----- FINAL REPORT -----

A PROJECT TO EVALUATE THE EFFICACY OF A WOODCHIP BIOREACTOR FOR DENITRIFICATION OF TERTIARY EFFLUENT FROM THE BOLTON WASTEWATER TREATMENT PLANT (LAKE GEORGE, WARREN COUNTY, NEW YORK)

Aerial photograph of the Bolton Wastewater Treatment Plant (foreground) looking northeast toward Green Island, the Narrows and Black Mountain (photo credit Visual Planet LLC)

Prepared For

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December 2021

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PREFACE

This report describes the results of a 31-month monitoring program conceived, designed, and implemented in response to the installation of a "green technology" woodchip bioreactor at the Town of Bolton Wastewater Treatment Plant. The goal of this Lake Champlain Sea Grant Project was to implement and conduct a thorough investigation of a woodchip bioreactor in an upstate New York wastewater treatment facility to determine the feasibility of using this 'green' infrastructure technology to remove nitrate-nitrogen from plant effluent which is discharged to ground water and then enters Lake George. The original and primary Project objectives were to (1) characterize the chemistry of the Bolton WWTP effluent, with particular emphasis on nitrate, ammonia and soluble reactive phosphorus of the effluent stream being denitrified through the bioreactor and side-by-side, the stream not being denitrified, and (2) monitor the improvement in ground water nitrate levels moving down-gradient from the WWTP during the study period. These efforts were undertaken in conjunction with a detailed documentation of treatment plant operations and measuring of unit process efficiency. The merging of these two program components produced a focused understanding of plant treatment efficiencies using this green technology and the potential impact of low-cost capital improvements and plant operation optimization.

ABSTRACT

The Bolton Wastewater Treatment Plant (Bolton WWTP) is located in the Town of Bolton, Warren County, New York, along the western shoreline of Lake George about 10 miles from the south end of the lake. The facility is situated on a series of higher elevation plateaus with respect to the level of Lake George and treated effluent from the facility is discharged to infiltration sand beds on the property for final polishing. The discharged effluent becomes incorporated into the local ground water and has an impact on two (2) different watersheds, depending upon which sand disposal beds are used for effluent discharge.

The identification of certain treatment plant unit processing deficiencies with regard to nitrate-nitrogen resulted in the construction of a woodchip bioreactor for the treatment of plant effluent before being discharged to the sand disposal beds. This installation at the Bolton WWTP is the first real time, *in-situ* application of this "green technology" for a small wastewater package plant world-wide.

A comprehensive monitoring program that focused on the woodchip bioreactor and other important Project components within and adjacent to the Bolton WWTP property was initiated on March 19th, 2019 and continued through September 30th 2021. The program included water sample and field data collection from bioreactor influent, monitoring wells and effluent, plant effluent discharge, SPDES Permit wells and Stewart Brook, as well as a detailed analysis and evaluation of treatment plant operations.

There were 66 bi-weekly field excursions and 642 water samples collected during the 31-month monitoring effort at a total of 14 sampling stations. The woodchip bioreactor was in operation a total of 679 days before the unit processor had to be shut down due to internal plugging.

Sample collection and processing were conducted according to standard protocol and samples were submitted to a laboratory certified to process and analyze chemistry samples for New York State SPDES permit operating requirements. The COVID-19 pandemic had a slight impact on the field monitoring effort.

The results reported herein provide compelling evidence that the woodchip bioreactor reduced the nitrate-nitrogen concentrations that occurred in the tertiary effluent discharged from the Bolton WWTP by about 41 percent when compared with tertiary effluent that was untreated following discharge from the treatment facility and disposal to the upper sand beds. The variability of removal depended upon many environmental factors including the concentration of influent nitrate, the temperature of the wastewater, the measure of dissolved oxygen in the wastewater as it traverses the woodchip matrix, the retention time of the wastewater within the bioreactor, the availability of a carbon source for the denitrifying bacteria, wastewater pH, and the flow characteristics of the wastewater through the woodchip matrix.

This "green technology" would perform in a similar effective and efficient manner in geographical and environmental situations comparable to the Bolton Landing demonstration project with more effective nitrate removal during the summer months and less effective nitrate removal during the winter months.

The most vital component to successful operation of this "green technology" regardless of the geographical location is the dedication of the wastewater plant operators who are required to pay attention to system details on a daily, if not hourly, basis and use their knowledge to fine tune the system when necessary.

Wastewater *denitrification* through this passive environmentally compatible technology should continue to move beyond concept into actual full-scale field applications. Future installations will benefit from the lessons already learned at the Bolton WWTP woodchip bioreactor facility, with additional bioreactor units at that location providing additional treatment capacity, further options for process optimization, and continued learning opportunities. The documented success of similar installations in other geographical areas will confirm the ability of this "green technology" to deal with excess reactive nitrogen in the realm of small community wastewater treatment plants.

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ACKNOWLEDGEMENT

The authors extend a special acknowledgement to Town of Bolton Supervisor Ronald Conover. This study would not have been implemented without his leadership and determination to deal with an adverse situation and advocate for the water quality of Lake George.

Funds for this monitoring program were provided by The FUND for Lake George, The Lake George Association (LGA) and The Lake Champlain Sea Grant Program. The FUND for Lake George and The Lake George Association provided in-kinds services, which allowed the participation of Chris Navitsky, The Lake George Waterkeeper and Brea Arvidson, LGA Manager of Water Quality Research in the monitoring program. The Town of Bolton provided in-kind services, which allowed the participation of Bolton WWTP Chief Operator Matt Coon and Assistant Operator Justin Persons, and Town Engineer Kathleen Suozzo.

The authors extend their appreciation to the other Program Team members including Matt Coon, Chief Operator, Town of Bolton WWTP, and Justin Persons, Assistant Operator, Town of Bolton WWTP.

2019 to 2021 Lake Champlain Sea Grant Program

A Monitoring Program to Evaluate the Efficacy of a Woodchip Bioreactor Installed at the Bolton Wastewater Treatment Plant, Lake George (Warren County), New York

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Final Report

Chapter 1

Executive Summary

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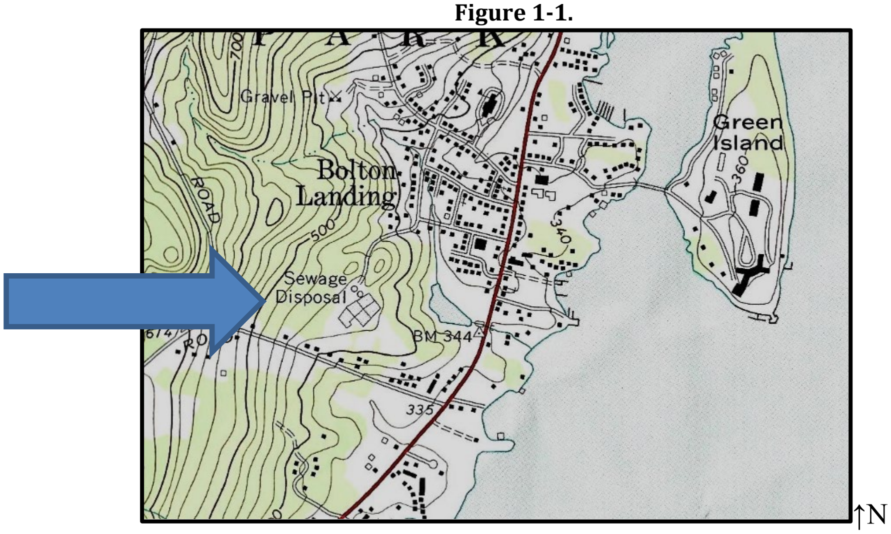
1.0 Project Location and Boundary

The Bolton Wastewater Treatment Plant (Bolton WWTP) is located in the Town of Bolton, Warren County, New York, along the western shoreline of Lake George, within the Lake Champlain drainage basin, and appears on the United State Geological Survey (USGS) 15-minute quadrangle map, *Bolton Landing, New York* (Figure 1-1).

Figure 1-1.



The facility is situated on map parcel #171.19-1-5 (Warren County Community Map) identified as the Bolton Sewer District, which has a surface area of 15.4 acres. There is an adjoining parcel to the north and west, lot 171.19-1-3 (Bolton Sewer District), with a surface area of 5.95 acres that includes the upper sand disposal beds. The operational portion of the treatment facility is located on map parcel 171.19-1-5. The facility is abutted on all sides by residential properties.

1.1 Background

Lake George is the largest body of water located entirely within the Adirondack Park in New York State. Historically, it has been called the "Queen of American Lakes" for its clear waters and inherent natural beauty, and the lake has been a popular tourist attraction since the late 1800s (West et al. 2001) and perhaps earlier.

Local concern for the preservation of water quality in Lake George has existed for many decades, primarily the result of activities initiated by the Lake George Association (LGA), the first lake conservation organization in the United States, formed in 1885. As a result of LGA efforts, the lake was classified as "AA Special" (Class AA-S) meaning (1) that water taken from the lake could be used as a public drinking water supply following treatment with chlorine and (2) that there shall be no discharge or disposal of sewage, industrial wastes or other wastes into these waters or into streams discharging to the lake (6 NYCRR 701.3(c)).

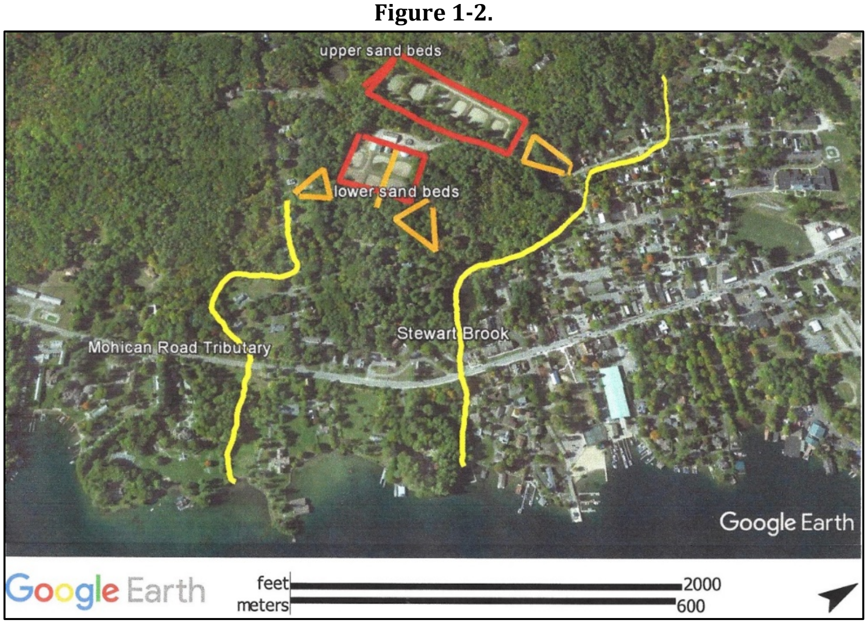
The construction of the Adirondack Northway, Interstate 87, in the 1960's greatly facilitated travel to the Lake George region and resulted in a surge in area tourism and recreation beginning in the late 1960s and early 1970s. With increased tourism and development along the south end and western shoreline of Lake George and the awareness of some individuals that WWTPs could contribute nutrients to Lake George, there was concern about the location and water quality of ground water discharge from WWTPs, in general, with respect to their impact on the lake (Aulenbach et al. 1974). The primary options were either the effective removal of nutrients in the wastewater prior to discharge to the sand beds or, alternatively, the diversion of wastewater out of the basin if the plant was not operating effectively.

In view of the strict discharge regulations and in consideration of the growing population of residents in the Town of Bolton, a sewage collection system and treatment plant were constructed during 1959 to 1960 and began operation soon thereafter. The regulation restricting the discharge of wastewater into the drainage basin of Lake George was interpreted to mean surface discharges, and the only alternatives for final effluent disposal were discharge into the ground or diversion outside the basin.

The Bolton WWTP was constructed on a stepwise series of deltaic sand deposits located ~1,600 to 2,400 feet from the Bolton Bay shoreline to utilize the sand as an infiltration area for treated wastewater effluent (Aulenbach and Fillip 1983). Further details related to the Bolton WWTP design and upgrades at the facility since its construction are presented in Chapter 2 of this report.

According to Rensselaer Fresh Water Institute scientists who first studied the Bolton WWTP in the early 1980s, the subsurface geology of the area was comprised of a ridge of bedrock that bisected the lower sand beds so that ground water flow originating from effluent disposal moved in two (2) directions, either south toward the Mohican Road Tributary or north toward Stewart Brook (Figure 1-2). Using a Rhodamine-WT dye study, effluent disposed to the upper sand beds was shown to move down-gradient and emerge along the Stewart Brook channel (Aulenbach and Fillip 1983).

Figure 1-2.



Using shallow wells installed in the region of the upper and lower sand beds, the early 1980s RFWI study also identified water quality issues related to the ground water that moved down-gradient following effluent disposal to the upper and lower sand beds. Within two (2) decades from the installation of the Bolton WWTP, high concentrations of nitrate-nitrogen and ortho-phosphorus were measured in ground water in the region of both sand bed disposal areas.

1.2 Local Awareness of Water Quality Problems

Simultaneous with operation of the Bolton WWTP beginning in 1960 was the addition of large quantities of effluent to the lower and upper disposal sand beds, resulting in 'extra' ground water entering the Mohican Road Tributary and Stewart Brook watersheds, which previously had not been a factor for these two drainages. The late Paul F. Donahue, Sr., Esq., a resident at 38 Mohican Road, had accumulated an extensive file of documents and communications with the Town of Bolton concerning emerging ground water on his property (dating to the 1960s) in an effort to resolve the problem. Mr. Donahue described the problem as originating after construction of the Bolton WWTP, when plant effluent was discharged to the lower sand beds for disposal.

Subsequent documentation of an emerging ground water seepage problem in the area was provided by Alpha Geoscience (2004) in a hydrogeological evaluation prepared for the Donahue family. This site and adjacent areas had historically experienced excessively wet conditions resulting from the discharge of water seepage across the ground surface that originated at higher elevations to the north and west of the property in the direction of the treatment facility.

The first known documentation of the Mohican Road Tributary having part of its source attributed to the Bolton WWTP occurred in Fuhs (1972), when he acknowledged that the Tributary is a "*trickle which must be considered mostly seepage from the irrigation field of the Bolton Landing sewage treatment plant and….. feeds a pond which bears heavy blooms of algae*."

Now, we 'fast forward' several decades to the water quality issues that have occurred over a period of recent years in Bolton Bay, particularly in the littoral zone and shoreline adjacent to the Bixby Estate. The beach along this section of shoreline had become unusable for recreational purposes due to nuisance algal growth attached to submerged aquatic plants or floating above the sand and was well-documented by Keppler et al. (2008). With regard to this nuisance algae situation, it is important to note here that Stewart Brook flows into Bolton Bay just north of the Bixby property, while the Mohican Road Tributary forms the south property boundary where it flows into Bolton Bay.

Eventually, confusing and contrasting information about whether the Bolton WWTP was operating within performance requirements designated through the SPDES permit testing and the ongoing water quality problems in Bolton Bay provided the basis for the design of another scientific investigation.

1.3 Documentation of Water Quality Problem

During 2016, the Program Team of Sutherland and Navitsky designed and implemented an extensive monitoring effort that included tracking certain treatment plant operations and extensive field sampling to determine the sub-surface direction and extent of ground water flow from the Bolton WWTP, particularly from the region of the lower sand beds, into the Mohican Road Tributary and Stewart Brook watersheds. Detailed results of the 2016 to 2017 investigation are presented and discussed in Sutherland and Navitsky (2017).

In summary, the 2017 report described treatment efficiencies at the Bolton WWTP as inadequate and in need of upgrade and/or replacement, and it was noted that the process to implement corrective action had been initiated. In the meantime, however, the effluent discharged from the plant continued to contaminate the ground water beneath the region of the facility and impacted the Mohican Road Tributary and Stewart Brook, which both flow into Bolton Bay, introducing high concentrations of nutrients which cause near-shore littoral zone water quality issues and renders the area unusable for recreation by local residents.

Editors Note: Over the past 4+ years since release of the 2017 report, dedicated attention has been given to the Bolton WWTP by the Chief Operator for optimal treatment efficiency.

The 2016 to 2017 study provided conclusive evidence that the lower sand beds are connected hydraulically to the Mohican Road Tributary and Stewart Brook watersheds. Rhodamine-WT dye applied to lower sand beds #2 or #4 appeared at the lower Mohican Road seepage area within two (2) days following dye addition. A similar experiment in lower beds #1 and #3 was detected in the channel of a culvert that drains to Stewart Pond within six (6) hours following dye addition.

Important findings reported in the 2017 report included the following:

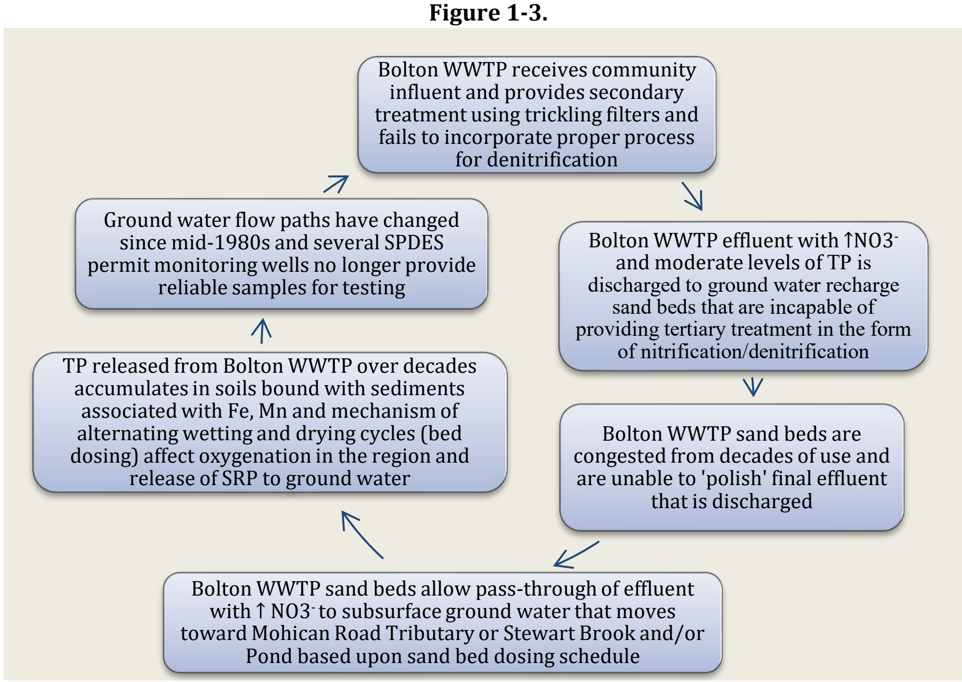
- The *mean* nitrate-nitrogen concentration measured in effluent discharged from the Bolton WWTP to the sand beds was 17.54 mg N·L, which was less than the 20 mg N·L specified in the SPDES permit, and neither the upper nor lower sand beds were capable of 'polishing' effluent with this high concentration, thus impacting ground water that moved down-gradient,

- A nitrate-nitrogen loading value of 74.5 tons was calculated for the Mohican Road Tributary from the Bolton WWTP for the 47-year period since the Fuhs 1970-1971 investigation; the loading value calculated for Stewart Brook since the 2008 Keppler study was 23.3 tons.
- A soluble reactive phosphorus loading value of 326 lbs. was calculated for the Mohican Road Tributary from the Bolton WWTP during the 47-year period since the Fuhs investigation; the SRP loading value calculated for Stewart Brook was 53 lbs. during the 9-years since 2008 Keppler study was conducted.

The nitrate-nitrogen and soluble reactive phosphorus loading amounts calculated for Stewart Brook were conservative estimates with respect to a 2008 starting date because Aulenbach and Fillip, in 1983, reported high average nitrate-nitrogen and ortho-phosphorus values of 6.40 mg N·L and 26.3 µg P·L, respectively, from a monitoring well that intercepted ground water moving toward Stewart Brook. It was not possible to use these data, however, because there were no samples collected from Stewart Brook to be compared with the ground water samples.

The conceptual diagram in Figure 1-3 defines the linkage between Bolton WWTP plant effluent and the eventual water quality impacts on the Mohican Road Tributary, Stewart Brook and Bolton Bay as described in the 2017 water quality report (Sutherland and Navitsky).

Figure 1-3.



1.4 An Innovative Pathway Toward Water Quality Solutions

Coincident with the release of the 2017 Sutherland and Navitsky report, the Town of Bolton consulting engineer for the wastewater facility (Kathleen Suozzo PE) submitted a process and facility review analysis to evaluate the plant's performance within its design parameters and pursuant to the regulatory standards of the New York State Department of Environmental Conservation (NYSDEC). The report also offered a series of short-term and long-term recommendations to upgrade the performance ability of the plant. One of the short-term recommendations in the report was to "*conduct a demonstration project involving the repurposing of one of the infiltration sand basins as a woodchip bioreactor for treatment of nitrate*." The installation of a woodchip bioreactor also was one of the recommendations included in the 2017 Sutherland and Navitsky report.

The Town of Bolton accepted the recommendation for installation of a woodchip bioreactor based upon the low cost of construction, the fact that the bioreactor could be constructed within the footprint of the existing WWTP, and potential benefit of reducing the nitrate-nitrogen concentrations leaving the plant in effluent discharged to local ground water.

The bioreactor for the Bolton WWTP was designed by Kathleen Suozzo PE, PLLC. Sand infiltration bed #10, which had been inactive for a considerable period of time and is the southernmost bed in the upper region of the WWTP property, was chosen for the site of bioreactor installation. The details of bioreactor installation including a timeline and step-by-step photographs are provided in Chapter 4 of this report. The woodchip bioreactor began treating Bolton WWTP tertiary effluent on October 10th, 2018, under a variety of environmental and operational conditions.

1.5 Woodchip Bioreactor Technology – Potential for Regional/World-wide Application

A thorough review of the scientific literature associated with woodchip bioreactors did not find any other examples of this technology being used to process the effluent from a small community package treatment plant. It appeared, therefore, that this was the first application of this technology, certainly in the United States, and perhaps on a global scale. Successful use of this technology in the northeast climate with variable environmental conditions could mean extensive application to other areas where situations similar to the Lake George scenario are occurring.

1.6 Affiliation with the Lake Champlain Sea Grant Program

This project was designed to specifically address the non-point source input of nitrate-nitrogen in the Lake George drainage basin. At the time, we realized that a similar scenario was, or could become, problematic within the Lake Champlain Basin with respect to community wastewater treatment systems up-gradient of the lake (4 percent of current runoff into the lake) and particularly agricultural runoff which contributes an estimated 41 percent of current total runoff into the lake.

Therefore, a successful demonstration of the pilot program would have widespread application within the Lake Champlain basin and beyond and was a technology that would relate directly to the *Lake Champlain Sea Grant Strategic Plan* focus and relevant goals including:

- *Resilient Communities and Economies–Goal 1*: Water resources are sustained and protected to meet emerging needs of the communities, economies, and ecosystems of the Lake Champlain basin.
- *Healthy Coastal Ecosystems–Goal 5:* Habitat, ecosystems, and the services they provide are protected, enhanced, and/or restored.
- *Healthy Coastal Ecosystems–Goal 6:* Land, water, and living resources are managed by applying sound science, tools, and services to sustain ecosystems.

Installation of the woodchip bioreactor at Lake George, and within the Lake Champlain Drainage Basin, provided the perfect opportunity to submit a grant proposal to the Lake Champlain Sea Grant Program for funding to evaluate the efficacy of this technology in the variable, seasonal climate of the northeastern region of the United States.

A proposal prepared and submitted for funding to the Lake Champlain Sea Grant Program during fall 2018 received positive reviews and received an award of $58,656, which with match ($38,971) resulted in a project total amount of $97,627. The details of the grant award are explained elsewhere (Chapter 5). Initially, the grant was awarded for a two-year period. Subsequent problems occurred when the COVID-19 pandemic interfered with Program sampling and a no-cost time extension was granted. The Program began in March 2019 and the Final Report is due December 31st, 2021.

1.7 Hypothesis, Goals and Objectives

The null hypothesis (***H_0***) being evaluated can be stated as follows: *The woodchip bioreactor will not reduce the nitrate-nitrogen concentrations that currently occur in the tertiary effluent discharged from the Bolton WWTP to existing sand infiltration beds which enters the local ground water and then impacts local tributaries discharging to Bolton Bay in Lake George (Warren County), New York.*

The goal of this Lake Champlain Sea Grant Project was to implement and conduct a thorough investigation of a woodchip bioreactor in an upstate New York to determine the feasibility of using this 'green' infrastructure technology to remove nitrate-nitrogen from wastewater treatment plant effluent which is discharged to ground water and then enters Lake George.

The original and primary objectives of this Project were to:

(1) Characterize the chemistry of the Bolton WWTP effluent, with particular emphasis on nitrate, ammonia and soluble reactive phosphorus of the effluent stream being denitrified through the bioreactor and side-by-side, the stream not being denitrified, and
(2) Monitor the improvement in ground water nitrate levels moving down-gradient from the WWTP during the study period.

As the Project entered a second year, however, additional objectives were established for this innovative 'green' technology including:

(3) Define the means and methods of characterizing the operation and efficiency of a full-scale woodchip bioreactor,
(4) Identify the causes of variable nitrate removal,
(5) Identify methods to optimize the nitrate removal efficiency of the woodchip bioreactor throughout the four seasons, and
(6) Advance collaboration with other researchers and field practitioners to further knowledge in the woodchip bioreactor field.

The cooperators involved in the Bolton WWTP Woodchip Bioreactor Project saw this situation as an opportunity to advance the science of an as yet unknown application of woodchip bioreactors for small community package treatment plants where similar high nitrate levels being discharged in effluent potentially could be an issue for receiving waters such as tributaries or lakes.

1.8 2019 to 2021 Program Description

The Program Team of Suozzo, Navitsky and Sutherland designed and implemented a comprehensive monitoring program that sampled 14 sites including the bioreactor and key locations on the Bolton WWTP property and an adjacent watershed on a 2-week basis. Further details related to the sampling program are presented in Chapter 5. A total of 642 samples were collected during the 31-month period of the Program.

1.9 Presentation of the Report

The material presented in this report describes and clarifies the variety of data collected during the 31-month Lake Champlain Sea Grant Program and also provides conclusions and recommendations. The report is organized as follows:

Chapter 1 is an Executive Summary of the 2019 to 2021 study and its findings, including conclusions and recommendations based upon an evaluation of the data collected.

Chapter 2 provides background on construction of the Bolton WWTP, a chronology of subsequent WWTP upgrades, a summary of the early 1980s RFWI scientific investigation related to the WWTP and surrounding area, a summary of the 2017 Sutherland and Navitsky report that describes the impact of the Bolton WWTP on the two (2) adjacent tributary watersheds, and a discussion of the response of the Town of Bolton to recommendations in the 2017 report.

Chapter 3 provides a brief description and discussion of the worldwide nitrogen cascade, reactive nitrogen (N_r), nitrogen and Lake George, denitrification and woodchip bioreactors, and application of denitrifying bioreactor technology to the Bolton Wastewater Treatment Plant.

Chapter 4 presents a description of the design, construction, and geographic feasibility of the Bolton Wastewater Treatment Plant woodchip bioreactor.

Chapter 5 presents a description of the 2019 to 2021 monitoring program and the methodology that was included in the program.

Chapter 6 presents a detailed description, summary and analysis of the physical and chemical data that were collected from the sampling sites associated with the Bolton WWTP woodchip bioreactor.

Chapter 7 provides a detailed summary and analysis of the Bolton Wastewater Treatment Plant performance before and during the woodchip bioreactor project including an analysis of NYSDEC State Pollution Discharge Elimination System (SPDES) permit monitoring well performance using DMR (Daily Monitoring Report) data.

Chapter 8 presents a thorough summary and analysis of Project data collected from Stewart Brook and compares the effect of the bioreactor with the results from the previous 2016 to 2017 study before the bioreactor was operational.

Chapter 9 presents a discussion about the potential use of woodchip bioreactors as treatment technology for low volume wastewater treatment in climatic conditions similar to the Bolton scenario and elsewhere and a cost estimation for nitrogen removal from wastewater using this technology

Chapter 10 presents background, a summary of the 2019 to 2021 woodchip bioreactor performance, discussion, conclusions, and recommendations.

Appendices at the end of the report contain important material referenced in the report.

1.10 Summary of 2019 to 2021 Woodchip Bioreactor Performance

The wastewater treatment efficiencies at the Bolton WWTP were described as insufficient by several recent studies (Cedarwood Engineering Services 2017, Sutherland and Navitsky 2017) and in serious need of upgrade and/or replacement to improve conditions which were contaminating the ground water beneath the region of the facility. In moving down gradient from the treatment plant, the ground water was impacting both the Mohican Road Tributary and Stewart Brook, which both flow into Bolton Bay, introducing high concentrations and loadings of nutrients which caused near-shore littoral zone water quality issues and rendered the area unusable for recreation by local residents.

As part of the Town of Bolton’s continuing initiative to optimize the Bolton WWTP operational efficiency, the Town Supervisor and Town Board authorized the installation of a woodchip bioreactor for tertiary denitrification of the wastewater effluent by establishing a Wastewater Treatment Plant Improvement Capitol Fund. A woodchip bioreactor demonstration project engineering proposal was prepared by the Town, submitted to the NYSDEC, and approved in July 2018. The FUND for Lake George awarded the Town with a grant to cover the cost of the woodchip bioreactor installation.

To our knowledge, the Bolton WWTP woodchip bioreactor is the first known application of this unit process technology for the *denitrification* of municipal wastewater effluent world-wide and the installation was evaluated under on-site field conditions while experiencing real-time, uncontrollable environmental conditions.

This report provides a summary of the 31-month investigation which was partially funded by the Town of Bolton, the Lake Champlain Sea Grant Program and The FUND for Lake George.

As previously stated in Section 1.7, the goal of this Project was to conduct a thorough investigation of a woodchip bioreactor at the Bolton WWTP to reduce nitrate-nitrogen from the final wastewater effluent prior to a groundwater discharge. The Project's Null Hypothesis ($\boldsymbol{H_O}$) being evaluated was:

> ***The woodchip bioreactor will not reduce the nitrate-nitrogen concentrations that currently occur in the tertiary effluent discharged from the BLWWTP to existing sand infiltration beds and ultimately the local groundwater.***

Based upon the results of this current study, the above-stated Null Hypothesis ($\boldsymbol{H_O}$) can be rejected in favor of the alternative hypothesis, that…... ***the woodchip bioreactor did reduce the nitrate-nitrogen***

concentrations that currently occur in the tertiary effluent discharged from the Bolton WWTP to existing sand infiltration beds and ultimately the local groundwater.

Furthermore, in addition to dis-proving the null hypothesis, the Project described herein was able to realize successful completion of all original and primary objectives as well as additional objectives that were identified as the Project entered the second year of data collection.

Project Objective (1) included characterizing and comparing the Bolton WWTP effluent with particular emphasis on the chemistry of the specific analytes in denitrified and non-denitrified portions of the effluent stream. Chapter 6, Section 6.1.3 characterizes the chemistry of the Bolton WWTP effluent, with particular emphasis on nitrate, ammonia and soluble reactive phosphorus of the effluent stream being denitrified through the bioreactor and side-by-side, the stream not denitrified.

Project Objective (2) referenced monitoring the improvement in ground water nitrate levels moving down-gradient from the Bolton WWTP upper sand disposal beds during the study period. Chapter 7 in its entirety detailed the performance of the Bolton WWTP during the period of the 2019 to 2021 woodchip bioreactor Project and also examined facility SPDES permit data extending back to 2008. The data mining back to 2008 was an effort to evaluate any trends within the plant and also in the ground water moving away from the upper sand beds which were used exclusively for plant effluent disposal when operation of the woodchip bioreactor went online. The latter sections of Chapter 7 focus on the improvements in ground water quality related to nitrate as exhibited in SPDES Monitoring Well #3 through the analysis of samples collected as part of the 2019 through 2021 monitoring program. In a similar manner, the final sections of Chapter 8 describe and identify the amount of nitrate loading to Stewart Brook that was alleviated because the woodchip bioreactor was able to reduce overall nitrate concentrations entering the ground water beneath the upper sand beds.

Project Objective (3) was to define the means and methods of characterizing the operation and efficiency of a full-scale woodchip bioreactor which was the overall emphasis of material presented in Chapter 6. And although this chapter provided extensive analysis and discussion of specific variables, it is difficult to isolate a single variable, especially in this on-site field application, where all variables must be considered at the same time.

Project Objective (4) is related to **Project Objective (3)** and the complexity of the effect of different environmental variables makes it extremely difficult, if not impossible, to separate the two (2) objectives because they are so completely interrelated. The complexity of the interaction among all of the parameters examined in this investigation is best realized when viewing the Operational Metrics Table (Table 6-3) which compares all of these variables at the same time.

Project Objective (5) involved using the 2019 to 2021 Bolton WWTP on-site investigation to identify means and methods to optimize nitrate removal efficiency of a woodchip bioreactor throughout four (4) seasons of the year in a newly constructed on-site theoretical unit processor. Once again, Chapter 6 contains a wealth of valuable information provided for future consideration in this regard including the following:

- Provide a method of continual and fairly consistent delivery of flow to the bioreactor unit utilizing gravity, a more discrete control device than an Agri Drain unit and a flow meter,
- An effluent flow meter also is a necessary monitoring device for a woodchip bioreactor in constant use,
- A variety of in-reactor monitoring wells at several locations and depths across the *influent* and *effluent* faces of the bioreactor aid in assessing conditions within the woodchip matrix and installation of several types of monitoring recorders in these wells, including level, temperature, and dissolved oxygen,
- There is the inevitable need for recharging the woodchips within the bioreactor matrix, and based upon the experience encountered with the Bolton WWTP woodchip bioreactor, an

influent "sacrificial front end" and *effluent* "sacrificial back end" sections are both design considerations for future woodchip bioreactors,

- Replacement of the permeable filter fabric surface cover of the unit processor with an impermeable membrane to prevent the biological activity observed in the demonstration project reported herein.

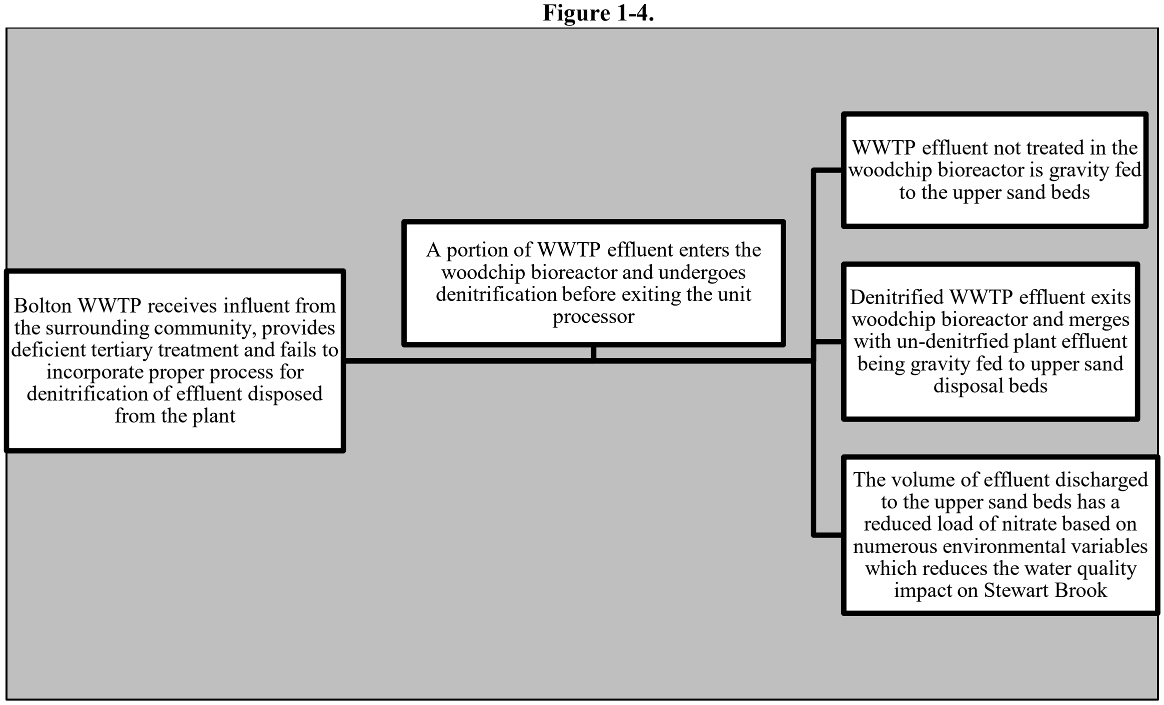
As a final consideration to adjust the current Bolton WWTP unit processor system to achieve greater nitrate removal in facility effluent on a year-round basis, the Town of Bolton, and the Town engineering consultant (KS) have designed two (2) new woodchip bioreactor units for installation at the Bolton facility during 2022.

Project Objective (6) specified advancing collaboration with other researchers and field practitioners to further knowledge in the woodchip bioreactor field. In this regard, there were numerous examples of Project outreach to Dr. Laura Christianson and collaborators at SUNY Stony Brook to discuss intricacies of the Bolton WWTP woodchip bioreactor and determine whether the experience of others conducting research in the bioreactor field could aid us with certain decisions and also facilitate improvements on the system under investigation.

As detailed above, the investigation and evaluation of the Bolton WWTP woodchip bioreactor (1) disproved the Null Hypothesis stated at the onset of the Project, (2) satisfactorily fulfilled all of the Project Objectives stated in the original conceptual proposal, and (3) realized completion of additional established objectives for this "green" technology subsequent to the start of the Project.

The conceptual diagram in Figure 1-4 defines the linkage between Bolton WWTP plant effluent and eventual water quality impacts on the Stewart Brook when the installed "green technology" woodchip bioreactor is processing some portion of the total daily effluent volume released from the facility.

Figure 1-4.



1.11 Conclusions

The following conclusions have been formulated following careful consideration of the data collected and the results received during the recently completed 31-month study of the woodchip bioreactor installed at the Bolton WWTP.

(1) The investigation reported herein provided compelling evidence that the woodchip bioreactor was capable of reducing the nitrate-nitrogen concentrations that occurred in the tertiary effluent discharged from the Bolton WWTP by about 38 percent, which decreased from the beginning of the study when compared with tertiary effluent that was untreated following discharge from the treatment facility and disposal to the upper sand beds

(2) While the reduction in nitrate-nitrogen was shown throughout the duration of this demonstration project, the variability of removal depends upon a myriad of environmental factors including the concentration of influent nitrate, the temperature of the wastewater, the measure of dissolved oxygen in the wastewater as it traverses the woodchip matrix, the retention time of the wastewater within the bioreactor, the availability of a carbon source for the denitrifying bacteria, wastewater pH, and the flow characteristics of the wastewater through the woodchip matrix.

(3) This "green technology" would perform in a similar effective and efficient manner in geographical and environmental situations comparable to Bolton Landing, a small community package plant, on the west side of Lake George (New York) in the northeastern United States with more effective nitrate removal during the summer months and less effective nitrate removal during the winter months.

(4) The key to successful operation of this "green technology" regardless of the geographical location is the interest and dedication of the wastewater plant operator(s) who are required to pay attention to system details on a daily, if not hourly, basis and use their knowledge to fine tune the system when necessary. The success of the Bolton WWTP demonstration project rested on the shoulders of Plant Operators Matt Coon and Justin Persons, while Kathleen Suozzo always was available and "on call" for technical assistance.

(5) Wastewater *denitrification* through this passive environmentally compatible technology continues to move beyond concept into actual full-scale field applications. Future installations will benefit from the lessons already learned at the Bolton WWTP woodchip bioreactor facility, with additional bioreactor units there providing additional treatment capacity, further options for process optimization, and continued learning opportunities.

(6) The installation and operation of the woodchip bioreactor in the region of the upper sand disposal beds had a significant effect on reducing the nitrate load to Stewart Brook through ground water moving down gradient from the disposal area.

1.12 Recommendations

The following recommendations have been developed after careful consideration of the water quality data collected during the current 31-month study reported herein. These recommendations are not presented in any particular order of importance except for the first recommendation which acknowledges that facility upgrades are required and essential to the future of development in the Bolton community in order to maintain stewardship with regard to the water quality of Lake George.

(1) The Town of Bolton, WWTP operations staff and the Town's engineering consultant (KS) should move forward with excavation of the plugged woodchips from the existing bioreactor and get the unit up and running as soon as possible.

(2) The Town of Bolton, WWTP operations staff and the Town's engineering consultant (KS) should move forward with installation of two (2) new woodchip bioreactor units with engineering improvements in the area of the upper sand beds and adjacent to the existing unit so that virtually all of the daily flow through the plant can be treated by this "green technology".

(3) According to the most recent 2021 Lake Champlain Basin Program (LCBP) State of the Lake Report, six (6) percent and 38 percent of the phosphorus load to Lake Champlain is generated by WWTPs and agriculture, respectively. In reviewing a series of recent technical reports dealing with Lake Champlain, it became clear that there is little, if any, data available on nitrate-nitrogen from these sources; most of the nitrogen data was reported bas TN (total nitrogen). We strongly advise the LCBP to investigate the nature of the nitrate problem in the drainage basin because it probably is a bigger issue than currently understood based upon a lack of appropriate nitrogen data collected.

(4) The Town of Bolton may want to consider providing an updated and more robust "Sewer Use Ordinance" to protect the existing infrastructure from wastewater characteristics that could upset plant operation. With the continual growth of the Bolton community, more stress is being put on the existing collection system and treatment system, which is 60 years old. Pretreatment standards for various wastewater constituents (i.e., organic loadings, pH ranges, oil and grease concentrations, inhibitory compounds), and routine monitoring of dischargers would benefit the operation of the Bolton WWTP.

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2019 to 2021 Lake Champlain Sea Grant Program

A Monitoring Program to Evaluate the Efficacy of a Woodchip Bioreactor Installed at the Bolton Wastewater Treatment Plant, Lake George (Warren County), New York

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Final Report

Chapter 2

Historical Information and the Town of Bolton Wastewater Treatment Plant

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2.0 Background

Lake George is the largest body of water located entirely within the Adirondack Park in New York State. Historically, it has been called the "Queen of American Lakes" for its clear waters and inherent natural beauty, and the lake has been a popular tourist attraction since the late 1800s (West et al 2001). Lake George and its surrounding drainage basin are included in the Lake Champlain drainage basin. The two bodies of water are connected via the La Chute River, the Lake George outlet at the north end.

Local concern for the preservation of water quality in Lake George has existed for many decades, and the lake was classified as "AA Special" (Class AA-S) meaning (1) that water taken from the lake could be used as a public drinking water supply following treatment with chlorine and (2) that there shall be no discharge or disposal of sewage, industrial wastes or other wastes into these waters or into streams discharging to the lake (6 NYCRR 701.3(c)).

