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CLEAN WATER ACT'S 50th ANNIVERSARY

The mighty Merrimack River—a Clean Water Act success story

Stakeholder collaboration achieves low level nitrogen removal and improved peak wet-weather capacity at Warren, Rhode Island

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WORKING FOR WATER QUALITY

Stakeholder collaboration achieves low level nitrogen removal and improved peak wet-weather capacity at Warren, Rhode Island

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ABSTRACT | At 50 years, the Clean Water Act (CWA) has directly and indirectly benefited not only our planet but also our citizens and economy. While innumerable people and programs have contributed to the CWA's success, the collaboration among stakeholders in our industry and communities has solidified it. Each group of stakeholders, including public officials and employees who manage and operate wastewater treatment facility facilities (WWTFs), regulators, funding agencies, contractors, equipment suppliers, researchers, trainers, and consultants, have contributed to maintaining and improving water quality. The evaluation, design, construction, and operation of the Warren, Rhode Island WWTF upgrade exemplifies how stakeholders throughout the wastewater industry can effectively collaborate to improve water quality and serve our communities.

KEYWORDS | Permitting, nitrogen removal, wet weather capacity, secondary clarification

BACKGROUND

The town of Warren is in eastern Rhode Island on a peninsula that separates Mount Hope Bay and Narragansett Bay. Warren is home to around 11,400 residents and numerous commercial and industrial businesses, most served by the municipal sewer system and the Warren wastewater treatment facility (WWTF). The WWTF is on the western edge of town, along the Warren River just upstream of where it discharges into Narragansett Bay. The WWTF was constructed in the 1940s and upgraded in 1981 to include secondary treatment. Although modest improvements were completed after the 1981 upgrade, most of the WWTF's mechanical and electrical systems were well past their useful life in 2010, when the planning for a plant upgrade was initiated in response to issuance of a new Rhode Island Pollutant Discharge Elimination System (RIPDES) permit.

PERMITTING COLLABORATION

The 2010 RIPDES permit included stringent total nitrogen (TN) limits based on an 80 percent nitrogen reduction in the summer (May–October) and a 20 percent reduction during the winter (November–April). These proposed TN reductions resulted in summer and winter permit monthly mass limits of 83.8 lb/day (38.0 kg/d) and 239.7 lb/day (108.7 kg/d), respectively, at a permitted flow of 2.01 mgd (7.61 ML/d). In addition, the 2010 RIPDES permit also included monthly concentration TN limits of 5.0 mg/L and 14.3 mg/L in the summer and winter, respectively, to reflect concentrations to meet the proposed mass-based limits at the permitted flow.

Moreover, because of the combination of new sewer connections and infiltration and inflow (I/I), the Warren WWTF regularly experienced flows higher than the RIPDES permit flow limit of 2.01 mgd (7.6 ML/d) (see Figure 2), suggesting an increase in the RIPDES permitted flow was required. These needs, along with an aging WWTF vulnerable to coastal storm events and on a constrained site, needed a collaborative solution among town officials, regulators, consulting engineers, equipment suppliers, construction contractors, and WWTF contract operations staff.

In response to the need for an upgrade together with the newly issued permit, the Town of Warren entered into a consent agreement with the Rhode Island Department of Environmental Management (RIDEM) to determine the required flow increase to include in a permit modification. It was recognized that such a permit modification could also include changes to TN and conventional pollutant concentration limits, so that the mass of the pollutants in the WWTF effluent would not increase.

Following a flow study, the Town of Warren, its consulting engineer, and RIDEM developed permit limits that would meet the water quality criteria of the WWTF discharge while providing flexibility to reduce the capital cost of the upgrade. The new permit included the following:

- Monthly flow limits of 2.53 mgd (9.58 ML/d) and 3.43 mgd (12.98 ML/d) that coincide with the periods when summer and winter seasonal nitrogen limits, respectively, are in effect
- Seasonal average mass limits for TN of 83.7 lb/day (38.0 kg/day) and 239.7 lb/day (108.7 kg/day) for summer and winter permit seasons, respectively, with these seasonal mass limits equating to seasonal concentration limits of 4.0 and 8.4 mg/L, respectively

