.

Equipment needed for a new magnesium hydroxide alkalinity feed system consists of the following:

- A continuous water source and fractional horsepower carrying water pump on the order of 5 to 10 gpm.
- A 55 gallon drum spill containment pallet.
- A fractional horsepower chemical feed pump for magnesium hydroxide feed.
- Miscellaneous small diameter PVC piping and tubing.
- Power, instrumentation, wiring and programming to start and stop the chemical feed pump whenever the influent flow to the Headworks starts and stops. The influent flow rate is fixed so chemical pacing will also be fixed.

Note: All of the above equipment must be explosion-proof rated due to the environment in the Headworks Building. It is assumed adequate flash mixing will be achieved in the yard piping between the Headworks and Cell 1A.

The estimated cost for the above work is $XXX and the breakdown can be found in **Appendix C**.

With regard to relocating the PAC chemical to the Headworks Building the following equipment would be required:

- A 55 gallon drum spill containment pallet.
- A fractional horsepower chemical feed pump for PAC feed.
- Miscellaneous small diameter PVC piping and tubing.
- Power, instrumentation, wiring and programming in order to start and stop the chemical feed pump whenever the influent flow to the Headworks starts and stops. The influent flow rate is fixed so chemical pacing will also be fixed.

Note: All of the above equipment must be explosion-proof rated due to the environment in the Headworks Building. It is assumed adequate flash mixing will be achieved in the yard piping between the Headworks and Cell 1A.

The estimated cost for the above work is $XXX and the breakdown can be found in **Appendix C**.

Regarding sludge removal from Cell 2A, the following work will be required:

- Clean all weed growth off of the floating cover in Cell 2A.
- Temporarily remove and store the floating cover for Cell 2A.
- Mobilize a floating dredge and mobile dewatering unit and diesel powered generator(s) to pump the sludge from Cell 2A to the dewatering unit.
- Collect the dewatered sludge in roll-off containers and transport dewatered sludge to a landfill facility for permanent disposal.
- Once all sludge is removed, reinstall the floating cover system over Cell 2A.

Note: The sludge removal operation from Cell 2A is likely to affect the final effluent quality produced by the WWTF while dewatering is occurring. The Town should notify NHDES and the EPA of this necessary maintenance activity prior to its undertaking to put them on notice.

The estimated cost for sludge removal and disposal from Cell 2A is $400,000 (10%) to $800,000 (5%) depending on sludge percent solids (refer to breakdown in **Appendix C**).

UNDERWOOD engineers

With regard to the installation of nitrification fixed film media in a separate tank outside of the lagoons in between Cells 1B and 2B, UE solicited proposals from Lemna Corporation and Triplepoint Environmental to provide this equipment. New equipment that would be required is as follows:

- Submersible pump for pumping from Cell 1B to the new tank.
- Plastic fixed film media with associated aeration diffusers and blowers.
- New buried concrete tank of sufficient size to house the nitrification media.
- Yard air and process piping.
- Electrical for the new aeration blowers.

The estimated cost for this work is $XXX. A breakdown of the costs can be found in **Appendix C**. Cut sheets on the Lemna polishing reactor (LPR) and the Triplepoint NitrOx reactor can be found in **Appendix D**.

Note: Lemna and Triplepoint have stated that they have done containerized pilot nitrification reactors in the past. We have requested proposals from each of them on a rent-to-own basis that could be piloted in advance of constructing something permanent. UE highly recommends piloting a temporary unit first.

Conclusions and Recommendations

Historically, aerated facultative lagoons have been an excellent choice for municipal wastewater treatment for small New England communities. However, in the last 20 years as tighter effluent limits have been imposed on New England communities, many aerated facultative lagoons have been abandoned and new mechanical activated sludge plants have been built in their place as aerated facultative lagoons are not able to meet low nitrogen/phosphorous/metals limits without significant modifications.