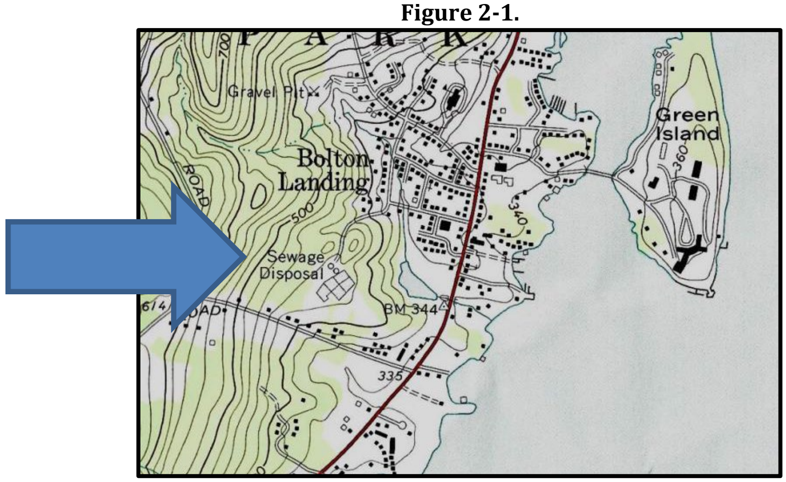
2.1 Construction of the Facility

In view of the strict discharge regulations to Lake George and in consideration of the growing population of areas along the shoreline, the Bolton Landing Sewer District was formed to serve the hamlet of Bolton Landing and Green Island in 1959, and the treatment plant was constructed in between 1959 and 1961 (Alpha Geoscience 2004). The regulation restricting the discharge of wastewater into the drainage basin of Lake George was interpreted to mean surface discharges, and the only alternatives for final effluent disposal were discharge into the ground or diversion outside the Lake George basin. For many local residents, this interpretation allowed the use of septic tanks with absorption fields for sewage treatment.

The Lake George basin is underlain by rock consisting of pre-Cambrian gneisses with valleys comprised of lower Paleozoic strata (Aulenbach et al. 1975). A few areas, however, contain natural delta sand deposits created by outwash from receding glaciers. The Town of Bolton Wastewater Treatment Plant (Bolton WWTP) was constructed on a series of delta outwash plateaus above Lake George on the west side of the basin, similar to the Village of Lake George Wastewater Treatment Plant located at the extreme southwest corner of the basin. Both facilities utilize sand beds as infiltration areas for treated wastewater effluent (Aulenbach and Fillip 1983).

The Bolton WWTP is located in the Town of Bolton, Warren County, New York, and appears on the United State Geological Survey (USGS) 15-minute quadrangle map, *Bolton Landing, New York* (Figure 2-1).

Figure 2-1.



The facility is located on map parcel #171.19-1-5 (Warren County Community Map) identified as the Bolton Sewer District, which has a surface area of 15.4 acres. There is an adjoining parcel to the north and west, lot 171.19-1-3 (Bolton Sewer District), with a surface area of 5.95 acres. The operational portion of the treatment facility is located on map parcel 171.19-1-5. The facility is bordered on all sides by residential properties.

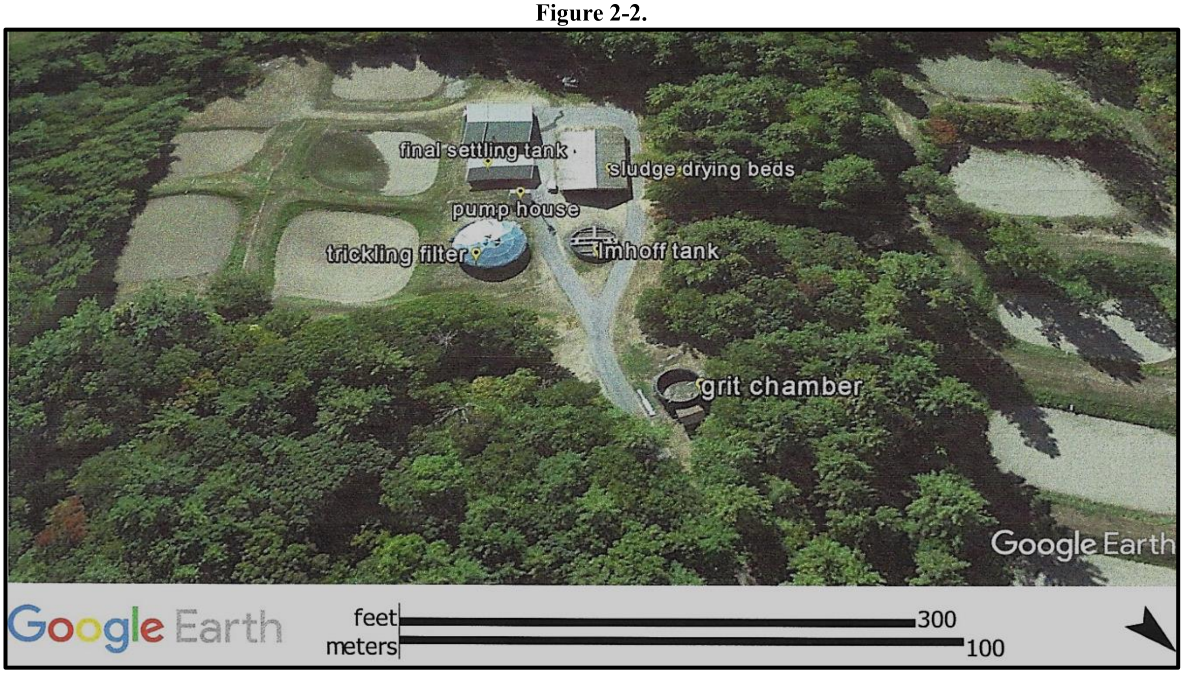
2.2 Plant Design and Operation

The original design of the wastewater treatment plant was summarized in detail by Aulenbach and Fillip (1983), and much of the information presented below was obtained from that source.

The Bolton WWTP was constructed during 1959 to 1960 with a design flow of 1,136 m^3 (cubic meters) per day (0.3 million gallons per day [mgd]). At that time, the collection system consisted of ~4,877 meters (m) (16,000 feet [ft]) of 20.3-centimeter (cm) (8 inch) and 1,524 m (5,000 ft) of 25.4 cm (10 inch) asbestos cement and vitrified clay pipe. The sewage flowed by gravity to one of two pumping stations from which it was pumped through a 25.4 cm (10 inch) ductile iron force main to the treatment plant.

The Bolton WWTP consists of a manually cleaned grit chamber controlled by a 15.24 cm (6 inch) throat Parshall flume which also measures the flow (Figure 2-2). The sewage then flows by gravity to the upper compartment of a 10.9 m (36 ft) diameter circular Imhoff tank where primary settling takes place; the Imhoff tank also takes reject water from the tertiary sand filters (circa 2001).

Figure 2-2.



The primary effluent is fed to a 16.7 m (55 ft) diameter rotary distributor trickling filter and then to a mechanically cleaned rectangular final settling tank. The unchlorinated plant effluent is discharged to sand filter beds on site. Digestion of the primary and return secondary sludge is accomplished in the lower chamber of the Imhoff tank.

The Bolton WWTP uses a rapid infiltration system for land treatment by flooding a basin or shallow pond with effluent. The basins must be nearly level to achieve a uniform depth of effluent which then dissipates by infiltration into the soil. The effluent in the soil is modified by physical, chemical, and biological processes and eventually reaches the ground water.

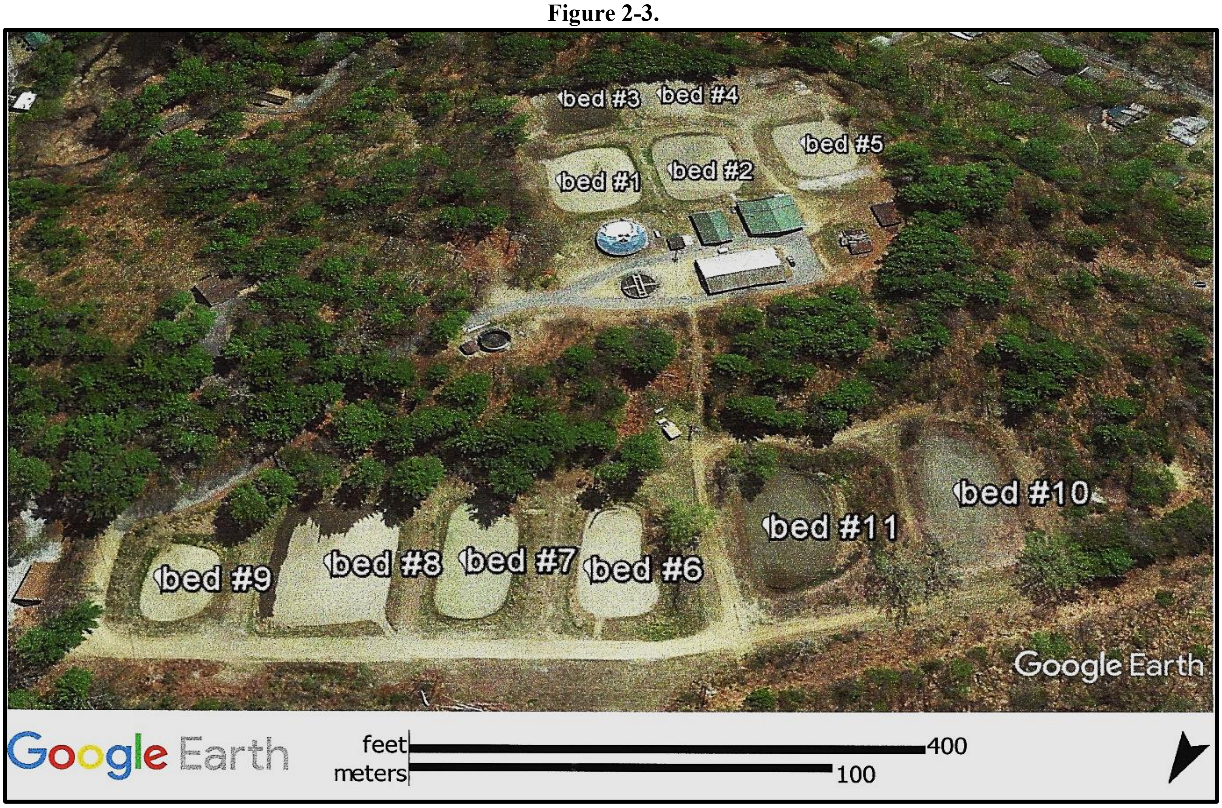
The original design of the treatment plant consisted of five sand infiltration beds constructed directly southeast and down-gradient of the facility, which included four main beds of about the same dimension (36.3 x 39.6 m; 119 x 130 ft) and a reserve bed (33.5 x 39.6 m; 110 x 130 ft). These beds were referred to as the "lower" sand beds and had a combined surface area of 7,077 m^2 (76,180 ft^2).

The lower sand beds were constructed by grading the existing sand and gravel and bringing in additional sand as required. The depth to bedrock of these beds was reported as 0.6 to 2.4 m (2 to 8 ft) by Aulenbach and Fillip (1983).

In 1965, four new beds (#6 to #9) were constructed directly northwest and up-gradient of the treatment plant and were referred to as the "upper" sand beds. These four beds varied in size but provided a total surface area of 3,450 m^2 (37,125 ft^2). Subsequently, two additional upper sand beds (#10 and #11) were constructed in 1984 (Cedarwood Engineering Services 2016), bringing the total number to six upper sand beds. The upper sand beds were constructed on a natural sand deposit that was reported (Aulenbach and Fillip 1983) to be as much as 20 m (65 ft) deep.

The relationship of the ***lower*** and ***upper*** sand beds to each other and to the layout of the Bolton WWTP is shown in Figure 2-3. The beds are numbered according to the current system of identification used by the treatment plant operator. It should be noted here that there are discrepancies in the bed numbering system that have occurred during the past several decades of operation, beginning with the study conducted by Aulenbach and Fillip (1983).

Figure 2-3.

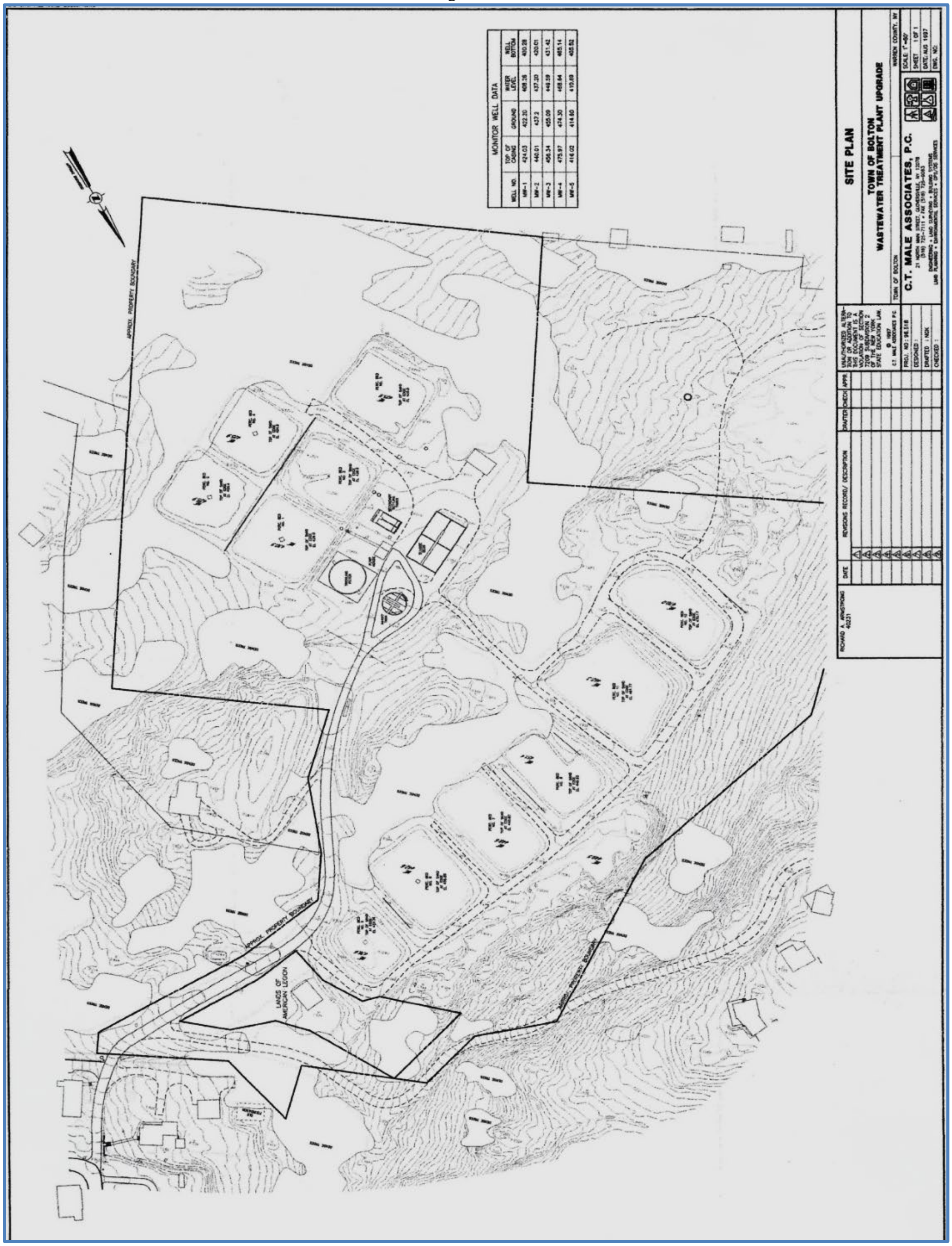


Sand beds #1 and #3 are dosed with effluent through a center-feed discharge device consisting of an upright 20.3 cm (8 inch) PVC pipe surrounded by a 1.2 m (4 ft) square concrete splash pad. The other lower beds are dosed through a pipe that enters one side of the bed. All plant effluent is dosed to a single bed at a time and the bed dosing sequence is random, chosen by the operator, and recorded in a daily logbook.

The ***lower*** sand beds are below the elevation of the main complex of the Bolton WWTP and are dosed via gravity feed. The ***upper*** sand beds are approximately 5.5 m (18 ft) higher in elevation than the effluent from the secondary clarifier and the effluent is pumped to these beds through a 20.3 cm (8 inch) PVC pipe. Although this line is buried below ground level, there is the potential for freezing during the winter and so the ***lower*** sand beds were used exclusively during cold weather until just recently (March 2019).

Figure 2-4 is a schematic of the existing conditions of major components of the Bolton WWTP.

Figure 2-4.



2.3 Chronology of Wastewater Treatment Plant Upgrades

The following material was taken from several different sources including

(1) the Aulenbach and Fillip (1983) report, which was a detailed study of the Bolton WWTP conducted under the auspices of the Rensselaer Fresh Water Institute,
(2) A January 27th, 1986, letter report from C.T. Male Associates, P.C. addressed to William Lamy, NYSDEC Region 5, Warrensburg, which provides details concerning ground water monitoring well locations for the Bolton WWTP,
(3) An August 14th, 1997, letter report from C.T. Male Associates, P.C. addressed to William Lamy, P.E., Sewer Administrator for the Warren County Department of Public Works, Warrensburg, which provides information and cost estimates related to rehabilitation of the existing leaching beds at the Bolton WWTP,
(4) A February 25th, 2004, hydrogeological evaluation by Alpha Geoscience of the Smith-Donahue property located at 38 Mohican Road, and
(5) The 2017 report of engineering review analysis prepared by Cedarwood Engineering LLC for the Town of Bolton, funded through the NYSDEC Environmental Facilities Corporation (EFC) Wastewater Infrastructure Engineering Planning Grant program. This funding program supports projects which will lead to the restoration or protection of a surface waterbody through identified improvements to a publicly owned wastewater treatment facility.
(6) Improvements completed at the WWTP since the 2017 engineering review analysis mentioned in (5) above and provided by Kathleen Suozzo P.E., PLLC and Matt Coon, Chief Operator, Bolton WWTP.

While the material presented in this section may not be complete, it does represent the most comprehensive source of information at the present time.

- Late 1950s – Bolton Landing Sewer District formed to serve the Hamlet of Bolton Landing,
- 1959-1961 – Bolton Landing Wastewater Treatment Plant was constructed with a design flow of 1,136 m^3 per day (0.3 mgd) and included a grit chamber, Imhoff tank, trickling filter, secondary clarifiers, and the five (5) lower sand infiltration beds (#1 -#5),
- 1973 – four (4) additional infiltration beds (#6-#9) constructed above the main treatment plant,
- 1984 – two (2) additional sand infiltration beds (#10-#11) adjacent and to the south of the sand beds added in 1973,
- 1995-1997 – the Town of Bolton rehabilitated three (3) lower sand infiltration beds,
- 1997 – an alum feed system was installed to provide effluent phosphorus removal through the secondary clarifiers in an effort to reduce the concentration of total phosphorus going to the sand infiltration basins,
- 2001 – Bolton WWTP received process improvements including an influent flow surge tank, tertiary filters, a new control building, and rehabilitation of eight (8) remaining sand beds,
- 2011 - new metal dome over the TF and change in TF media from stone to crossflow plastic media for enhanced biological treatment of wastewater,
- 2018 - new sludge pumps, piping, valves, air compressor, and controls for improved sludge handling from the secondary clarifiers,
- 2018 - new diffusers and piping in the EQ tank, which provided for improved mixing and aeration of influent wastewater; this project was completed with Town staff.
- 2018 - new instrumentation at the EQ tank; this new instrumentation allowed for greater flow control through the EQ tank, which protects downstream unit processes.
- 2018 - new chemicals were trialed and selected for use for phosphorus sequestering in the final effluent; Slack Plus, a multi-purpose polyaluminum chloride blend is the chemical in use.
- 2018 - a permanent soda ash feed system was installed by operations staff; the soda ash is dosed to the final effluent to maintain the pH within permit limits.

- 2018 - new instrumentation was installed at the Town's Main Pump Station which provided for remote communications between operations staff and the pumps at the pump station.
- 2018 - new isolation valves at the Main Pump Station which allows isolation of the various pumps at the station and facilitates alternating those pumps as needed to maintain proper levels in the wet well.
- 2018 - installation of the woodchip bioreactor for effluent denitrification which was funded by the Town and a grant from The FUND for Lake George.
- 2019 - new pump and controls for the upper sand infiltration bed pump system; this new pump services the woodchip bioreactor year-round.
- 2019 - new sewer jet power washer to maintain integrity and cleanliness of sewer mains within the collection system.

A copy of the current NYSDEC SPDES Permit #NY0093688 is provided in Attachment 1.

2.4 Scientific Investigations of the Bolton Wastewater Treatment Plant

The construction of the Adirondack Northway, Interstate 87, from Albany northward in the 1960's greatly facilitated travel to the Lake George region and resulted in a surge in area tourism and recreation starting in the late 1960s. The high rate and concentration of development along the southwest and west shores of the lake from Lake George Village to the Town of Bolton during the 1970s and 1980s, resulted in some environmental problems, including increased rates of contaminated runoff in streams that drained developed areas (Sutherland et al. 1983).

As the regional tourism industry rapidly grew, so did concern for Lake George water quality, and the awareness that treatment plants in the basin potentially could contribute nutrients to the lake, raising concern about the quality of ground water influenced by these facilities (Aulenbach et al. 1974). The primary options for any in-basin treatment plant were either the effective removal of nutrients in the wastewater prior to discharge to the sand beds or, alternatively, the diversion of wastewater out of the basin if the plant was not able to operate efficiently.

2.4.1 Rensselaer Fresh Water Institute

An early 1980s study by Aulenbach and Fillip (1983) included an extensive sampling program that was conducted at the Bolton WWTP. Because there is no mention of the specific year of the study, the date only can be estimated. Even now, the early study by these RFWI scientists remains the most comprehensive scientific investigation conducted at the Bolton WWTP.

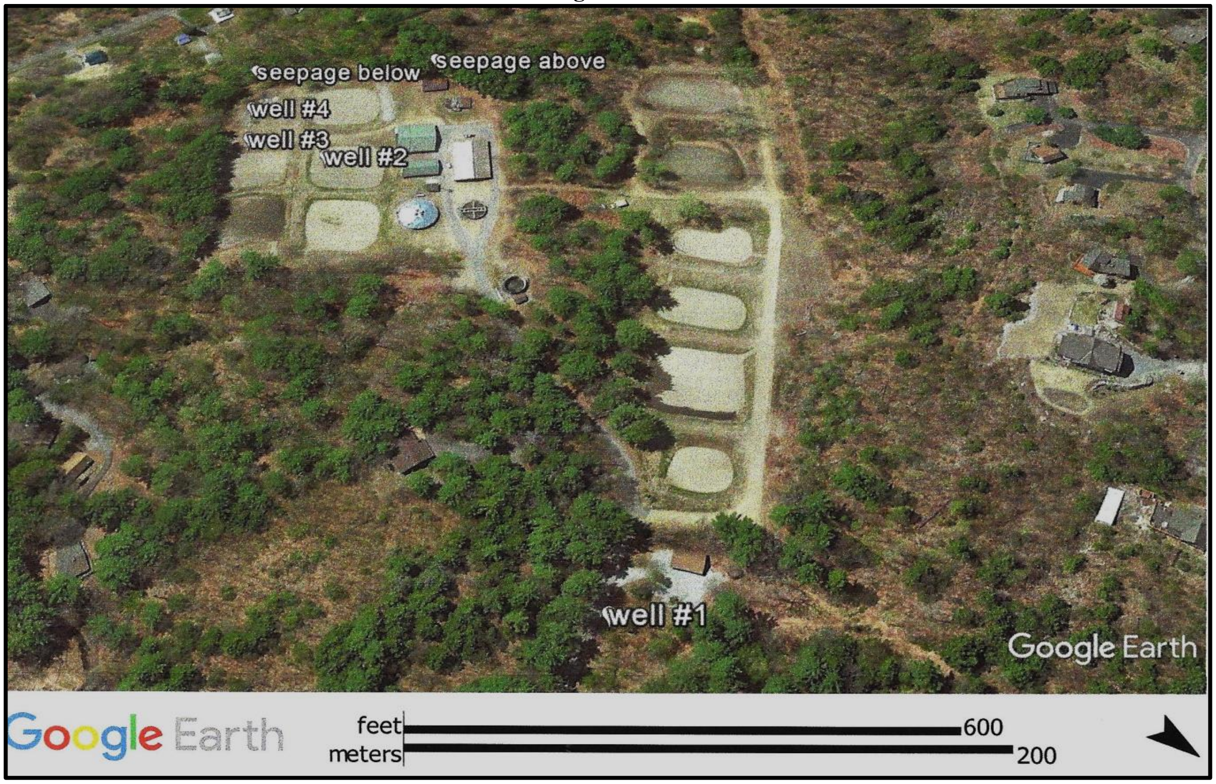
Background. The RFWI study was conducted prior to the installation of the SPDES permit monitoring wells at the treatment plant and the scientists installed a series of driven well points and screens so that the ground water adjacent to the sand beds could be sampled (Figure 2-5).

There were five (5) ground water wells installed, including well #1, located down-gradient of the upper sand beds, and wells #2, #3, #4A and #4B, which were installed in the lower sand bed region to collect ground water samples and trace the subsurface flow of effluent as it moved from the lower beds in a down-gradient direction. Wells #4A and #4B were installed at 5.5 and 13.5 ft below ground surface, respectively, to sample both shallow and deep ground water movement from the sand beds.

Also shown in Figure 2-5 are the locations of 'seepages' (Aulenbach and Fillip's description) adjacent to the Bolton WWTP that were sampled. The seepages were further described in the 1983 report as an 'open ditch' constructed by treatment plant personnel to "divert run-off in this area from heading toward homes along Mohican Road".

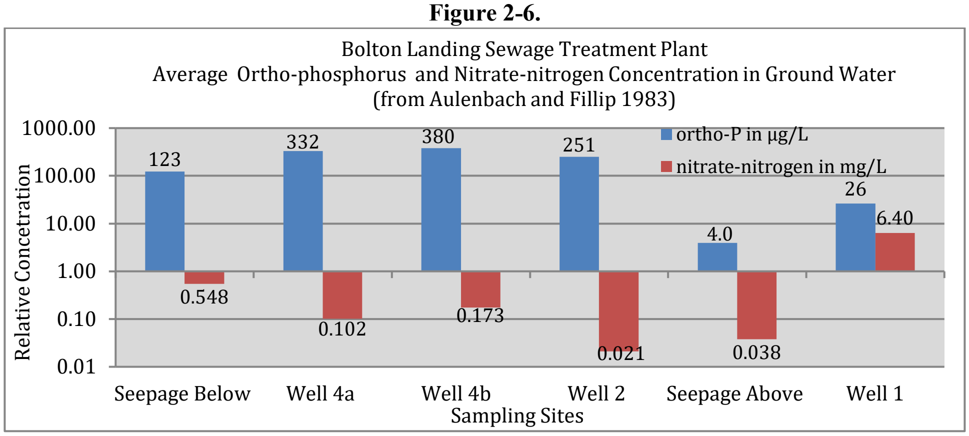
The seepages above and below the plant (Figure 2-5) were sampled when flow was observed. And, finally, a Rhodamine-WT dye study conducted on the upper sand beds, which is described and discussed later in this chapter.

Figure 2-5.



Nutrients. For purposes of the current report, the RFWI data collected from the Bolton WWTP monitoring wells and the two (2) seepages south of the treatment plant have been summarized in Figure 2-6 which presents their results for ortho-phosphorus and nitrate-nitrogen analysis.

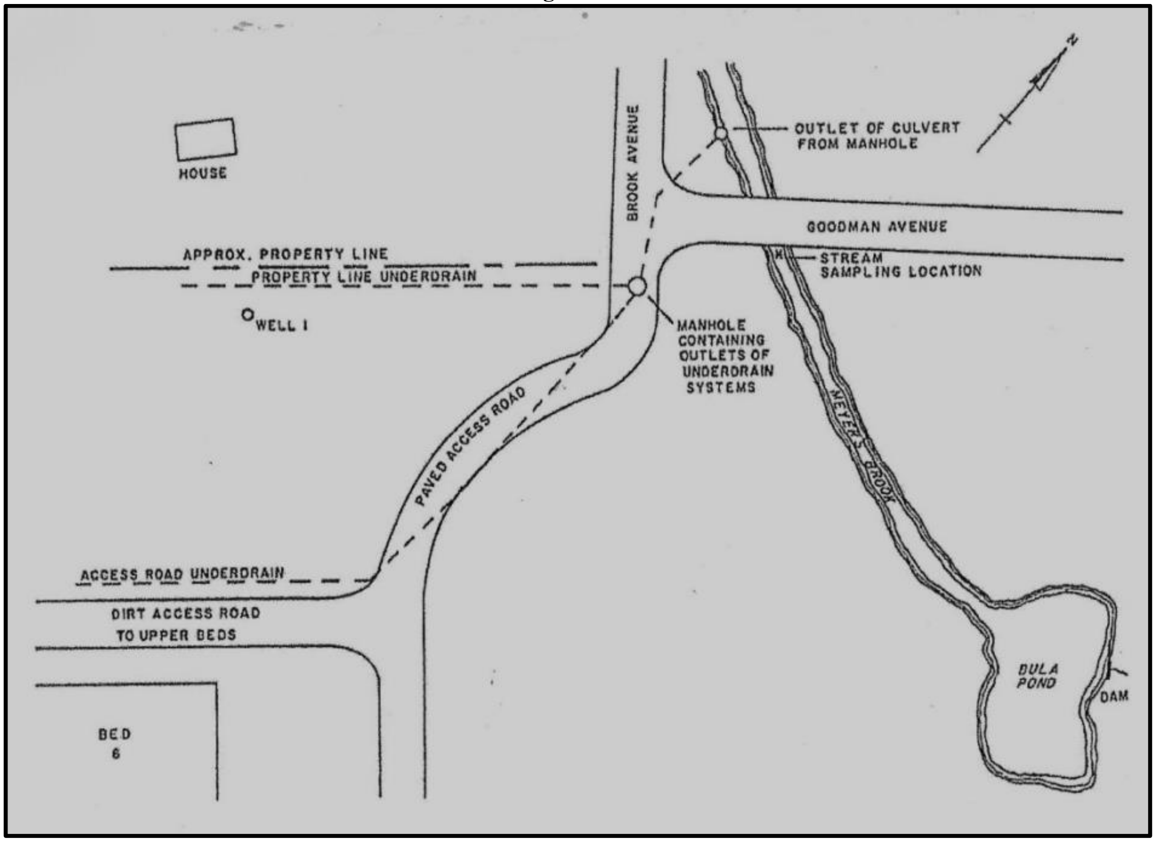
Figure 2-6.



The ***y**-axis* on the above figure is presented in logarithm scale to display the full range and relative magnitude of the various concentrations reported.

Rhodamine-WT dye study. A ground water tracer study was conducted on the upper sand beds to define the direction of flow from this area. The dye was added to bed #7 (actually bed #8 according to the present numbering system) and samples were collected from a series of stations (Figure 2-7) including (1) Monitoring Well #1, (2) the outlet of the property line underdrain at the catch basin, (3) the outlet of the access road underdrain in the catch basin, (4) the outlet of the drain as it empties into Stewart Brook, (5) Stewart Brook, just south of Goodman Avenue, and (6) the outlet of Stewart Pond as it flows over the dam. At the time of the tracer study, plant effluent had been added to Bed #8 for the previous 3 weeks and continued to receive effluent during the period of the dye study.

Figure 2-7.



The dye was added to Bed #8 on May 25th and was detected on May 30th at (1) the outlet of the property line underdrain, (2) the outlet of the culvert that drains into Stewart Brook, and (3) in Stewart Brook. The dye was detected at the Stewart Pond dam/spillway on June 2nd. No dye was detected in Monitoring Well #1 or the access road underdrain.

2.4.2 Alpha Geoscience

The late Paul F. Donahue, Sr., Esq., a resident at 38 Mohican Drive, located to the south and down-gradient of the Bolton WWTP, experienced considerable ‘wet’ problems on his property and accumulated an extensive file of documents and communications with the Town of Bolton concerning the matter (dating to the 1960s) in an effort to resolve the problem. Mr. Donahue described the problem as originating after construction of the Bolton WWTP when plant effluent was discharged to the lower sand beds for disposal.

The problem of emerging ground water (seepage) subsequently was documented for Mr. Donahue by Alpha Geoscience in a 2004 report of a hydrogeological evaluation of the area north and west of his property toward the WWTP. The report acknowledged that concurrent with operation of the Bolton WWTP in 1960 was the addition of large quantities of effluent to the lower disposal sand beds, resulting in ‘extra’ ground water leaving the area which had not previously been a factor. The well-drained characteristics of the area contributed to the emerging ground water and seepage problems.

2.4.3 The Lake George Waterkeeper and The FUND for Lake George

We now ‘fast forward’ to water quality issues that occurred over an extended period in Bolton Bay during the early-to-mid 2010s, particularly in the littoral zone and shoreline adjacent to the Bixby Estate which is shown in Figure 2-8 ( ). The beach along this section of shoreline was unusable for recreational purposes due to nuisance algal growth attached to submerged aquatic plants or floating above the sand (Keppler et al. 2008).

Figure 2-8.

As shown in the figure above, Stewart Brook enters Bolton Bay just north of the Bixby property and Mohican Road Tributary forms the south boundary of the property as it flows into Bolton Bay.

Background. The Bolton Bay water quality issues along with confusing and contrasting information about whether the Bolton WWTP was operating within performance requirements designated through the SPDES permit testing program provided the incentive for the design of a ground water and tributary monitoring work-plan and study. The study design included tracking certain WWTP operations and extensive field sampling to determine the sub-surface direction and extent of ground water flow from the Bolton WWTP, particularly from the region of the lower sand beds. The study was initiated during April 2016, continued through May 2017, with results detailed in a final report (Sutherland and Navitsky 2017).

Ground water movement. Sutherland and Navitsky determined that treatment efficiencies at the Bolton WWTP were inadequate, and that discharged effluent enters ground water leaving the area and ultimately impacts Stewart Brook and another watershed, Mohican Road Tributary, located to the south and down-gradient of the treatment plant. Although present at the time of the Aulenbach and Filip study, the Mohican Road Tributary was not described in the 1983 report. There was, however, earlier documentation of the tributary by Fuhs (1972), when he acknowledged that the tributary is a "*trickle which must be considered mostly seepage from the irrigation field of the Bolton Landing sewage treatment plant…..*".

As it turns out, the specific sand beds used for effluent disposal at the Bolton WWTP determine which watershed is affected by ground water moving down-gradient and away from the facility. As shown in Figure 2-9 below, and as determined by Aulenbach and Filip (1983), effluent discharged to the upper sand disposal beds moves with the ground water toward Stewart Brook.

As for the lower sand disposal beds, effluent discharged to beds #1 and #3 moves with the ground water toward Stewart Pond (Figure 2-9; direction of large yellow arrow), while effluent discharged into beds #2, #4, and #5 moves toward the Mohican Road Tributary (Sutherland and Navitsky 2017). And while Aulenbach and Filip (1983) had explained this same ground water movement due to a rock ledge that separated the lower sand beds, the Sutherland and Navitsky study provided conclusive evidence that the lower sand beds are connected hydraulically to the Mohican Road Tributary and Stewart Brook watersheds with a dye study. Rhodamine-WT dye applied to lower sand beds #2 or #4 appeared at the lower Mohican Road seepage area within 2 days from addition of the dye. A similar experiment in lower beds #1 and #3 was detected in the channel of a culvert that drains to Stewart Pond within 6 hours of dye addition.

Figure 2-9.

Nutrients. The 2017 report issued by Sutherland and Navitsky revealed that excessive amounts of NO_3-N and SRP had been problematic in the Mohican Road Tributary for decades, extending back to at least the time when Fuhs conducted his 1970 to 1971 study. The problem was caused by ground water movement from the lower beds following effluent discharge, and the authors initially estimated that 74.5 tons of NO_3-N and 326 lbs. of SRP had entered Bolton Bay via this tributary since the early 1970s. These estimates recently were revised to 60 tons of NO_3-N and 261.5 lbs. of SRP following correction of an error in the data (Sutherland et al. 2020).

Sutherland and Navitsky (2017) also described nutrient loading issues to Bolton Bay via Stewart Brook which receives ground water moving down-gradient from the upper sand disposal beds at the Bolton WWTP. These Stewart Brook results will be described in a later chapter of this report.

2.5 Impact of the Wastewater Treatment Plant on Adjacent Tributary Watersheds

The 1983 report issued by RFWI scientists contains an abundance of scientific information that helped to characterize the Bolton WWTP during its early history and its operating efficiency during that same time period. They reported the movement of effluent discharged to the lower sand beds in different directions but were unable to prove that movement conclusively. They also noted a bedrock outcropping between the location of the original treatment plant and the upper sand beds and surmised that this feature of the landscape affected the flow path of ground water from the upper sand beds to move in a northeast direction, toward Stewart Brook, which they subsequently proved with the Rhodamine dye study described earlier.

The Rhodamine-WT dye study described in the 1983 report provided valuable information on the time of travel for ground water moving down-gradient from the upper sand beds toward Stewart Brook. It took the tracer dye 5 days to reach the culvert outfall to the brook which is a total distance of ~800 feet from the center of the bed; a simple calculation shows that the ground water with dye moved about 160 feet per day following application to the bed.

The authors (Aulenbach and Fillip 1983) concluded from their study that the Bolton WWTP had little to no significant impact upon the quality of Lake George. They recommend that the upper sand beds be used as much as possible in the treatment regimen since these beds achieve much greater treatment efficiency, particularly with regard to phosphorus removal.

The authors of the more recent study (Sutherland and Navitsky 2017) do not agree with the conclusions presented by Aulenbach and Fillip in their 1983 report because they appear to be ignoring several implications of the nutrient data and ground water movement that they described so well during their investigation, including the following:

(1) Their dye tracer study demonstrated that effluent discharged to the upper sand beds enters the ground water and moves southeast and enters Stewart Brook within a matter of days. And even though the average nitrate-nitrogen measured in the well associated with the upper beds was high, they discount the fact that this nutrient is directly transported to the stream and then to Lake George. Instead, they appear to have decided that denitrification occurred during the travel time from the monitoring well to Stewart Brook which would reverse any impact of available nutrient having entered the stream. Unfortunately, there was no sampling conducted in Stewart Brook to determine the impacts of ground water from the treatment plant on stream water quality.

(2) Regrettably, the RFWI scientists restricted their experimental vision to the boundaries of the treatment plant and did not investigate the consequences of the seepage areas south and west of the property. Back then, even cursory investigation would have revealed the Mohican Road Tributary, which is the culmination of all seepages originating at higher elevations along the north and south side of Mohican Road. Furthermore, the tributary was well-known prior to the early 1980s study. In fact, a study conducted in 1970 to 1971 by Fuhs (1972) sampled the Mohican Road Tributary during a 13-month period and attributed water quality problems directly to the Bolton WWTP.

2.6 Discussion.

The good news to report here is that following release of the 2017 report that identified issues at the Bolton WWTP, the Town decided to stop using the lower sand disposal beds except during periods of emergency when the upper sand disposal beds could be not used. Thus, all plant effluent would be discharged to the upper sand disposal beds to relieve water quality impacts that resulted from disposal to the lower sand disposal beds, primarily affecting Mohican Road residents.

Bolton WWTP personnel pumped effluent exclusively to the **upper** sand beds from August 1st, 2017, through December 30th, 2017, when the effluent pump malfunctioned, and effluent had to be discharged to **lower** sand beds #1 and #3. Pump replacement and re-wiring was completed on April 18th, 2018; effluent disposal to the **upper** sand beds was initiated on that date and continued until April 30th, 2019, when disposal of effluent to all **upper** sand beds was taken offline due to downstream process and pump station limitations, i.e., the Bolton WWTP was experiencing heavy snow melt, precipitation, and high ground water. The high influent flow subsided within two weeks, and effluent disposal to the **lower** sand beds was discontinued (mid-May 2019).

The response at the Lower Mohican Road Seepage (LMRS) sampling site to the termination of Bolton WWTP effluent disposal to **lower** sand beds #2 and #4 during 2017 was significant and continues to be realized at the present time. The residents at 38 Mohican Road reported an abrupt decline of 'wet' conditions surrounding their property and were able to maintain portions of their lawn during the 2017 and 2018 growing seasons that had not been possible during the past several decades following construction of the wastewater facility.

2.7 Conclusions

Although the impact of the Bolton WWTP on the water quality of Lake George was suspected for some time, recent studies elucidated the exact nature of the impact as excessive nutrients being discharged in plant effluent to the sand disposal beds. The effluent high in nitrate-nitrogen and soluble reactive phosphorus enters the ground water and then moves down-gradient into the Mohican Road Tributary and Stewart Brook watersheds depending upon which sand beds are used for disposal. Both tributaries flow into Bolton Bay where there have been nuisance aquatic algae and attached vegetation issues for many years. The termination of effluent disposal to the lower sand beds by the Town of Bolton relieved some long-term "wet" problems down-gradient of the facility and improved the water quality of the Mohican Road Tributary with respect to nutrient loading. The next priority in terms of water quality improvement should be the reduction of high nitrate-nitrogen concentrations in the effluent disposed to the upper sand beds.

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A Monitoring Program to Evaluate the Efficacy of a Woodchip Bioreactor Installed at the Bolton Wastewater Treatment Plant, Lake George (Warren County), New York

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Final Report

Chapter 3

The Nitrogen Cascade, Reactive Nitrogen and Lake George, Potential Solutions

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3.0 Nitrogen

Carbon (C), oxygen (O), nitrogen (N), phosphorus (P), and sulfur (S) are the elements required for life and, except for nitrogen, generally are available on a global scale to sustain forms of life from single-celled organisms to higher vertebrates. Paradoxically, while N has the greatest total abundance of all these elements in the planet's reservoirs, it also is the element least readily available to sustain life. This is because almost all available N is in the form of molecular nitrogen (N_2), a triple chemical bond that is not easily broken and usable by most organisms (Galloway et al. 2003).

Compounds of N in nature are categorized as nonreactive and reactive. N_2 is non-reactive and requires significant energy to break the bond through either high temperature or a small group of specialized N-fixing microbes. Reactive N (Nr) comprises all active N compounds in the Earth's atmosphere and biosphere including

- Inorganic reduced forms of N such as ammonia [NH_3], ammonium [NH_4^+],
- Inorganic oxidized forms of N such as nitrogen oxide [N_2O], nitric acid [HNO_3], nitrous oxide [N_2O], and nitrate [NO_3^-], and
- Organic compounds such as proteins, amines, urea, and nucleic acids.