Figure 1. Key stakeholders in the success of the Clean Water Act

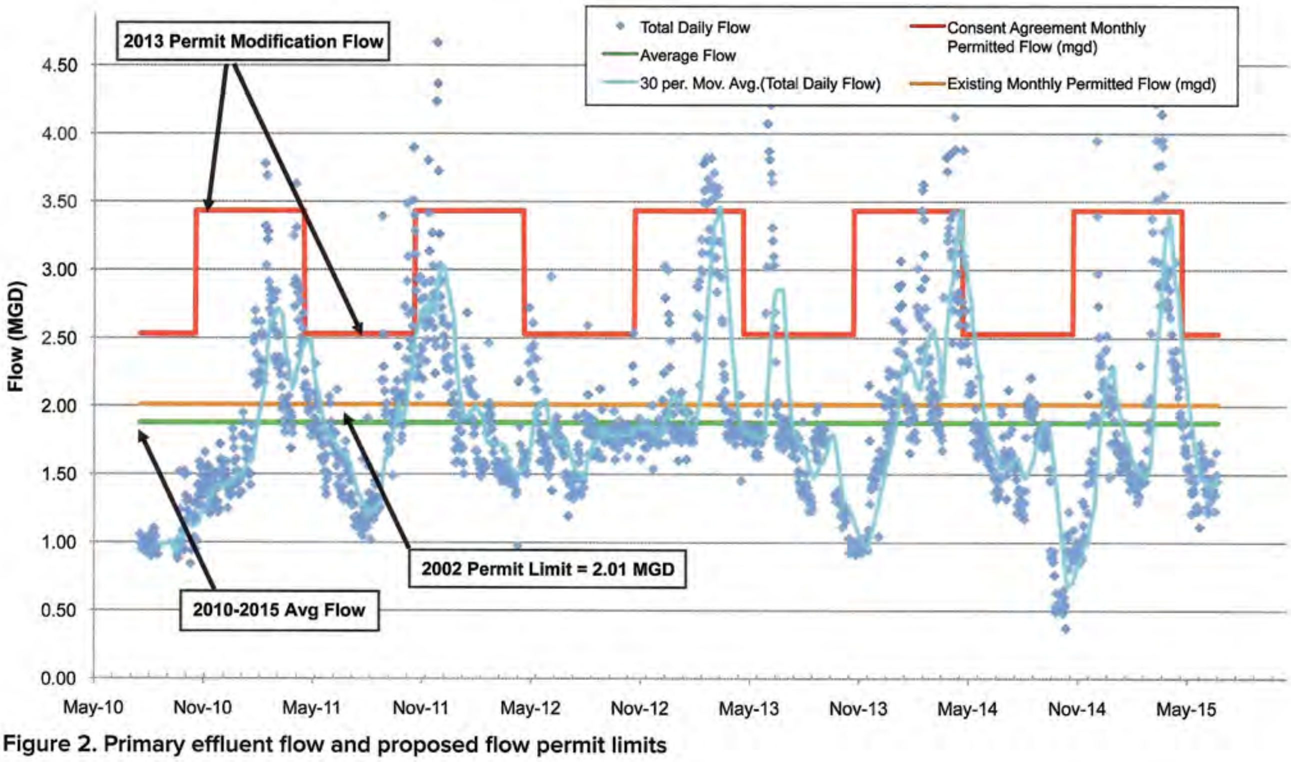

Figure 2. Primary effluent flow and proposed flow permit limits

Table 1. Summary of flow and nitrogen permit considerations

Permit Season	Flow MGD (ML/d)	Monthly Mass Limit lbs/d (kg/d)	Seasonal Mass Limit lbs/d (kg/d)	Equivalent Conc. based on Seasonal Load Limit mg/L	Monthly Avg. Conc. Limit in Permit mg/L
Limits from 2010 RIPDES Permit					
Winter	2.01 (7.61)	239.7 (108.7)	N/A	14.3	14.3
Summer	2.01 (7.61)	83.8 (38.0)	N/A	5.0	5.0
Limits using typical monthly flow limit approach					
Winter	3.43 (12.98)	239.7 (108.7)	N/A	8.4	8.4
Summer	3.43 (12.98)	83.8 (38.0)	N/A	2.9	2.9
Limits from 2013 RIPDES Permit Modification					
Winter	**3.43 (12.98)**	**N/A**	**239.7 (108.7)**	**8.4**	**9.5**
Summer	**2.53 (9.58)**	**N/A**	**83.8 (38.0)**	**4.0**	**5.0**

Figure 3. WWTF prior to upgrade

- Monthly concentration limits for TN of 5.0 and 9.5 mg/L for summer and winter permit seasons, respectively
- Reduction in monthly average BOD5 and TSS limits to 23.8 mg/L and 14.6 mg/L summer and winter permit seasons, respectively, due to the increase in flow

This permit development process enabled the Warren WWTF to be designed for a higher TN concentration (5 mg/L vs. 2.9 mg/L without the seasonal flow limits) at a lower flow rate (2.53 mgd vs. 3.43 mgd [9.58 ML/d vs. 12.98 ML/d]) during the summer, when more stringent limits need to be met. Although the WWTF site's limited space required a compact treatment technology, the more accommodating permit limits allowed both proprietary and conventional technologies and equipment to be considered. Table 1 summarizes the flow and TN pollutant values included in the permits.