In instances where an ammonia only nitrogen limit is issued as opposed to a total nitrogen limit, and where total phosphorous and metals limits are not extremely low, it is possible to upgrade and retrofit lagoons to achieve those limits. Very few communities have attempted to go this route, but Troy did choose to go this way in 2006 and for many years, was successful in meeting their ammonia limits. In recent years, the Troy facility has not been meeting their ammonia/phosphorus/copper limits with regularity and this is likely due to sludge accumulation in the lagoons over time and inefficient chemical edition.

Based on UE's analysis of recent data and the plant's current configuration, we believe that it is reasonable to perform some lower cost optimization improvements and pilot them to see if the plant can be brought into, or close to, compliance with the 2021 limits. That said, we also recommend that Troy begin planning for and saving for a full scale upgrade in accordance with the AO issued on 9/29/22. Further, as permit limits continue to be ratcheted down, it may become necessary to abandon the lagoon process in the future which could be as little as one or two permit cycles or five to ten years. In today's dollars (2022) mechanical activated sludge plant upgrades cost on the order of $50/gallon. At the permitted design flow of the Troy WWTF of 0.265 MGD, this would equate to an upgrade of $13.25 million.

The Troy WWTF is currently out of compliance with its 2021 limits and is under the watchful eye of the NHDES and EPA. The EPA issued AO requires the Town to study alternatives, identify the preferred upgrades to bring the plant into compliance, and present an implementation schedule which will be written into a second AO.

The AO study must be completed by 9/29/24. In the meantime, UE recommends Troy pilot the three improvements noted herein: automated alkalinity feed at the Headworks; automated PAC addition at the Headworks; and out-of-lagoon fixed film media nitrification treatment between Cells 1B and 2B. These systems could be set up during the first 9 months of 2023. As the most critical period for the pilot study will be the cold weather, the Town can monitor the ammonia/total phosphorus/copper removal during the winter of 2023/2024 and use this information for decision making in the AO study.

UE further recommends that the Troy Sewer Department have a full rate study performed in 2023 to establish appropriate rates to fund asset management of the treatment and collection system and a major WWTF upgrade.

Value Added Discussions

The AO that Troy received on September 29, 2022, requires the Town to procure professional engineering services to assist with study, cost estimating, selection of preferred upgrade alternative(s), and implementation schedule to bring the WWTF into compliance with the NPDES permit limits issued to the Town in 2021. The AO includes a compliance schedule of 24 months to complete the above work and provides relief during that timeframe with interim limits for ammonia, total phosphorus and copper.

The full-scale upgrades necessary to being the facility into compliance will be costly, especially if the Town wishes to match its permitted flow rate. The Town is currently on the 2022 NHDES CWSRF propriety list (ranked #5) for a $4.465M upgrade to go off of its receiving stream and construct rapid infiltration basins (RIBs) for groundwater disposal of the plant effluent. The most recent reports are that a sufficient site cannot be found to build RIBs and remaining on the receiving stream is most likely. The Town is also ranked #1 for up to $100,000 in principal forgiveness for a CWSRF wastewater planning project.

The Town has the opportunity to contact the NHDES and request to utilize the $100,000 planning principal forgiveness to perform the study required by the recently issued AO. This will still require a warrant article in 2023, but it could be for only the $100,000 study and not the full value of the RIB application since actual costs of an alternative upgrade are still unknown. UE recommends doing this ASAP.

Further, the Town requested that UE provide some conceptual level costs for lagoon improvements, should that be the preferred upgrade recommended in the AO study yet to be performed. One of the largest costs would be for sludge removal. Based on the average sludge depth measurements taken by Town staff in October 2022, the estimated range of costs for sludge removal from Cell 2A is $400,000 to $800,000, depending on sludge percent solids. For Cells 1A, 1B and 2B combined, the estimated sludge removal cost is $250,000 to $500,000. UE also estimated the sludge removal costs for the abandoned lagoon based on an average sludge depth of 2 feet to be $0.625M to $1.25M.

To upgrade the abandoned lagoon with similar technology as Cells 1A and 1B and add an out-of-lagoon fixed film nitrification reactor in between Cells 2A and 2B equipment only budgetary price from Lemna was $XXX. As a rule of thumb, the total project cost including engineering and construction is typically 3 to 4 times the equipment costs or $XXX to $XXX in this case.