3.1 The Nitrogen Cascade

In the face of world-wide efforts to feed a burgeoning population in the 20th and 21st century through the application of fertilizers and increased cultivation of land, the anthropogenic production of food and energy has become the dominant process that breaks the triple bond in N_2, creating Nr that disseminates in the Earth's atmosphere, hydrosphere and biosphere with an assortment of consequences, which are magnified over time as Nr moves through the biogeochemical pathway. The same Nr atom can cause multiple effects in atmospheric, terrestrial, freshwater, and marine ecosystems as well as on human health. Galloway et al. (2003) have termed this sequence of Nr geochemical effects as the *nitrogen cascade*. As the cascade progresses, the origin of Nr becomes unimportant and Nr does not cascade at the same rate through the various environmental systems. Some systems can accumulate Nr which cause lag times in the remainder of the cascade, slowing down the process. The accumulation of Nr in certain reservoirs can enhance the effect of Nr in that particular system. The only way to eliminate Nr accumulation is to convert Nr back to N_2 (Galloway et al. 2003).

3.2 Nitrogen and Water Quality

Introductions of excess Nr in aquatic ecosystems can be particularly dangerous, stimulating eutrophication and acidification. The following material discusses the process of eutrophication because the topic of this report, Lake George, currently is not susceptible to acidification.

3.2.1 Eutrophication.

In marine and freshwater systems, this is a process defined as an increase in the rate of supply of organic matter and the contemporaneous increases in primary production in these ecosystems (Nixon 1995). And while eutrophication is not necessarily problematic because nutrients are required for growth and reproduction in aquatic systems, it does become an issue when excessive nutrients are discharged to a receiving environment.

Primary production in aquatic ecosystems is facilitated by the nutrients N and P, one or both of which usually are in a limiting supply. However, in situations where either one or both of these nutrients are discharged to the receiving water bodies in excess due to anthropogenic practices, a multitude of adverse effects can occur (Rabalais et al. 2009). As continuous delivery of excessive nutrients occurs in a receiving body of water, the phytoplankton most capable of assimilating these nutrients are increasingly favored over, and out-compete, other species of phytoplankton that depend on other factors for successful growth and development. The result of this continued process can be a specific selection, or diversity, of phytoplankton, such as cyanobacteria, that ultimately will affect other, higher, levels of the ecosystem.

3.2.2 Human Health Effects.

Nr in the form of [NO_3^-] is linked to several health-related effects including thyroid dysfunction, colon cancer, methemoglobinemia and ovarian cancer in humans (Inoue-Choi et al. 2015, EWG Tap Water Database 2017, Powlson et al. 2008, Sadeq et al. 2008)

3.3 Nitrogen and Lake George

A major goal of the Lake George Offshore Chemical Monitoring Program, initiated in 1980 and continuing through the present time, was to evaluate the consequences of nutrient loading in the lake (Boylen et al. 2014). The results of this 30-year study showed that concentrations of total nitrogen in the lake had declined during that time period, with enhance decreases during the 1990s which resulted from the Clean Air Act restrictions on nitrogen and sulfur emissions from nationwide combustion sources. Monitoring for other reactive forms of nitrogen such as nitrate and ammonia revealed concentrations near or below the detection limit (10 $\mu g\ N{\cdot}L^{-1}$) which corroborated the declining trend of total nitrogen during the entire period.

The results of the 30-year monitoring program on Lake George suggest that the element nitrogen is not a water quality issue on a lake-wide basis. However, it must be remembered that this long-term program reported the results obtained from samples collected along the main axis of the lake from south-to-north and did not investigate the water chemistry of near-shore, littoral zone areas where significant inputs can occur from either tributaries or ground water entering the lake or direct runoff along the lake shoreline.

In fact, two recent studies of wastewater treatment plants located within the Lake George drainage basin have revealed a significant issue, in both instances, with a reactive form of nitrogen, nitrate [NO_3^-], being continuously discharged at high concentrations by tributaries that are adjacent to these facilities. Both of these facilities were constructed on glacial outwash sand deposit plateaus with the intent that the sand could be utilized as an infiltration substrate for treated wastewater effluent (Aulenbach et al. 1975).

In the case of the Village of Lake George Wastewater Treatment Plant, located in the southwest corner of the Lake George drainage basin, the facility sits at a higher elevation and ground water from the area drains north to West Brook before entering Lake George. It was possible in this instance to compare recent data with historical data and use simple desk-top calculations to demonstrate that the facility had discharged 154 tons of nitrate-nitrogen during a period of 40+ years (Sutherland and Navitsky 2015).

At another WWTP in the hamlet of Bolton Landing located on the west side of Lake George, about 10 miles from the south end, the facility has two different sets of sand disposal beds for effluent discharge, and two different tributaries potentially are affected depending upon which sand beds are used for disposal. In this study, the historical data were not as extensive as for the Village of Lake George facility. Even so, in spite of large gaps in the data, similar desktop calculations showed that 60 tons of nitrate had been discharged to the near-shore area of Lake George during a 50-year period.

The results from both recent WWTP studies in the Lake George basin prompted the respective local governments, the Village of Lake George, and the Town of Bolton, to address these serious water quality issues and stop the point-source related nitrogen cascade from entering Lake George by converting reactive N back to nonreactive N_2.

The Village of Lake George WWTP currently is undergoing a total remediation scheduled for completion during December 2021 with the installation of three SBRs (Sequence Batch Reactors) which will allow for more precise control of oxygen during the nitrification-denitrification process and effectively remove the Nr from entering West Brook and, eventually, Lake George.

The Town of Bolton response to the water quality issue of nitrogen loading to Lake George is presented later in this chapter.

3.4 Denitrification and Woodchip Bioreactors

The basic concept of denitrifying bioreactors (DNBRs) is as follows: excavated trenches filled with a source of organic carbon source which are installed to improve the denitrification process for the treatment of Nr in the form of NO_3^- collected in surface runoff from agricultural landscapes and tertiary recirculating aquaculture systems (RAS).

The removal of nitrogen from wastewater can be thought of as a three-step process, which includes *ammonification*, *nitrification,* and *denitrification*. *Ammonification* (aka mineralization) occurs in the processing, or septic, tank and converts the organic nitrogen in wastewater to ammonia by way of bacteria. *Nitrification* occurs in the soil absorption system and oxidizes ammonia dissolved in the wastewater to nitrate using a specialized group of bacteria that require an inorganic source of carbon such as carbonate or carbon dioxide. The last step involves a bacteria-mediated reduction of nitrate to nitrogen gas (*denitrification*), which requires an organic carbon food source for the bacteria and also can occur in anoxic micro-zones of the soil absorption system. It is this last step in which DNBRs containing wood by-products (lignocellulose) are introduced to facilitate denitrification.

3.4.1 Agriculture

Woodchip bioreactors have accumulated several decades of history successfully mitigating nitrate-enriched agricultural runoff in the mid-western states (Christianson et al. 2012, Christianson et al. 2013), which has primarily focused on reducing Nr loading to the Gulf of Mexico and the well-documented hypoxic zone (Van Meter et al. 2018). In addition, the technology is finding increasing interest in nutrient sensitive watersheds in the New York Finger Lakes region (Hassanpour et al. 2017) and the Chesapeake Bay watershed (Kobell 2014) where excessive Nr loading also has caused hypoxic conditions.

Christianson et al (2012) has summarized a number of earlier studies in the Midwest and Ontario, Canada where percent reduction of nitrate ranged from a low of ~12% to a high of ~74%. Christianson et al. (2013) presented summary information for a series of bioreactors in central Iowa where the life expectancy is 10-20 years following which the woodchip material can be replaced and the process initiated once again.

3.4.2 Aquaculture

This is a fast-growing industry where anthropogenic contributions of Nr necessitated some means of reducing loading to receiving bodies of water. Thus, recirculating aquaculture systems (RAS), during recent years, have incorporated DNBRs to provide tertiary treatment prior to discharging effluent (von Ahnen et al. 2018). However, a primary issue with these systems is the presumptive reduction of lifespan from system clogging associated with high organic solids loading and the potential for bacterial overgrowth. While this application of DNBRs still is relatively new, cost benefit studies (Lepine et al. 2018) indicate that this denitrification approach offers low-cost treatment and similar removal efficiency for well-established applications in the agricultural industry.

3.4.3 DNBRs – Beyond Proof of Concept

In view of the accelerated research that had occurred in the area of DNBRs during the 2000s and 2010s, Christianson and Schipper (2016) firmly established that DNBRs had moved beyond proof of concept for treatment of nitrate in drainage water, ground water and some wastewater. The authors prepared an introduction to a special section in the Journal of Environmental Quality which hosted a collection of 14 research papers that expanded the peer-reviewed literature of DNBRs into new locations, applications, and environmental conditions.

3.5 DNBRs - Wastewater Treatment Applications and Limitations?

Commercial wastewater treatment and individual septic systems are another major source of Nr production in the global *nitrogen cascade* that have received far less attention with regard to the application and feasibility of DNBRs to convert Nr back to N_2.

3.5.1 Individual Septic systems.

According to a 2017 article by Lopez-Ponnada et al. (2017), approximately 60 million people in the United States are served by individual septic systems. Taking this estimate one step further means that the remaining ~270 million individuals in the US population are either served by community wastewater treatment plants (WWTP) or not served by any treatment system, which translates to an incredibly large amount of Nr moving through the environment.

DNBRs are considered an appropriate technology for these types of treatment systems because they have minimal mechanical energy and chemical inputs and use plant-based and, usually, locally based available materials (woodchips) and provide necessary ground water recharge and opportunity for water reuse close to the site of wastewater generation (Lopez-Ponnada et al. 2017).

One of the more comprehensive publications dealing with on-site septic systems was released in 2015 by the Barnstable County (MA) Department of Health. This document was a summary of various research efforts to incorporate wood-based products into on-site septic system treatment for the purpose of nitrogen removal. The information provided in the report was a collaboration of efforts with contributions from the State of Florida Onsite Sewage Nitrogen Removal Study (FOSNRS), the University of Rhode Island, the University of Waterloo, the Washington State Department of Health, Geomatrix LLC, Dalhousie University, and The State University of New York at Stony Brook.

With the exception of the material presented above, there is not much else to be found in the scientific literature with regard to the application of DNBRs with on-site septic systems.

3.5.2 Commercial Treatment Plants.

The authors were unable to find any relevant scientific literature dealing with DNBRs and the treatment of wastewater from commercial plants.

3.6 Application of DNBR Technology to the Bolton Wastewater Treatment Plant

Coincidentally, as the co-authors of the 2016 to 2017 Bolton WWTP study (Sutherland and Navitsky 2017) were completing the Final Report that documented the excessive loading of nitrate-nitrogen to Lake George from the Bolton WWTP, the consultant for the Town of Bolton (co-author KS) proposed the installation of a woodchip bioreactor at the site of one of the upper sand disposal beds previously used for plant effluent discharge in order to treat the Nr leaving the facility in disposed effluent. Following the design phase of the project, the use of this technology was approved by the New York State Department of Environmental Conservation (NYSDEC) for a demonstration pilot project and the Town of Bolton secured funding for this project and allocated the funds for a demonstration project of this new technology. In addition, The FUND for Lake George provided a Water Quality and Water Clarity Grant to the Town that was applied to upgrading the Bolton WWTP, including assistance with the installation of the woodchip bioreactor.

To our knowledge, this is one of the first full-size denitrifying woodchip bioreactors designed in this style for treating municipal wastewater in the United States and in the world. Successful use of this technology in this environment would mean potential wide-spread, low-cost application for other global areas where wastewater treatment is a concern and could provide a low-cost denitrification process to retrofit existing, outdated WWTPs. One important challenge for the successful operation of the Bolton WWTP woodchip bioreactor is the demonstration of efficient nitrate removal during cold winter periods which usually are the periods when this technology diminishes due to bacterial activity in cold environments.

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Final Report

Chapter 4

Design, Construction and Feasibility of the Bolton WWTP Woodchip Bioreactor

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4.0 Background

The Bolton WWTP was designed and constructed during the late 1950s to early 1960s using the best technology available at the time for wastewater treatment. Since then, however, the facility periodically has demonstrated an inability to denitrify effluent with occasional exceedance of the permitted limit for nitrate-nitrogen.

During 2017, the Town of Bolton consulting engineer (Kathleen Suozzo PE) for the wastewater facility submitted a process and facility review analysis to evaluate the plant's performance within its design parameters and pursuant to the regulatory standards of the NYSDEC. The report also offered a series of short-term and long-term recommendations to upgrade the performance ability of the plant. One of the short-term recommendations in the report was to "*conduct a demonstration project involving the repurposing of one of the infiltration sand basins as a woodchip bioreactor for treatment of nitrate*."

The installation of a woodchip bioreactor also was one of the recommendations that resulted from a two-year study of the Bolton WWTP and adjacent watersheds (Sutherland and Navitsky 2017). This study demonstrated the loading of the plant nutrients, nitrate-nitrogen, and soluble reactive phosphorus, to Stewart Brook and the Mohican Road Tributary and eventually Bolton Bay in Lake George.

The Town of Bolton accepted the recommendation for installation of a woodchip bioreactor based upon the low cost of construction, the fact that the bioreactor could be constructed within the footprint of the existing WWTP, and potential benefit of reducing the nitrate-nitrogen concentrations leaving the plant in effluent discharged to local ground water.

4.1 Design, Review and Permitting of the Bioreactor

The bioreactor for the Bolton WWTP was designed by Kathleen Suozzo PE, PLLC and a copy of the design plans is included in Attachment #2. Sand infiltration bed #10, which had been inactive for a considerable period of time and is the southernmost bed in the upper region of the WWTP property, was chosen for the site of bioreactor installation.

The following is a timeline that provides an overview of the separate phases of design, review and permitting of the bioreactor:

- May 2018 – Town of Bolton submits a copy of the Bolton Woodchip Bioreactor Demonstration Project proposal to the Region 5 office of the NYSDEC for review,
- July 2018 – The Region 5 office of the NYSDEC granted approval of the woodchip bioreactor plan for the Bolton WWTP as a 'pilot project' because the innovative technology of the proposed treatment system was not included in the NYSDEC *Design Standards for Intermediate Sized Wastewater Treatment Works* (2014 Edition),
- July 2018 – The FUND for Lake George awarded the Town of Bolton a $50,000 grant for construction and operation of the woodchip bioreactor,
- July 2018 through October 2018 – This is the period during which construction of the bioreactor occurred at the Bolton WWTP property,
- October 10th, 2018 – The woodchip bioreactor began treating Town of Bolton WWTP tertiary effluent under a variety of environmental and operational conditions

According to the NYSDEC Pilot Project Acceptance letter dated July 19th, 2018, the Town of Bolton would be responsible for evaluating the data collected during the 'pilot project and determining its effectiveness in meeting SPDES permit limits.

4.2 Installation of the Woodchip Bioreactor

Bioreactor construction utilized the Town WWTP operations staff, Town Highway Department, a private contractor, and the Town engineering consultant.

The dimensions of the bioreactor were 100 feet long by 20 feet wide by 4 feet deep. The following is a pictorial history of the bioreactor installation with photographs provided courtesy of Katheen Suozzo PE PLLC, the Town of Bolton consulting engineer.

Figure 4-1. Upper sand infiltration bed #11 prior to installation

Figure 4-2. Grading of the base of the woodchip bioreactor during installation

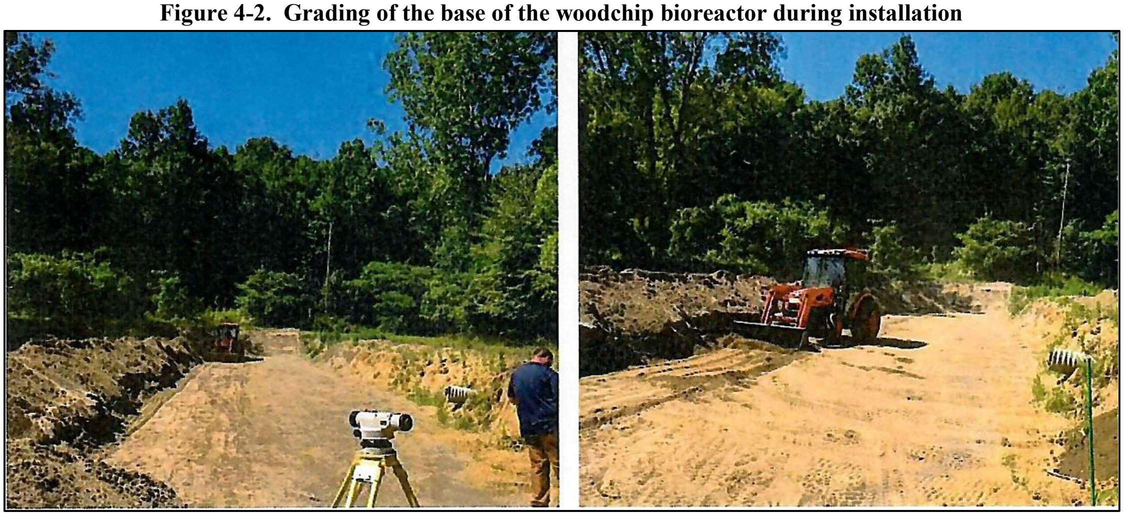

Figure 4-3. Installing the plywood wall supports and final grading of the bottom

Figure 4-4. Installing 45 mil pond liner inside the woodchip containment area; rolls 60 ft long by 10 ft wide

Figure 4-5. Pond liner installed

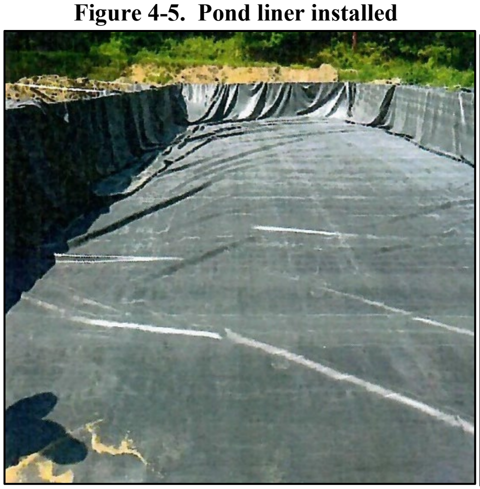

Figure 4-6. Filling the area with hardwood and softwood chips

Figure 4-7. More filling with woodchips and grading the interior

Figure 4-8. **Positioning the effluent flow control structure**

Figure 4-9. Effluent discharge header through end wall

Figure 4-10. Filter fabric covers woodchips to protect from soil

Figure 4-11. Bioreactor near completion

The Bolton WWTP Woodchip Bioreactor became operational on October 10th, 2018.

4.3 Woodchip Bioreactor Integration with Bolton Treatment Plant Operation

The bioreactor receives treatment plant effluent from a 2000-gallon concrete tank (visible in background of above photograph) adjacent to the influent chamber of the bioreactor. Treatment plant effluent is pumped to the tank through a small capacity pump station with a 10 hp Ebara submersible sewage pump (Model #100DLMFU67.5), which was new and installed in April 2018. The pump station sizing, and operational characteristics of the pump necessitated the concrete reservoir to provide more consistent flow for the bioreactor. The concrete tank has an overflow to discharge tertiary effluent to the down-gradient infiltration sand beds during periods when the bioreactor cannot process all of the incoming flow. The bioreactor flow can be controlled by a gate valve.

4.4 Woodchip Bioreactor Technology – Potential for Regional/World-wide Application

A thorough review of the scientific literature related to woodchip bioreactors did not find any other examples of this technology being used to process the effluent from a small community package treatment plant. It appears, therefore, that this is the first application of this technology, certainly in the United States, and perhaps on a global scale. Successful use of this technology in the northeast climate with variable environmental conditions could mean extensive application to other areas where situations similar to the Lake George scenario are occurring, i.e., small rural municipalities with older wastewater treatment technologies.

4.5 Lake Champlain Sea Grant Program – Opportunity for Funding

This project specifically addresses the non-point source input of nitrate-nitrogen in the Lake George drainage basin. A similar scenario likely was, or will become, problematic within the Lake Champlain Basin with respect to community wastewater treatment systems up-gradient of the lake (currently 6 percent of current runoff into the lake) and particularly agricultural runoff which contributes an estimated 38 percent of current total runoff into the lake.

Regardless of the source of nitrate-nitrogen, it is highly mobile in soils and inevitably will leach into down-gradient water bodies where it can promote eutrophication, alter ecosystem productivity and biodiversity. Excess nitrogen also is linked to several health-related effects including thyroid dysfunction, colon cancer, methemoglobinemia and ovarian cancer in humans (Inoue-Choi et al. 2015, EWG Tap Water Database 2017, Powlson et al. 2008, Sadeq et al. 2008)

A successful demonstration of the proposed pilot program would have widespread application within the Lake Champlain basin and beyond and is a technology that would relate to the *Lake Champlain Sea Grant Strategic Plan* focus and relevant goals including:

- *Resilient Communities and Economies - Goal 1* – Water resources are sustained and protected to meet emerging needs of the communities, economies, and ecosystems of the Lake Champlain basin.
- *Healthy Coastal Ecosystems – Goal 5* – Habitat, ecosystems, and the services they provide are protected, enhanced, and/or restored.
- *Healthy Coastal Ecosystems – Goal 6* – Land, water, and living resources are managed by applying sound science, tools, and services to sustain ecosystems.

Installation of the woodchip bioreactor at Lake George, and within the Lake Champlain Drainage Basin, provided the perfect opportunity to submit a grant proposal to the Lake Champlain Sea Grant Program for funding to evaluate the efficacy of this technology in the variable, seasonal climate of the northeastern region of the US.

4.6 LCSG Program Award for the Bolton WWTP Woodchip Bioreactor

A proposal prepared and submitted for funding to the Lake Champlain Sea Grant Program during the fall of 2018 received positive reviews and was granted an award of $58,656, which with match ($38,971) resulted in a project total amount of $97,627. The original proposal included weekly sampling and was scheduled to cover a one-year period. However, several reviewers thought that it would be best to extend the project over a two-year period to sample replicate seasons during the year. In the end, the proposal was changed to cover a two-year period with bi-weekly sampling instead of weekly sampling.

4.7 Literature Cited

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2019 to 2021 Lake Champlain Sea Grant Program

A Monitoring Program to Evaluate the Efficacy of a Woodchip Bioreactor Installed at the Bolton Wastewater Treatment Plant, Lake George (Warren County), New York

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Final Report

Chapter 5

Description of the 2019 to 2021 Monitoring Program and Methodology

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5.0 Background

About the same time that Sutherland and Navitsky were preparing the 2017 report describing the inefficient treatment problems with the Bolton facility, the Town of Bolton consulting engineer for the WWTP (co-author Kathleen Suozzo, PE) was preparing a report of short-term and long-term alternatives for upgrading the wastewater treatment facility (Cedarwood Engineering Services 2017). One of the alternatives proposed was the installation of a woodchip bioreactor in an upper sand bed used for effluent disposal. The Town approved this recommendation, obtained funding from several sources to cover the cost of design and installation of the bioreactor, and the installation was implemented, with the bioreactor becoming operational during October 2018.

The purpose of this report is to describe, in some detail, the performance characteristics of the woodchip bioreactor during a 27-month demonstration in an uncontrolled, non-laboratory setting with financial assistance provided by the Lake Champlain Sea Grant (LCSG) Program.

5.1 Hypothesis, Goals and Objectives

The null hypothesis (***H_0***) being tested can be stated as follows:

The woodchip bioreactor will not reduce the nitrate-nitrogen concentrations that currently occur in the tertiary effluent discharged from the Bolton WWTP to existing sand infiltration beds which enters the local ground water and then impacts local tributaries discharging to Bolton Bay in Lake George (Warren County), New York.

The goal of this Lake Champlain Sea Grant Project was to implement and conduct a thorough investigation of a woodchip bioreactor in an upstate New York wastewater treatment facility to determine the feasibility of using this 'green' infrastructure technology to remove nitrate-nitrogen from plant effluent which is discharged to ground water and then enters Lake George.

The original and primary objectives of this Project were to:

(1) Characterize the chemistry of the Bolton WWTP effluent, with particular emphasis on nitrate, ammonia and soluble reactive phosphorus of the effluent stream being denitrified through the bioreactor and side-by-side, the stream not being denitrified, and
(2) Monitor the improvement in ground water nitrate levels moving down-gradient from the WWTP during the study period.

As the Project entered a second year, however, additional objectives were established for this innovative 'green' technology including:

(3) Define the means and methods of characterizing the operation and efficiency of a full-scale woodchip bioreactor,
(4) Identify the causes of variable nitrate removal, and
(5) Identify methods to optimize the nitrate removal efficiency of the woodchip bioreactor throughout the four seasons, and
(6) Advance collaboration with other researchers and field practitioners to further knowledge in the woodchip bioreactor field.

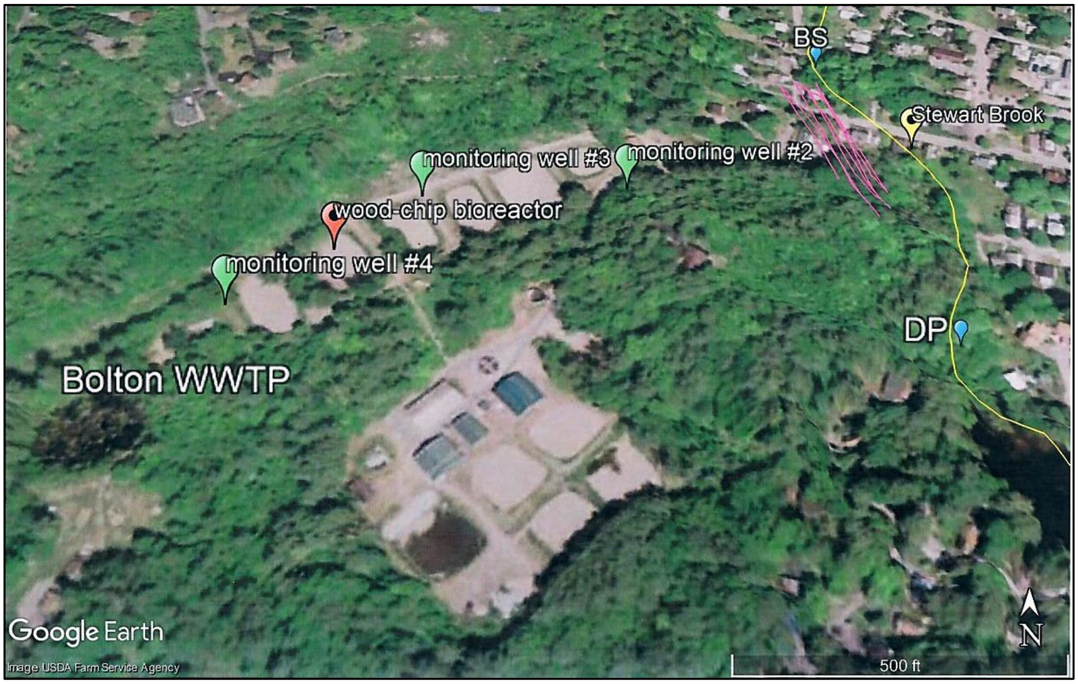
The cooperators involved in the Bolton WWTP Woodchip Bioreactor Project saw this situation as an opportunity to advance the science of an as yet unknown application of woodchip bioreactors for small, older technology community package treatment plants where similar high nitrate levels being discharged in effluent potentially could be an issue for receiving waters such as tributaries or lakes.

5.2 Location and Description of Monitoring Program Components

The original proposal identified 13 sampling sites that would be sampled for chemistry and field measurements bi-weekly; a 14^{th} site was added about 9 months into the Project.

The locations of the sampling sites are shown in Figure 5-1. The sites include the woodchip bioreactor with *influent*, *effluent* and *six* (*6) bioreactor monitoring wells* along the length of the unit, *two (2) existing monitoring wells* down-gradient of the bioreactor and infiltration sand beds that receive bioreactor effluent, a *background (control) monitoring well* not affected by WWTP effluent, and *two (2) sites on Stewart Brook* which receives ground water from the infiltration sand beds.

Figure 5-1.



The 14th site added after the Project was underway was the *bed effluent*, the untreated plant effluent combined with treated effluent emitted from the bioreactor prior to discharge to the infiltration sand beds.

5.2.1 Bioreactor and Wells

As described in Chapter 4, the bioreactor was installed on the site of a previously used sand disposal infiltration bed (#11) in the upper region of the Bolton WWTP property. Figure 5-2 shows the final stages of bioreactor construction.

Figure 5-2.

The *effluent* control structure is in the foreground of the photograph, with the *influent* control structure at the opposite end. The six (6) PVC *bioreactor monitoring wells* are shown installed at the 25-, 50- and 75-

foot distances from the influent end of the bioreactor. Three *monitoring wells* (#1, #4, and #5) are installed to the 2-foot depth in the bioreactor; the other three *monitoring wells* (#2, #3, and #6) are installed to the 4-foot depth in the bioreactor.

The *bed effluent* outlet is shown discharging to one of the upper sand infiltration beds in Figure 5-3; the bed effluent is a composite of both untreated effluent from the treatment facility and treated effluent discharged by the bioreactor.

Figure 5-3.

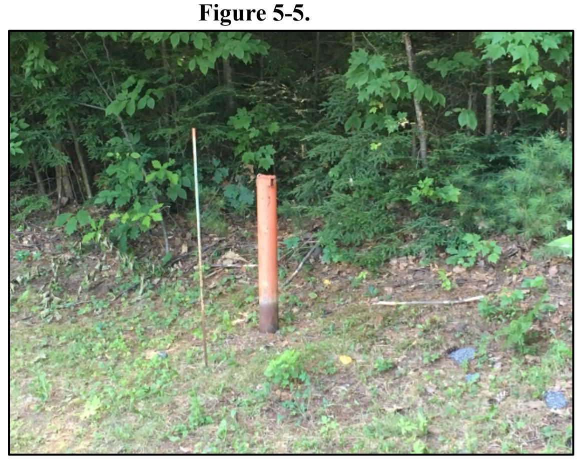
The *bed effluent* sampling site was added after the Project had been in progress for about three (3) months. The beds utilized for effluent disposal are varied on about a daily basis.

5.2.2 Ground Water Monitoring Wells

Two (2) *ground water monitoring wells* included in the study were located down-gradient of the upper-level sand disposal infiltration beds and it made sense to include these sampling sites to evaluate the effect of the bioreactor on nitrate-nitrogen concentrations in ground water flowing toward Stewart Brook. The approximate location of both wells is shown in Figure 5-2; Figures 5-4 and 5-5 are photographs of the individual well heads for *monitoring well #3* and *monitoring well #2*, respectively.

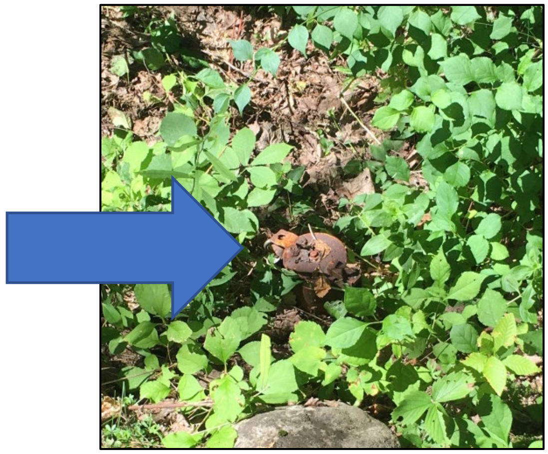
Figure 5-4.

Figure 5-5.



A third monitoring well (#4) is located up-gradient of any ground water movement away from the upper-level sand beds (see Figure 5-2) and was selected as a site that would provide water quality characteristics of ground water not impacted by the Bolton WWTP. Figure 5-6 is a photograph of the head for *monitoring well #4*.

Figure 5-6.



These monitoring wells are part of the New York State Department of Environmental Conservation SPDES (State Pollution Discharge Elimination System) permit requirement for operation of the Bolton facility and are sampled monthly in fulfillment of permit conditions.

5.2.3 Stewart Brook

The upper sand disposal beds are in the Stewart Brook watershed and the water quality of this tributary is impacted by ground water that moves down-gradient from this region (see Figure 5-1). The scribbled area along Stewart Brook in Figure 5-1 indicates where ground water moving down-gradient emerges as seepage and enters Stewart Brook. Sampling sites for this Project were selected above and below the area where seepage enters the tributary channel.

The *Brook Street* sampling site is located above the region where seepage enters the channel, and a photograph of the sampling site is shown in Figure 5-7.

The *Dula Place* sampling site (Figure 5-8) is below the area where seepage enters the tributary channel.

5.3 Overview of Sampling Program

The original proposal submitted to the LCSG Program requested funding for a one-year study which would sample a variety of sites on a weekly basis for chemistry and field measurements. However, based upon specific reviewer comments and a proposal review discussion document received from the LCSG Program, the proposed project was extended to cover a two-year period without any additional funding, so the sampling frequency was adjusted to bi-weekly.

Project sampling occurs every two (2) weeks; some sampling dates correspond to the WWTP's monthly SPDES sampling, other sampling dates do not correspond. In addition to the Project samples collected, the Bolton WWTP operations staff monitors and records daily flow through the WWTP, and flow volume treated through the bioreactor.

The monitoring program was initiated on March 19th, 2019 and concluded on September 14th, 2021. There was a total of 65 field sampling excursions. Not all stations were sampled on each sampling date (explained below).

The matrix presented in Table 5-1 summarizes the successful field excursions to each sampling site during the monitoring program. A total of 642 samples were collected from the 14 sampling sites during the 31-month period of the monitoring program.

All bi-weekly field sampling was conducted within a 1-to-2-hour window on the same day. The collected samples were returned to the WWTP following collection and placed in a refrigerator. The samples were picked up and delivered that same day, along with a completed Chain of Custody form, to the Phoenix Environmental Laboratories, Inc. in Manchester, CT. A 'blind' duplicate sample usually was collected.

At the Phoenix Lab, the samples were analyzed regularly for nitrate-nitrogen (NO_3-N), ammonia-nitrogen (NH_3-N), soluble reactive phosphorus (SRP), and occasionally for dissolved organic carbon (DOC), iron (Fe) and alkalinity.

5.3.1 Routine Sample Collection

The Project included bi-weekly sampling of the sites described above. The bioreactor and associated sites were sampled by Bolton WWTP personnel while the Stewart Brook sites were sampled by The Lake George Waterkeeper and The FUND for Lake George personnel.

Bioreactor influent. A view looking down into this structure is presented in Figure 5-9. The channels located on either side of the structure hold panels, or stop logs, which control the amount of flow moving into the bioreactor.

Figure 5-9.

A well bailer was lowered into this structure to collect enough water for the chemistry samples and the field measurements.

Table 5-1.

	Lake Champlain Sea Grant Program – 2019 to 2021 Bolton WWTP Woodchip Bioreactor Study													
	Bioreactor Sampling Sites								Bed	Monitoring Wells			Stewart Brook	
Date	Infl	MW1	MW2	MW3	MW4	MW5	MW6	Effl	Effluent	#3	#2	#4	BS	DP
3/19/2019	x	x	x	x	x	x	x	x		x	x	x	x	x
4/2/2019	x	x	x	x	x	x	x	x		x	x	x	x	x
4/16/2019	x	x	x	x	x	x	x	x		x	x	x	x	x
4/30/2019										x	x	x	x	x
5/14/2019	x		x	x	x	x	x	x		x	x	x	x	x
5/28/2019	x	x	x	x	x	x	x	x		x	x	x	x	x
6/11/2019	x	x	x	x	x	x	x	x		x	x	x	x	x
6/25/2019	x	x	x	x	x	x	x	x		x	x	x	x	x
7/9/2019	x	x	x	x	x	x	x	x		x	x	x	x	x
7/23/2019	x		x	x			x	x		x		x	x	x
8/6/2019	x		x	x			x	x		x	x	x	x	x
8/20/2019													x	x
9/3/2019	x		x	x			x	x		x	x	x	x	x
9/17/2019										x	x		x	x
10/1/2019	x		x	x			x	x					x	x
10/15/2019	x		x	x			x	x					x	x
10/29/2019	x		x	x			x	x		x	x	x	x	x
11/11/2019	x		x	x			x	x		x	x	x	x	x
11/26/2019	x	x	x	x	x	x	x	x	x	x	x	x	x	x
12/10/2019	x	x	x	x	x	x	x	x	x	x	x	x	x	x
12/23/2019	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1/7/2020	x	x			x	x		x	x	x	x	x	x	x
1/21/2020	x		x	x			x	x	x	x	x	x	x	x
2/4/2020	x		x	x			x	x	x	x	x	x	x	x
2/18/2020	x		x	x			x	x	x	x	x	x	x	x
3/3/2020	x		x	x			x	x	x	x	x	x	x	x
3/17/2020													x	x
3/31/2020														
4/14/2020	x			x				x	x	x			x	x
4/28/2020	x			x				x	x	x			x	x
5/12/2020	x			x				x	x	x			x	x
5/26/2020	x			x				x	x	x			x	x
6/9/2020	x			x				x	x	x	x	x	x	x
6/23/2020	x		x	x			x	x	x	x	x	x	x	x
7/7/2020	x		x	x			x	x	x	x	x	x	x	x
7/21/2020	x		x	x			x	x	x	x	x	x	x	x
8/4/2020	x		x	x			x	x	x	x			x	x
8/18/2020	x		x	x			x	x	x	x	x		x	x
9/1/2020	x		x	x			x	x	x	x	x		x	x
9/15/2020	x		x	x			x	x	x				x	x
9/29/2020	x		x	x			x	x	x	x			x	x
10/13/2020	x		x	x			x	x	x	x			x	x
10/27/2020	x		x	x			x	x	x	x			x	x
11/10/2020	x		x	x			x	x	x	x			x	x
11/24/2020	x		x	x			x	x	x			x	x	x
12/8/2020	x		x	x			x	x	x	x	x	x	x	x
12/22/2020	x		x	x			x	x	x	x		x	x	x
1/5/2021	x		x	x			x	x	x	x	x	x	x	x
1/19/2021	x		x	x			x	x	x	x	x	x	x	x
2/2/2021	x		x	x			x	x	x	x	x	x	x	x
2/16/2021	x		x	x			x	x	x	x		x	x	x
3/2/2021	x		x	x			x	x	x	x	x	x	x	x
3/16/2021	x		x	x			x	x	x	x	x	x	x	x
3/31/2021	x		x	x			x	x	x	x	x	x	x	x
4/13/2021	x		x	x			x	x	x	x	x	x	x	x
4/27/2021	x			x			x	x	x	x	x		x	x
5/11/2021	x		x	x			x	x	x	x	x	x	x	x
5/25/2021	x			x			x	x	x	x	x	x	x	x
6/8/2021									x	x	x	x	x	x
6/22/2021										x	x	x	x	x
7/6/2021										x	x	x	x	x
7/20/2021													x	x
8/3/2021													x	x
8/17/2021													x	x
8/31/2021													x	x
9/14/2021													x	x
9/28/2021													x	x
total collected	54	11	46	52	12	12	47	53	41	54	42	42	65	65
table color-coding	bio down		pandemic		well dry		contamination		not in program yet					

Bioreactor monitoring wells. These structures were shown in Figure 5-2; they are placed in pairs along the 100-foot length of the bioreactor and sampled with a well bailer. Standard protocol prior to sampling is to flush each well with twice the volume of water contained in the well at the time of sampling.

Bioreactor effluent. The device is similar to the influent structure presented in Figure 5-9 and also is sampled with a well bailing device.

Bed effluent. The sampling technique for this end-of-pipe structure is to hold bottles under the discharge until full.

Ground water monitoring wells. These sites are sampled with a well bailer after 'flushing' the well with twice the volume in the well at the time of sampling.

Stewart Brook. Both sites are sampled mid-channel for chemistry and field measurement by rinsing a PE container 3xs with tributary water and then filling the container which is used to fill the sample bottles and run field measurements. Tributary flow was measured by dividing the channel into equal segments of width (stream), measuring the depth (ft) and velocity ($ft^3 s^{-1}$) at the centerline (C_L) of each segment with the flow probe at the 0.6 depth above the stream bed, then calculating the cross-sectional area, velocity, and discharge for each segment, and summing the segment flows to determine total channel discharge.

All chemistry samples collected in the field immediately were transferred to sample containers provided by the contract laboratory, Phoenix Environmental Laboratories Inc., 587 East Middle Turnpike, P.O. Box 370, Manchester CT 06040, as follows:

- 1-250 mL polyethylene (PE) bottle preserved *as is* for NO_3-N,
- 1-250 mL PE bottle preserved with H_2SO_4 for NH_3, soluble reactive phosphorus (SRP),
- 1-250 mL amber glass bottle preserved as is for DOC

Phoenix is certified to analyze chemistry samples collected as part of the New York State Department of Environmental Conservation SPDES (State Pollutant Discharge Elimination System) permit system. Collected samples were refrigerated, then placed on ice and delivered to the analytical laboratory on the same day as collected in the field, accompanied by a completed Chain of Custody form.

5.3.2 Field Measurements

Water temperature and dissolved oxygen (concentration-saturation) were measured *in-situ* using a Yellow Springs Instrument (YSI) ProODO™ Optical Dissolved Oxygen meter. Subsamples of collected water were analyzed on-site for specific conductance, total dissolved solids and pH using an Ultrameter II™ (Myron L Company). Tributary flow was gaged using a top setting wading rod in combination with a Hach FH950 portable velocity flow meter with electromagnetic sensor.

5.3.3 Analytical Laboratory Methods

The analytical techniques followed by the Phoenix Laboratory for analysis of the chemistry samples are summarized in Table 5-2 below.

Table 5-2.

PARAMETER	ANALYTICAL METHOD
Nitrate as nitrogen	Colorimetric (US EPA Method 353.2)
Ammonia as nitrogen	Colorimetric (US EPA Method 350.1)
Soluble reactive phosphorus	Colorimetric (Standard Methods 4500-PE-99)
Dissolved organic carbon	Colorimetric (Standard Methods 5310B-11)
Iron	Colorimetric (US EPA Method 200.7)
Alkalinity	Titrimetric (Standard Methods 2320B-11)
Temperature	Thermometric (Standard Methods 2550 B-2000)
Total dissolved solids	Gravimetric (Standard Methods 2540-C)
Dissolved Oxygen	Optical (ASTM Method D888-09(C))
Specific conductance	Wheatstone bridge type meter (US EPA Method 120.1)

The table also includes standard procedures for measurements of dissolved oxygen and conductance.

5.3.4 Complications from COVID-19 Pandemic

Bioreactor sampling was interrupted in mid-March 2020, pursuant to a necessary restructuring of the Town of Bolton WWTP operating schedule brought about by the ongoing COVID-19 viral pandemic. In late March, a revised temporary sampling schedule was developed and implemented. The original sampling schedule resumed for the June 23 sampling event.

The continuing COVID-19 pandemic caused a second change in the bioreactor monitoring procedures. In December 2020, staffing at the Bolton WWTP again reverted to single operator attendance and implementation of just the basic operation and maintenance activities at the WWTP, pursuant to the Town's health and safety protocol. The field collection of water samples at each site for chemical analysis continued as before; however, some of the field measurements (e.g., dissolved oxygen and alkalinity) were suspended.

5.3.5 No-cost Extension of the Project

Considering the Project sampling disruption caused by the COVID-19 pandemic, it seemed reasonable to request a no-cost Project extension to complete additional bioreactor sampling. In particular, it seemed feasible to complete the winter of 2020 to 2021 sampling as well as the spring and summer seasons so that these could be compared with previous seasons sampled.