WWTF PROCESS EVALUATION AND DESIGN

The 2013 modification to the RIPDES permit initiated a facilities plan to evaluate the needed improvements to upgrade the Warren WWTF, particularly the biological treatment process, to provide capacity for the increased flows and to achieve TN limits. The evaluation of biological treatment alternatives was completed in two steps. The first step screened several technologies. The second step evaluated the three most favorable technologies that would provide the target flow capacity and fit on the constrained WWTF site. The three processes evaluated were (1) magnetite-ballasted activated sludge, (2) integrated fixed-film activated sludge (IFAS), and (3) variable operating mode (VOM), which incorporates several conventional activated sludge treatment configurations. The evaluation determined that the VOM process had the lowest capital and operating costs, with a net present worth cost 25 percent lower than the next-lowest-cost alternative.

Again, the WWTF's limited space to construct additional tank volume was a key factor in evaluating the biological treatment alternatives. The original 1981 aeration tank reactors, piping gallery, and secondary clarifiers were all constructed as continuous units that did not include a flow distribution structure immediately upstream of the secondary clarifiers. As shown in Figure 3, the layout was designed to split the flow to the two reactors, but not to recombine the flow prior to secondary clarification. With no space in the piping gallery to construct a new flow distribution structure prior to secondary clarification, the design could not incorporate a third secondary clarifier without significant rework of the piping gallery with the associated capital cost. This constraint guided the design toward using only the two existing secondary clarifiers and adding a flow distribution structure at the beginning of the new reactor train rather than between reactors and secondary clarifiers, as is common.

The VOM configuration for the Warren WWTF includes two treatment trains with eight zones per train. The process configuration includes the following:

- Two pre-swing zones that can be operated as either aerobic (aerated) or anoxic (un-aerated but mixed) reactors
- Two post-swing zones that can be operated as aerobic or anoxic reactors

- Capability to draw internal mixed liquor recycle (IMLR) flow from either of the post-swing zones or to turn these pumps off completely
- Ability to operate in a modified version of the contact stabilization mode to protect the secondary clarifiers from washout due to excessive solids loading during storm events, while still providing some TN removal

The contact stabilization mode of the activated sludge process relocates the feed point of the primary effluent to the contact zone, typically 50 percent or more down the length of the reactor train. As the return activated sludge (RAS) flow is still added to the beginning of the reactor train, the stabilization zone holds solids at RAS concentration, effectively storing the RAS solids and lowering the mixed liquor suspended solids (MLSS) concentration in the contact zone. As secondary clarifier capacity relates directly to MLSS concentration entering the clarifier, the contact stabilization mode allows manipulation of the biological solids inventory; this increases secondary clarifier capacity during wet weather events by lowering the solids loading rate on the secondary clarifiers.

Each operating mode also can add alkalinity or supplemental carbon to enhance the process. Sodium hydroxide can be added to the reactor influent to increase alkalinity as well as pH, and it is commonly used during the winter and spring when I/I is higher, with corresponding lower influent alkalinity. A commercial carbon product can be added as a supplemental carbon source to the reactor influent or to either of the post-swing zones. Supplemental carbon can be added year-round to any of the operating modes but is likely needed only when the WWTF is operating with the four-stage Bardenpho process during the summer when TN limits are lower.

These features allow the VOM process to operate in three primary modes depending on the seasonal permit limits and operating conditions. Volumes of the aerobic and anoxic zones can be altered by changing the operating environment (aerobic, anoxic, or low dissolved oxygen aerobic) of each reactor zone. The three operating modes are shown in Figures 4a, 4b, and 4c.