The Lake Champlain Sea Grant Program approved a no-cost Project extension, with sampling scheduled to continue through September 2021 and a Final Report due on December 31st, 2021. Problems occurred, however, and the bioreactor became plugged and was shut down on June 1st, 2021. An investigation of the system plugging was conducted, and the results are presented in a later chapter of this report. In spite bioreactor plugging, sample collections on Stewart Brook continued through September 2021.

5.3.6 Unscheduled Shutdown of the Bioreactor

There were several instances during the Project when the bioreactor had to be shut down for a period of time. These unscheduled shutdowns are described in detail in Attachment #3 which presents the performance of the woodchip bioreactor during the period of the study.

5.4 Overview of Data Management, Analysis and Sharing

All data (both field measurements and laboratory analytical) collected and received during this project were stored in a Master Excel File Database exclusive to the project and formatted to provide ease of access and comprehension of stored information to all end users of the data.

5.4.1 Data management

Field data were entered into the Project Master Excel file following the completion of each excursion and the Master Project Excel file was updated on a regular basis when chemistry data were received from the Phoenix Laboratory, usually within one week following receipt of samples.

The Master Excel File contains an initial "Read Me" informational worksheet that explains the format of the data in subsequent worksheets in the file and any calculations that have been performed to provide data summary in the worksheets.

The Master Excel File contains separate worksheets for each type of site sampled during the project including *bioreactor influent*, *bioreactor effluent*, *bioreactor monitoring wells*, *ground water monitoring wells*, *Stewart Brook sites* and the *background ground water well*.

Each sampling site worksheet (*bioreactor influent*, *bioreactor monitoring wells*, *bioreactor effluent*, *ground water monitoring wells*, *tributary sites*, and *background monitoring wel*l) also has an adjacent worksheet that contains graphs that provide a visual summary of the data.

The format used in developing the storage of project data is critical to ease of understanding and accessibility of data to all end users. The individual worksheets for each type of Project sampling station have a ***header row*** format for data entry into columns that are appropriate for each sampling station. An example of a **header row** that was 'cut and pasted' from a sampling site summary worksheet in the

Project Master Excel file is presented below; it is an example of a **header row** that incorporates all of the variables that were of interest during the monitoring program for the variety of sampling sites included in the Project.

Sampling Site	Sampling Year	Sample size (n)	Depth of Water in	Gallons of Water in Pipe	Water temp (^{0}C)	DO (mg/L)	DO (% sat)	SRP (mg/L)	NO3-N (mg/L)	NH3-N (mg/L)	pH (s.u.)	spC (µS/cm)	TDS (ppm)	Alkalinity (mg/L)	Flow (cfs)	Flow (mgd)

In the actual Excel file, individual rows entered below the header row would contain data, entered in the columns, collected during each field excursion to the site.

5.4.2 Data analysis

This report describes the results of a 31-month real-time, interactive demonstration study to determine the feasibility successfully utilizing the woodchip unit process for denitrification in a small community wastewater treatment plant operating in the northeastern United States. This particular facility had been shown to discharge high concentrations of nitrate-nitrogen via ground water to an adjacent tributary watershed and then to a recreational lake (Lake George) which resulted in nuisance algae and attached macrophyte growth in the near-shore littoral zone near the tributary outflow.

To our knowledge, the Bolton WWTP woodchip bioreactor is the first known world-wide application of this woodchip denitrification technology to treat influent wastewater in a small community package plant. Located in a region of upstate New York that is subjected to a wide range of climatic conditions such as temperature (hot to freezing) and precipitation (wet to frozen), successful application of this technology would have profound implications for use in other similar areas experiencing similar conditions.

Given the unique natural of the process design and this one-off installation, the actual data analysis for this situation will depend upon the simple calculation of mean values and standard deviations so that different parts of the treatment process can be compared for efficiency and effectiveness with parts of the system that are untreated. More sophisticated data analysis would have been prudent for a series of installations at the Bolton facility; however, this was not the case, although more units are planned for construction in 2022.

5.4.3 Data Sharing Plan

The data generated by this will Project be shared in entirety with Lake Champlain Sea Grant Program by December 2023, or sooner, if the peer-reviewed scientific article is accepted for publication prior to that time. The Final Report for the proposed project and the Master File Database also will be posted on The Lake George Association and the Town of Bolton websites for access by interested users.

One additional feature of the data management plan proposed for this project is the inclusion of a second Master Excel File Database that contains all of the historical data collected for the Bolton WWTP effluent, monitoring wells and tributaries during the previous five (5) years so that comparisons and evaluations can be performed with current project data and previous data.

5.5 Literature Cited

Cedarwood Engineering Services, PLLC. 2017. Draft Town of Bolton, New York Wastewater Treatment Facility Engineering Report, January 2017. Funded by the NYSDEC/NYSEFC Planning Grant Program.

Sutherland, J.W. and C. Navitsky. 2017. *Final Report. Bolton Bay (Lake George, Warren County) Water Quality Assessment. A Monitoring Program to Evaluate Current Water Quality Issues*. Prepared for The Fund for Lake George and the Town of Bolton. 150 pp. + appendices.

US EPA Methods are from: US EPA, Methods for Chemical Analysis of Water and Wastes, US EPA-600/4-79-020, Cincinnati, Ohio (Revised March 1983).

2019 to 2021 Lake Champlain Sea Grant Program

A Monitoring Program to Evaluate the Efficacy of a Woodchip Bioreactor Installed at the Bolton Wastewater Treatment Plant, Lake George (Warren County), New York

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Final Report

Chapter 6

Performance of the Bolton Wastewater Treatment Plant Woodchip Bioreactor Project

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6.0 Introduction

As detailed in Chapter 2, the Town of Bolton wastewater treatment plant (WWTP), circa 1960, lacks a unit process for effluent denitrification. The existing unit processes consist of flow equalization, primary clarification (i.e., Imhoff tank), secondary aerobic treatment (trickling filter with crossflow plastic media and recycle), secondary clarification with chemical sequestering of soluble phosphorus and pH adjustment, tertiary effluent filtration (i.e., Parkson Dynasand continuously backwashed up flow sand filtration with chlorination) and final dispersal into natural sand infiltration beds. The existing unit processes successfully handle all permitted wastewater constituents (i.e., BOD, TSS, Total Phosphorus, Ammonia, and pH) and settleable solids during most permit sampling periods. A unit process for nitrate reduction was never included in the WWTP's original design.

As part of the Town's continuing initiative to optimize WWTP operational efficiency, the Town Supervisor and Town Board authorized the installation of a woodchip bioreactor for tertiary denitrification of wastewater effluent by establishing a Wastewater Treatment Plant Improvement Capitol Fund. A woodchip bioreactor demonstration project engineering proposal was prepared by the Town, submitted to the NYSDEC for review, and approved in July 2018.

Woodchip bioreactors (aka denitrification bioreactors) have been used over the past decade to treat agricultural drain tile runoff, primarily in the midwestern United States (see Chapter 3). The first woodchip bioreactors saw application in the farm fields of Iowa under the direction of Dr. Laura Christianson (Christianson et al. 2012, Christianson et al. 2013), where seasonally nitrate-enriched runoff was intercepted and treated. This technology also has been tested in a few applications for the treatment of recirculating aquaculture wastewater. More recent work is being conducted in the Chesapeake Bay watershed, and the Finger Lakes region in New York State. The Bolton WWTP woodchip bioreactor is the first known unit process for the *denitrification* of municipal wastewater effluent and was evaluated in actual field conditions.

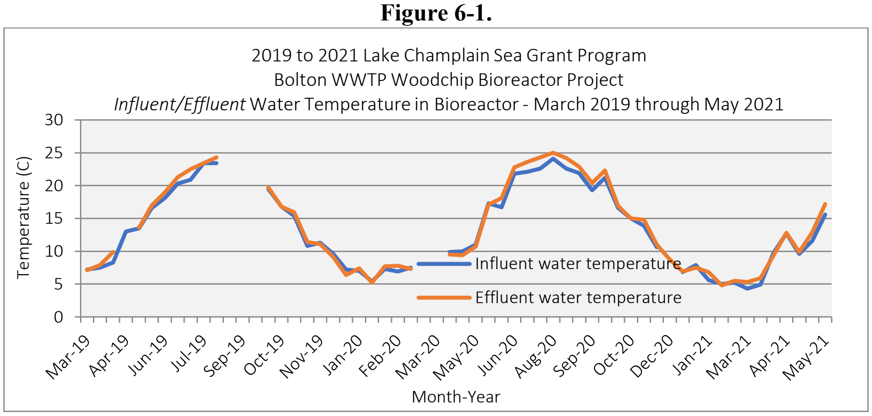
6.1 Results of the 2019 to 2021 Bioreactor Monitoring Program

There were gaps in the flow data and overall operation of the unit processor due to the bioreactor being shut down, and a summary of shutdown information is provided in Attachment #3. For the purposes of discussion and full disclosure in this section of the report, the bioreactor was offline a total of 126 days, which means that the unit processor was operational a total of 679 days during the study period.

6.1.1 Physical Characteristics

Temperature. An important characteristic of wastewater *influent* to the woodchip bioreactor due to the effect on nitrate removal efficiency. The *mean* temperature of the bioreactor *influent* and *effluent* during the study were 13.5ºC and 13.9ºC, respectively, and the bi-weekly results are summarized in Figure 6-1.

Figure 6-1.



The pattern of *influent* and *effluent* temperature in the woodchip bioreactor mirrors the ambient outside temperature which is higher in the summer months and lower in the winter months because the majority of the tanks in the WWTP process are either exposed directly to the outside or in unheated shelters.

Nitrate removal efficiency is greater during the warmer wastewater temperatures and lower efficiencies are expected when wastewater temperatures are colder. Coupled with the low wastewater temperature is the hypothesis that reduced activity by cellulolytic bacteria within the wood chips also adversely impacts the removal efficiency by reducing the availability of a carbon source.

Flow. Flow through the woodchip bioreactor is an important operational parameter and was totaled daily. In the initial stages of the woodchip bioreactor operation (October 2018) and into the early weeks of this study (March 2019), flow through the bioreactor was gauged by the V-notched weir in the bioreactor *influent* structure, the Agri Drain structure, which is the standard flow measurement mechanism for the agricultural bioreactor applications.

For this study, however, a more definitive method of exact flow measurement was required.

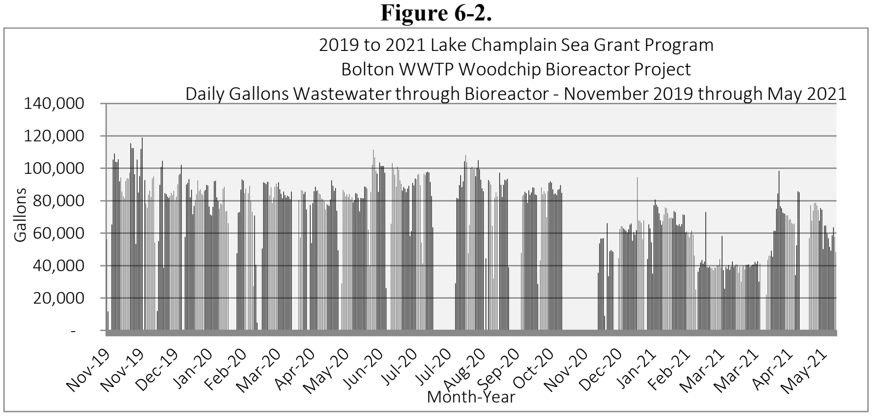
The Town's consultant installed a Greyline in-pipe flow meter in the 6-inch discharge pipe from the *effluent* Agri Drain flow control structure into the sampling manhole. This flow meter was read every day; the meter reports instantaneous and total flows. This flow meter was installed four (4) months into the study and was operational on July 25, 2019.

Prior to the installation of this flow meter, flows were reported as the depth of water over the *influent* V-notch weir, which operations staff noted could vary throughout the day depending on the pump cycle of the plant tertiary pump station supplying effluent to the 2000-gallon bioreactor *influent* reservoir.

The *mean* daily flow through the bioreactor was 72,900 gallons per day (gpd) during the study period with a high flow of 118,947 gallons on November 29, 2019, and a low flow of 30,125 gallons on March 17, 2021. It should be noted that lower flows were noted on days bordering meter malfunctions.

The daily flow totals are summarized in Figure 6-2. Of particular note here is the fact that after the resumption of bioreactor operation in November 2020, flows through the bioreactor were less than historically seen prior to shut down.

Figure 6-2.

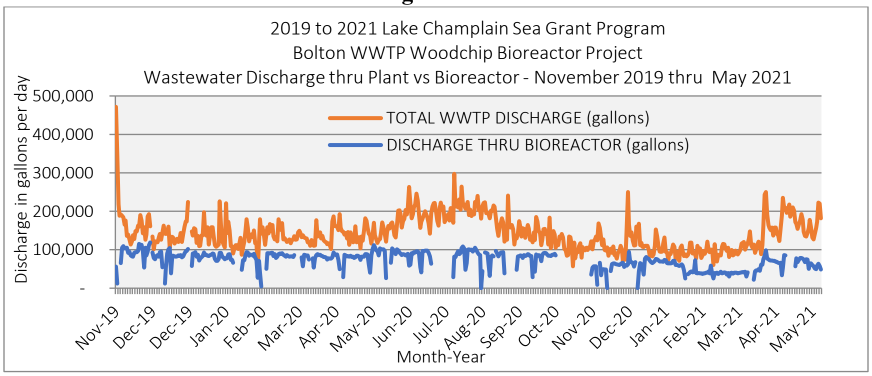


This flow reduction was intended operationally to optimize *denitrification* through greater retention time during a period when higher than typical influent nitrate concentrations and colder wastewater temperatures were observed.

The bioreactor was designed and installed as a demonstration project and was not intended to handle the capacity of all wastewater flow through the Bolton WWTP, which currently is permitted for 300,000 gpd.

The comparison of total plant wastewater flow and wastewater flow through the bioreactor during the period from November 2019 through May 2021 is shown in Figure 6-3.

Figure 6-3.



Flow through the bioreactor and retention time of *effluent* in the bioreactor are indirectly related, i.e., greater flow through the bioreactor will result in a decrease in retention time. The retention time within the bioreactor influences the extent of denitrification, i.e., longer retention times promote greater denitrification. Detention time was manually adjusted to accommodate the nitrate concentration and *influent* water temperature. Data showed that high *effluent* nitrate levels could be a result of higher-than-normal flows through the bioreactor. Therefore, bioreactor retention time was a focus of daily operation, having to factor in the flows experienced through the WWTP, as well as other factors such as *influent* nitrate concentrations and temperature.

Bioreactor monitoring well water level. This is a field parameter specific to the bioreactor and is the depth of water in the bioreactor at a particular location (note that the depth was not static and varied through the bioreactor). The depth to water level in each deep well was measured during each sampling event prior to purging the well and collecting field measurements and chemistry samples. The deep bioreactor monitoring wells were well points (#2, #3 and #6) at a depth of approximately 48 inches below the top of the bioreactor and 25, 50 and 75 feet, respectively, from the *influent* end of the unit.

The *mean* depth in bioreactor monitoring well #2 over the study period was 24.7 inches with a minimum recorded depth of 14 inches on two occasions and a maximum recorded depth of 34 inches on January 21, 2020. The mean depth in bioreactor monitoring well #3 over the study period was 26.3 inches with a minimum recorded depth of 14 inches on September 29, 2020, and a maximum recorded depth of 40 inches April 2, 2020. The average depth in bioreactor monitoring well #6 over the study period was 27.1 inches with a minimum recorded depth of 16 inches on July 23, 2019, and a maximum recorded depth of 40 inches measured on two occasions.

The depth of water across the bioreactor was manually controlled by the operations staff by adjusting the number of "stop logs" at the bioreactor *influent* and *effluent*; stop logs are 6-inch-high heavy plastic sheets that slide into the slots within the Agri Drain structures. The stop logs act similarly to the flashboards at dam overflows. The stop logs were adjusted periodically to allow either longer or shorter retention times within the bioreactor. At other times, the stop log heights were standardized, and the rate of denitrification was the observed variable. The rate of denitrification also was influenced during these times by the *influent* nitrate concentrations and the wastewater temperature. There is a complex synergy of operational parameters within the bioreactor, which must be considered when these data are reviewed.

During the warmer weather months of 2019, when wastewater *effluent* temperature at the Bolton WWTP reached 25°C, the level of water in the bioreactor had to be reduced to limit both the retention time and the complete consumption of *influent* nitrate-nitrogen by the denitrifiers. Once nitrate-nitrogen is consumed by the denitrifying bacteria, the bacteria turn to sulfates as their electron acceptor producing hydrogen sulfide gas, a telltale sign that all nitrate-nitrogen has been consumed. To facilitate shorter retention time, several of the *effluent* weirs were removed, reducing the level of wastewater.

During the latter months of 2019, samples collected from all bioreactor monitoring wells exhibited discoloration. Oxidation of the bioreactor stainless steel monitoring well points was suspected because the *influent* and *effluent* samples had no discoloration. In late December 2019, these monitoring well samples were analyzed for iron; levels as high as 339 mg Fe·L were reported. The presence of iron in these samples prevented accurate characterization of nitrate-nitrogen, alkalinity, and dissolved oxygen in the water, and caused interruption of data collection at these sites. Operations staff replaced the bad well points with custom 2-inch PVC wells in the same locations as the previous well points by early 2020.

6.1.2 Chemical Characteristics

A summary of the chemical characteristics of the bioreactor *influent* and *effluent* are presented in Table 6-2 and include *minimum*, *maximum* and *mean* values, and the sample size (*n*) for the variable reported.

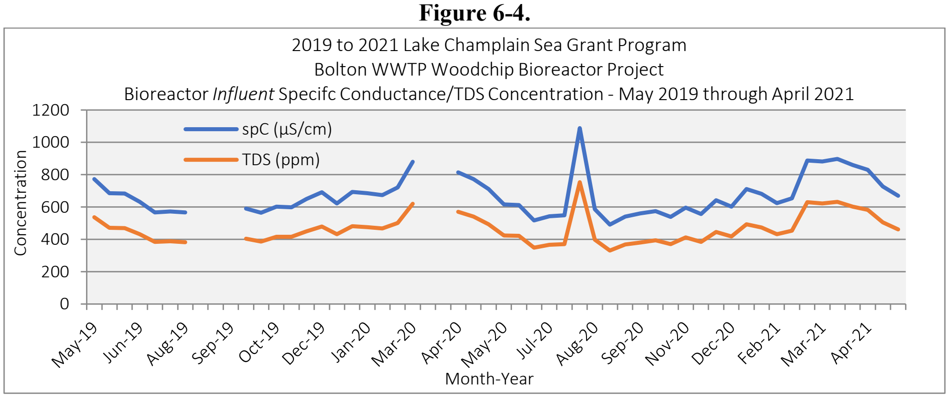
Table 6-2.

	spC (µS/cm @ 25C)	TDS (mg/L)	pH (s.u.)	DO (% sat)	DO (mg/L)	Alkalinity (mg/L)	NO_3-N (mg/L)	NH_4-N (mg/L)	SRP (mg/L)
BIO INFLUENT									
minimum	491.1	330.8	6.11	62.6	5.3	20	4.4	0.05	0.005
maximum	1088	753.5	7.73	109.5	13.1	100	25.4	10.1	1.25
mean	671.4	464.0	6.90	85.0	8.9	56.3	14.5	1.1	0.3
n	54	54	54	54	54	54	54	54	54
BIO EFFLUENT									
minimum	490	326.5	6.21	0.2	0.02	21	0.01	0.025	0.005
maximum	879.6	619.9	7.21	75.0	8.03	128	19.0	8.960	1.07
mean	640.4	441.3	6.78	8.21	0.95	72.98	8.85	1.03	0.18
n	53	53	53	53	53	53	53	53	53
	= value reported is one-half the lowest detection limit								

Specific conductance and total dissolved solids (TDS). Specific conductance (spC) is a measure of water's resistance to flow of an electrical current; resistance to flow decreases as ionized salt content of the water increases (i.e., spC increases) and promotes electric current flow. Water with low concentration of major ions has the greatest resistance to electron flow (i.e., low spC), while seawater with a high concentration of these ions has less resistance to electron flow. The term "dissolved solids" refers to any minerals, salts, metals, cations, or anions dissolved in water which are small enough to pass through a 2-micron filter. TDS comprise inorganic salts and small amounts of organic matter. By definition, therefore, TDS concentration is less than spC concentration and there is a relationship between the two (2) analytes. The *effluent* from WWPTs contains dissolved solids and important components of the TDS load include phosphorus, nitrogen, and organic matter in addition to the inorganic salts described above.

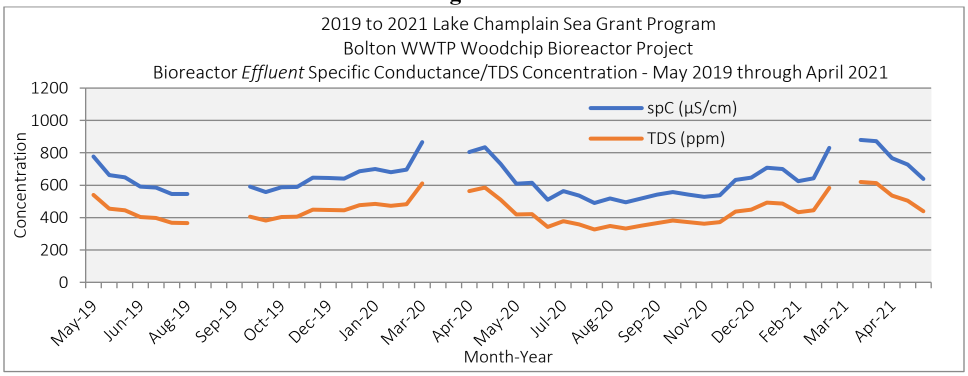
The bi-weekly spC and TDS concentrations for the bioreactor *influent* are presented in Figure 6-4.

Figure 6-4.



The spC and TDS concentrations of the bi-weekly measurements for the bioreactor *effluent* are presented in Figure 6-5.

Figure 6-5.

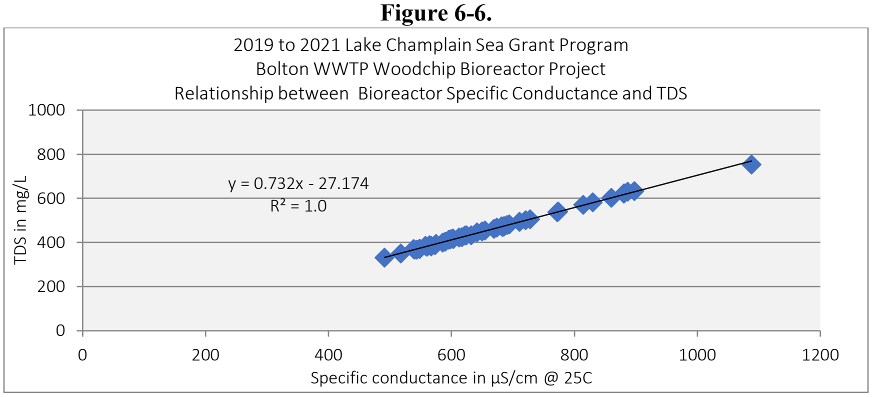


The spC concentrations measured for the bioreactor *influent* ranged from 491.1 to 1088 µS·cm @ 25C while bioreactor *effluent* concentrations during the study ranged from 490 to 879.6 µS·cm @ 25C. The *mean* spC concentration for the bioreactor *influent* and *effluent* during the study is presented in Table 6-2; values were 671.4 and 640.4 µS·cm @ 25C, respectively.

There was a seasonal pattern to the spC and TDS concentrations with higher values recorded during the late winter, which could indicate inflow/infiltration entering the collection system consisting of surface runoff influenced by road salt from winter road maintenance. There is no significant change between the *influent* and *effluent* levels indicating that the woodchip bioreactor does not provide any treatment for the major components of spC or TDS.

spC and TDS are important water quality parameters that are correlated and usually expressed by a simple equation: TDS = k spC. The value k will increase along with the increase of ions in water. However, the relationship is not always linear; it depends on the activity of specific dissolved ions activity in the liquid and ionic strength (Kumer er al. 2015). Unlike natural water or fresh water, which is very linear, the correlation between TDS and spC in wastewater may not have a clear correlation because the water is heavily influenced by many contaminants (Rusydi 2018). Figure 6-6 shows the correlation between spC and TDS for the woodchip bioreactor, which demonstrates a strong relationship.

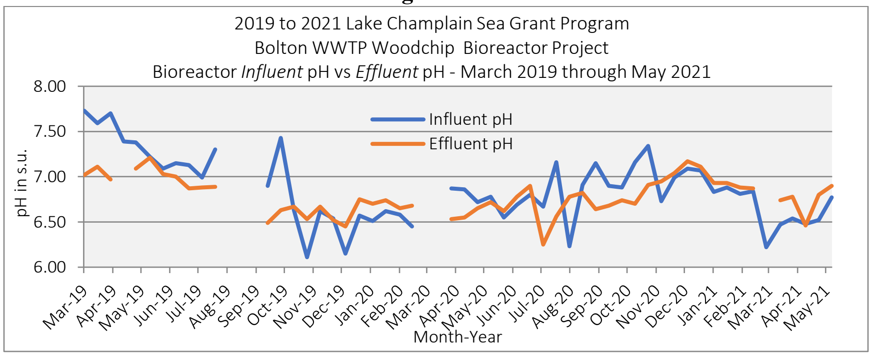
Figure 6-6.



pH. This is a mathematical transformation of the hydrogen ion [H^+] concentration and expresses the acidity or basicity of water. The lowercase 'p' in pH refers to the 'power' or exponent, and pH is defined as the negative logarithm of the hydrogen ion concentration [H^+]. A change in one pH unit represents a ten-fold change in hydrogen ion concentration. Conditions become more acidic as pH decreases and more basic as pH increases.

pH measurements of bi-weekly data collected for bioreactor *influent* and *effluent* are shown in Figure 6-7.

Figure 6-7.



All of the recorded values for pH were above pH 6.0 for the *influent* and *effluent* with an *influent* range from 6.11 to 7.73 and the effluent from 6.21 to 7.21. The average pH is shown in Table 6-2 for the bioreactor influent and effluent and were 6.90 and 6.78 s.u., respectively. It is stated that the optimum pH values for denitrification are between 7.0 and 8.5 (Dangcong et al. 2004).

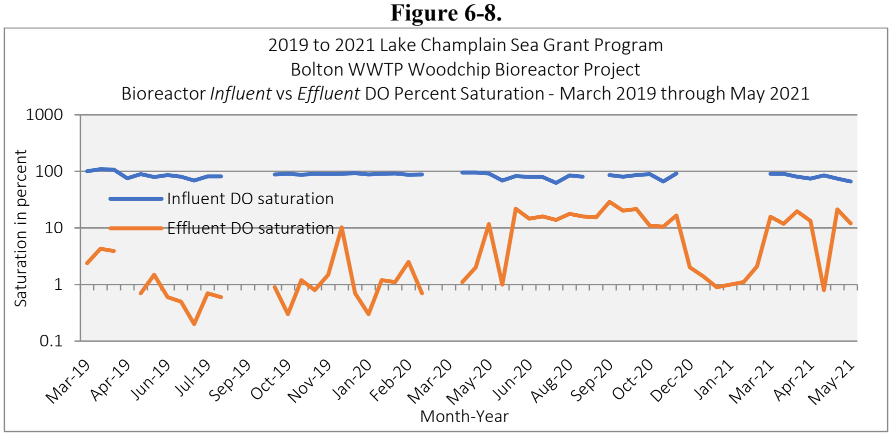
Mokhayeri (2010) stated that pH increases in denitrification process as a result of the alkalinity produced. However, a drop in pH of the bioreactor influent was observed during the second half of our study and it is unknown if this drop was the result of wastewater operations or influence from the bioreactor material.

Dissolved oxygen (concentration and percent saturation). Dissolved oxygen (**DO**) affects ground water quality and is required for the respiration of aerobic microorganisms and decomposition in the subsurface soils by microorganisms that metabolize the organic material moving through the soil interstices. The maximum concentration of **DO** that can occur in water is a function of temperature, with higher concentrations of **DO** occurring at low water temperatures than at high temperatures.

The denitrification process in the bioreactor is maximized by anoxic, or low **DO**, conditions, preferably less than 0.2 mg/L (Seitzinger et al. 2006). Heterotrophic bacteria reduce nitrate (NO_3-N) to nitrogen gas (N_2) in the presence of an organic carbon source and lack of oxygen. It has been reported that long retention times can provide adequate time to deplete **DO** levels as laboratory tests have shown that the time required to deplete the **DO** levels in **DO**-saturated water is approximately 1 hr. in aged, 2-year-old woodchip media (Robertson, 2009).

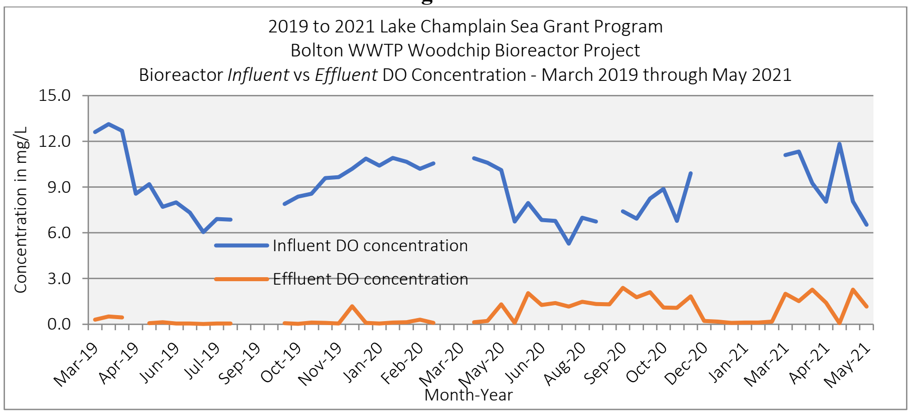
A comparison of the *influent* and *effluent* **DO** saturation levels for the bi-weekly sampling is presented in Figure 6-8. The *y-axis* of the figure is in logarithm scale instead of normal scale to provide a better representation of the data.

Figure 6-8.



A comparison of the *influent* and *effluent* **DO** concentrations for the bi-weekly sampling is presented in Figure 6-9.

Figure 6-9.



The *influent* **DO** concentration and saturation ranged from 5.3 mg/L and 62.6 percent to 13.1 mg/L and 109.5 percent, with mean values of 8.9 mg/L and 85.0 percent, respectively. The *effluent* DO concentration and saturation ranged from 0.02 mg/L and 0.2 percent to 8.03 mg/L and 75.0 percent, with mean values of 0.95 mg/L and 8.2 percent, respectively. The average reduction in **DO** concentration was just under 90 percent, from 8.9 mg/L to 0.95 mg/L and the average reduction in **DO** saturation was just over 90 percent, from 85.0 percent to 8.2 percent.

Upon review of the data, higher influent **DO** concentration coincided with greater depth of water in the bioreactor monitoring wells, which could be attributed to the water elevation being closer to the surface where there could be oxygen exchange through the permeable filter fabric used to seal the woodchip bioreactor. Also, higher **DO** concentrations of the *influent* coincided with winter months when the water temperature was lowest allowing for increased **DO** concentrations. Additionally, the *effluent* **DO** saturation and concentration were higher during the second half of the study.

The **DO** Meter used in the study was a YSI 55 handheld dissolved oxygen meter. The unit has a replaceable membrane and measures water temperature and dissolved oxygen. The unit is one of the older models and has a slow measurement stabilization rate.

The newer model, the YSI ProDigital meter, utilizes optical sensor technology and has an internal self-calibration capability. Its response time is far quicker than the old Model 55, which since has been discontinued by YSI. Some of the higher **DO** data may reflect the instrument's slow response time, especially during colder field conditions.

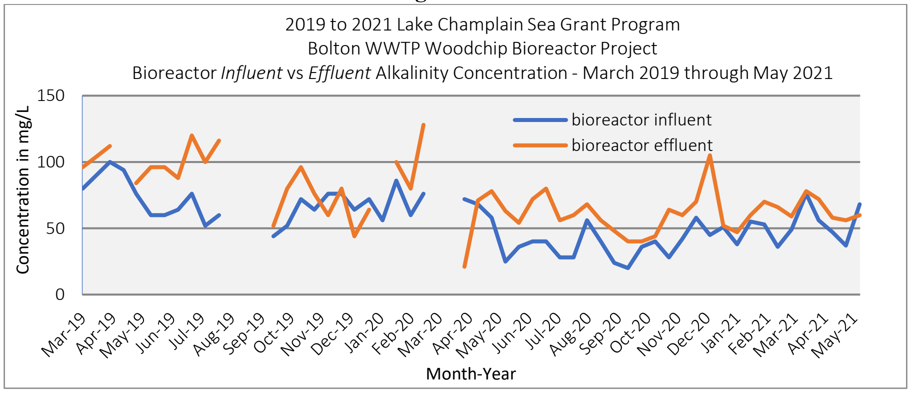
Alkalinity. This analyte is a measure of the capacity to neutralize acids and in wastewater results from the presence of the hydroxides, carbonates, and bicarbonates of elements such as calcium, magnesium, sodium, potassium or of ammonia. Wastewater is normally alkaline, receiving its alkalinity from the water supply, ground water and the material added during domestic use.

The concentration of alkalinity in wastewater is important for this study where ammonia is removed as part of nitrification and converted to nitrate. Aerobic bacteria can use ammonia for food and use DO to convert ammonia to nitrates. To adequately nitrify, alkalinity levels should be a minimum of eight times the level of ammonia in wastewater.

In denitrification, alkalinity is generated at 3.57 g of $CaCO_3$ (mg/L alkalinity) per gram of NO_3-N reduced to N_2. Therefore, a good/poor nitrogen removal and short-cut nitrification/denitrification can be indicated or validated by alkalinity values and alkalinity difference between influent and effluent (Li 2007).

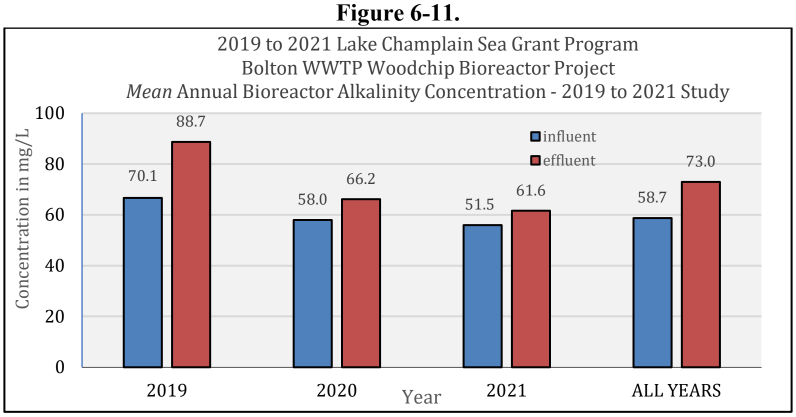
A comparison of influent and effluent bioreactor alkalinity from the bi-weekly sampling excursions for the study is presented in Figure 6-10.

Figure 6-10.



The *mean* annual alkalinity values of the bioreactor *influent* and *effluent* measured during the study are summarized in Figure 6-11.

Figure 6-11.



As evident from the data in Figure 6-11, the *mean* concentration of alkalinity in the bioreactor *influent* decreased between 2019 and 2020 from 70.1 to 47.3 mg/L then increased slightly to 51.5 mg/L during 2021. The alkalinity in the bioreactor *effluent* exhibited a continual decrease in *mean* concentration during the study from 88.7 to 66.2 to 61.6 mg/L. The difference between the mean alkalinity of the bioreactor *influent* and *effluent* increased through the study from +18.67 to +18.9 to +10.1 mg/L.

Alkalinity is lost during *nitrification* (conversion of ammonia to nitrate), and alkalinity is produced during *denitrification* (conversion of nitrate to nitrogen gas). Important parameters for *denitrification* are anoxic conditions (DO should be less than 1 to 2 mg/L with optimum concentration of 0.2 mg O_2/L) (Seitzinger et al. 2006) , pH (can occur between pH 7.0 to 8.5; recommended range of 7.2) (Dangcong et al. 2004), temperature (optimum range between 20ºC to 35ºC but occurring as low as 3ºC) (Robertson and Merkley (2009) and available carbon.

Other variables include the concentration of nitrate available (higher concentration creates greater availability), temperature and retention time. As shown by the data (Figure 6-11), there was an increase in alkalinity from the *influent* to the *effluent*, indicating occurrence of denitrification.

6.1.3 Nutrients

Nitrogen. An important nutrient used by phytoplankton and aquatic plants to produce biomass in streams, lakes, and ponds. Sources of nitrogen include wastewater treatment plants, runoff from fertilized lawns and croplands, failing septic systems, runoff from animal manure and storage areas to name a few.

The principal forms of nitrogen of concern to wastewater treatment are **total nitrogen (TN), total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), organic nitrogen (ON), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N) and nitrogen gas (N_2)**. **TN** includes all forms of nitrogen found in water and consists of organic and inorganic forms that include nitrate (NO_3^-), nitrite (NO_2^-), ionized ammonia (NH_4), un-ionized ammonia (NH_3^+) and nitrogen gas (N_2).

The relationships of these forms of nitrogen are as follows:

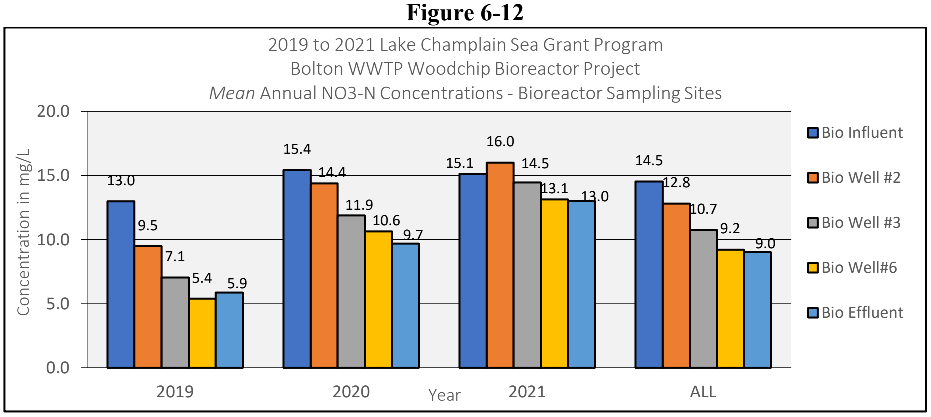
Total nitrogen (TN) = Organic nitrogen (ON) + Ammonia-nitrogen (NH_3-N) + Nitrate-nitrogen (NO_3-N) + Nitrate (NO_2)

TKN consists of **NH_3-N** and **ON**. A municipal WWTP with an effluent containing more than 5 mg/L of TKN is not fully nitrifying. **NH_3-N** is the first inorganic nitrogen product of organic decomposition by bacteria and is present in lake water primarily as NH_4^+ and NH_4OH. Ammonia (NH_3) is un-ionized; ammonium (NH_4^+) is ionized. pH is the major environmental variable that determines the proportion of NH_3 or NH_4^+ in water.

NO_3-N is produced by the bacterial conversion of organic and inorganic nitrogenous compounds from a reduced to an oxidized state and is readily assimilated by algae and green plants. Collectively, **nitrate** and **ammonia** provide most of the nitrogen available for assimilation by green plants. In the present study, only **NO_3-N** and **NH_3-N** were included in the test pattern for chemical analytes.

The *mean* annual **NO_3-N** data measured at the five sampling sites along the woodchip bioreactor unit processor during the study are presented in Figure 6-12.

Figure 6-12



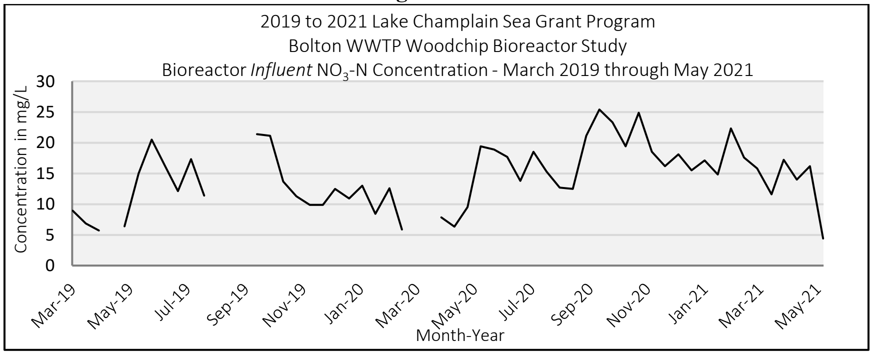
The *mean* **NO_3-N** concentration among the bioreactor sampling sites varied from 5.4 (Bio Well #6 – 2019)) to 16.0 mg N·L (Bio Well #2 – 2021). The general trend for NO_3-N concentration in the series of bioreactor well sites was a decrease from *influent* to *effluent*, indicating successful denitrification in the bioreactor.

As shown in Figure 6-12, the difference between *mean* annual *bioreactor influent* and *effluent* **NO_3-N** decreased over the study period from 7.1 (2019) to 5.7 (2020) to 2.1 mg N·L (2021) with an overall *mean* reduction of 5.5 mg N·L. The percentage of **NO_3-N** reduction decreased annually from 54.7% (2019) to 37.0% (2020) to 13.9% (2021) with an overall reduction of 37.8% during the study.

Overall, the bioreactor reduced *effluent* **NO_3-N** concentration to a mean of 9.02 mg N·L, which is below the 10 mg N·L ground water standard stated in the SPDES permit for the operation of the Bolton facility.

The seasonal NO3-N concentrations for the bioreactor influent during the period of the study from March 2019 through May 2021 are presented in Figure 6-13.

Figure 6-13.



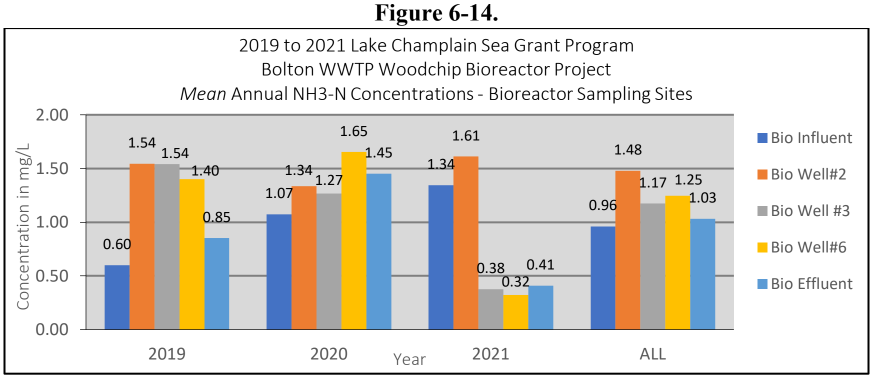
Conditions that could have influenced the reduction of denitrification through the bioreactor process over time could be the higher **NO_3-N** concentrations in the bioreactor *influent* indicating changes in wastewater characteristics. During 2020, the seasonality of the Bolton WWTP can be seen in the high influent NO_3-N concentrations to the bioreactor starting in late May, increasing significantly in mid-September, and remaining high through February 2021 (Figure 6-13). At times, the 2020 and 2021 influent nitrate concentrations were twice the concentrations measured in 2019.