Mixer-aerator installation in post-swing zone

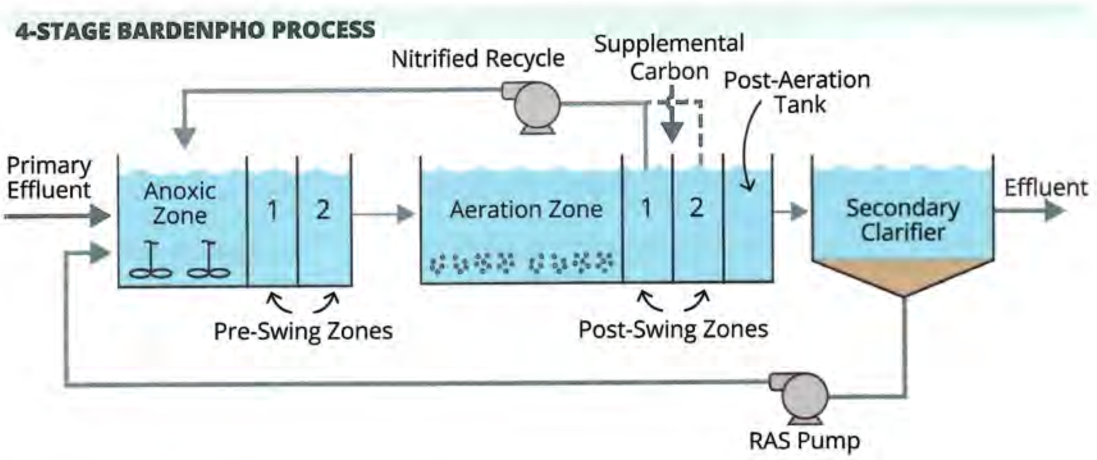

Figure 4a. Four-stage Bardenpho process with dual anoxic and aerobic zones. This mode was the basis of design for summer conditions. The process can achieve an effluent TN of less than 5 mg/L.

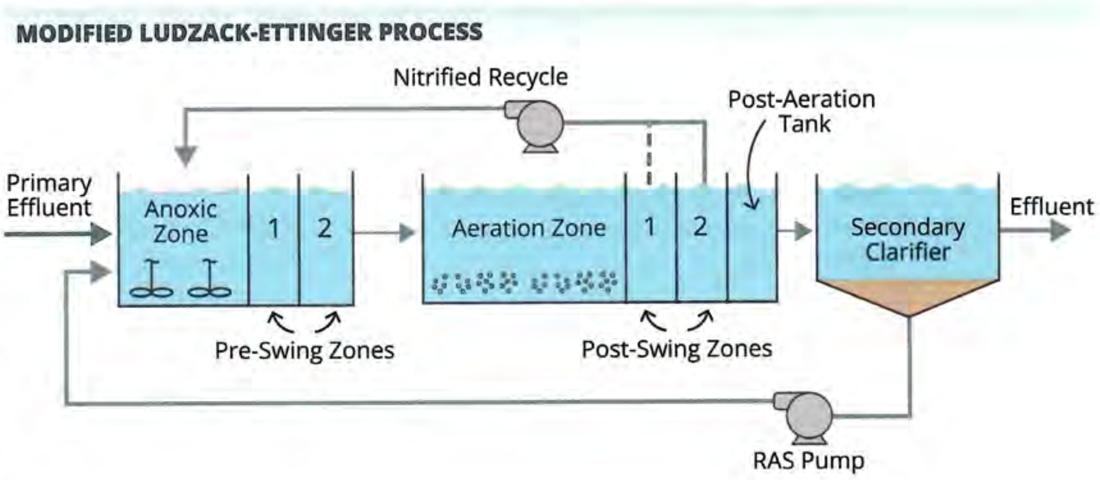

Figure 4b. Modified Ludzack-Ettinger (MLE) process with a pre-anoxic zone and main aeration zone. Changing from the four-stage process to MLE simply requires activating the aeration system in the post-swing zones and changing the IMLR pump suction location. This mode was the basis of design for winter conditions. The MLE process can achieve an effluent TN of less than 8 mg/L.

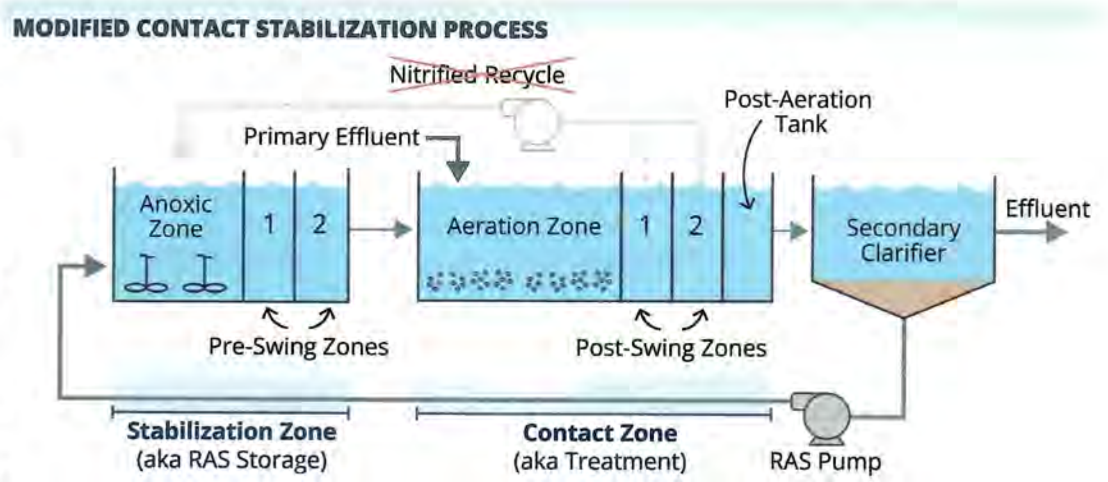

Figure 4c. Modified contact-stabilization process that stores solids in the stabilization zone and provides treatment in the contact zone. The variation of this operating configuration allows portions of each train to be maintained as anoxic zones to continue to provide some nitrogen removal during high flow events. This mode was the basis for design when flows exceeded winter season maximum week flow of 4.43 mgd (16.77 ML/d). When used as an intermittent, short-duration operating mode, the modified contact stabilization process can achieve an effluent TN of between 8 and 12 mg/L.

Incorporating these three activated sludge operating modes allows the system to operate as a compact, high-biomass process for up to moderate wet weather flow conditions. The switch to the modified contact stabilization process can then be used to manipulate the solids concentration at the end of the reactor train to stay within the limits of the secondary clarifier capacity during severe wet weather events to help prevent solids overload and washout. Owing to the high peak hourly flow to maximum monthly flow ratio of the Warren WWTF influent, the VOM process reduced the reactor size by 40 percent compared to using a conventional design approach.

For swing zone flexibility in the modified contact stabilization process, each zone required the ability to independently mix and aerate the MLSS. In addition, modeling of the system during the design phase determined that under low-loading cold weather conditions, the oxygen demand of the main aeration zones would result in mixing-limiting conditions. As a result, combined aeration and mixing systems were investigated, and a proven proprietary technology in the modeled circumstances was selected.

Additional recommended WWTF improvements included new influent screening, new primary and secondary clarifier mechanisms, primary effluent pumps, rotary drum thickening, a standby generator, a new electrical service, and a new SCADA system, as well as structural, architectural, and HVAC improvements.

RESILIENCY TO ADDRESS CLIMATE CHANGE

Resiliency of both the process and the physical facilities to severe weather, storm events, and high flows was considered while planning the WWTF upgrade. Process resiliency was achieved with the VOM process, which allows different operating modes depending on permit limits, storm magnitude, and operating conditions at the time of the storm. Specifically, the combination of a process configuration that could be quickly adjusted to increase wet weather capacity, mechanical equipment that could function over a wide range of operating conditions, and extensive operational training to proactively control the process were essential in achieving excellent effluent quality over a wide range of flows associated with storm events.

To address the WWTF's physical resiliency, the upgrade required protection from flooding, severe storms, projected sea level rise, and wave action. Resiliency features included relocation of electrical equipment and motor drives above the projected flood elevation and replacing pumps and mixers with units having submersible motors where raising motors was not feasible. The evaluation of the site structures and equipment was completed in cooperation with RIDEM and the Rhode Island Coastal Resource Management Council (CRMC) and was consistent with the flood protection and resiliency recommendations of the 2016 update to TR-16, "Guides for the Design of Wastewater Treatment Works," published by NEIWPCC. Incorporating various resiliency features into the project was important in securing funding from the Rhode Island State Revolving Fund Program.

STARTUP AND PROCESS OPTIMIZATION

As little growth was projected for the town's sewer service area, the upgraded WWTF was projected to start up at approximately 80 percent of design loading. Figure 5 shows the primary effluent flows to the secondary plant since startup and illustrates the actual flows compared to the seasonal limits developed during permitting.

Pre-anoxic and pre-swing zones

The upgraded WWTF started operation with the new VOM process configuration using one train in August through October 2019 while the second train was being constructed. During the winter of 2019–2020, the process was operated in MLE mode using both trains and achieved an effluent TN of approximately 5.5 mg/L. The consent agreement required compliance with the new permit limits starting on June 1, 2020. During the summer of 2020, the VOM configuration was changed to the four-stage Bardenpho mode and averaged an effluent TN of less than 3 mg/L, well below both the seasonal and monthly TN permit limits. Operation at the end of the summer in 2020 also included a trial of the supplemental carbon feed and control system, which demonstrated the capability to reduce the effluent TN to approximately 2 mg/L. Current WWTF performance does not require the addition of supplemental carbon to achieve summer permit compliance.