The degradation of the woodchips in the bioreactor, the carbon source, could also be another factor in reduced *denitrification*. Other metrics that effect *denitrification* efficiencies are water temperature, quantity of water treated through the bioreactor and retention time, discussed elsewhere in this chapter.

We hypothesize that the decrease in **NO_3-N** removal efficiencies during cold weather, when wastewater temperatures are single digits (^oC), is due to insufficient available carbon. The bioreactor woodchips are the source of carbon for the denitrifying bacteria, and historic and recent research indicates temperature sensitivity of cellulolytic bacteria (Holt et al. 1983, Desvanx 2006, Jang et al. 2019). Researchers at Stony Brook University Center for Clean Water Technology have been investigating the growth dynamics of cellulolytic bacteria in the Center's Nitrogen Removing Biofilters (NRBs) through the various seasons (unpublished). Sobiezuk et al. (2006) and other have identified the variability of the COD/N ratio as it relates to microbial denitrification. Narkis et al. (1979) have defined a BOD/NO_x-N ratio of 2.3 to ensure 100% denitrification. The impact of lowered wastewater temperatures, the reduced availability of a carbon source during cold weather due to the temperature sensitivity of cellulolytic bacteria, and the requisite C/N ratio for successful nitrate reduction present important areas for future research.

The *mean* annual **NH3-N** concentrations for the bioreactor sampling sites are presented in Figure 6-14.

Figure 6-14.



The bioreactor sampling site **NH3-N** concentrations varied from 0.32 mg N·L (Bio Well #6 – 2021) to 1.65 mg N·L (Bio Well #6 – 2020). There was no trend apparent for **NH_3-N** in the series of bioreactor sample sites during the study.

The increase in *effluent* **NH3-N** concentrations between 2019 (0.85 mg N·L) and 2020 (1.45 mg N·L) may be explained in two (2) ways. First, WWTP operation staff noted seasonality of high **NO3-N** *effluent* concentrations, which suggest that a seasonal influx of **NH3-N** might be occurring within the wastewater treatment flow path. This influx would have to enter the system prior to the trickling filter, since the Bolton WWTP trickling filter successfully nitrifies throughout the year. It is suspected that accumulated sludge within the Imhoff tank is releasing **NH3-N** back into the waste stream under anaerobic conditions during this time of year. The Bolton Imhoff tank acts as a primary clarifier as well as the repository for secondary clarifier solids and tertiary filtration reject water. To verify the hypothesis, operations staff began to monitor the concentration of **NH3-N** and alkalinity through the wastewater treatment train. In September 2020, sampling indicated *influent* bioreactor alkalinity levels of less than 20 mg/L, indicating extraordinary nitrification through the WWTP trickling filter.

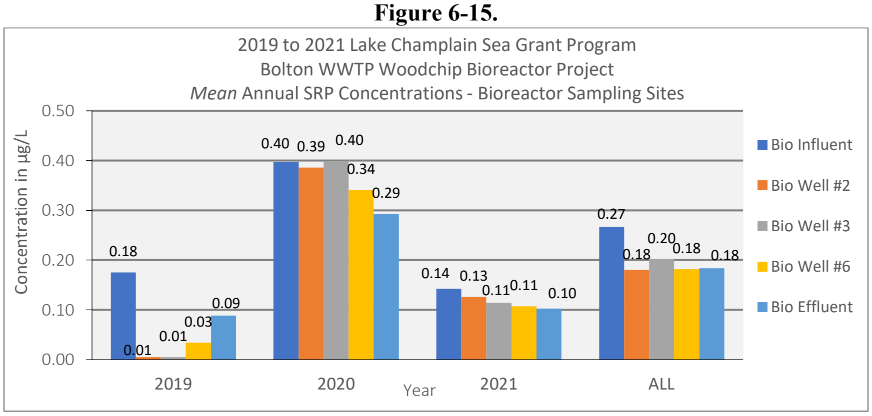
Second, in December 2020, bioreactor sampling showed significant **NH3-N** production within the bioreactor, where *influent* **NH3-N** of 0.95 mg N·L increased to a concentration of 8.96 mg N·L in the bioreactor *effluent*. There was a significant increase in alkalinity, which could not be correlated to the stoichiometric relationship of alkalinity recovery from *denitrification* (i.e., each mg/L of **NO3-N** removal returns 3.57 mg/L of alkalinity). This unexpected event may have been an indication of *ammonification*, as seen and described in Lepine et al. 2016. However, subsequent sampling events in January 2021 did not indicate any *ammonification* and **NH3-N** was reduced through the bioreactor. Continued attention was directed toward the issue of *ammonification* or dissimilatory reduction of nitrate to ammonium (*DRNA*) in early 2021 but there was no evidence of DRNA through the bioreactor.

Heterotrophic denitrification and DRNA are two microbial processes competing for the resources of **NO3-N** and organic carbon (COD). Various environmental conditions (i.e., oxidation state of the media, carbon/nitrogen ratio, pH, temperature, and microbial species) favor *DRNA* over *denitrification* (Lepine et al. 2016). The cause of this unusual *ammonification* event may have been due to accumulated suspended solids or microbial decomposition, but the cause was not definitively determined.

Phosphorus. The control of phosphorus from municipal wastewater treatment plants is a key factor in preventing eutrophication of surface waters because this nutrient can impair water quality at much lower concentrations than nitrogen. The usual forms of phosphorus that occur in wastewater solutions include (1) **inorganic phosphorus** from detergents and household cleaning products such as soap, which are present as **orthophosphate** and are referred to as available or reactive P, and **polyphosphate**, which is comprised of orthophosphate molecules linked together in chains derived from detergents and other cleaners, and (2) **organic phosphate**, which is contributed by human feces and food residues.

The current monitoring program measured **soluble reactive phosphorus (SRP)** and the annual *mean* concentrations are presented in Figure 6-15.

Figure 6-15.

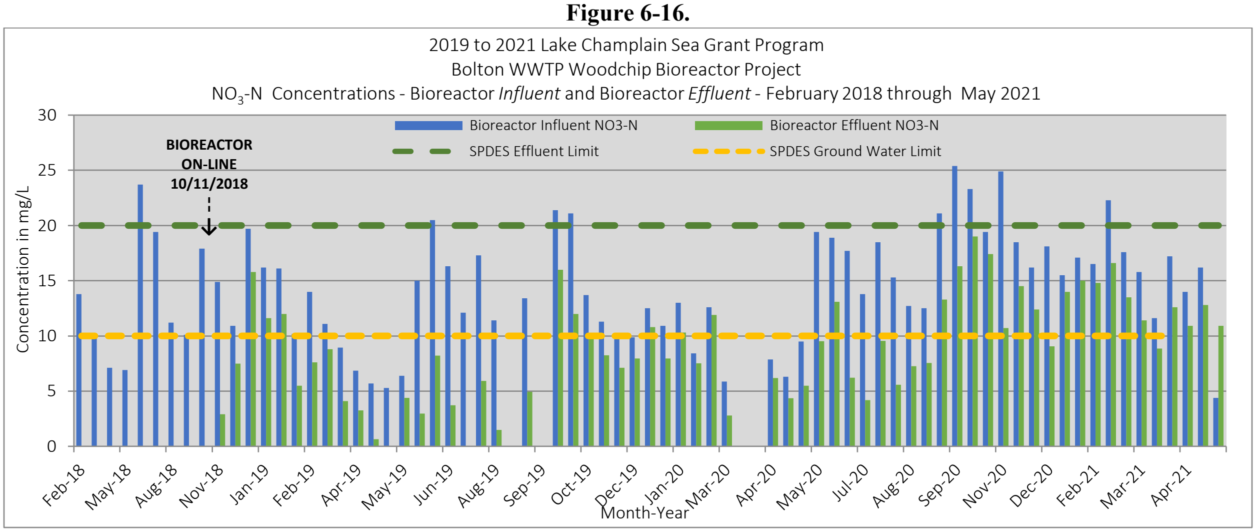


As shown in Figure 6-15, there was a reduction from *mean* annual *influent* to *effluent* **SRP** each year during the study with an average reduction in **SRP** over the study period of 33 percent.

6.2 Variability in Bioreactor Treatment Efficiency

Denitrification is the conversion of nitrate (NO_3) to nitrogen gas (N_2). Denitrifying bioreactors are an approach where solid carbon substrates (often fragmented wood products) function as a carbon and energy source to support the anaerobic bacteria. This technology was installed at the Bolton WWTP as a pilot project in 2018 to investigate the potential for cost-effective nitrate reduction. The following graph, Figure 6-16, summarizes the **NO_3-N** concentrations for Bolton WWTP treated *effluent* entering the *influent* chamber of the bioreactor and the corresponding concentrations of **NO_3-N** in the *effluent* leaving the bioreactor and then being discharged at one of the facility's upper sand beds.

Figure 6-16.



The following graph, Figure 6-17, summarizes the percent removal of NO_3-N from the Bolton WWTP effluent that enters the bioreactor:

Figure 6-17.

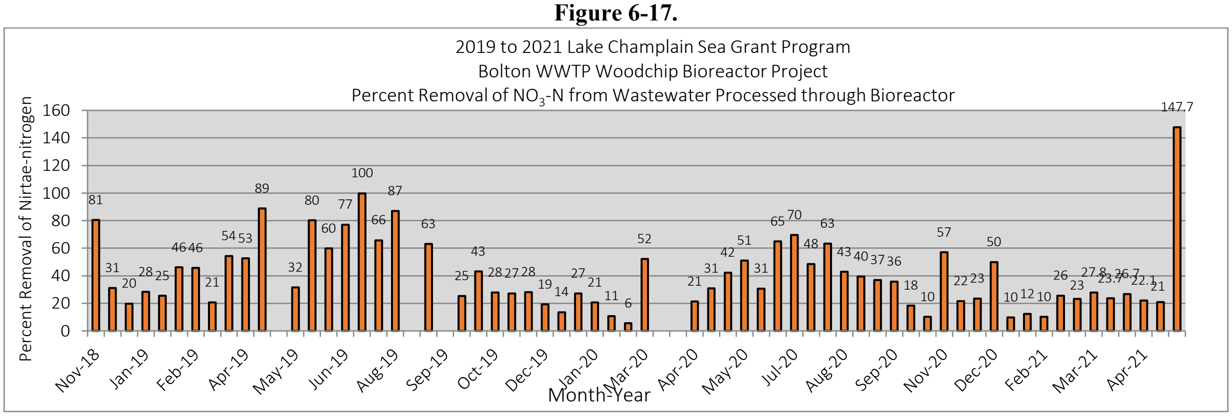


Table 6-3 summarizes some of the important operational metrics of the Bolton WWTP woodchip bioreactor across seasonal variations in the WWTP operations since August 2019. As shown by the data, the efficiency of NO_3-N removal varied throughout the study and there are various operational parameters influencing the degree of denitrification within the woodchip bioreactor, including water temperature, *influent* nitrate concentration, dissolved oxygen levels, detention time, and availability of a suitable carbon source (Schipper et al. 2010). These operational parameters, and others, are discussed below.

Table 6-3.

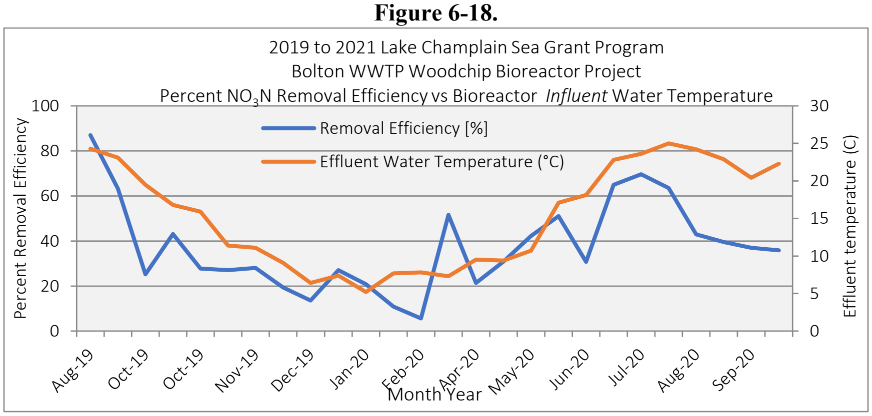
Date	Bioreactor Influent [mg/L]	Bioreactor Effluent [mg/L]	Removal Efficiency [%]	Effluent Water Temperature [°C]	Flow (gpd)	Estimated Residence Time [hrs.]	N Removal [lb./day]	N Removal [g/m3/day]
8/6/19	11.4	1.5	87.0	24.3	89,801	5.8	7.4	9.9
9/3/19	13.4	4.9	63.2	23.1	119,484	4.3	8.4	8.5
10/1/01	21.4	16.0	25.2	19.5	97,461[1]	5.3	4.4	5.4
10/15/1	21.1	12	43.1	16.8	92,868	5.6	7.1	9.1
10/29/1	13.7	9.9	27.8	15.9	87,659	5.9	2.8	3.8
11/11/1	11.3	8.2	27.1	11.4	92,012	5.6	2.3	3.1
11/26/1	9.9	7.1	28.1	11.1	85,145	8.6	2.0	2.8
12/10/1	9.9	8.0	19.4	9.1	89,880[2]	6.7	1.4	1.9
12/23/1	12.5	10.8	13.6	6.4	83,529	8.3	1.2	1.7
1/7/20	10.9	7.1	27.1	7.4	86,931	8.2	2.1	3.0
1/21/20	13.1	8.0	20.8	5.2	76,369	9.3	1.7	2.7
2/4/20	8.4	7.5	10.8	7.7	73,482	10.0	0.6	0.9
2/19/20	12.6	11.9	5.6	7.8	87,535	8.4	0.5	0.7
3/3/20	5.9	2.8	51.6	7.3	89,192[3]	8.2	2.3	3.0
4/14/20	7.9	6.2	21.3	9.5	88,720	8.7	1.2	1.7
4/28/20	6.3	4.4	30.9	9.4	89,197	8.2	1.4	1.9
5/12/20	9.5	5.5	42.3	10.7	80,737	9.6	2.7	4.0
5/26/20	19.4	9.5	51.0	17.1	62,247	11.1	5.1	9.9
6/9/20	18.9	13.1	30.7	18.1	95,000[4]	6.8	4.6	5.8
6/23/20	17.7	6.2	64.9	22.8	88,458	6.8	8.5	11.5
7/7/20	13.8	4.2	69.7	23.6	89,551	7.2	7.2	9.6
8/4/20	15.3	5.6	63.5	25.0	81,717	6.8	6.6	9.7
8/18/20	12.7	7.25	42.9	24.2	99,924	5.2	4.5	5.5
9/1/20	12.5	7.56	39.5	22.9	64,657	8.7	2.7	4.9
9/15/20	21.1	13.3	37.0	20.4	82,371[5]	6.8	5.4	7.8
9/29/20	25.4	16.3	35.8	22.3	78,825	6.6	6.0	9.1
10/13/2	23.3	19.0	18.4	16.9	84,537	5.1	3.0	4.3
10/27/2	19.4	17.4	10.3	15.0	84,922[6]	7.6	1.4	2.0
11/10/2	24.9	10.7	57.0	14.8	55,000[7]	14.1	6.5	14.2
11/24/2	18.5	14.5	21.6	11.0	53,723[8]	8.8	1.8	4.0
12/8/20	16.2	12.4	23.5	8.8	62,681[9]	8.2	2.0	3.8
12/22/2	18.1	9.1	49.9	6.9	60,618	10.7	4.6	9.0
1/5/21	15.5	14.0	9.68	7.5	54,303	14.3	0.7	1.5
1/19/21	17.1	15.0	12.3	6.8	69,209	8.7	1.2	2.1
2/2/21	16.5	14.8	10.3	4.8	38,646	13.4	0.5	1.7
2/16/21	22.3	16.6	25.6	5.5	42,403	13.2	2.0	5.7
3/2/21	17.6	13.5	23.3	5.3	58,230	5.9	2	4.1
3/16/21	15.8	11.4	27.8	5.9	39,123	13.2	1.4	4.4
3/31/21	11.6	8.9	23.7	9.3	30,103	20	0.7	2.7
4/13/21	17.2	12.6	26.7	12.8	61,357	7.7	2.4	4.6
4/27/21	14	10.9	22.1	9.9	65,518	7.6	1.7	3.1
5/11/21	16.2	12.8	21	12.9	77,397	8.3	2.2	3.4

[1] No flow data on 10/1/19 so numbers from 10/8/19 were used.
[2] No flow data on 12/10/19 so numbers from 12/12/19 were used.
[3] Inaccurate flow meter readings in bioreactor from 3/3/20. Value in table is based on percentage of total WWTP flow going through Bioreactor (63.8%) from 3/5/20 and this was applied to 3/3/20 total WWTP to estimate bioreactor flow.
[4] No flow data on 6/9/2020, flow adjusted from 6/8/2020 was used.
[5] No flow data on 9/15/20 so numbers from 9/9/20 were used.
[6] No flow data on 10/27/20; numbers from 10/26/20 were used.
[7] No flow data on 11/10/20; manual measurement was conducted.
[8] No flow data on 11/24/20; numbers from 11/25/20 were used.
[9] No flow data on 12/8/20; numbers from 12/11/20 were used.
[10] On 2/2/21, we believe that the laboratory switched (or mis-read) labels on bottles because influent nitrate as 14.8 mg/L and effluent was 16.5 mg/L and alkalinity stoichiometric calculations showed that nitrification did occur in the bioreactor.
[11] On 2/16/21, the water level seems lower than normal; we suspect volumetric removal rate to be overestimated.

6.2.1 Influent Wastewater Temperature

This variable has a significant impact on the degree of *denitrification*, as documented in this study and on-site field research by others (Christianson et al. 2012). Biological denitrification can occur between 5C and 30C, with an increase in efficiency as water temperature increases. For the Bolton bioreactor, the summertime seasonal high wastewater temperatures promoted increased removal efficiencies. During the cold Adirondack winter season, efficiencies dropped off to 20% or less, with wastewater temperatures dropping to less than 6C. The comparison between bioreactor *influent* wastewater temperature and NO_3-N removal efficiencies is summarized in Figure 6-18.

Figure 6-18.



Low water temperature during cold seasons significantly limits the bioreactor performance, which is likely related to low metabolic activity of denitrifying microorganisms at low temperatures (Christianson et al. 2012b, David et al. 2016). There is no practical method to increase these seasonally low wastewater temperatures. An operational modification to increase hydraulic residence time during colder weather periods does seem to be slightly effective.

6.2.2 Hydraulic Residence Time (HRT)

HRT within the bioreactor also has a significant impact on the extent of *denitrification*. Longer retention times, eight (8) or more hours, especially during the colder winter season, improves efficiency (Din Dar et al. 2020). For example, during the eighth quarter of this study, the flows treated within the bioreactor were reduced from flows of the previous quarter to verify the extent of denitrification as the hydraulic retention time increased. The results varied. The March 2, 2021, sampling event had a calculated **HRT** of 5.9 hours, water temperature of 5.3C with a nitrate reduction of 23.3 percent: the March 31, 2021, sampling event had a calculated **HRT** of 20 hours, water temperature of 9.3C with a nitrate reduction of 23.7 percent. For further comparison, the November 10, 2020, sampling event had a calculated HRT of 14.1 hours, water temperature of 14.8C and a nitrate removal of 57 percent.

Retention time is not the only variable at play here; there are a myriad of environmental factors contributing to the extent of *denitrification* within the woodchip bioreactor. The availability of a suitable carbon source, coupled with the influent **NO_3-N** concentrations and dissolved oxygen levels, all impact the *denitrification* process synergistically. From a theoretical perspective, the longer retention times would improve efficiency. Excessive retention times, however, have the potential to exhaust the nitrate supply, driving methyl mercury production as a byproduct of further anaerobic biological processes.

6.2.3 Internal Hydraulics

Internal hydraulics of the woodchip bioreactor also contribute to the efficiency of *denitrification*. As documented in the later stages of the Bolton bioreactor study, the woodchips in certain regions became plugged with biological and organic solids, greatly affecting the internal hydraulics. Preferential flow paths developed, leading to short-circuiting of the wastewater flow, reducing detention times, and reducing the removal efficiency. Christianson et al. (2016) researched the development of preferential flow paths with tracer tests and determined when tracer residence time was less than the theoretical HRT by more than10%, this can indicate short-circuiting.

6.2.4 Bacterial Assemblage

The bacterial assemblage within the woodchip bioreactor also impacts NO_3-N reduction. The bacterial species involved in *denitrification* prefer anaerobic conditions, preferably with a **DO** concentration <0.2 mg/L. Many of the bacterial species involved in the cycling of nitrogen are facultative, in that they can exist throughout a range of **DO** concentrations. Throughout the front end of the bioreactor, the wastewater **DO** concentrations were well above *denitrification* thresholds, thus promoting aerobic biological processes and likely contributing to the eventual plugging of the initial 6 to 8 feet of the woodchips. Another aspect of the biological assemblage within the bioreactor involves the activity of the cellulolytic bacteria, those temperature-sensitive species that convert the woodchip carbon into a soluble form for use by the denitrifying bacteria. The relationship between cellulolytic bacteria and the denitrifying bacteria, especially during the colder wastewater temperature season, is thought to affect denitrification efficiency by impacting the carbon: nitrogen ratio (personal conversation with SUNY Stony Brook researchers).

6.2.5 Carbon/Nitrogen ratio

This ratio is another operational matrix variable within the woodchip bioreactor system that impacts removal efficiency. Soluble carbon, as supplied by typical wastewater constituents or by the activity of the cellulolytic bacteria, is critical for proper *denitrification*. A ratio of 4.67:1 (C:N) has been reported in the literature as optimal for biological *denitrification* using glucose, sodium acetate and/or methanol (Sobieszuk 2006). However, a more recent research paper (How et al. 2021) identified C/N ratios of 2 to 3 for an up-flow sludge blanket (USB) reactor for domestic wastewater. Even at these lower C/N ratios, it is obvious that during low temperatures and the reduced metabolism of the cellulolytic bacteria, enhanced *denitrification* would be challenging. The **BOD_5** of the Bolton plant tertiary *effluent* rarely goes above 5 mg/L; chemical oxygen demand (**COD**) of the *effluent* is not measured directly. Bioreactor *influent* samples indicate a Dissolved Organic Carbon (**DOC**) concentration typically <1.0 mg/L.

The Bolton woodchip bioreactor was designed for tertiary treatment of municipal wastewater, which at the bioreactor *influent* was devoid of residual carbon sources. The **BOD_5** of the bioreactor influent was typically less than 5 mg/L, coupled with low suspended solids. There were periods when clarifier solids were carried over into the *influent* to the bioreactor, yet during these times the bioreactor was taken offline to protect its integrity.

6.3 General Description of Bioreactor Influent and Bypass Flow (Bed Effluent)

The Bolton woodchip bioreactor was designed to allow a variable *influent* flow, controlled by the gate valve on the *influent* line, with the gate valve manually adjusted by operations staff. The *influent* gate valve controls the flow from the reservoir into the Agri Drain structure and is a rough control which does not offer fine tuning flow adjustment. The *influent* control valve was a site-specific addition to the bioreactor application in a wastewater treatment plant intended to provide a more constant flow. As discussed previously, all tertiary effluent from the main Bolton WWTP facility is discharged to either the "lower sand infiltration beds" by gravity or is routed to the "upper sand infiltration beds" through a simplex pump station. This pump station discharges into a 2,000-gallon concrete reservoir, from which the bioreactor is dosed on a continuous basis. It should be noted that the *influent* chamber/reservoir is designed to be above grade to provide gravity flow with the discharge from the reservoir above the highest stop log elevation of the Agri Drain structure (see Figure 6-19 for component details).

The pump to the upper beds is a Gorman Rupp with a reported duty point of 350 gpm @ 54 ft. TDH. The pump cycles frequently during the summer busy season, approximately 30 to 40 times/hour. Within the reservoir is an overflow pipe, set at a higher elevation than the bioreactor feed pipe, so that any excess *effluent* not treated through the bioreactor flows by gravity through a separate underground pipe which runs parallel to the bioreactor and connects to the bioreactor discharge in a newly installed manhole specifically to allow sampling of the bioreactor *effluent*.

Figure 6-19.

Flows are measured by a Greyline flow meter, an in-pipe flow meter, installed in the 6-inch PVC discharge line from the bioreactor. This combined *effluent*, consisting of a blend of both denitrified *effluent* and non-denitrified *effluent*, flows by gravity into one of four (4) active "upper sand infiltration beds". This combined final *effluent* is the "*bed effluent*". The use of the infiltration sand beds is an operator decision, based on how much flow is being treated (i.e., bed #8 is the largest bed and can handle a large flow volume for many days). Otherwise, beds are rotated anywhere from 3 to 4 days, depending on the season and ground water levels (i.e., bed #11 is seasonally impacted by high ground water).

The percentage of denitrified and non-denitrified *effluents* in this *bed effluent* varies daily and diurnally and is a function of the flow characteristics from the 2,000-gallon reservoir. The by-pass in the reservoir is simply an open pipe custom drilled above what is expected to be the very high flow event water level. Under most conditions, the bypass would see flow during the busy summer diurnal time periods. Again, the bypass flow would be minor during off-season times or middle of the night. The operators adjust the flow coming from the equalization tank, based on their experience, to maintain constant flow through the downstream unit processes. It should be noted that when the "*bed effluent*" sample is collected, it is an instantaneous grab sample, representing the flow pattern at that specific time.

6.4 Stoichiometry/Mass Balance of Denitrification

Denitrification is a microbially facilitated process where nitrate (NO_3^-) is reduced and ultimately produces molecular nitrogen gas (N_2) through a series of intermediate gaseous nitrogen oxide products. Facultative anaerobic bacteria perform *denitrification* as a type of respiration that reduces oxidized forms of nitrogen in response to the oxidation of an electron donor such as organic matter.

Denitrification occurs in anoxic conditions by heterotrophic bacteria where an organic carbon source and no oxygen are present. The *denitrification* rate is affected by the type and amount of carbon source. In the woodchip bioreactor, the development of the anoxic zone occurs under saturated conditions that limit oxygen transfer. In the woodchip bioreactor, wood chips provide the organic substrate with simple carbohydrates in the form of cellulose. Under these conditions, bacteria utilize the combined oxygen to process (oxidize) the available carbon.

The forms of nitrogen are as follows:

$$NO_3^- \longrightarrow NO_2^- \longrightarrow NO \longrightarrow N_2O \longrightarrow N_2$$

Each step is enacted by specific enzymes that are in charge of the production of the intermediate products listed. Under the conditions in which **DO** concentration in solution is quite low, N_2 is expected to be the final product; but, more intermediate of variable **DO** levels may arrest denitrification with the formation of NO_x (Bradley and Weil, 2002).

The general reaction for complete denitrification relating NO_3^- and organic matter forms N_2, carbon dioxide (CO_2) and bicarbonate (HCO_3) is as follows:

$$5CH_2O \ + \ 4NO_3^- \longrightarrow 2N_2 \ + \ HCO_3^- \ + \ CO_2 \ + \ 3H_2O$$

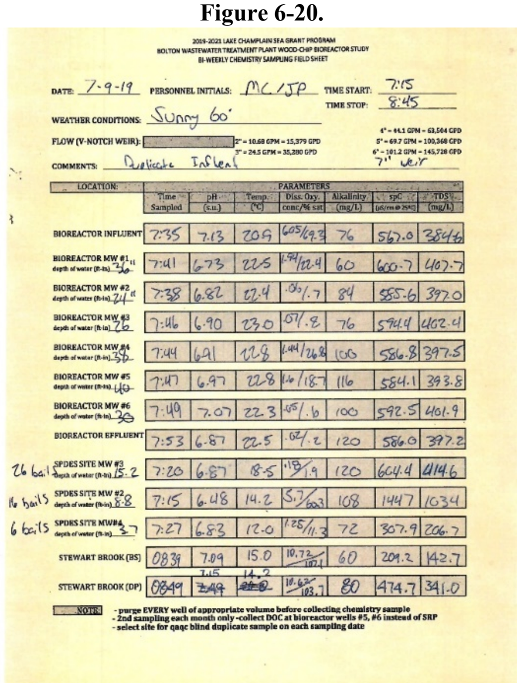
Based on the specified stoichiometry of the *denitrification* reaction above, 1.25 moles of dissolved organic carbon are capable of reducing each mole of NO_3^- to N_2 if the **DO** level in the solution is low enough not to inhibit the process. The HCO_3^- is of interest because this release of alkalinity increases the solution's pH. The recommended pH range for denitrification is 7.0 to 7.5.

The variability in *denitrification* rates may be ascribed to varying environmental conditions such as nitrate concentrations, temperature, and organic carbon availability.

6.5 Operation of Bioreactor

During the operation of the Bolton WWTP woodchip bioreactor, staff conducted daily monitoring of the facility and unit processor. The woodchip bioreactor was commissioned in October 2018, and the LCSG monitoring program was initiated in March 2019. Prior to the LCSG monitoring program, the Bolton WWTP staff collected bioreactor samples concurrent with the monthly SPDES Permit sample collection. Beginning in March 2019, bioreactor samples were collected every two (2) weeks, as described in Chapter 5. Some of these LCSG sample dates coincided with the monthly SPDES samplings; the SPDES sampling program included six (6) hour composite samples of the Bolton WWTP influent and effluent. All the bioreactor samples were grab samples. A typical field monitoring sheet used during the LCSG sample collections is shown below in Figure 6-20.

Figure 6-20.



2019-2021 LAKE CHAMPLAIN SEA GRANT PROGRAM
BOLTON WASTEWATER TREATMENT PLANT WOOD-CHIP BIOREACTOR STUDY
BI-WEEKLY CHEMISTRY SAMPLING FIELD SHEET

DATE: 7-9-19 PERSONNEL INITIALS: MC/JP TIME START: 7:15
TIME STOP: 8:45

WEATHER CONDITIONS: Sunny 60'

FLOW (V-NOTCH WEIR): 2" = 10.68 GPM = 15,379 GPD; 3" = 24.5 GPM = 35,280 GPD; 4" = 44.1 GPM = 63,504 GPD; 5" = 69.7 GPM = 100,368 GPD; 6" = 101.2 GPM = 145,728 GPD

COMMENTS: Duplicate Influent 7" weir

LOCATION:	Time Sampled	pH (s.u.)	Temp. (°C)	Diss. Oxy. conc/% sat	Alkalinity (mg/L)	spC (µS/cm @ 25°C)	TDS (mg/L)
BIOREACTOR INFLUENT	7:35	7.13	20.9	6.05/69.3	76	567.0	384.6
BIOREACTOR MW #1 depth of water (ft-in) 36"	7:41	6.73	22.5	1.94/22.4	60	600.7	407.7
BIOREACTOR MW #2 depth of water (ft-in) 24"	7:38	6.82	22.4	.06/1.7	84	585.6	397.0
BIOREACTOR MW #3 depth of water (ft-in) 26	7:46	6.90	23.0	.07/.8	76	594.4	402.4
BIOREACTOR MW #4 depth of water (ft-in) 38	7:44	6.91	22.8	1.44/26.8	100	586.8	397.5
BIOREACTOR MW #5 depth of water (ft-in) 40	7:47	6.97	22.8	1.6/18.7	116	584.1	393.8
BIOREACTOR MW #6 depth of water (ft-in) 30	7:49	7.07	22.3	.05/.6	100	592.5	401.9
BIOREACTOR EFFLUENT	7:53	6.87	22.5	.02/.2	120	586.0	397.2
26 bails SPDES SITE MW #3 depth of water (ft-in) 15.2	7:20	6.87	18.5	.18/1.9	120	604.4	414.6
16 bails SPDES SITE MW #2 depth of water (ft-in) 8.8	7:15	6.48	14.2	5.7/60.3	108	1447	1034
6 bails SPDES SITE MW#4 depth of water (ft-in) 3.7	7:27	6.83	12.0	1.25/11.3	72	307.9	206.7
STEWART BROOK (BS)	0839	7.09	15.0	10.72/102.1	60	209.2	142.7
STEWART BROOK (DP)	0849	~~7.49~~ 7.15	~~21.0~~ 14.2	10.62/103.7	80	474.7	341.0

NOTE:
- purge EVERY well of appropriate volume before collecting chemistry sample
- 2nd sampling each month only -collect DOC at bioreactor wells #5, #6 instead of SRP
- select site for qaqc blind duplicate sample on each sampling date

Daily monitoring of the woodchip bioreactor by operation staff generally included recording the total flow to the 2,000-gallon reservoir (using the Bolton WWTP *effluent* flow meter reading), recording the daily flow through the bioreactor, and general physical observations of the bioreactor field. During snow cover conditions, the area around the monitoring wells and the *influent* and *effluent* Agri Drain control structures was cleared of snow to facilitate monitoring and sample collections. During the daily operations checks, the operators would, on occasion, verify the depth of the flow over the V-notch weir in the Agri Drain structure, primarily if the WWTP was experiencing unusually high flows or if other downstream unit processes were exhibiting any operational issues (i.e., clarifier rising sludge, trickling filter sloughing, tertiary sand filter water clarity changing, etc.) The *influent* flow control valve was not adjusted daily, as a constant flow was desired, and the *influent* flow control valve was very sensitive to even small adjustments.

Figure 6-21.

Figure 6-22.

The Bolton WWTP operations staff frequently communicated with the project collaborators on the bioreactor's operational parameters. The wastewater flow being treated through the bioreactor was carefully monitored, with consideration given to seasonal variation in total plant flow volume and wastewater temperature. During the colder weather months, the flow through the bioreactor was reduced to allow for longer detention time and improved denitrification rates. This adjustment was accomplished by adjusting the bioreactor *influent* gate valve. The Agri Drain outlet stop logs, which are 6-inch-high stiff rubber plates, also were manually adjusted to vary the depth of water within the bioreactor.

6.6 Maintenance of the Bioreactor

The BLWTP woodchip bioreactor, was designed to be an efficient, low maintenance unit process for *denitrification* of domestic wastewater. The design was based on the proven application of this technology to treat nitrate-enriched agricultural runoff, for which minimal maintenance by farmers was desired. There were several maintenance issues that surfaced during the operation of the Bolton WWTP woodchip bioreactor, including the following:

- The original construction of the bioreactor included filter fabric around the *influent* and discharge collection headers. These headers were closed-end 6-inch PVC pipe with ¾-inch holes drilled 6-inches OC around the entire pipe. The pipes were originally wrapped in filter fabric as a protective measure. Within several months of operation, the discharge header failed to pass treated *effluent* out of the bioreactor and plugging of the filter fabric was suspected. The bioreactor was taken offline, and the *effluent* end of the bioreactor was excavated in November 2018. The filter fabric was verified to be plugged with woodchip fines. The filter fabric was removed, and the accumulated *effluent* again flowed freely out of the bioreactor. Communications with other researchers indicated that similar effluent discharge header plugging issues were noted when filter fabric was used on agricultural applications (L. .Christianson, personal communications).
- In late August 2019, the Bolton WWTP woodchip bioreactor was taken offline due to surface accumulation of influent along the leading edge of the bioreactor. Plugging of the front end of the woodchip matrix was suspected. On August 23, 2019, Town personnel and a private contractor carefully excavated the front end of the bioreactor. The first six (6) feet of woodchips were removed, and replacement woodchips were installed. The removed woodchips appeared to have heavy organic accumulations and the integrity of the woodchips had broken down. At this same time the filter fabric around the influent pipe was removed. With the addition of new wood chips, the bioreactor heavy waterproof liner was reinstalled, and the bioreactor resumed its original condition. Figures 6-24 and 6-25 detail the operation and the condition of the bioreactor. It was interesting to note that the degradation of the woodchips was only noted in the first six (6) feet or so of the woodchip matrix.
- During the next year and a half of bioreactor operation, routine flushing of the bioreactor took place. This maintenance program was designed to flush out any accumulated organic buildup within the woodchip matrix on a periodic basis. The operations staff flooded the bioreactor to its maximum capacity, allowed the water to saturate the bioreactor bed, and then the *effluent* stop logs all were removed to allow water to rush out of the bioreactor. This maintenance practice was completed when the operations staff noted that the *influent* flow was decreasing and/or that water began pooling on the bioreactor surface near the *influent* end. Thereafter, the maintenance flushing was done on a monthly basis, depending upon operations staff availability. During 2020, operations staffing at the Bolton WWTP was curtailed to comply with the Town's COVID-19 pandemic response to safeguarding staff. The flushing program was successful in restoring operational efficiency, yet over time became less successful.
- In June 2021, the bioreactor experienced severe plugging issues and was shut down to prevent breaching of the structure. On June 23, 2021, the bioreactor bed was excavated the entire length to reveal the condition of the wood chips. That investigation is reported in Section 6.8.

6.7 Operational Challenges

The Bolton WWTP woodchip bioreactor described herein is a unique installation for this proven denitrification unit process. As a full-scale, on-site, in-field installation, operational challenges were to be expected, and were encountered. Those challenges helped to refine operations, and the resolution of those challenges will lead to modified design, construction, operation and monitoring of the process. Bioreactor design modifications are discussed in more detail in the following section.

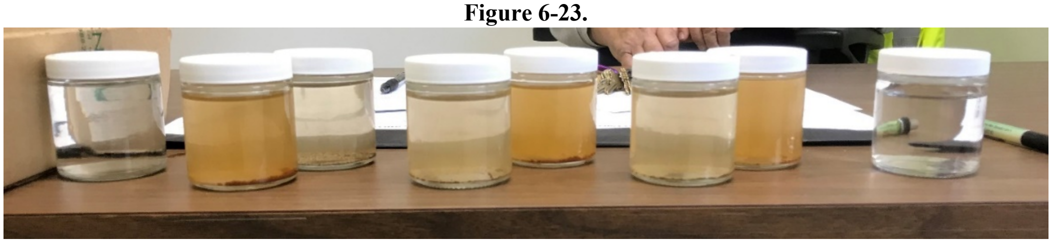
6.7.1 Media Clogging

The most challenging issue in the current woodchip bioreactor demonstration was the periodic plugging of the woodchip matrix, which appeared to be a result of several situations including buildup of fines in the media, decomposition of woodchips and possible accumulated suspended solids or microbial decomposition The discussion of the history of clogging events is presented in detail in Section 6.8.1.

6.7.2 Iron Contamination

During the latter months of 2019, all bioreactor monitoring wells were exhibiting discolored water samples. Oxidation of the bioreactor monitoring wells was suspected because the influent and effluent samples were not affected by discoloration. Please refer to Figure 6-23.

Figure 6-23.



In late December 2019, these monitoring well samples were analyzed for iron; levels as high as 339 mg/l were reported. The presence of iron in these samples prevented accurate characterization of the water relative to **NO_3-N**, alkalinity and **DO**. This situation resulted in short-term data disruption. The stainless-steel monitoring wells points were replaced by operations staff with custom 2-inch PVC wells in the same locations as the previous well points. The deeper wells were replaced but the shallower wells were never replaced and remained out of the sampling program due to the lower water levels.

6.7.3 Ammonia Concentrations and Release

The monitoring of **NH3-N** is an important parameter for operations staff. Starting in May 2020, the seasonality of the Bolton WWTP was evident with high influent **NO_3-N** concentrations to the bioreactor which increased significantly in September 2020. The bioreactor successfully reduced *effluent* **NO_3-N** concentrations below the 10 mg N·L ground water standard, except during the September 15th and September 29th sampling events, when the *influent* **NO_3-N** concentrations were double the previously measured concentrations. Operations staff noted this seasonality of high **NO_3-N** *effluent* concentrations, which suggested that a seasonal influx of **NH3-N** might be occurring within the wastewater treatment flow path. This influx would have to occur prior to the trickling filter, since the Bolton unit successfully nitrifies throughout the year. It was suspected that accumulated sludge within the Imhoff tank was releasing **NH3-N** back into the waste stream under anoxic conditions during this time of year. The Bolton Imhoff tank acts as a primary clarifier as well as the repository for secondary clarifier solids and tertiary filtration reject water. The operations staff decided to monitor the concentration of **NH3-N** and alkalinity through the wastewater treatment train. The September 29, 2020, sampling indicated influent bioreactor alkalinity levels of less than 20 mg/l, indicating extraordinary *nitrification* through the trickling filter.

The December 22, 2020, samples showed excellent **NO_3-N** removal even with low wastewater temperatures. However, this sampling also showed significant **NH3-N** production within the bioreactor, where the *influent* **NH3-N** was 0.95 mg N·L and increased to 8.96 mg N·L in the bioreactor *effluent*. There also was a significant increase in alkalinity, which cannot be correlated to the stoichiometric relationship of alkalinity recovery from *denitrification* (i.e., each mg/L of **NO_3-N** removal returns 3.57 mg/L of alkalinity).

This event was discussed with Dr. Laura Christianson, who cited a paper by Lepine et al. 2016 discussing potential of *ammonification* and was something that Dr. Christianson had experienced on occasion in her research. The next sampling event did not exhibit high **NH_3-N** or *ammonification*, and **NH_3-N** was reduced through the bioreactor. The operations staff decided to flush the bioreactor, which was a process practiced during the warmer months, but had not been conducted two months prior to the *ammonification* event. Staff continued to focus on the issue of *ammonification* or dissimilatory reduction of nitrate to ammonium, (DRNA) and no evidence of DRNA was discovered in the bioreactor. The *ammonification* event might have been caused by accumulated suspended solids or microbial decomposition.

The fate of **NH_3-N** through the Bolton WWTP system has been discussed previously, and it is noted that the trickling filter does an excellent job of nitrification. The robustness of this older technology was verified when, in late May 2021, the Bolton WWTP trickling filter was experiencing severe mechanical issues. The gravity-fed rotator arms failed to distribute wastewater uniformly over the plastic crossflow media, resulting in excess **NH_3-N** moving through the remaining downstream processes, until it arrived at the woodchip bioreactor. Interestingly, during the May 25, 2021, sampling event, the excess **NH_3-N** entered the bioreactor at a concentration of 10.1 mg N·L and was discharged at 2.67 mg N·L, with a theoretical 53 mg/L reduction in alkalinity. Clearly, the bioreactor was not denitrifying. The *influent* bioreactor **NO_3-N** concentration was 4.40 mg N·L with a discharge **NO_3-N** concentration of 10.9 mg N·L. The bioreactor during this unique operational sequence also exhibited a reduction in alkalinity, which corresponded to within 20 percent of the theoretical alkalinity consumption in *nitrification*.

6.7.4 Maintenance

Maintenance challenges that affected the operation of the bioreactor included the influent pump, flow meter, and bioreactor flushing. There were problems experienced with the pump station to the upper beds that prevented use of the upper beds and the bioreactor. Problems with the flow meter included dead batteries and loose wires, which sometimes allowed flow through the bioreactor but not the opportunity to collect data. The bioreactor flushing became a routine maintenance practice for operations staff, which took the bioreactor offline and temporarily reduced efficiency by requiring the reestablishment of microbes and bacteria.