In the fall of 2020, the WWTF experienced mechanical problems that tested the VOM configuration. In November, one of the IMLR pumps was damaged by a piece of concrete falling into the IMLR chamber, which disabled the impeller. Two weeks later, a second IMLR pump was also damaged by an unknown object, possibly a tool or piece of metal conduit that fell into the other IMLR pump chamber. Both pumps were inoperable and, because of supply chain challenges associated with Covid-19, the WWTF had no IMLR pump capability for four months.

To achieve permit compliance, the VOM process was operated in four-stage Bardenpho mode so that the aerobic zones were completely nitrifying, and denitrification was accomplished by the dual anoxic zones. Unlike typical four-stage Bardenpho mode with IMLR pumps operating, a greater percentage of denitrification was performed in the second-stage, post-swing zone, anoxic reactors. Performance during this challenging period achieved an average TN of 7 mg/L, below the winter monthly average limit of 9.5 mg/L.

Upon delivery of one repaired and one new IMLR pump in March 2021, WWTF staff cleaned and inspected the tank to confirm no objects were within that could damage the repaired or replaced

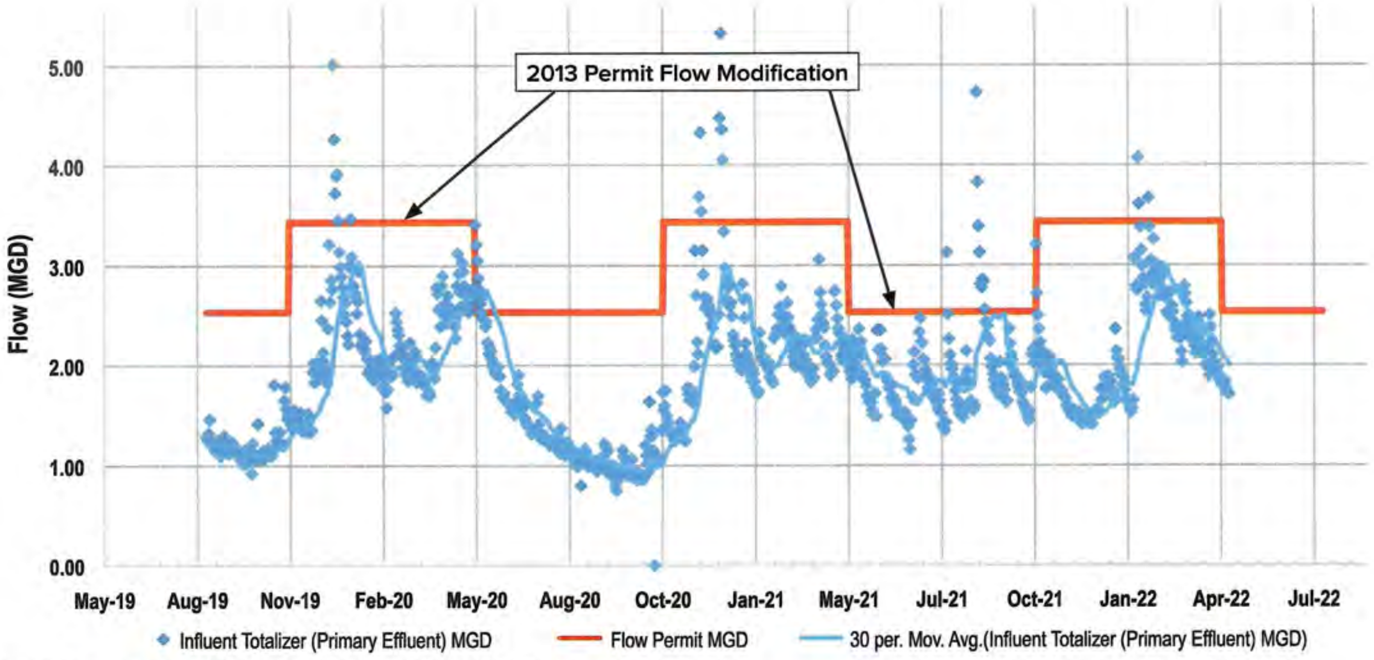

Figure 5. Primary effluent flows since WWTF startup

IMLR pumps. To do so, however, the two trains had to be emptied of MLSS inventory, one at a time. WWTF operators faced two options: (1) waste roughly 50 percent of the solids inventory to reduce the MLSS concentration below the limit of secondary clarifier overload if wet weather flows were experienced or (2) operate in the modified contact stabilization mode. The WWTF operators decided to use the modified contact stabilization process and modulate the RAS flow to provide the needed secondary clarifier capacity while achieving the TN permit compliance. Over the three weeks that it took to fully clean and inspect all the reactors, the

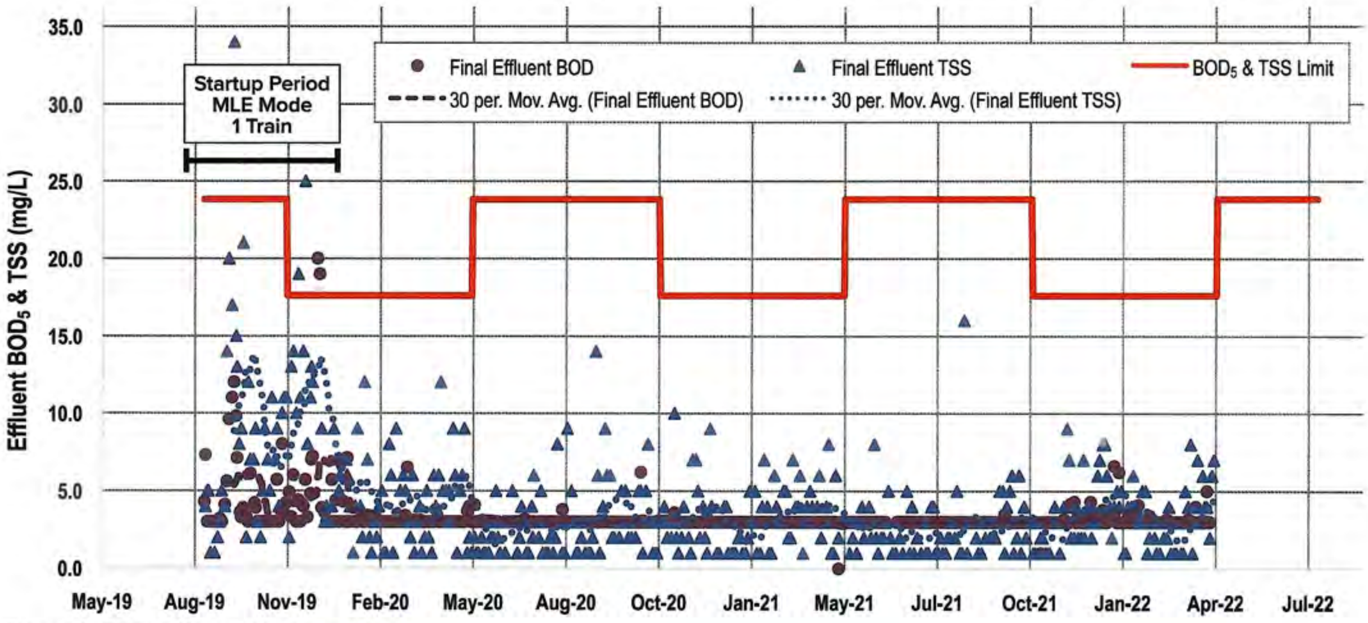

Figure 6. Final effluent BOD_5 and TSS

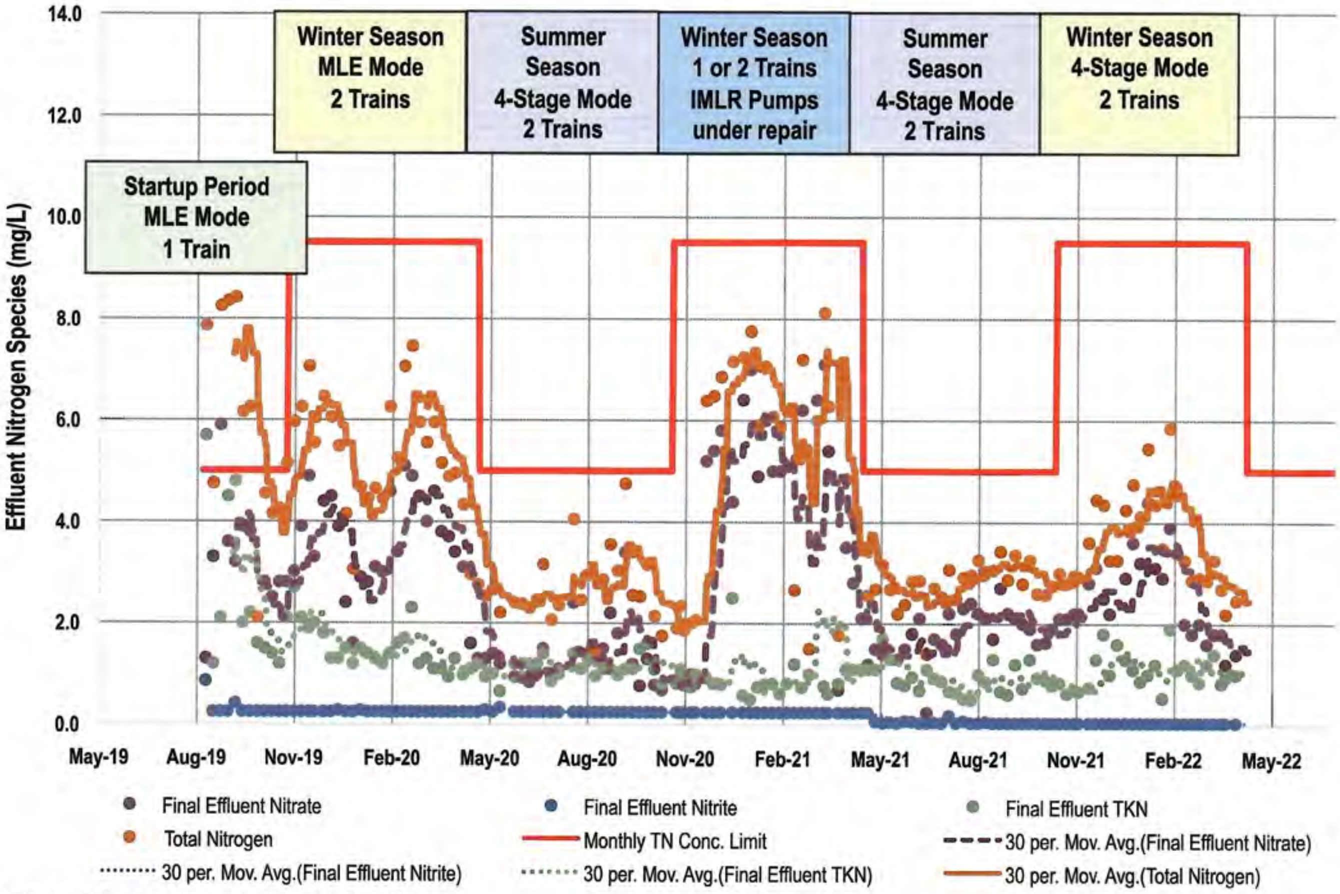

Figure 7. Final effluent nitrogen species

system achieved effluent TN of approximately 7 mg/L as well as low BOD5 and TSS.

Following tank inspection and cleaning, the IMLR pumps were placed back into service just before the summer. Similar to 2020, WWTF process performance during the summer of 2021 achieved an effluent TN of approximately 3 mg/L even though flow increased, including conditions in September when weekly, daily, and peak hourly flows were all the highest ever recorded at the WWTF due to rainfall associated with Tropical Storm Ida.

Performance during the summer and fall of 2021 benefited from ongoing optimization. The combination of operating using precise control of solids retention time, dissolved oxygen concentrations, and RAS rate, while actively managing the sludge volume index, contributed to the WWTF achieving effluent performance of less than 5 mg/L for BOD5 and TSS and 3 mg/L for TN during Tropical Storm Ida, and lowering effluent TN during the winter of 2021–2022 compared to prior years.

SUMMARY

The success of the CWA in developing and implementing water quality improvements in watersheds across New England depends on collaboration and cooperation of key stakeholders. The Warren WWTF upgrade is an example of this, from the collaborative permitting to the innovative and effective design, construction, and startup. At each step of the process, teamwork among stakeholders and participants was integral to accomplishing an effective, affordable water quality improvement that can serve the town for decades.

ACKNOWLEDGMENTS

Many individuals and organizations contributed to this project. Most important was the support and drive of the Town of Warren, especially Town Manager Kate Michaud and Director of Planning Bob Rulli. In addition, Dave Komiega, Norm Blank, and Eric Komiega from the contract operations firm, H2OInnovation (formerly with Suez), were and continue to be instrumental in the transition to the upgraded WWTF and its performance. Also, thanks to the staff at RIDEM and to Hart Engineering, the project general contractor.

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