6.8 Bioreactor Shutdown Due to Plugging

Woodchip bioreactors have demonstrated their ability to use porous wood material to create an environment conducive for the process of *denitrification* to occur. However, there is concern demonstrated in various research papers for the potential of clogging of the material that will reduce the efficiency of *denitrification* and possibly lead to hydraulic failure. The following discusses bioreactor clogging during this current study.

6.8.1 Progression of Events

The woodchip bioreactor pilot project began accepting *effluent* from the Bolton WWTP in October 2018. There was success from the beginning of the monitoring study (March 2019) with a 64 percent reduction in **NO_3-N** in the first quarter of the study. However, during the second quarter, the bioreactor was taken offline on August 16, 2019, due to breaching along the bioreactor's influent face. On August 23, 2019, the cause of this breaching was found to be waterlogged and plugged wood chips within the first five (5) feet of the 100-foot-long bioreactor bed (see Figures 6-24 and 25).

The area appeared to be filled with biological solids, likely from enhanced biological activity during the warm summer season, when wastewater temperatures were approaching 25C. The compromised wood chips were removed and replaced with new wood chips from the original installation stockpile. The bioreactor was put back online August 26, 2019, and within a week, removal efficiency was at 63%.

During the warmer months of 2019 and the first year of the study (March 2019 through February 2020), when wastewater effluent temperatures at the Bolton WWTP reached 25C, the level of water in the bioreactor had to be reduced to limit both the retention time and the complete consumption of the influent nitrate by the denitrifiers. To facilitate shorter retention time, several of the effluent weirs were removed, reducing the level of wastewater in the bioreactor to below the mid-level monitoring well depths. This situation created a larger zone that was not saturated, increasing the aerobic zone. The removal of the weirs possibly created more hydraulic forces in the bioreactor that could have caused compacting or moving woodchips. This lower water level also was experienced in the fourth quarter of the study, i.e., the shallow sampling wells in the bioreactor remained out of the sampling program due to seasonally lower water levels in the unit, resulting in a greater unsaturated zone in the top half of the bioreactor.

Figure 6-24.

Figure 6-25.

During the 10th quarter of the study (April 2021 through June 2021), the **NO_3-N** removal efficiency of the woodchip bioreactor consistently decreased from about 27 percent to 21 percent, even as the water temperature increased and the flow through the bioreactor was reduced. On May 2021, there was an increase in **NO_3-N** concentration through the bioreactor, this event coincided with the malfunctioning of the Bolton WWTP's trickling filter. **NH_3-N** was not being adequately nitrified through the trickling filter. **NH_3-N** remained in the wastewater *influent* to the bioreactor, where *nitrification* occurred, resulting in an increase in **NO_3-N** concentration in the bioreactor *effluent*. Additionally, wastewater solids were being carried over into the bioreactor, which ultimately plugged and was taken offline on June 1, 2021. At a project meeting of the researchers on June 17, 2021, it was decided to perform an exploratory investigation of the bioreactor.

6.8.2 Exploratory Investigation

The exploratory investigation of the bioreactor occurred on June 23, 2021. Local contractor, Barry Kincaid, who provided the original bioreactor wood chip material and aided in construction, provided a rubber tract, small excavator to perform the forensic examination. After discussion, it was determined to excavate a trench down the center of the bioreactor to the full depth of the material (4 feet) to see the condition of the woodchips. There had been no flow through the bioreactor for over three weeks and the bioreactor was dry. Excavation started about 5 feet into the bioreactor to prevent the sidewalls from caving in due to the sandy sub-base material supporting the liner.

The following are notes from the exploratory investigation:

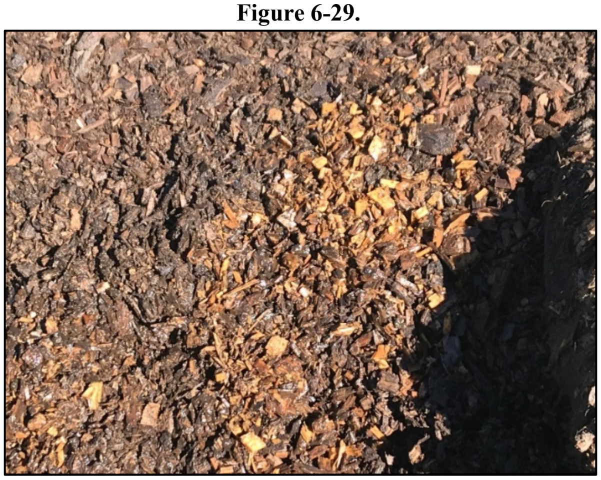
- At the start of the excavation (Sta 0+05), the first 2 feet of woodchip depth consisted of a very dense material with a low percentage of large wood chips and a high percentage of fine material. The material was a dark brown/black color, possibly indicating degradation. The bottom 6 inches were clean woodchips with a brighter tan/orange color; there was a higher percentage of whole wood chips and there was 4 inches of standing water in the bottom of the trench. Please refer to Figures 6-26 through 6-29; photographs taken on June 23rd, 2021).

Figure 6-26.

Figure 6-27.

Figure 6-28.

Figure 6-29.



- There was a change in the woodchips at Sta 0+15. There was more color in the woodchips, and less fines and dirt. The woodchips appeared to be smaller in size than original but were more intact. There was about 12 inches of clean woodchips at the bottom of the trench.
- At Sta 0+50, the depth of the good woodchips started 12 to 15 inches from the surface, which was the greatest depth of good condition woodchips in the bioreactor. Please see Figure 6-30.

Figure 6-30.

- There was a clear gradient of the boundary between the apparently degraded woodchips in the upper layer and the cleaner, intact woodchips in the lower layer of the trench; this started at a depth of 42 inches at Sta 0+05 and rose to a depth of 12 inches at Sta 0+50, then decreased to a depth to 36 inches at Sta 0+85.

Figure 6-31.

Figure 6-32.

6.8.3 Laboratory Testing

With respect to the bioreactor plugging, the project research team had several meetings regarding the status of the project and the direction to take following the investigation and observations of bioreactor material. Since the bioreactor was going to be offline for an extended period, the team decided to request a work-plan revision and fund re-allocation from the Lake Champlain Sea Grant Program to allow for testing and analysis of the woodchip materials. The revision and re-allocation were approved.

The project team made numerous contacts to various analytical laboratories and environmental service facilities to determine what type of testing could be done to determine the nature of the bioreactor plugging phenomenon and whether it was biological, organic from woodchip breakdown or a combination. Proposals included the use of mechanical sieve testing for determination and comparison of dirt-like material to woodchip material, which would speciate by size of materials only and not determine possible origin; SEM-EDS (scanning electronic microscope – energy dispersive x-ray spectroscopy) analysis to look at the elemental profile of the sample material and understand if a particular particle is carbon-based (assumed to be woodchips) or metal-based (assumed to be soils); and Raman Spectroscopy to identify the particles as either cellulose or a breakdown product of cellulose to determine if the woodchips were breaking down. Although these analyses would be very beneficial at evaluating the type of particles, it was determined to be very expensive, limited to specific particles and would not cover a wider range of samples. It was decided to proceed with a less complex analysis to focus on total and volatile solids, which would distinguish sediments and wastewater sludges, and sieve sizes.

Three (3) separate locations along the 100-foot length of the bioreactor were selected for the collection of woodchip samples for laboratory analysis, including Sta 0+25 (Sample Site A), Sta 0+50 (Sample Site B), and Sta 0+80 (Sample Site C). At each station, samples were collected at four different depths including (1) just below the filter fabric, (2) at a 2-foot depth, (3) at 3-foot depth and, (4) within the water-logged material at the bottom. This sampling strategy resulted in a total of 12 samples collected. Samples were collected on September 2, 2021, by hand excavating the bioreactor, placing the material in gallon Ziploc bags, and storing the samples on ice. The woodchips were very compacted, and the samples were collected using a hand rake and some hand digging to extract the samples.

The collected woodchip samples were delivered the same day to the Darrin Fresh Water Institute in Bolton Landing, NY. The results of the Volatile Solids analysis are presented in Table 6-4.

Table 6-4.

Sample	Percent Solids	Percent Volatile Solids
A-1	71.2%	61.3%
A-2	25.4%	0.7%
A-3	28.0%	0.6%
A-4	27.0%	0.7%
B-1	31.9%	2.6%
B-2	29.4%	0.4%
B-3	24.5%	0.4%
B-4	26.4%	1.1%
C-1	50.6%	54.2%
C-2	23.6%	0.3%
C-3	25.6%	0.3%
C-4	25.7%	1.2%

The highest percent of solids at each station along the length of the bioreactor occurred just below the filter fabric at the top, indicating that these were the densest samples with the most material. The highest percent of volatile solids at each sample location were just below the filter fabric at the top also, indicating these had the most sediment/soil material. These results indicated that there was higher amount of soil/mineral material in the upper sample, possibly indicating migration into the bioreactor. It is unlikely there was any wastewater sludge material in this area as the water depth in the bioreactor never reached above 40 inches or approached the height of samples collected at depth (1).

The percent of solids for the 2-foot depth, 3-foot depth and the waterlogged bottom depth all were below 30 percent, indicating less dense samples consisting more of woodchips. The percent of volatile solids for depths at 2', 3' and the waterlogged depth were around 1.0% or below with the highest percentage of volatile solids of the three lowest samples being in the water-logged samples (4). This indicates there were very fewer sediments or sludge materials at these depths and most the material was wood chips but that there could be settling of finer soil material at the lowest level of the bioreactor. It should be noted that the percent of volatile solids in the upper sample (1) follows the clean woodchip gradient line with the higher percentages in Locations A and C with Location B having a lower percentage.

The results of the Manual Sieve analysis are presented in Table 6-5.

Table 6-5.

	Particle Size:				
Sample Location	**Gravel: >2mm**	**Coarse Sand: <2mm,>0.5mm**	**Medium to Fine Sand: <0.5mm, >0.25mm**	**Very fine Sand: <0.25mm, >0.125mm**	**Silt/Clay: <0.125mm,>0.063mm**
A-1	45.5%	37.0%	13.8%	0.2%	0.0%
A-2	96.6%	2.3%	0.0%	0.0%	0.0%
A-3	97.6%	0.6%	0.0%	0.0%	0.0%
A-4	100.3%	0.4%	0.0%	0.0%	0.0%
B-1	82.9%	8.8%	0.5%	0.1%	0.0%
B-2	95.1%	4.1%	0.0%	0.0%	0.0%
B-3	94.9%	1.1%	0.0%	0.0%	0.0%
B-4	86.9%	0.6%	0.0%	0.0%	0.0%
C-1	70.2%	22.3%	1.2%	0.2%	0.0%
C-2	89.5%	3.7%	0.1%	0.0%	0.0%
C-3	96.2%	1.3%	0.0%	0.0%	0.0%
C-4	91.8%	0.7%	0.0%	0.0%	0.0%

It is important to note here that all samples were collected within the boundaries of the bioreactor liner/fabric and that the woodchips installed when the bioreactor was constructed ranged in size from one-half inch to 2 inches; therefore, all samples should have been classified as gravel under the sieve analysis. It is understood a small amount of fines may be present but there should only be a very small percentage of fines present unless there was degradation of the woodchip material or deposition of material transported from the wastewater influent.

From the sieve analysis (Table 6-5), the upper samples taken just below the filter fabric (1) exhibited the highest percentage of particles <2 mm (coarse sand or finer) with Sample Location A-1 showing the greatest percentage of fines at 51 percent <2 mm and Sample Location C-1 showing a percentage of fines <2 mm at 23.7 percent. It should be noted that Sample Locations A and C were the locations that exhibited the greatest depth of degraded woodchip material from the exploratory excavation discussed previously. Sample Location B-1 percentage of fines <2 mm was 9.4 percent. It was evident from the sieve analysis that samples collected just below the filter fabric had the highest percent of fine particles at each Sample Location indicating that there was apparent breakdown of woodchips or migration of soil material into the bioreactor through the filter fabric. The sieve analysis also demonstrates the deeper the collected sample (from just below the filter fabric (1) to 2-foot depth (2) to 3-foot depth (3) to water-logged area (4)), there was a corresponding decrease in finer particles at each Sample Location A, B and C. This indicates the finer particles were originating either from the degradation of the upper woodchips or migration of soil material into the bioreactor.

There is consistency of results between the Volatile Solids analysis and the Sieve Analysis with regard to the higher percentage of apparent soil material being located in the upper samples taken just below the filter fabric (1) and decrease with depth of the sample taken with a slight percentage increase for the lowest sample (water-logged samples (4)), which still remains significantly lower than the upper sample (1). Since it is assumed that the woodchip/organic material would turn to ash during the heating, the volatile material remaining would be soil/mineral material.

It is of interest to note here is that in all three sampling locations along the length of the bioreactor, the uppermost woodchip matrix (i.e., the woodchips directly under the permeable filter fabric) exhibited the most extensive breakdown of the material. This correlates exactly with what was visually observed. The smell also indicated that the woodchips were decomposing, similar to what one would expect to see in a compost pile. And the *influent* portion of the woodchip matrix directly below the filter fabric showed the greatest degradation of the woodchips. Conversely, the bottom layer of woodchips at the *influent* end of the matrix (i.e., sample A-4) showed the least degradation, verifying the fact that under anaerobic conditions the woodchips would retain their structure and could offer extended denitrification capacity.

This same degradation of the woodchips near the surface (i.e., samples B-1 and C-1) offers the premise that the upper matrix of the woodchip bioreactor tends to be impacted by surface precipitation and aerobic conditions, leading to the natural degradation of the wood. An alternative cover for the bioreactor, one that includes a more impermeable membrane and/or a deeper soil cover would alleviate this situation. Other bioreactor design modifications are discussed in the following section.

6.8.4 Potential Causes of Plugging

As detailed in Section 6.8.1, there was evidence of clogging of the woodchip bioreactor through the pilot study. The WWTP operation staff were very aware of this and monitored the bioreactor daily to assess potential problems, being proactive to address this issue as demonstrated by the routine flushing of the bioreactor. The research team was also cognizant of this potential and Kathy Suozzo was in contact with Dr. Laura Christianson during the study to discuss observations and findings.

There is evidence in the literature of clogging potential of denitrifying bioreactors and well as concern expressed. Christianson et al. (2016) stated conventional knowledge indicates frequent woodchip replacement due to media clogging and there is a need for better understanding of the potential for clogging, especially for wastewater application. It was noticed that influent wastewater took progressively longer to move into the woodchips, likely due to a combination of (1) woodchip settling, (2) clogging due to removed wastewater solids and/or accumulated bacterial growth and (3) pulsed flow system pushing the chips away from the inlet. David et al. (2016) and Hoover et al. (2016) reference the decomposition of woodchips as impacting the hydraulics of a bioreactor.

In review of the exploratory excavation and the sample analysis, there does appear to the degradation of woodchips in the upper layer of the bioreactor. The bioreactor was constructed with filter fabric over the woodchips as referenced in other research papers (Sutphin and Kult, 2010). This material will allow the exchange of air and oxygen with the surface as there was only a 6-inch cover of soil as well as surface water infiltration. During the excavation, there was biology activity observed in the bioreactor consisting of earthworms and root penetration. Woli et al. (2010) and Doheny (2002) recommended using a liner due to site conditions.

Bioreactor water level fluctuation could result in potential degradation of woodchips by creating unsaturated conditions combined with the potential oxygen exchange. Christianson et al. (2016) found that woodchip in the unsaturated top 15 cm of the bioreactor in a study were potentially degrading more so than the bottom woodchips. Moorman et al. (2010) similarly reported aerobic woodchips near the top of denitrification wall had shortened life compared to deeper placed, more consistently anaerobic chips.

There is the concern of the wastewater solids decomposition and accumulation causing clogging, which appeared to be one of the reasons resulting in the routine flushing by WWTP operation staff.

6.9 Woodchip Bioreactor Design Modifications

Following operation of the Bolton WTTP woodchip bioreactor from October 2018 through May 2021, design elements and operational methods were evaluated. As discussed previously, this denitrification process is a passive and reliable unit process, which has found extensive application in treating nitrate-enrich agricultural runoff. In those applications, the bioreactors were in use only during runoff events, and were in a resting state at other times. The Bolton WWTP woodchip bioreactor was functional as a full-scale, field-functioning system which was operational year-round throughout varying environmental conditions and to our knowledge, is the first application at a municipal wastewater treatment plant.

During the tenure of the Bolton WWTP woodchip bioreactor, means and methods of operation, maintenance, monitoring, and process optimization were evaluated and developed. While each installation is unique, certain basic standards can be developed. These include the following:

- Provide a method of continual and fairly consistent flow to the bioreactor, including the ability to gravity flow to the *influent* end of the bioreactor. Typically, this can be accomplished through a storage reservoir, the flow from which is controlled and measured continuously to provide a steady influx of NO_3-N-rich wastewater into the bioreactor. The Bolton WWTP woodchip bioreactor *influent* valve was a standard water shut off valve, similar to a curb stop. The control of this valve was done by the valve key, which did not offer fine adjustments. A more sensitive pinch valve would be ideal, although valve cost and installation concerns are to be considered. The original agricultural in-field woodchip installations relied exclusively on the Agri Drain influent structure, which had a simple V-notch weir as the flow measuring mechanism. For continual usage, a more discrete control device, plus a flow meter, would be required.
- An effluent flow meter also is a necessary monitoring device for a woodchip bioreactor in constant use. The newer flow measuring devices are self-contained with data recording capabilities and extended-life batteries.
- As was evidenced at the Bolton WWTP woodchip bioreactor installation, a variety of in-reactor monitoring wells greatly aids in assessing conditions within the woodchip matrix. Future woodchip bioreactors should be outfitted with a series of 2-inch PVC monitoring wells placed at various depths, at numerous locations and across the *influent* and *effluent* faces of the woodchip matrix. The *influent* and *effluent* series of monitoring wells would be especially important for monitoring the condition of the woodchips in these particularly vulnerable locations.
- Based upon the operating experience with the Bolton WWTP woodchip bioreactor, and as demonstrated by other researchers (Christianson et al. 2020), there is the inevitable need for recharging the woodchips within the bioreactor matrix. In the case of the Bolton WWTP bioreactor, the influent woodchip matrix exhibited "plugging" issues after approximately one year of continuous intensive use. Open excavation within the front six (6) feet or so of the woodchip matrix revealed degraded woodchips and biological solids build up. The woodchips further into the matrix showed none of this degradation. Replacement of these deteriorated wood chips was accomplished, after which the NO_3-N removal efficiency returned to about 60 percent. A "sacrificial front end" is a design consideration for future woodchip bioreactors.
- After the BLWWTP woodchip bioreactor was taken offline in June 2021 and the entire woodchip matrix was exposed, similar woodchip degradation was noted throughout the entire length of the bioreactor. The degradation was most notable in the upper sections of the 4-foot-deep woodchip matrix. Visual observations and the samples collected in September 2021 verified the degradation, with an increase in volatile solids of the upper matrix woodchips and a reduction in the particle sizes. This degradation was especially prominent at the *influent* and discharge

regions of the woodchip bioreactor. From these observations, an *effluent* "sacrificial back end" section is a worthy design modification consideration.

- Pursuant to the June 2021 excavation of the Bolton WWTP woodchip bioreactor and investigation into the condition of the woodchip matrix, it was clear that the upper reaches (i.e., the upper foot or so of the woodchips) exhibited more woodchip degradation than further into the woodchip depths. This area also exhibited a more "compost-like" character; it clearly was within the root zone of the vegetative cover. There was a landscape filter fabric covering the woodchips, with approximately 6 inches of topsoil and then the vegetative cover. It is presumed that the upper reaches of the woodchip matrix was a biologically active area with alternating wet/dry cycles under an adequate oxygen regime. This apparently was sufficient to cause the normal degradation of the wood chips. As a potential design modification, an impermeable membrane could cover the entire top of any future woodchip bioreactor, with perhaps a foot of more of topsoil to support a vegetative cover or a stone cover to hold the membrane down. If the top is covered with a vegetative cover crop, then the area should be sloped to provide adequate surface drainage off of the field.
- Figure 6-33 is a proposed redesign for two (2) new woodchip bioreactors for the Bolton WWTP.

6.10 Discussion

The information presented in this chapter details the numerous environmental, chemical and design variables that could impact the efficiency of nitrate removal in the Bolton WWTP woodchip bioreactor. Although this chapter provided analysis of specific variables, it is difficult to isolate a single variable, especially in this in-field application, where all variables must be considered at the same time. With that said, the necessity of an informed and active treatment plant operator who is willing to understand and react to these variables is vital for the effective application of the woodchip bioreactor technology.

It can be said that water temperature may have the greatest effect on nitrate removal efficiency and is very cyclic with the seasons of cold temperatures greatly reducing efficiencies of denitrifying bacteria and their ability to process available carbon.

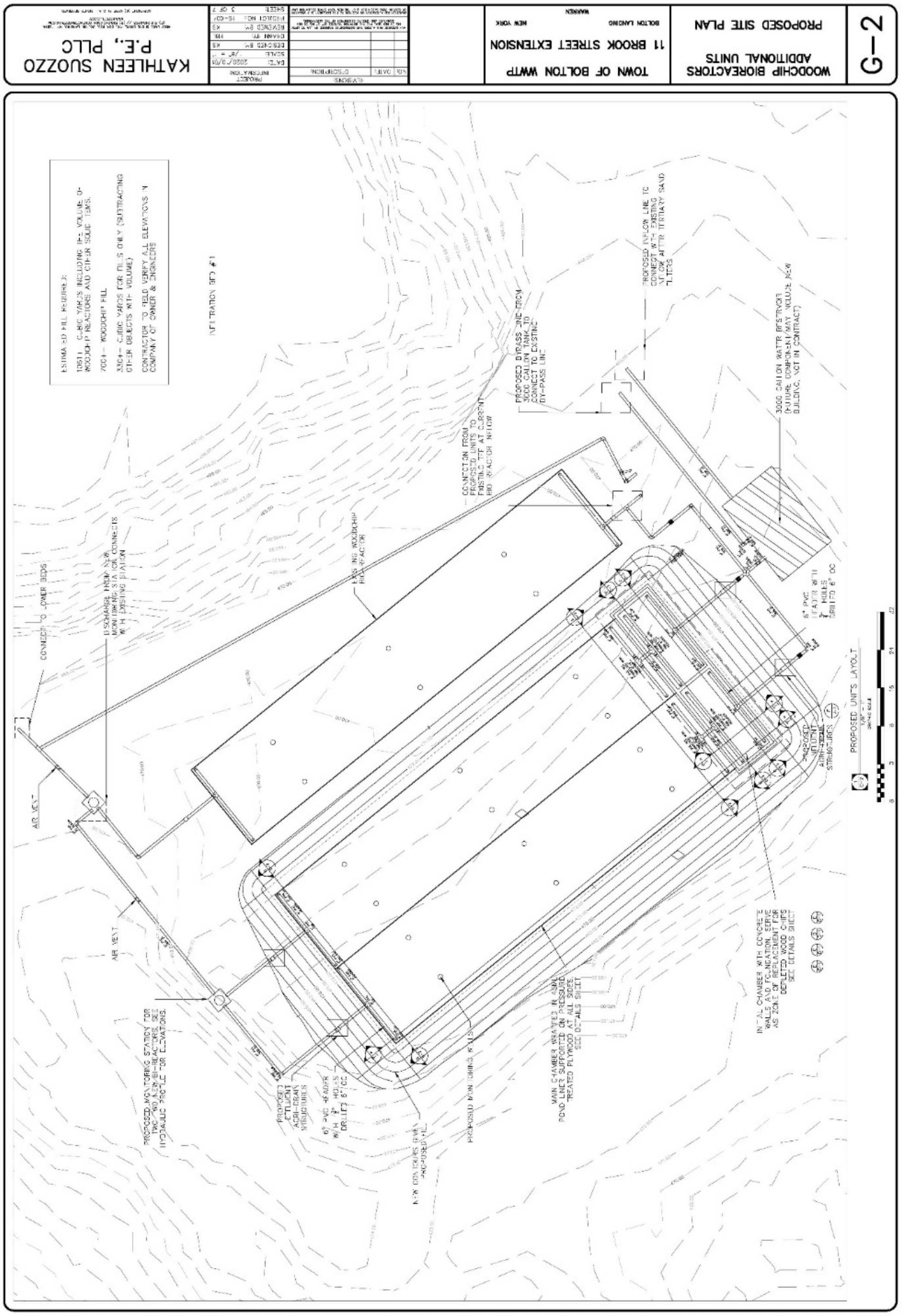
Important operational considerations include the treatment plant flows, both daily and seasonal, to determine adequate discharge to the bioreactor to maximize Hydraulic Residence Time (HRT) along with achieving the anoxic, or low dissolved oxygen, conditions. Another important operational parameter is alkalinity, which relies on anoxic conditions and increased in concentration through the bioreactor.

Influent nitrate-nitrogen concentrations entering the bioreactor had a significant impact on the *denitrification* efficiency and *effluent* concentration in the Bolton WWTP woodchip bioreactor, as observed during this study, and *influent* nitrate-nitrogen concentrations nearly doubled during the course of this investigation. The woodchip bioreactor was effective at the reduction of soluble reactive phosphorus (SRP), another nutrient of concern in wastewater treatment plant effluent.

An unfortunate result of this pilot program was the clogging of the woodchip bioreactor, which appeared to have several potential causes. Perhaps the woodchips installed contained too many fines which could have caused earlier clogging and should have been washed. Perhaps the porosity should be greater by increasing the effective size of the woodchip and limiting the smaller particles that may reduce flow paths. Another factor was the use of a permeable filter fabric over the woodchip chamber that allowed oxygen and water to enter, resulting in degradation of the woodchips into finer, mulch-like material.

Other design recommendations from the Town Engineer and treatment plant operations staff will be implemented into additional woodchip bioreactor cells planned for by the Town of Bolton to improve nitrate removal including areas for the "sacrificial" degradation of woodchips, improved monitoring wells and appropriate meters.

Figure 6-32.



KATHLEEN SUOZZO
P.E., PLLC
TOWN OF BOLTON WWTP
11 BROOK STREET EXTENSION
WOODCHIP BIOREACTORS
ADDITIONAL UNITS
PROPOSED SITE PLAN
G-2

In conclusion, the overall nitrate removal efficiency of the Bolton WWTP through this study was an average of 41 percent, which decreased from the beginning of the study due to the previously discussed reasons and demonstrates the effectiveness of this technology. But what cannot be overlooked is the importance of the facility operation staff for the success of this project and that their attention to the operation procedures detailed in this chapter and the numerous parameters that need to be monitored will determine the success of this technology in the future.

6.11 Conclusions

As previously stated in Chapter 5, the goal of this Lake Champlain Sea Grant project was to conduct a thorough investigation of a woodchip bioreactor at the Bolton WWTP to reduce nitrate-nitrogen from the final wastewater effluent prior to a groundwater discharge.

The project's null hypothesis (H_O) being tested was:

> ***The woodchip bioreactor will not reduce the nitrate-nitrogen concentrations that currently occur in the tertiary effluent discharged from the BLWWTP to existing sand infiltration beds and ultimately the local groundwater.***

Based upon the results of this current study, the above-stated null hypothesis can be rejected in favor of the alternative hypothesis, that: The woodchip bioreactor *did* reduce the nitrate-nitrogen concentrations that currently occur in the tertiary effluent discharged from the Bolton WWTP to existing sand infiltration beds and ultimately the local groundwater.

In Chapter 6, Section 6.1.3 characterizes the chemistry of the Bolton WWTP effluent, with particular emphasis on nitrate, ammonia and soluble reactive phosphorus of the effluent stream being denitrified through the bioreactor and side-by-side, the stream not denitrified, which was the first project objective.

The second project objective included the monitoring of the improvement in ground water nitrate levels moving downgradient from the Bolton WWTP during the study period. This objective is demonstrated in Chapter 7, Figure 7-18, which summarizes the nitrate-nitrogen permit exceedances from 2008 through September 2021. One can attribute the decline in nitrate-nitrogen exceedances from 2019 through September 2021 to the installation of the woodchip bioreactor in the area of the upper sand beds and the ability of this unit process to reduce the nitrate-nitrogen concentrations leaving the Bolton facility in its wastewater effluent.

The third objective was to define the means and methods of characterizing the operation and efficiency of a full-scale woodchip bioreactor. Data reported herein clearly shows a reduction in the concentration of nitrate-nitrogen post woodchip bioreactor treatment, with a notable exception during the May 25, 2021, sampling event. It was during this time that the facility trickling filter was not adequately nitrifying the wastewater, resulting in further *nitrification* through the woodchip bioreactor. Detailed "means and methods" revealed during this study included such critical operational practices as routine monitoring of the influent flow, wastewater temperature, dissolved oxygen concentrations through the bioreactor, and influent nitrate-nitrogen concentrations. Additional operational practices included observations of the WWTP front end unit processes, including excess solids entering the bioreactor, or surfacing of wastewater along the bioreactor. Careful operator observations of the entire wastewater treatment processes aids in the optimization of this tertiary denitrification system.

The variability of nitrate-nitrogen removal through the woodchip bioreactor is described in detail in this Chapter 6. Identifying the causes of this variability, the fourth objective of this study, has revealed a myriad of environmental and operational issues that contribute to this variability. The synergy of a variety of environmental conditions, such as wastewater temperature, influent nitrate-nitrogen concentrations, dissolved oxygen concentrations, availability of a suitable carbon source, retention time through the bioreactor, and/or preferential flow paths through the bioreactor all contribute to the rate of denitrification experienced by the woodchip bioreactor. These environmental conditions are all described in detail within Chapter 6.

Optimization of the nitrate-nitrogen removal efficiency of the woodchip bioreactor throughout the four seasons was the fifth objective of this study. The Bolton WWTP woodchip bioreactor is an in-field full-scale system, operating in the highly variable Adirondack Mountain climate. Winter wastewater temperatures can drop to 5C, or less, and summer wastewater temperatures can climb to 25C. Wastewater temperature is one of the most critical operational metrics that impacts denitrification, as discussed in Section 6.1.1 and 6.2.1. Colder wastewater temperatures inhibit both the organisms involved in denitrification as well as the cellulolytic bacteria responsible for the conversion of the wood cellulose into usable sugars for the denitrifying organisms. Warmer wastewater temperatures can accelerate the denitrification process, resulting in undesirable byproducts, including methyl mercury. Bioreactor retention times must be carefully monitored during the warmer wastewater temperature periods to prevent complete denitrification. Judicious monitoring of the chemical characteristics of the influent wastewater and the environmental conditions throughout the four seasons are included in the "means and methods" for denitrification optimization in the woodchip bioreactor.

For the sixth objective of this study, the collaboration with other researchers and field practitioners in the woodchip bioreactor field, the Bolton WWTP woodchip bioreactor cooperators have communicated throughout the study with others in this exciting and developing field. The cooperators have shared operating data with researchers at University of Illinois, Stony Brook University's Center for Clean Water Technology, Cornell University, the Conservation Fund Freshwater Institute in Arlington, VA, the New York State Department of Environmental Conservation, and the USDA-ARS Soil and Water Management Research Unit in St. Paul, MN, among others. Open communications continue.

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Lake Champlain Sea Grant Program

Bolton Wastewater Treatment Plant Woodchip Bioreactor Project

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2021 Final Report

Chapter 7

Bolton Wastewater Treatment Plant Performance during the Woodchip Bioreactor Project

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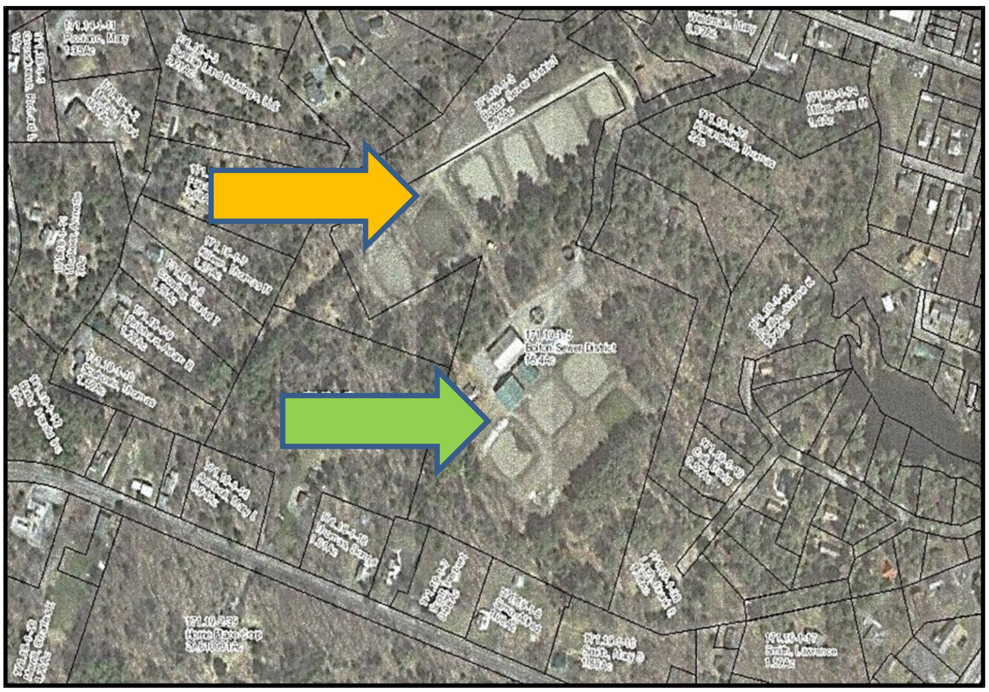
7.0 Introduction

This chapter presents a summary of the SPDES Permit Discharge Monitoring Report (DMR) data collected at the Bolton WWTP beginning during the previous 2016 to 2017 study (Sutherland and Navitsky 2017) and through the current 2019 to 2021 monitoring program associated with the woodchjp bioreactor project to examine trends that might be occurring. The historical background of the facility was provided earlier in Chapter 2.

7.1 Bolton Facility Background

An image of tax map parcels that contain the Bolton WWTP is shown in Figure 7-1 (compass direction 'north' is at the top of the figure). The facility, located in the center of the figure, is bordered on all sides by residential properties and almost entirely located on map parcel 171.19-1-5 (green arrow) identified as the Bolton Sewer District, with a surface area of 15.4 acres. There is an adjoining parcel to the north and west, map parcel 171.19-1-3 (Bolton Sewer District, orange arrow), with a surface area of 5.95 acres. The operational portion of the treatment facility is located on map parcel 171.19-1-5, the larger parcel near the center of Figure 7-1.

Figure 7-1.

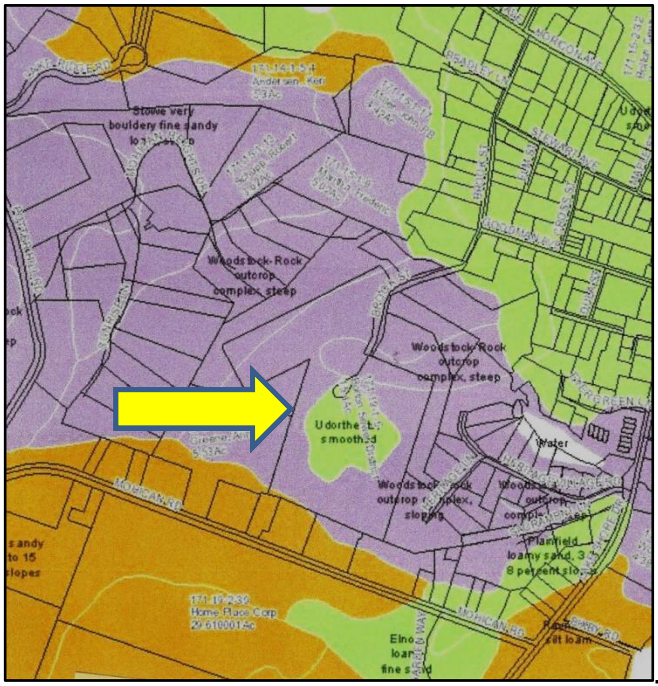


The configuration of the Bolton WWTP lot parcels is irregular. The treatment plant was constructed on the surface of a series of plateaus comprised of delta sand deposits, left by receding glaciers, in order to utilize the sand as an infiltration area for treated wastewater effluent. This is the same strategy used during the construction of the Village of Lake George Wastewater Treatment Plant (Sutherland and Navitsky 2015).

The elevation of the operational portion of the Bolton WWTP lies between 425 to 475 feet AMSL (above mean sea level) proceeding from the region of the lower sand beds north-northwest to the level of the upper sand beds, which now contain the woodchip bioreactor processing unit, and which are used exclusively for disposal of treated wastewater effluent from the facility except during times of emergency.

A soils map for the area encompassed by Route 9N, Mohican Road and Potter Hill Road that includes the Bolton WWTP is provided in Figure 7-2 (http://www.warrencountyny.gov/gis/).

Figure 7-2.



The entire area is comprised of *Woodstock-Rock outcrop complex*, varying from steep to sloping terrain. This map unit consists of shallow, excessively drained Woodstock soils and areas of Rock outcrop in bedrock-controlled areas on hillsides, hillcrests, and mountaintops, and is about 55 percent Woodstock soils, 20 percent areas of Rock outcrop, and 25 percent other soils. A small pocket of *Udorthents, smoothed* is located in the area occupied by the lower sand beds (in Figure 7-2). This map unit consists of moderately-to-excessively well-drained soils on uplands, in valleys or on lowland plains.

The soils information for the area has been presented to highlight the fact that the map units associated with the Bolton WWTP and surrounding areas are well-drained. We know from previous studies conducted during the early 1980s by the Rensselaer Fresh Water Institute (RFWI) that ground water leaves the region of the WWTP in different directions depending upon which treatment plant sand disposal beds are utilized for effluent discharge (Aulenbach and Fillip 1983). This ground water directional flow information and the results from the investigations conducted at the Bolton WWTP were presented in Chapter 2.

7.2 Results

7.2.1 State Pollution Discharge Elimination System Permit Program

The New York State Department of Environmental Conservation (NYSDEC) protects New York State's water resources through various regulations, policies, and partnerships. The NYSDEC's Division of Water with support of legal staff manages the compliance and enforcement components of the State Pollutant Discharge Elimination System (SPDES) permit program.

In 1975, the United States Environmental Protection Agency (US EPA) authorized New York State to implement the National Pollutant Discharge Elimination System (NPDES) program to regulate all wastewater discharges to surface waters in the state. The states' Environmental Conservation Law (ECL) established the SPDES program and provides NYSDEC with additional legal authority to regulate wastewater discharges to ground water. The SPDES permits are issued pursuant to Article 17 of the ECL and state regulations to 6 NYCRR Part 750.

A SPDES permit establishes strict performance standards and operating conditions that are designed to protect the state's water resources. As a single facility with significant wastewater discharge to sand beds (and then to ground water), the Bolton WWTP was issued an individual operating permit. These permits may incorporate current water quality standards, effective implementation of best management practices (BMPs) by permitted facilities, and timely sampling, analysis and reporting to NYSDEC on the quality of wastewater discharged under the SPDES permit.

A copy of the renewed SPDES permit issued to the Town of Bolton during June 1997 is provided in Attachment #1 at the end of this report. According to the existing permit for the facility, effluent discharges shall be monitored monthly and nutrient limitations for effluent leaving the plant are limited as follows: nitrate-nitrogen, 20 mg N·L, and phosphorus, 0.5 mg P·L; a separate upper limit of 10 mg N·L of nitrate-nitrogen measured at the SPDES permit monitoring wells is a condition of the permit.

A unique feature of the SPDES program is the requirement for 'significant' permittees to submit monitoring data to the NYSDEC on a Discharge Monitoring Report (DMRs). The DMRs contain a variety of data collected during plant operation and the NYSDEC processes this information to help direct its compliance assurance activities.

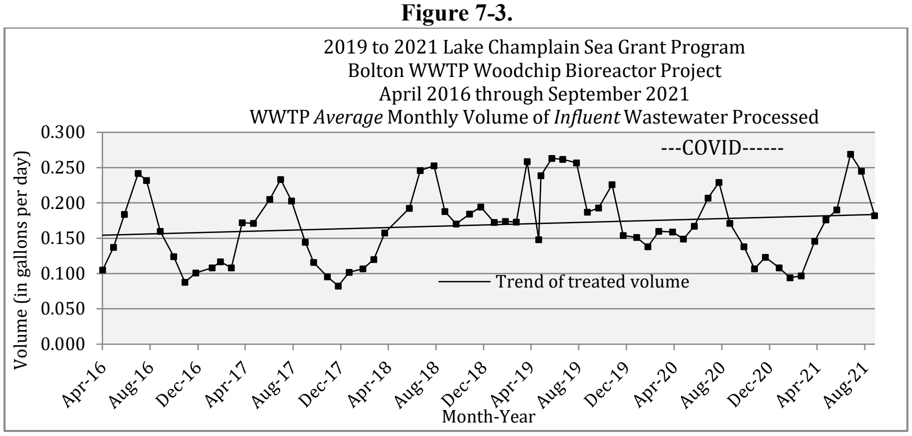
7.2.2 Discharge Monitoring Reports (DMRs)

The Bolton WWTP DMR is submitted on a monthly basis. An additional condition of the SPDES permit is the monthly sampling of monitoring wells #1 through #5 which, at the time of installation during the mid-1980s, were located to intercept ground water flow as it moved from the area of the treatment plant toward lower elevations. The location of the SPDES permit monitoring wells on the Bolton WWTP property were presented and described in Chapter 2.

7.2.3 Plant Wastewater Influent

The *average* monthly *influent* volume of wastewater (in mgd) treated at the Bolton WWTP from April 2016 through September 2021 is summarized in Figure 7-3.

Figure 7-3.



The SPDES permit issued by the NYSDEC for operation of the facility allows 300,000 gallons per day (gpd) of wastewater to be treated.

The *average* daily volume of wastewater treated (±standard deviation) each month during the period was 0.169 (±0.052) mgd. As shown in Figure 7-3, the pattern of treated wastewater volume is linked to the seasonal tourist economy of the region, with elevated volumes during the summer seasons and the lowest volumes occurring during the winter months.

As shown in Figure 7-3 with data going back to April 2016, the seasonal pattern of wastewater volume treated repeats itself during each annual cycle.

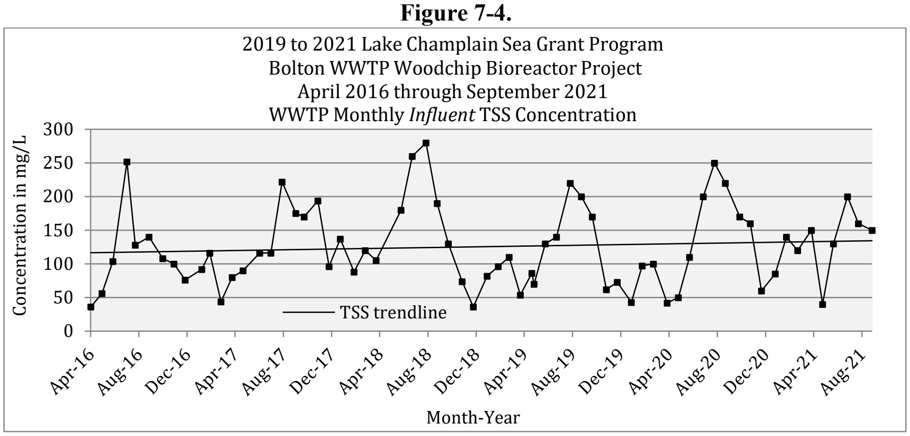
The impact of the 2020 COVID pandemic on reduced tourism and lower volumes of wastewater treated is apparent in Figure 7-3 with the mid-summer (August 2020) volume noticeably reduced compared with mid-summer volumes shown for 2019 and 2021.

There has been a slight increased trend of wastewater volume treated at the Bolton facility during the previous five (5) years with an approximate increase of about 5,000 gallons per day treated during each annual cycle since 2016.

Current WWTP plant monitoring of influent includes temperature, pH, total suspended solids (TSS), 5-day biochemical oxygen demand (BOD_5), total phosphorus (TP), nitrate-nitrogen (NO_3-N), and ammonia-nitrogen (NH_3-N). Influent pH is not discussed here except to mention that it is measured at the plant twice each day and the values recorded as *maximum* and *minimum* readings.

Total suspended solids (TSS) are a total quantity measurement of organic and inorganic solid particles per volume of water contained in the influent and the concentration is expressed as milligrams of TSS per liter of influent (mg TSS·L). This type of material is objectionable in wastewater because the small particles can clog small pore spaces in filters and in sand or soil to which the treated wastewater is discharged. The monthly *influent* TSS concentrations during the period from April 2016 through September 2021 are shown in Figure 7-4.

Figure 7-4.



The *average influent* TSS concentration (±standard deviation) during the period was 125.5 ± 60.4 mg TSS·L, and the concentration of TSS ranged from about 35 to 280 mg/L.

The highest TSS concentrations occurred during the summer months and the lowest TSS concentrations occurring during the winter months when the volume of wastewater treated at the facility was the lowest.

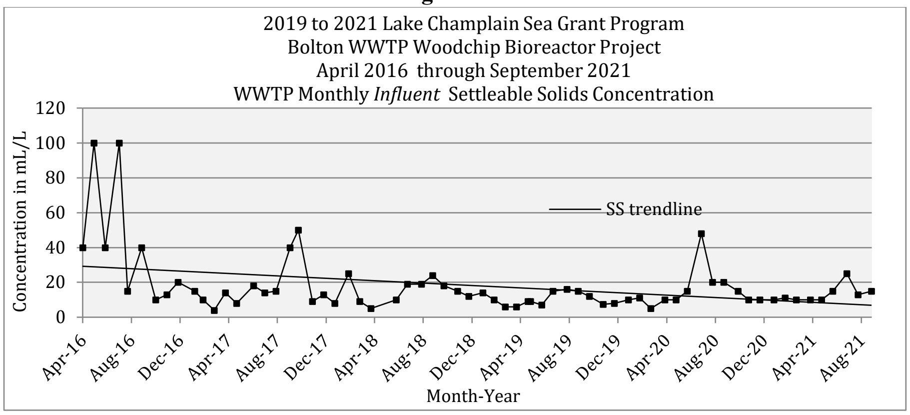
Overall, there was a slight increase in TSS concentration during the period from April 2016 through September 2021 as shown by the trendline in Figure 7-4

Settleable solids (**SS**) are defined as solids that sink and do not occur in the surface water when tested after the collected sample has been allowed to settle undisturbed for a period of time (60 minutes); these solids are contained as part of the TSS discussed above and the concentration is expressed in terms of volume, e.g., as mL SS·L.

The range of settleable solids in *influent* entering the Bolton treatment facility during the period from April 2016 through September 2021 was from 4.0 to 100.0 mg SS·L (Figure 7-5) and averaged 18.0 (±17.6) mg SS·L.

Almost all of the variability in the wide range of SS concentrations occurred during early 2016 when readings during May and July reached 100.0 mg SS·L.

Figure 7-5.



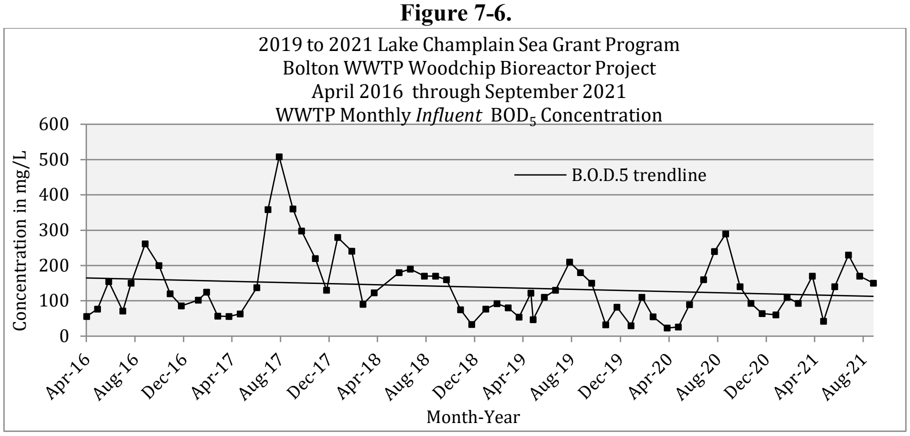
Otherwise, there were only 6 months when concentrations exceeded 20 mg SS·L, and the trendline for SS in Figure 7-5 shows that the concentration has been decreasing steadily since early 2016.

B.O.D.$_5$ is a commonly measured constituent of wastewater because large organic molecules are easily decomposed by bacteria and require oxygen for decomposition, eventually releasing carbon dioxide and water. The amount of oxygen required for this process is known as the *biochemical oxygen demand* (BOD) and is expressed as mg BOD_5·L. The 5-day BOD is measured by the quantity of oxygen consumed by microorganisms during a 5-day period and is the most common measure of the amount of biodegradable organic material contained in wastewater.

It should be noted that BOD serves as the food source for the denitrifying bacteria that are needed in systems where bacteria mediate the nitrogen removal process. BOD is desirable in these situations because the nitrification/denitrification process requires sufficient BOD to support the bacterial growth to accomplish this process.

The *average* WWTP *influent* BOD_5 (± standard deviation) during the period from April 2016 through September 2021 was 117 (±62) mg·L^{-1} and the monthly sample results for this period are summarized in Figure 7-6.

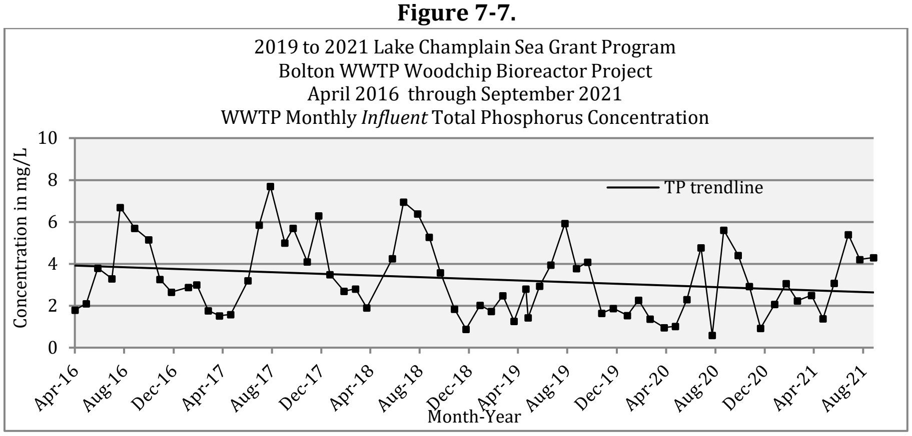
Figure 7-6.



In general, BOD_5 concentrations varied from about 20 to 300 mg BOD_5·L except for a period during 2017, from July through November, when *average* values all were above 200 mg BOD_5·L (Figure 7-6). Since that time, there only were three results more than 200 mg TSS·L and, as the trendline in Figure 7-6 shows, there has been a steady decline in the *influent* concentration of TSS.

Total phosphorus (**TP**) concentrations in *influent* wastewater entering the Bolton facility ranged from 0.60 to 7.70 mg TP·L during the period from April 2016 through September 2021 and averaged 3.28 (±1.73) mg TP·L. Figure 7-7 summarizes the monthly sample results for *influent* TP concentrations.

Figure 7-7.

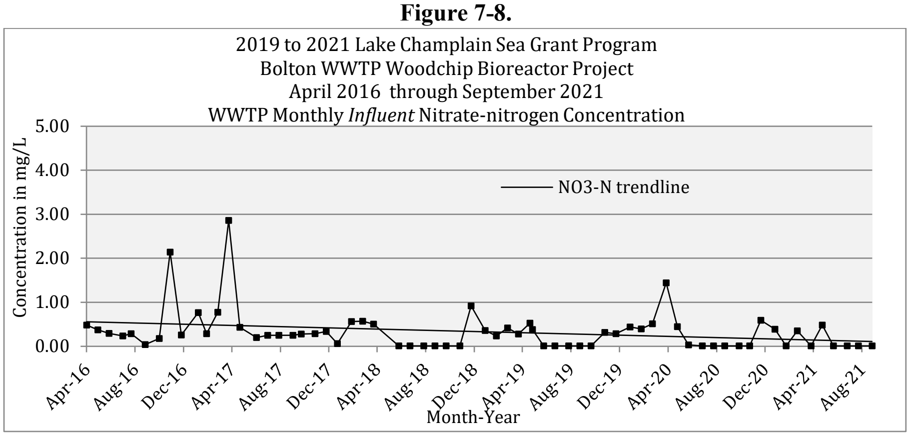


As with other parameters measured at the Bolton facility that were discussed above, there was a definite annual pattern of average TP concentrations in the *influent* wastewater, with higher concentrations in the busy summer months and lower concentrations during the winter months.

In addition, as shown by the TP trendline in Figure 7-7, there has been a steady decrease in wastewater *influent* TP concentrations during the period of record.

Nitrate-nitrogen (**NO_3-N**) concentrations in wastewater entering the Bolton plant ranged from less than analytical detection (0.01 mg N·L) to 2.86 mg N·L during the period and averaging 0.33 (±0.47) mg N·L. Figure 7-8 summarizes the monthly sample results for *influent* NO_3-N concentrations collected.

Figure 7-8.



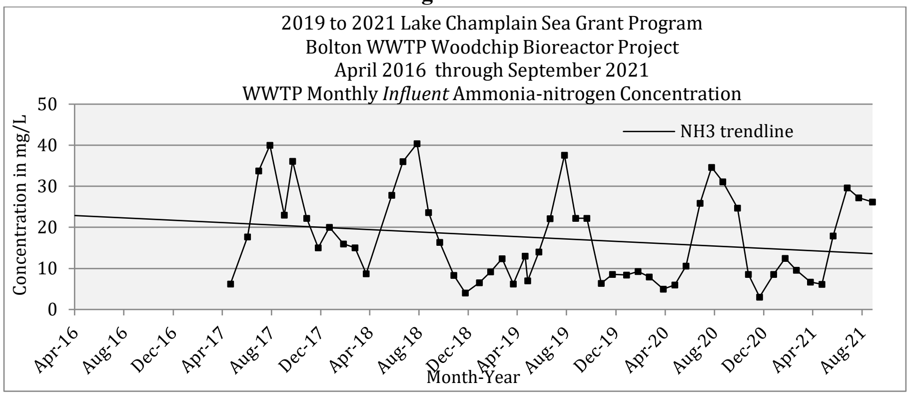
In contrast to the other wastewater influent parameters discussed in this section, the peaks in NO_3-N concentrations corresponded to the colder months of the year while the lower concentrations occurred during the late spring and summer months (Figure 7-8).

As shown in Figure 7-8, the nitrate-nitrogen trendline has been decreasing during the period from April 2016 through September 2021.

Ammonia-nitrogen (**NH_3-N**) concentrations in *influent* wastewater entering the Bolton facility first were analyzed in May 2017 and have varied since that time, ranging from 3.05 to 40.4 mg N·L and averaging 17.3 (±10.7) mg N·L through September 2021.

The monthly concentration of NH_3-N in *influent* entering the facility since May 2016 is summarized in Figure 7-9.

Figure 7-9.



As with some of the other parameters discussed in this section, the peaks and valleys for NH_3-N were closely related to the periods of high flow from increased tourism and low flow associated with the winter months in the area, respectively.

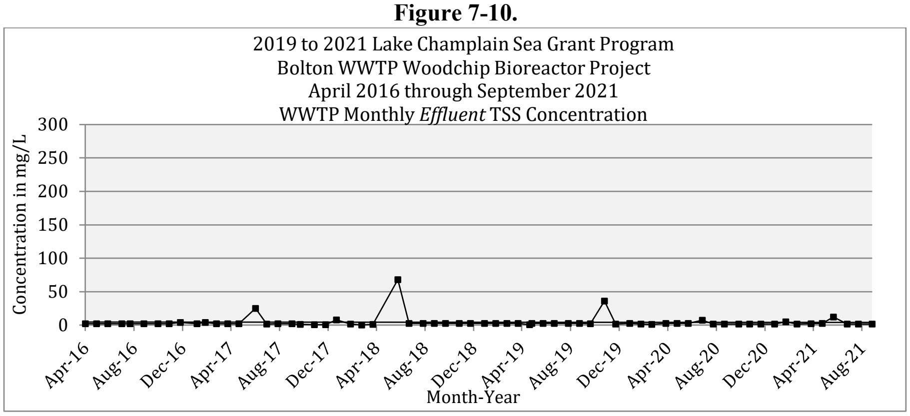
And, as indicated by the NH_3-N trendline in Figure 7-9, there has been a steady decline in influent NH_3-N concentration entering the facility since May 2017.

7.2.4 Plant Wastewater Effluent

Effluent is the final product of wastewater treatment discharged to the sand disposal beds for final water quality 'polishing.' Parameters measured in the Bolton plant *effluent* and discussed in this section include TSS, settleable solids, BOD_5, total phosphorus, nitrate-nitrogen, ammonia-nitrogen, and Total Kjeldahl Nitrogen (TKN).

Total suspended solids (TSS) concentrations measured in *effluent* leaving the Bolton facility from April 2016 through September 2021 are summarized in Figure 7-10.

Figure 7-10.

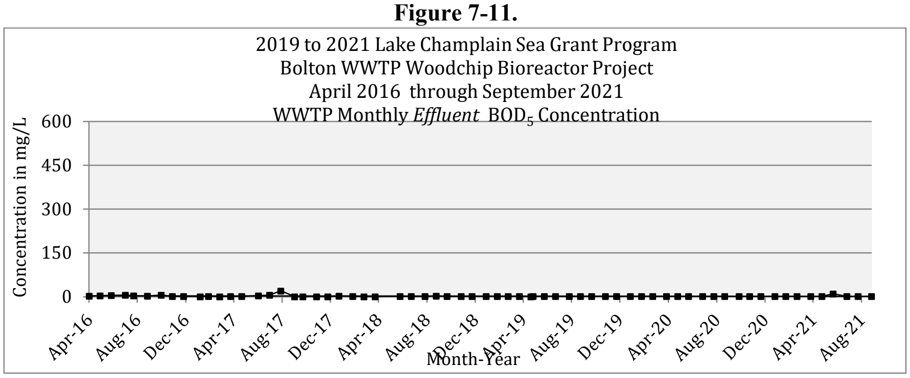


During the 66 months of Bolton plant *effluent* TSS data plotted in Figure 7-10, there were 18 months (27 percent) when TSS concentrations were reported above the lowest level of detection (the minimum level of detection for the analytical laboratory was 4.0 mg TSS·L, and all results below detection were reported as 2.0 mg TSS·L). Furthermore, from a comparison of Figure 7-10 with Figure 7-4, we can see that all TSS are removed from *influent* to the Bolton WWTP by unit processing in the facility before being discharged as *effluent*.

Settleable solids (SS) in plant *effluent* were below the level of detection (0.1 mL SS·L) for the entire 66-month period reported herein and are not presented in graphic format.

B.O.D.$_5$ in plant *effluent* from April 2016 through September 2021 averaged 3.1 (±1.7) mg BOD_5·L. The range of concentrations was from below detection (4.0 mg BOD_5·L) to 20.8 mg BOD_5·L with 17 readings above the minimum detectable level and all of the readings occurred during 2016 and early 2017. The visual summary of BOD_5 measurements in plant effluent is presented in Figure 7-11.

Figure 7-11.

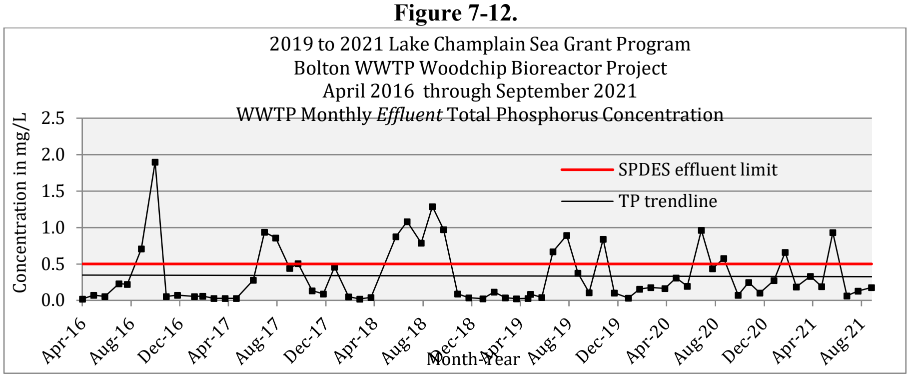


As with TSS described above, a comparison of Figures 7-6 and 7-11 shows that all BOD_5 is removed from wastewater processed through the Bolton facility before being discharged as *effluent* to the local ground water.

Total phosphorus (**TP**) in treated wastewater becomes a vegetation growth nutrient when discharged to a receiving body of water such as a stream, pond, or lake. The SPDES permit issued by the NYSDEC that regulates operation of the Bolton WWTP sets an upper limit for TP of 0.5 mg P·L for *effluent* discharged to the sand beds.

As shown in Figure 7-12, there was considerable variation in the TP concentration measured in *effluent* during the period from April 2016 through September 2021, with high concentrations of TP during mid-summer and low concentrations during the winter months.

Figure 7-12.



During the 66-month period shown in Figure 7-12, the TP concentration had an *average* of 0.34 (±0.39) mg P·L and there were 17 months when the concentration exceeded the SPDES permit effluent limitation of 0.50 mg P·L. Overall, however, there was a 10-fold reduction in TP concentration between *influent* and *effluent* streams with *influent* TP concentration having an *average* of 3.28 (±1.73) mg P·L.

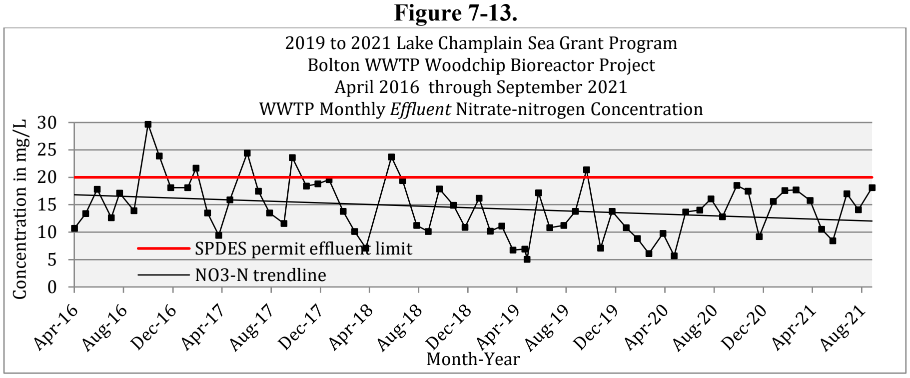
Nitrate-, ammonia- and total Kjeldahl nitrogen are various forms of nitrogen and effective removal of these analytes from wastewater is important because certain forms of nitrogen can act as nutrients and stimulate plant growth and cause human health effects in receiving waters such as Lake George that serve as a water supply for some residents.

The removal of nitrogen is accomplished through the biological oxidation of nitrogen from ammonia to nitrate (*nitrification*), followed by *denitrification*, the reduction of nitrate to nitrite gas, which subsequently is released to the atmosphere and thus removed from water.

The SPDES permit for the Bolton WWTP lists the upper limit of nitrate-nitrogen in the *effluent* discharge pipe as 20 mg N·L, while the upper limit allowed at the monitoring wells is 10 mg N·L. Concentrations more than these values are considered a violation of the SPDES permit conditions.

The *average* **nitrate-nitrogen (NO_3-N)** concentration measured in *effluent* during the 66-month period beginning in April 2016 was 14.4 (±5.1) mg N·L, which is significantly higher than the *average* of 0.33 (±0.47) mg N·L in the *influent* stream and indicates the problem at this facility with *nitrification-denitrification* process. Figure 7-13 summarizes the monthly *effluent* NO_3-N concentrations.

Figure 7-13.

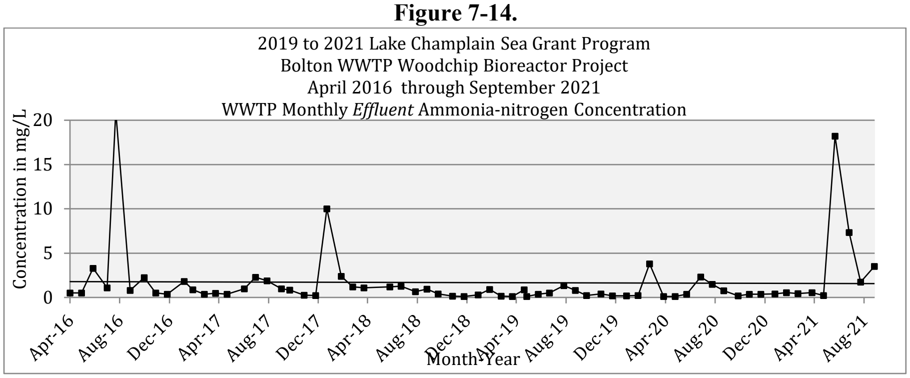


The facility *effluent* NO_3-N concentrations discharged to the sand beds were more than 20 mg N·L on only 7 occasions during the 66-month period, and the NO_3-N trendline in Figure 7-13 clearly shows that *effluent* concentrations have been declining during the entire period.

It is interesting to note that since the inception of the current LCSG Program woodchip bioreactor project at the Bolton WWTP in March 2019, there was only one (1) instance when the NO_3-N concentration exceeded the 20 mg N·L limit specified in the SPDES permit (October 1st, 2019; 21.4 mg N·L).

The **ammonia-nitrogen (NH_3-N)** concentration measured in the facility *effluent* since April 2016 was 1.68 (±3.58) mg N·L compared with the *influent* stream which averaged 17.3 (±10.7) mg N·L. Figure 7-14 summarizes the monthly concentrations and shows that values of ammonia were below 5.0 mg N·L during the entire period except on 5 occasions.

Figure 7-14.

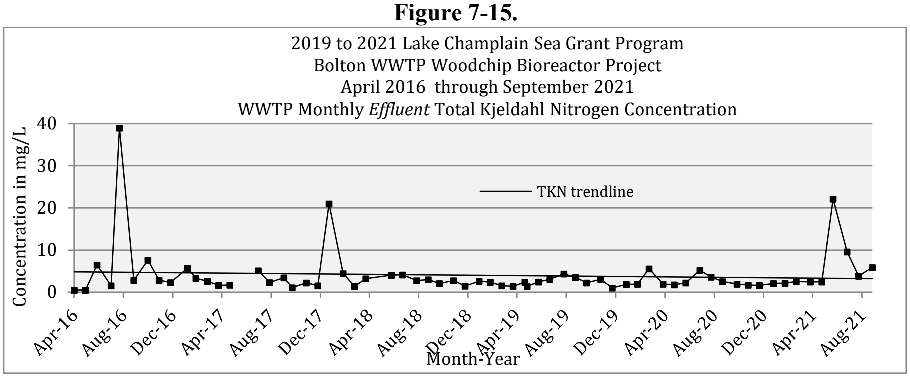


As shown in the figure above, the trendline for the ammonia-nitrogen concentration since April 2016 has been flat, indicating that no apparent increasing or decreasing trend is occurring. There were, however, three (3) months since June 2021 when ammonia-nitrogen concentrations in *effluent* leaving the facility were in excess of 2.0 mg N·L (see Figure 7-14).

Total Kjeldahl nitrogen (**TKN**) is the sum of organic substances, ammonia-nitrogen (NH_3-N) and ammonium-nitrogen (NH_4-N) in the chemical analysis of soil, water, and wastewater, and is required for regulatory reporting at many treatment plants as a measure of monitoring operations and the efficiency of nitrogen breakdown into forms that have minimal impact on the environment.

TKN in the *effluent* of the Bolton facility averaged 4.00 (±5.72) mg N·L from April 2016 through September 2021 and the summary of these data is presented in Figure 7-15.

Figure 7-15.



There were only three (3) occasions when the TKN concentration in the effluent was above 10 mg N·L and the TKN trendline indicates that the concentration has been gradually declining since April 2016.

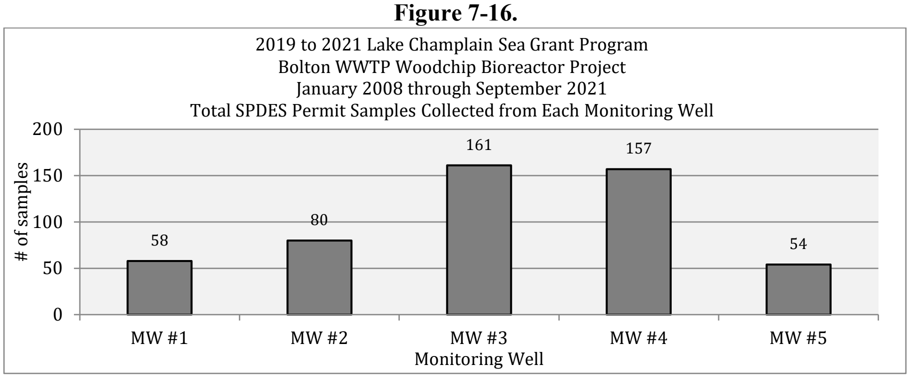
7.2.5 SPDES Permit Monitoring Wells

Background of the Bolton WWTP SPDES permit monitoring wells (MWs) was described in Chapter 2. This section presents the monthly results for the MWs intercepting ground water moving away from the WWTP property. The SPDES permit issued by the NYSDEC for plant operation limits nitrate-nitrogen (NO_3-N) at 10.0 mg N·L and total phosphorus (TP) at 0.5 mg P·L in the ground water.

The 2017 report on the Bolton WWTP summarized DMR data going back to 2008 to evaluate the MWs associated with the plant SPDES permit. DMR data for the five (5) SPDES MWs has been updated for this report to evaluate any ground water nutrient trends from January 2008 through September 2021.

Monitoring well (MW) productivity. From January 2008 through September 2021, there were a total of 165 SPDES permit testing periods at the Bolton facility. Figure 7-16 summarizes the total SPDES permit samples collected from each MW during the period.

Figure 7-16.



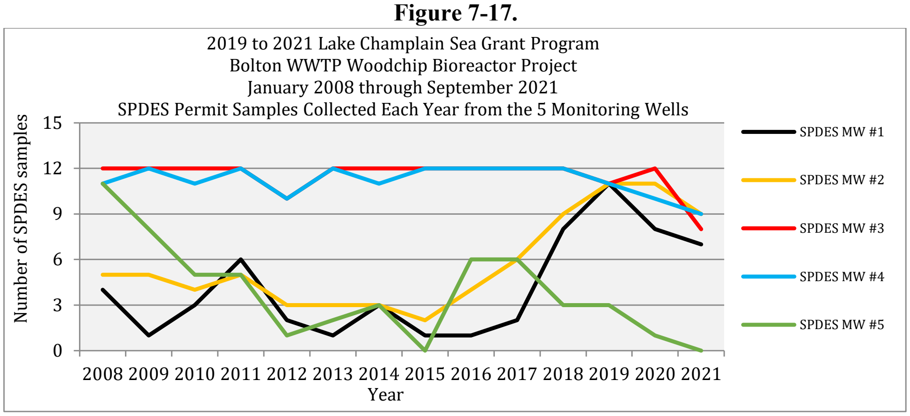
Based upon the total number of samples collected from the SPDES permit MWs shown in Figure 7-16, MWs #1, #2 and #5 appear unable to provide regular samples for SPDES testing. There are several factors that affect the data shown in Figure 7-16, however, that should be considered:

(1) During the 14 years of plant operation summarized above, disposal of plant *effluent* followed a specific pattern of discharge with disposal (by pumping) to the upper sand beds during the growing season and disposal to the lower sand beds (by gravity) during the winter months, and
(2) During 2017, the Town of Bolton developed and passed a resolution that discontinued use of the lower sand infiltration beds for disposal of treatment plant effluent unless an emergency occurred which prevented use of the upper sand beds. Since September 2017, the upper sand beds have been used for *effluent* disposal a total of ~43.5 months and the lower sand beds have been used for effluent disposal a total of ~7.5 months for several reasons including pump repair, pump replacement, high water infiltration (from storm events).

The above information should be considered when an evaluation of the productivity of the SPDES monitoring wells is conducted.

In addition to the above considerations, SPDES MW annual productivity is summarized in Figure 7-17 using additional data compiled with DMR reports from January 2008 through September 2021.

Figure 7-17.



The productivity of MWs #1, #2, and #5 was variable each year between 2008 and 2018, while MWs #3 and #4 were highly productive throughout the same period.

MWs #1, #2 and #3 are adjacent to, and down-gradient of, the upper sand disposal beds and would produce fewer SPDES samples during the winter months when effluent discharge went to the lower beds (through winter 2018 to 2019) and ground water in the upper area was lower due to frozen soils and precipitation, accumulating snowpack, and no regular pattern of effluent discharge.

It was determined during the 2016 to 2017 study that MW#4 did not intercept ground water from any of the sand disposal beds on the Bolton WWTP property and was a "back-ground" well that intercepted ground water from higher elevations west and north of the facility.

It appears that MW#5 was poorly placed when installed and is adjacent to, but not directly down-gradient, of any lower sand beds and probably intercepts ground water from northwest of the lower sand beds.

From the data presented in Figure 7-17, all MWs except #5 exhibited increasing productivity once the lower sand disposal beds were no longer used and plant effluent was pumped year-round to the upper sand beds for disposal.

7.2.6 Recent Bolton WWTP SPDES Permit Performance

The current SPDES permit standard evaluates the effectiveness of treatment at the Bolton facility by the concentration of NO_3-N and (TP) measured in the MWs. In this section, DMR data from the Bolton facility from January 2008 through September 2021 are summarized and presented in different formats to examine long-term trends in SPDES permit violations that may not be apparent otherwise.

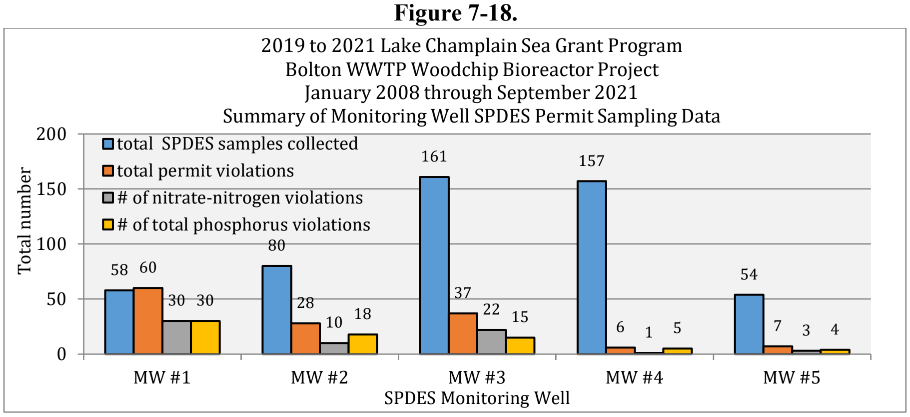
Summary of SPDES permit sampling – January 2008 through September 2021. Table 7-1 summarizes SPDES permit sampling in MWs #1 through #5 from January 2008 through September 2021 including total number of samples collected, total nitrate-nitrogen violations, total phosphorus violations and the percent of violations for both nutrients with limitations.

Table 7-1.

	MW #1	MW #2	MW #3	MW #4	MW #5
total monthly SPDES samples possible	165	165	165	165	165
total monthly SPDES samples collected	58	80	161	157	54
percent (%) total possible samples collected	35	48	98	95	33
# NO_3-N violations	30	10	22	1	3
% NO_3-N violations	52	13	14	<1	6
# TP violations	30	18	15	5	4
% TP violations	52	23	9	3	7

Figure 7-18 summarizes the Table 7-1 data in bar graph format to provide a better visual comparison of the data from the five (5) MWs.

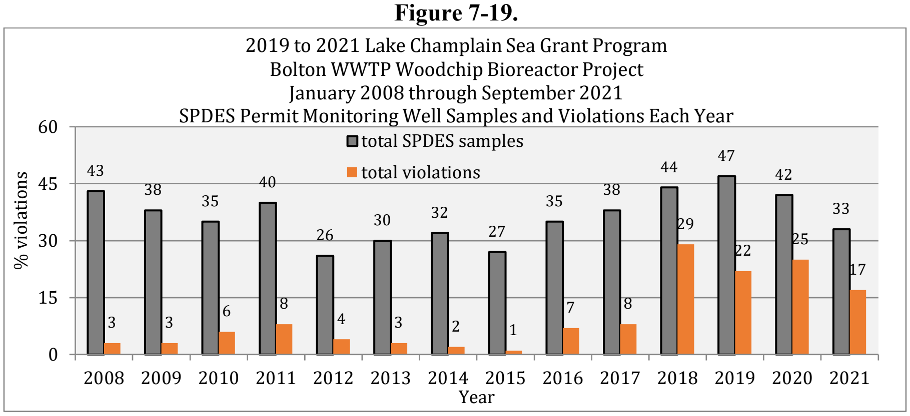
Figure 7-18.



During the 14 years summarized in Figure 7-18, the highest percent of SPDES permit violations occurred in MW#1, with 30 NO_3-N and 30 TP sample violations, a 52 percent violation rate for each nutrient. MWs #2 and #3 followed with the next highest percent of total violations, then MW #5 and MW #4. (Table 7-1, Figure 7-18).

Figure 7-19 summarizes the total number of annual SPDES permit violations (both NO_3-N and TP) at the Bolton facility between 2008 and September 2021. Total permit violations increased from 2008 (3) through 2011 (8) and then decreased to 1 violation in 2015.

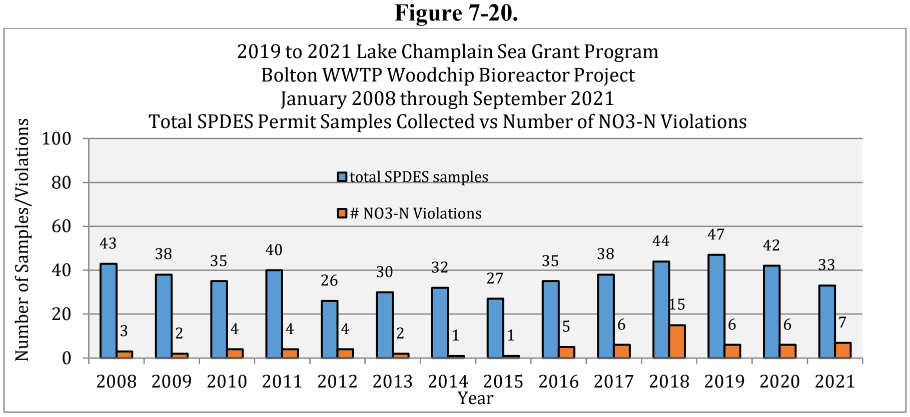
Figure 7-19.



Thereafter, violations reached an annual high of 29 in 2018 and decreased to 17 through September 2021. These data suggest that the almost continuous operation of the woodchip bioreactor at the Bolton facility starting in March 2019 had an overall impact of reducing the total number of violations through the period by its ability to reduce nitrate-nitrogen in the effluent stream leaving the facility.

The annual permit violation data become even more interesting if the NO_3-N and TP samples are separated and examined individually. Figure 7-20 summarizes the NO_3-N permit violations from 2008 through September 2021.

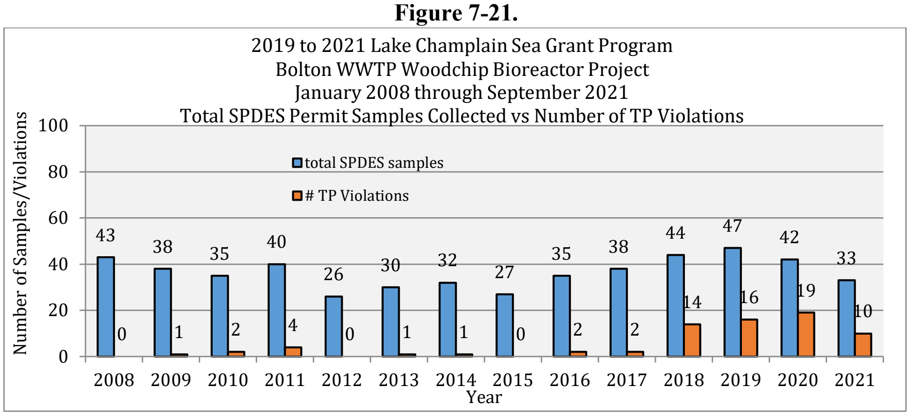
Figure 7-20.



Once again, it is interesting to attribute the decline in NO_3-N violations from 2019 through September 2021 to the installation of the woodchip bioreactor in the area of the upper sand beds and the ability of this unit processor to reduce the NO_3-N concentrations leaving the Bolton facility in wastewater effluent. There will be more evidence and discussion related to this topic later.

Figure 7-21 summarizes the TP SPDES permit violations that occurred from 2008 through September 2021 compared with the total SPDES samples collected each year. In contrast to the NO_3-N pattern of violations, TP violations were extremely low from 2008 through 2017 and then increased dramatically thereafter with 14 violations in 2018, 16 violations in 2019, 19 violations in 2020 and 10 violations currently documented through September 2021.

Figure 7-21.

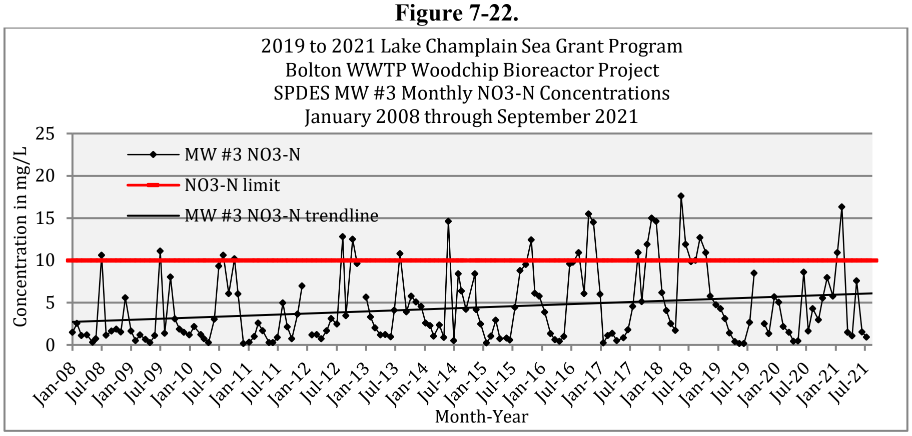


The pattern of increasing TP SPDES violations since 2018 is interesting and warrants further evaluation and discussion which will be provided below.

Bolton WWTP SPDES Monitoring Well #3. Some insight into the ability of the sand disposal beds to 'polish' effluent received from the Bolton treatment plant can be gained by looking at the long-term record of SPDES results for certain ground water monitoring wells on the Bolton WWTP property. At the present time, MW #3 is the most suitably located well to collect reliable SPDES permit samples from ground water that is affected by the discharge of plant effluent to the upper sand beds.

Figure 7-22 summarizes the monthly NO_3-N concentrations measured in SPDES MW#3 from January 2008 through September 2021 and suggests that there has been a trend of increasing NO_3-N concentration in SPDES samples collected from MW #3.

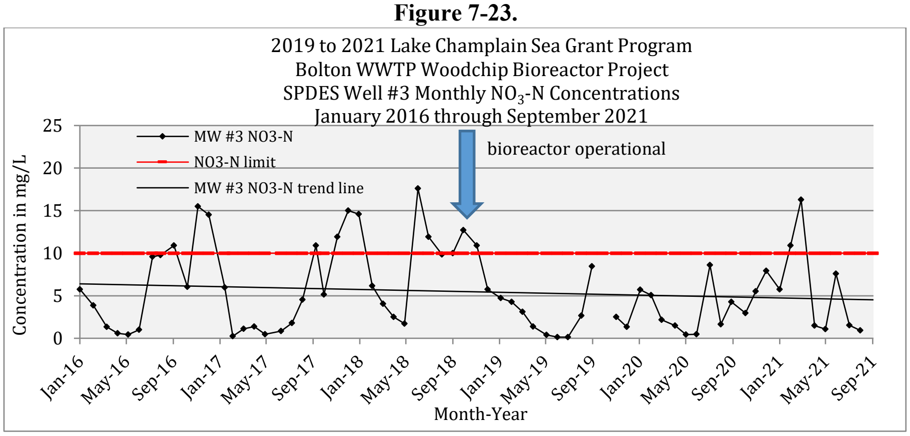
Figure 7-22.



Although most of the reported concentrations are below the threshold of 10 mg N·L, the NO_3-N trendline in Figure 7-22 predicts that increasingly more samples will be reported as SPDES permit violations in the future when looking at the data from January 2008 through September 2021.

A more detailed look at Figure 7-22, however, suggests that a change in the annual pattern of NO_3-N concentration occurred late during 2019 and continued through the end of September 2021, as shown in Figure 7-23 which covers that time period.

Figure 7-23.

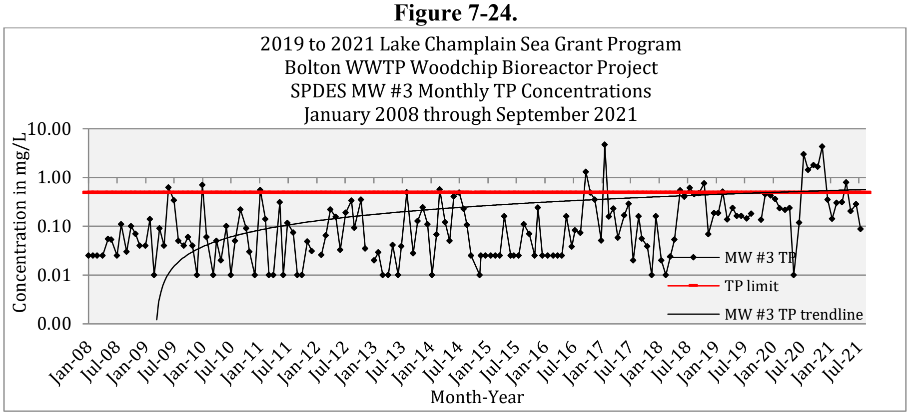


From January 2016 through September 2018, there were a total of nine (9) NO_3-N concentration violations measured in MW #3, with a similar recurring pattern of concentration exhibited during each annual cycle. Beginning in October 2018, a noticeable decrease in the pattern of NO_3-N concentrations occurred, and only two (2) NO_3-N monthly concentrations exceeded the SPDES permit limit through the end of September 2021.

All of this change with NO_3-N concentrations described above occurred coincident with the operation of the woodchip bioreactor beginning early in October 2018 (Figure 7-23) and suggests that the unit process of this technology was able to cause significant changes in the levels and pattern of NO_3-N concentrations measured in MW #3 down-gradient of the upper sand beds and up-gradient of Stewart Brook where the ground water from the higher elevations eventually emerges.

A summary of TP measured in MW #3 during the period from January 2008 through September 2021 (Figure 7-24) provided related results to the NO_3-N pattern in Figure 7-22, although the trend for TP was not as significant as the NO_3-N trendline.

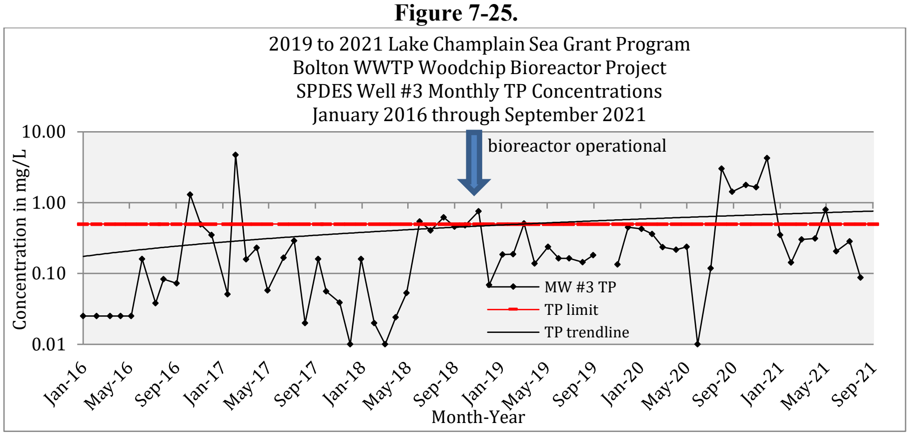
Figure 7-24.



The reader should note that the *y-axis* in Figure 7-24 is in logarithm scale to accurately display the wide range of TP values measured for the SPDES permit TP samples collected from MW #3.

A more detailed look at Figure 7-24, however, suggests that a change in the annual pattern of TP concentration occurred late during 2019 and continued through the end of September 2021, as shown in Figure 7-25 which covers that time period.

Figure 7-25.



From January 2016 through September 2018, there were a total of four (4) TP concentration violations measured in MW #3, and the TP concentrations pattern during that time was very scattered/irregular (Figure 7-24). Then, beginning in October 2018, a noticeable change in the pattern of TP concentrations occurred. With the exception of three (3) samples collected between October 2018 and September 2021, all measured TP concentrations were above 0.10 mg P·L, which was a major shift in concentrations when compared with the previous period from January 2016 through October 2018.

Although it is too soon to tell based upon the limited data presented above, it appears that continuous use of the upper sand beds for effluent disposal following installation and operation of the woodchip bioreactor in October 2018 has changed the subsurface characteristics of the soils and ground water in this region of the Bolton WWTP property. The conditions in this area could well be similar to conditions described in the region of the lower sand beds where ground water impacts two (2) different watersheds and phosphorus appears to be stored in the soil following years of effluent disposal to these areas (Sutherland and Navitsky 2017). We hypothesize that phosphorus released from the treatment plant over the past several decades has accumulated in the soils of the lower sand beds and is bound with sediments.

The primary constituents in soil chemistry that affect phosphorus dynamics are iron and manganese, and the key to release of bound phosphorus is the alternating wetting and drying cycles when the beds are dosed with effluent. Wetting (dosing) adds phosphorus to the beds (loading), while alternating wet-dry cycles affect oxygenation in the soils and the binding capacity of associated minerals. In oxygenated environments, concentrations of iron and manganese generally are $<100\ \mu g \cdot L^{-1}$ because these constituents form oxide and oxy-hydroxide complexes that are not soluble in oxidizing conditions (Deutsch 1997). As oxygen is consumed in the aquifer below the beds, concentrations of iron and manganese tend to increase with the dissolution of these complexes. There appears to be a general association between dissolved iron and elevated phosphorus conditions which suggests that reducing conditions that mobilize iron may facilitate transport and release of dissolved (soluble) phosphorus (Welch et al. 2010).

Data for the other Monitoring Wells were not summarized in this manner in this report because the number of samples was much lower, and no significant trends were observed.

6.2 Discussion and Summary

The historical information presented in this chapter confirms that the Bolton WWTP was not removing nitrate from wastewater treated within the plant prior to the effluent being discharged to the sand beds.

Furthermore, the sand beds receiving the effluent were not providing any treatment which meant that high nitrate concentrations were entering the ground water with the direction of movement dependent upon which sand beds are being used for effluent discharge.

The purpose of the sand beds is primarily for disposal while polishing effluent to a minimal extent as it moves toward the ground water table, not to facilitate the process of nitrogen removal from the effluent.

The 2017 report about the Bolton facility considered that the subsurface pattern of ground water movement down-gradient of the Bolton WWTP had changed during the past several decades since the SPDES permit monitoring wells were installed in the late 1980s. At that time, only two (2) of the five (5) monitoring wells (MW#3 and MW#4) were able to provide reliable monthly SPDES samples for testing. It now appears that the productivity of MW #1 and #2 have increased since the time that plant effluent has been discharged exclusively to the upper sand beds.

In addition, the water quality characteristics of samples collected from MW #4 do not appear to represent ground water influenced by effluent disposal to the upper sand beds. Instead, the water quality characteristics of MW #4 appear closely related to ground water moving east and south from higher elevations through the treatment plant property.

The most important finding to be realized from the material presented in this chapter is the fact that nitrate-nitrogen concentrations have decreased substantially in the ground water down-gradient of the upper sand disposal beds and this decrease coincides with the installation and operation of the woodchip bioreactor technology at the Bolton WWTP.

6.3 Literature Cited

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Sutherland, J.W. and C. Navitsky. 2017. *Final Report. Bolton Bay (Lake George, Warren County) Water Quality Assessment. A Monitoring Program to Evaluate Current Water Quality Issues*. Prepared for The Fund for Lake George and the Town of Bolton. 150 pp. + appendices.

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Lake Champlain Sea Grant Program

Bolton Wastewater Treatment Plant Woodchip Bioreactor Project

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2021 Final Report

Chapter 8

Water Quality Results Past and Present – Stewart Brook Watershed

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8.0 Background

The Bolton WWTP is situated on a series of stepwise plateaus along the west side of the Lake George drainage basin within the Town of Bolton. The plateau elevations vary from ~425 feet (AMSL) in the area of the lower sands beds to ~475 feet (AMSL) at the highest point adjacent to the upper sand beds; the elevation of Lake George is 320 feet (AMSL).

Two (2) lot parcels with a total surface area of ~21.5 acres comprise the Bolton WWTP and numerous outcroppings of bedrock occur in this area. The facility was constructed during 1959 and 1960 to utilize the natural delta sand deposits, created by outwash from receding glaciers, as an infiltration area for treated sewage effluent. The location and design of the Bolton WWTP is similar to the Village of Lake George Wastewater Treatment Plant which also was studied recently (Sutherland and Navitsky, 2015).

RFWI scientists conducted an early 1980s study and reported that ground water leaving the region of the WWTP flows in different directions depending upon which sand infiltration beds were used for effluent disposal. Treatment plant effluent discharged to the upper beds (utilized only during the ice-free seasons) moved down-gradient in a north-northeast direction and entered Stewart Brook near the intersection of Brook Street and Goodman Avenue. Aulenbach and Fillip (1983) established the connectivity of the upper infiltration beds to Stewart Brook by conducting a Rhodamine-WT dye study. The connectivity of the upper infiltration beds with Stewart Brook is hand-drawn in the upper portion of Figure 8-1 below.

Figure 8-1.

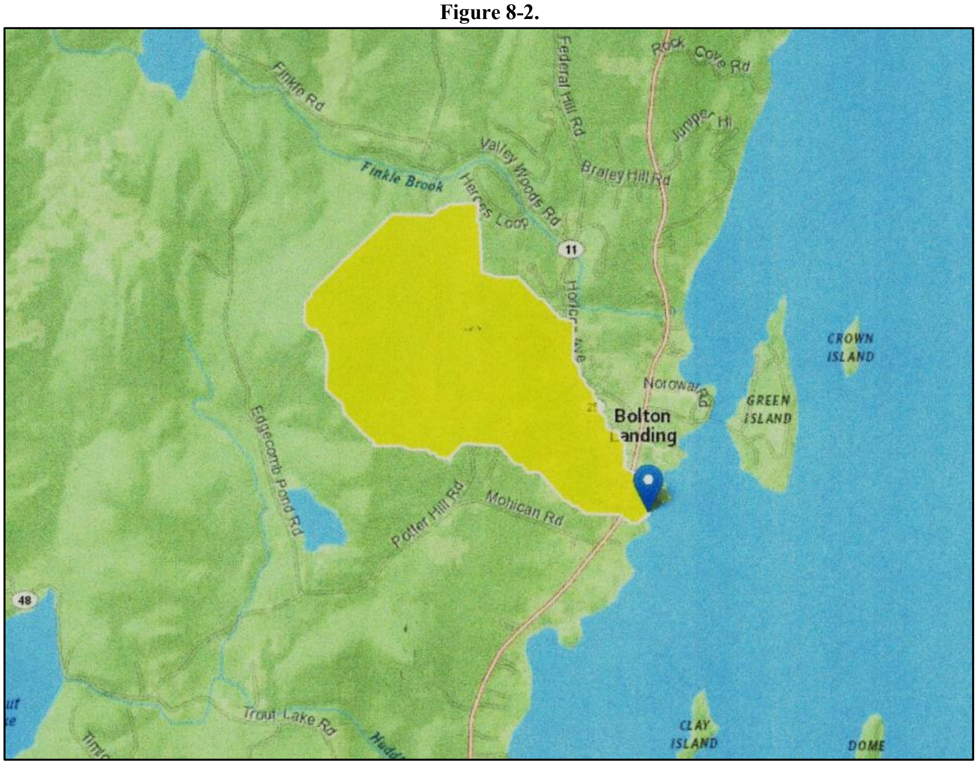
The subsurface drainage characteristics of the lower infiltration beds were described by Aulenbach and Fillip as being more complex, also shown in Figure 8-1. They described these beds as bisected in an east-west direction by a subsurface ridge of bedrock (yellow line at lower sand beds) that resulted in treatment plant effluent applied to the north lower sand beds traveling toward Stewart Pond, while effluent applied to the south lower sand beds traveled toward Mohican Road. The data presented in their 1983 report substantiates the movement of ground water toward Mohican Road but failed to provide solid evidence of ground water movement toward Stewart Pond when treatment plant effluent was applied to the two (2) northern lower sand beds. Sutherland and Navitsky (2017) confirmed this movement of ground water down-gradient from the lower infiltration beds to Stewart Pond using separate Rhodamine dye studies.

The Sutherland and Navitsky study during 2016 and 2017 provided conclusive evidence that the lower sand beds are hydraulically connected to both the Mohican Tributary and Stewart Brook watersheds depending upon which beds are used for effluent disposal. Following release of their report, however, the Town of Bolton adopted a resolution that specifically prohibited use of the lower sand beds for effluent disposal except in the case of an emergency, which has occurred on only two occasions since mid-2018. Thus, current nutrient loading to Mohican Road Tributary and Stewart Brook from the lower infiltration beds is from legacy nutrient concentrations of nitrate-nitrogen and soluble reactive phosphorus in these watersheds from previous use of these sand beds for effluent disposal except during current emergencies.

8.1 Description of the Stewart Brook Watershed

The Stewart Brook watershed is located in the Hamlet of Bolton Landing (Warren County, New York). Figure 8-2 is an outline of the watershed (http://streamstatsags.cr.usgs.gov/streamstats/).

Figure 8-2.



The USGS software lists the watershed surface area as 0.71 mi^2 (454 acres) and the length along the main channel from the outflow into Lake George to the basin divide at the top of the watershed as 1.8 mi.

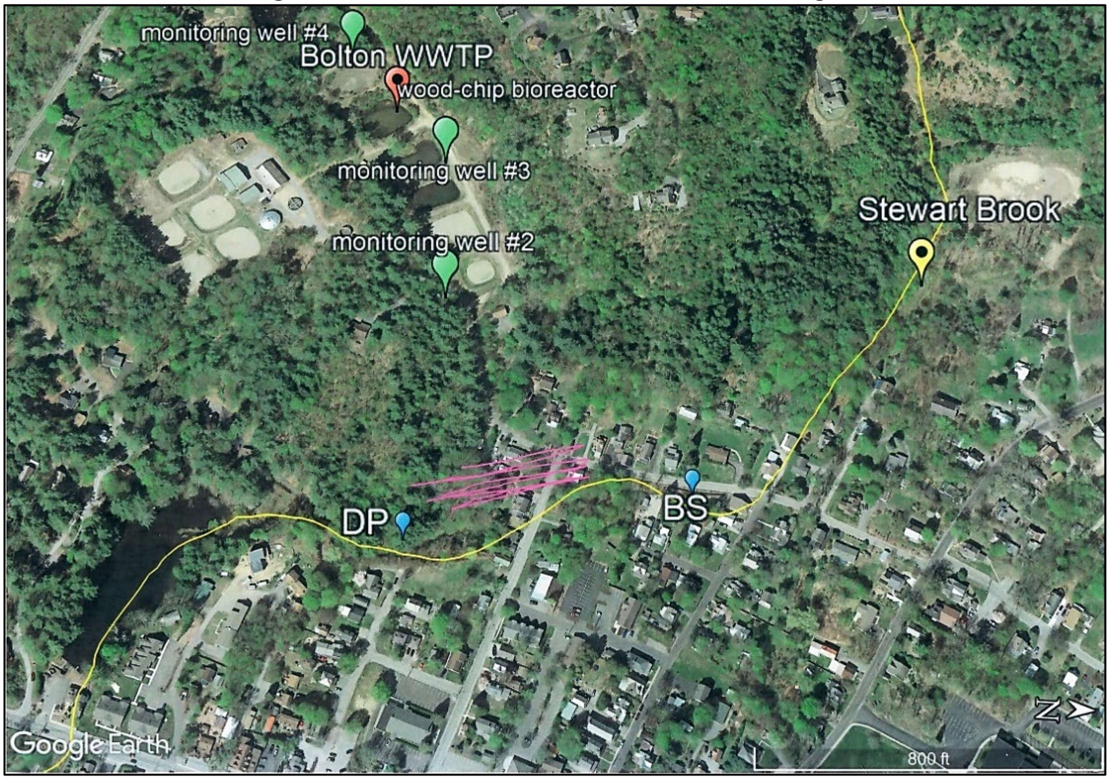
As mentioned above, a portion of the south boundary of the watershed divides the lower sand beds of the Bolton WWTP so that effluent applied to beds #1 and #3 (within the watershed) enters the ground water and moves north and east toward Stewart Pond (Aulenbach and Fillip 1983).

Stewart Brook exhibits a well-defined channel from the outflow into Lake George back through Stewart Pond and the developed area of Bolton Landing and has its origin at higher elevations to the west of Potter Hill Road.

8.2 Location and Description of Program Sampling Sites

Stewart Brook is affected by ground water moving down-gradient from the upper region infiltration sand beds of the Bolton WWTP. To properly document the effect of the treatment facility on this tributary during the current LCSG Program study, it was necessary to select two stations along the tributary channel to monitor water quality. As ground water moves down-gradient in a north-easterly direction from the upper sand beds, it emerges and enters Stewart Brook (yellow line) in the area of purple shading in Figure 8-3.

Figure 8-3. need to add BL site and MW #1 to this figure



The Brook Street (**BS**) station on Stewart Brook is located ***above*** the influence of treatment plant ground water and the Dula Place (**DP**) site is located ***below*** the area. The **DP** sampling station also was part of the previous 2016 to 2017 study (Sutherland and Navitsky 2017), while the station monitored ***above*** the influence in that study was located slightly north and west of the **BS** site and was Bradley Lane (**BL**).

The description of Stewart Brook methodology associated with the current LCSG Program was described in Chapter 5 and is the same methodology and field procedures followed during the 2016 to 2017 study of the Bolton WWTP and its effect on the Mohican Road and Stewart Brook tributaries.

The Bradley Lane (**BL**) station is being used as a surrogate station for the Brook Street (**BS**) station in this report when comparing the impact of the Bolton WWTP on the water quality of Stewart Brook during the previous (2016 to 2017) and current (2019 to 2021) studies.

8.3 Results - Previous (2016 to 2017) and Current (2019 to 2021) Sampling Programs

The material in this chapter describes the physical and chemical characteristics of Stewart Brook above and below the area where ground water from the upper sand beds enters the channel and compares the influence of each characteristic using data collected during the 2016 to 2017 and the 2019 to 2021 studies.

A comparison of water quality data collected during the two studies is not as straight-forward as one might imagine for several reasons including the following:

1) The length of the 2016 to 2017 study was 14 months, beginning in April 2016 and ending in May 2017, while the length of the 2019 to 2021 study was 31 months, beginning in March 2019 and extending through September 2021.
2) The earlier study collected data at bi-weekly intervals during the ice-free season and at monthly intervals during the winter months, while the 2019 to 2021 study collected data at bi-weekly intervals throughout the entire period.
3) There were certain analytes measured during the 2016 to 2017 study (total phosphorus, total nitrogen, chloride) that are not summarized in Table 8-1 because they were not included in the test pattern for the 2019 to 2021 study. Similarly, some analytes measured in the 2019 to 2021 study (ammonia-nitrogen, alkalinity) were not measured in the earlier study of the Bolton WWTP and these data are not included in this summary and comparison.

Table 8-1 summarizes the physical and chemical analytes collected from the Stewart Brook stations *above* (**BL** and **BS**) and *below* (**DP)** where ground water from the upper sand beds emerges and enters the tributary with the potential to affect water quality. The table compares data collected during the 2016 to 2017 and 2019 to 2021 studies and provides *minimum*, *maximum*, *mean* values, the *standard deviation* for each analyte, and the number of samples (*n*) collected.

Table 8-1.

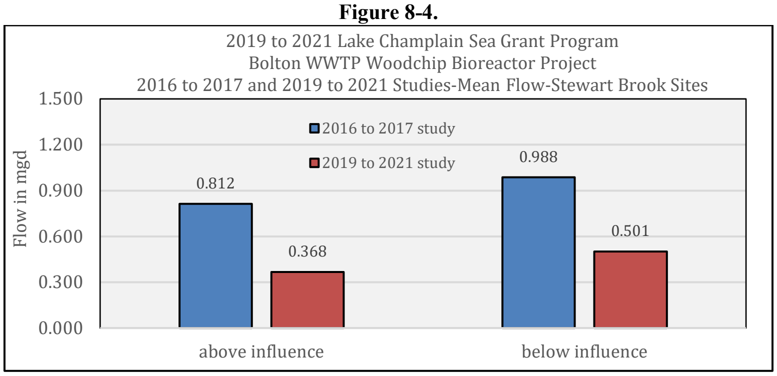
	Stewart Brook							
	Flow	Temp	Dissolved Oxygen	pH	Specific Conductance	TDS	NO_3-N	SRP
	(mgd)	(°C)	(% saturation)	(s.u.)	(µS/cm @ 25C)	(mg/L	(mg/L)	(mg/L)
Bradley Lane (*above*)								
Sutherland and Navitsky (2016 to 2017)								
Minimum value	0.006	0.9	88.3	6.93	68.3	46.7	0.005	0.50
Maximum value	10.743	19.8	99.9	8.25	463.8	315.8	0.17	6.8
Mean value	0.812	9.7	96.0	7.63	198.4	132.8	0.09	0.002
Standard deviation	2.240	6.1	3.2	0.38	78.8	53.3	0.04	0.001
Sample size (n)	20	20	20	20	20	20	20	20
Brook Street (*above*)								
LCSG (2019 to 2021)								
Minimum value	0.012	0.0	91.5	6.16	94.7	62.7	0.01	0.005
Maximum value	1.732	19.8	109.9	8.82	261.5	178.3	0.48	0.02
Mean value	0.368	8.9	102.6	7.50	180.9	119.5	0.12	0.005
Standard deviation	0.439	6.4	5.20	0.61	44.4	29.3	0.08	0.002
Sample size (n)	59	65	65	65	63	63	65	65
Dula Place (*below*)								
Sutherland and Navitsky (2016 to 2017)								
Minimum value	0.022	1.3	89.2	6.79	82.1	56.2	0.02	0.50
Maximum value	11.452	17.2	101.1	8.15	497.4	342.4	8.70	0.009
Mean value	0.988	9.9	94.8	7.60	268.7	183.1	2.00	0.003
Standard deviation	2.591	5.9	3.4	0.36	114.4	79.0	2.43	0.002
Sample size (n)	20	20	20	20	20	20	20	20
Dula Place (*below*)								
LCSG (2019 to 2021)								
Minimum value	0.080	0.0	83.3	6.60	142.1	96.7	0.43	0.005
Maximum value	1.985	17.5	121.8	8.45	614.0	414.0	8.88	0.06
Mean value	0.501	9.3	100.0	7.55	355.3	241.9	3.45	0.006
Standard deviation	0.475	5.6	7.4	0.41	135.4	94.6	2.47	0.007
Sample size (n)	63	65	65	65	62	62	65	65
#.## = value reported one-half lower limit of detection								

In the case of some parameters summarized above, e.g., flow, there was a wide range of values as indicated by the high values for *standard deviation* and a comparison of *mean* values was not helpful in evaluating the data between the two (2) studies. In many cases, the most beneficial comparison of data from both studies for the purposes of discussion were individual graphs of the specific data measured over the period of the study being discussed. The following material presents and describes the data summarized above in greater detail.

8.3.1 Physical characteristics

Flow. The *mean* flow values measured at the *above* and *below* sampling stations on Stewart Brook during the two (2) studies are summarized in Table 8-1 and Figure 8-4.

Figure 8-4.



The *mean* flow measured at the Bradley Lane sampling station during the 2016 to 2017 study was 0.812 (±2.240) cfs while the mean flow measured at the Brook Street sampling station a few hundred feet below the Bradley Lane station during the 2019 to 2021 study was 0.368+ (±0.439) cfs (Table 8-1). While it would seem that the *mean* values from the 2 studies should be similar in magnitude, an extremely high *maximum* flow value measured at Bradley Lane (10.743 mgd) occurred during a period of rainfall and snowmelt in April 2017 and a similar magnitude storm event did not occur during the 2019 to 2021 study.

The same *maximum* flow phenomenon occurred at the Dula Place monitoring station (Table 8-1, Figure 8-4) during the earlier study from the April 2017 storm event (11.452 cfs) which skewed the *mean* value (0.988 cfs) and *standard deviation* (2.591 cfs) of the study data while the 2019 to 2021 study data from that station were not as dramatic in terms of *mean* value (0.501 cfs) and *standard deviation* (0.475 cfs).

In spite of the different range and magnitude of tributary flow at the Stewart Brook sampling stations when comparing the two (2) studies, plots of the seasonal flow pattern measured during the previous (Figure 8-5) and the current (Figure 8-6) effort at the stations show the similarity of flow characteristics with high flows during spring and early summer and low flow during mid-summer, fall and early winter.

Figure 8-5.

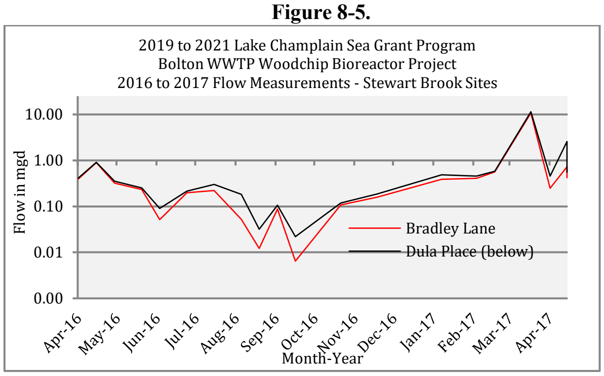
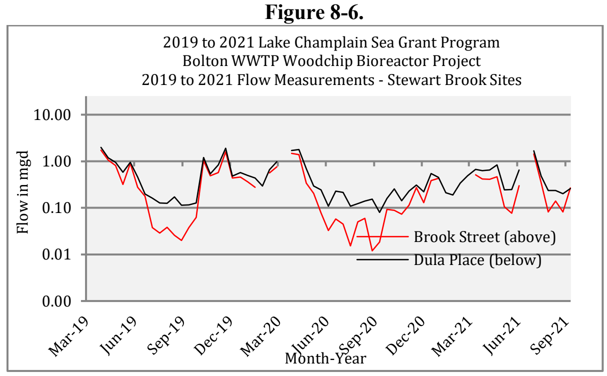


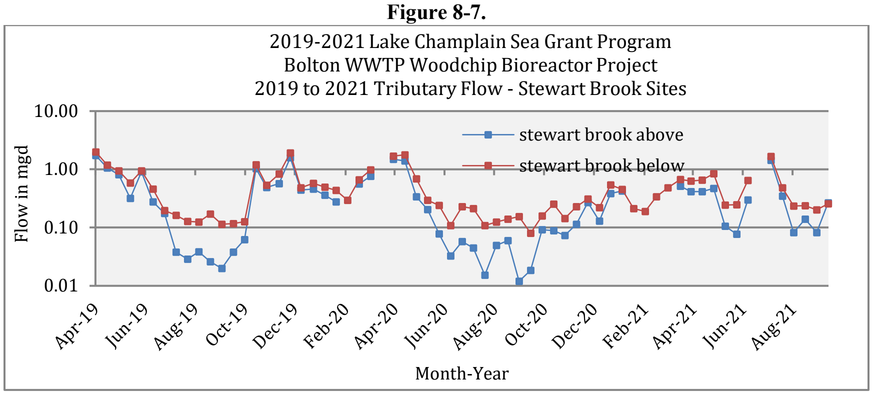
Figure 8-6.



Please note that the *y-axis* in both of the above figures is in logarithm scale to properly display the wide range of flow values measured during both studies.

If we enlarge Figure 8-6 for the current study to provide more detail (see Figure 8-7), the difference in flow between the Brook Street (*above*) and the Dula Place (*below*) stations becomes more apparent and can be attributed to the daily treated effluent from the Bolton WWTP which is discharged to the *upper* sand beds and enters Stewart Brook between these two (2) stations as ground water emerging from the higher elevations to the west (see Figure 8-3).

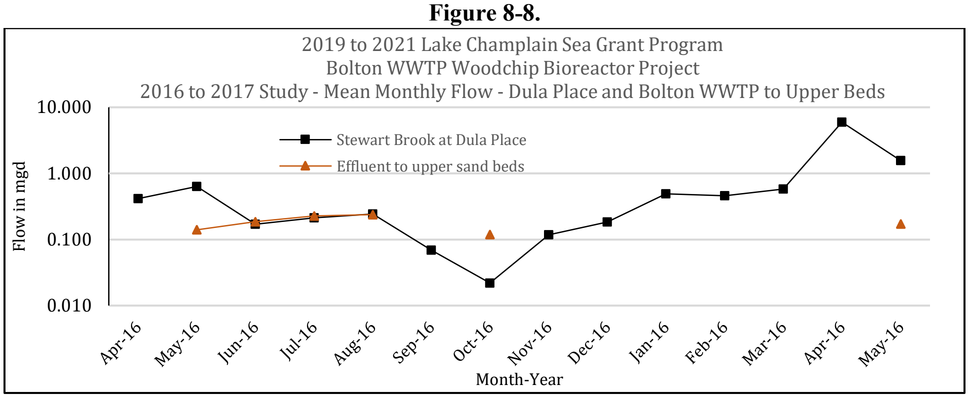
Figure 8-7.



The largest flow differences between *above* and *below* stations occur during the late spring-summer-early fall each year when the daily volume of wastewater entering the plant for treatment is at its highest value due to seasonal tourism.

Figure 8-8 summarizes the *mean* monthly flow (in mgd) at the Dula Place sampling station on Stewart Brook during the 2016 to 2017 study and the mean monthly flow (in mgd) discharged to the upper sand disposal beds after processing through the Bolton facility during the same period.

Figure 8-8.



During the period when this 2016 to 2017 study was being conducted, the upper sand beds were used for effluent disposal only during the ice-free time of the year (May through October), but not all of the time during that period, with the plant operator alternating between upper and lower sand beds.

As shown in Figure 8-8, effluent disposal to the upper sand beds occurred during six (6) months of the 14-month investigation and

(1) contributed all of the flow measured at the Dula Place station during June, July, and August 2016 and,
(2) exceeded the flow measured at Dula Place during October 2016 by a 10-fold order of magnitude.

There are several possible explanations for the disparity between upper bed discharge (0.119 mgd) and tributary flow (0.022 mgd) mentioned above including (1) evaporation from the surface of the sand beds, (2) uptake by vegetation growing in the sand beds, and (3) the October value for tributary flow was based upon only one (1) cross-sectional gaging measurement which did not represent an accurate monthly *mean* value for Stewart Brook.

Figure 8-9 summarizes the *mean* monthly flow (in mgd) at the Dula Place sampling station on Stewart Brook during the 2019 to 2021 study and the *mean* monthly flow (in mgd) discharged to the upper sand disposal beds after processing through the Bolton facility during the same period.

Figure 8-9.

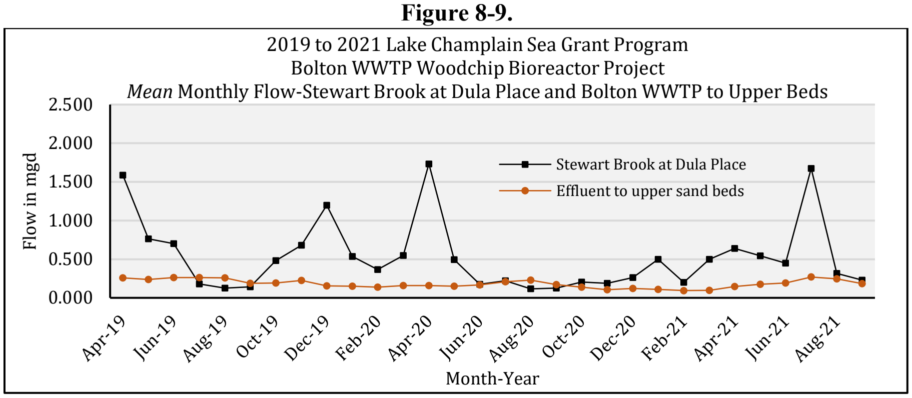


Figure 8-9 gives a better understanding of the contribution of effluent volume discharged to the upper sand beds to the flow measured at the Dula Place sampling station, especially because the upper sand beds have been used for effluent disposal continuously since operation of the woodchip bioreactor was initiated. From March 2019 through September 2021, the *mean* volume of effluent discharged on a monthly basis ranged from 0.094 mgd to 0.269 mgd, while at the same time, the *mean* flow in the tributary at Dula Place ranged from 0.116 to 1.734 mgd.

There were three (3) months during the summer of 2019, July, August, and September, when the *mean* flow of effluent to the upper beds exceeded the *mean* flow measured in Stewart Brook (Figure 8-8). Similarly, there were two (2) months during the summer of 2020, August, and September, when the *mean* flow of effluent to the upper sand beds exceeded the *mean* flow measured in the Stewart Brook channel. The reasons for the apparent discrepancy in the above data were offered above for the situation that occurred during the 2016 to 2017 study.

Table 8-2 summarizes the number of days during the two investigation (2016 to 2017 and 2019 to 2021) when plant *effluent* was discharged to the upper sand beds and the *mean* wastewater flow calculated for these periods using daily flow data from the DMRs of the facility operational records.

Table 8-2.

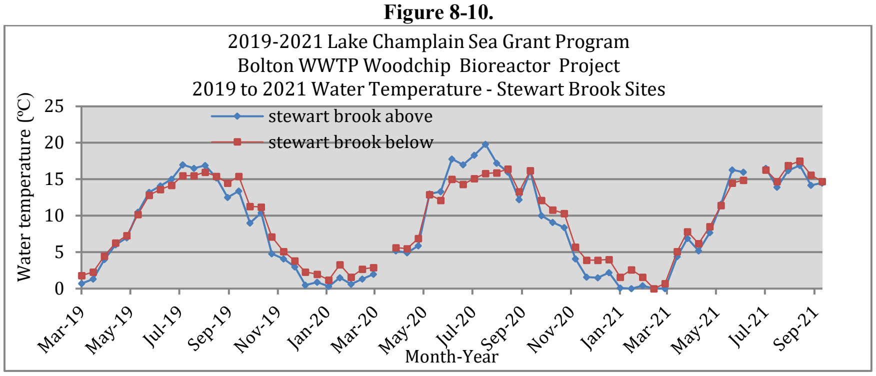
Scientific Investigation	Days of Effluent to Upper Sand Beds	Average Effluent Flow to Upper Sand Beds
2016 to 2017	119	0.180
2019 to 2021	903	0.182

These data are important in the context of material presented in this chapter and will be used later on to calculate and compare nutrient loading from the upper sand beds to Stewart Brook with other data from the individual investigations.

Temperature. Although summarized in Table 8-1, water temperature was not expected to show any difference between the two studies due primarily to the range of seasonal values that occur each year and the low sample size (n) in each dataset.

The real impact of water temperature was noticeable, however, when comparing measurements collected during 65 field excursions in the current 2019 to 2021 study at the *above* and *below* stations on Stewart Brook as shown in Figure 8-10.

Figure 8-10.



The large influx of ground water between the two sampling stations on a continuous basis had the effect of cooling the tributary temperatures measured at Dula Place (*below* station) in the summer months and warming the temperatures measured there during the winter months, as shown in Figure 8-10 above. The ambient temperature of ground water emerging into the channel is about 13C throughout the year.

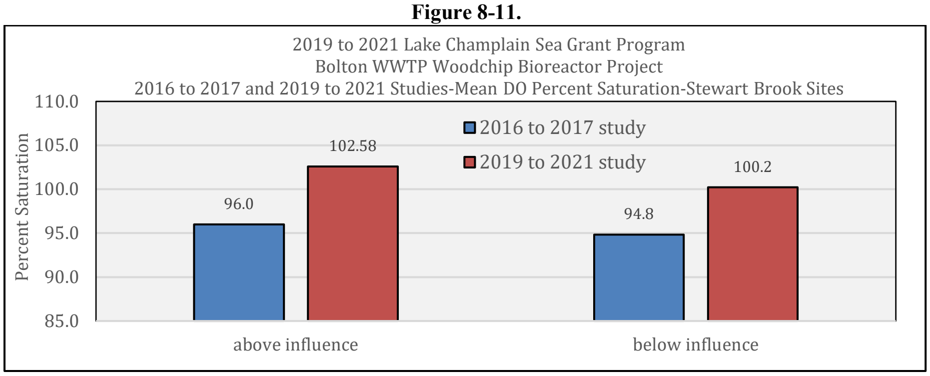
8.3.2 Chemical characteristics

Dissolved oxygen percent saturation. The maximum concentration of dissolved oxygen that can occur in water is a function of water temperature. Higher concentrations of dissolved oxygen occur in low than at elevated temperature. Dissolved oxygen levels in water often are reported in 'percent saturation' since the calculation corrects for temperature and removes bias from the oxygen concentration readings.

After wastewater effluent is discharged to sand beds for recharge, bacteria can remove substantial amounts of dissolved oxygen and add carbon dioxide as water passes through the soil and the unsaturated zone and toward Stewart Brook. When this situation occurs, we would expect that ground water emerging from the slope southwest of the Brook Street-Goodman Avenue intersection would show some level of oxygen depletion compared with ambient dissolved oxygen in tributary channel flow.

The *average* oxygen percent saturation values for samples collected from the Stewart Brook sampling sites during the two studies compared herein are shown in Figure 8-11.

Figure 8-11.



Some oxygen depletion clearly is evident when comparing the *mean* values of percent saturation in tributary flow *above* and *below* the zone of ground water influence for both studies being compared.

Figures 8-12 and 8-13 present the seasonal progression of percent saturation of dissolved oxygen *above* and *below* the zone of ground water influence for the 2016 to 2017 and 2019 to 2021 studies. The difference between the individual *above* and *below* values is more apparent for the 2019 to 2021 study due to the greater number of measurements during the period of time summarized in the two (2) graphs (n = 20 vs n = 65, respectively).

Figure 8-12.

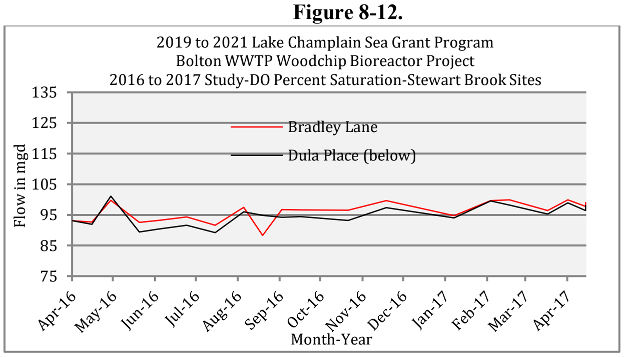
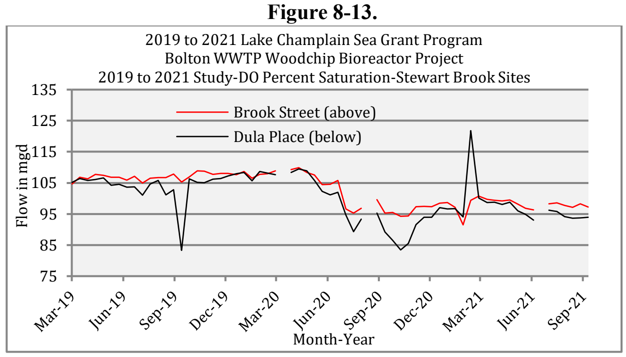


Figure 8-13.

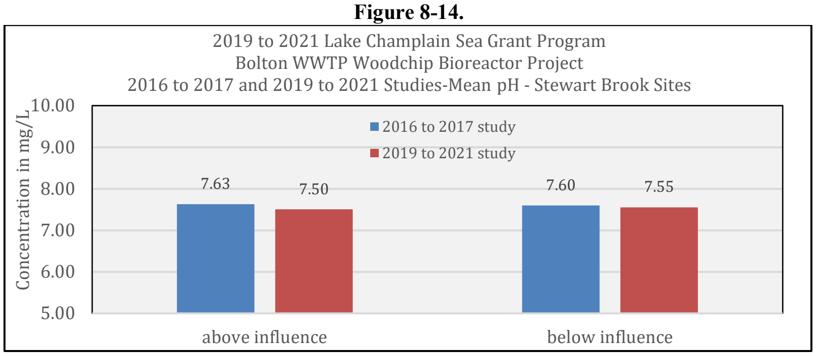


There were occasions during the current investigation when the difference between the percent saturation *above* and *below* the area of ground water intrusion was as much as 20 to 30 percent.

pH. 'pH' is a mathematical transformation of the hydrogen ion [H^+] concentration and expresses the acidic or basic nature of water. The lowercase 'p' in pH refers to 'power' or exponent, and pH is defined as the negative logarithm of the hydrogen ion [H^+] concentration. A change of one (1) pH unit represents a ten-fold (10x) change in the hydrogen ion concentration.

Figure 8-14 summarizes the mean pH values for the *above* and *below* sampling sites when comparing the two studies (2016 to 2017 and 2019 to 2021).

Figure 8-14.



There is nothing noteworthy about the *mean* pH values at either site except that they all are close to neutrality (pH=7.0) and the results between the two studies are consistent with regard to the difference in mean pH between the *above* and *below* sampling sites. The annual cycle of pH measurements at the *above* and *below* sampling sites on Stewart Brook are presented in Figure 8-15 for the 2016 to 2017 study and Figure 8-16 for the recently completed 2019 to 2021 study.

Figure 8-15.

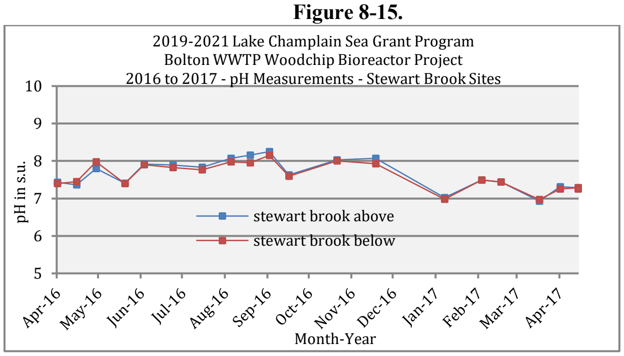
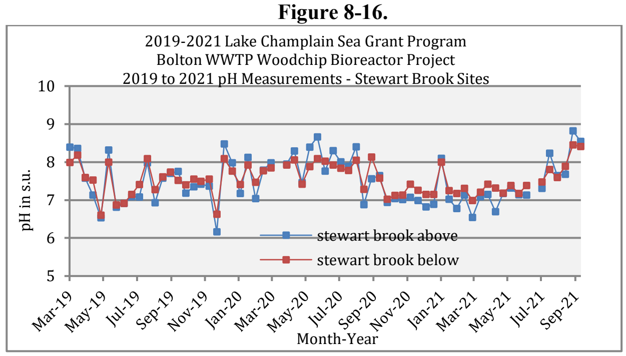


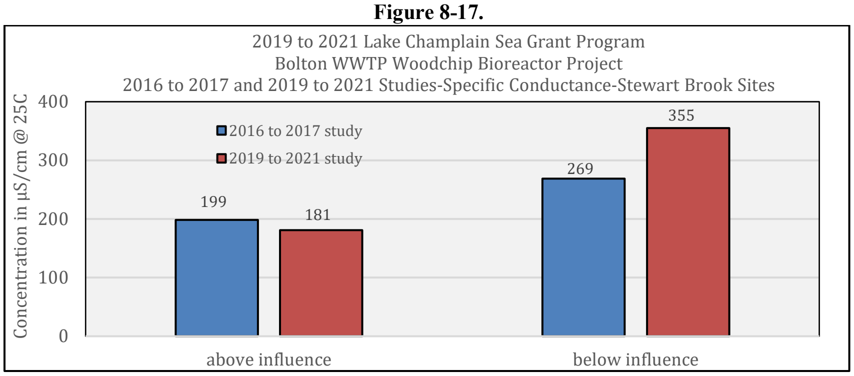
Figure 8-16.



Fewer pH values were measured during the 2016 to 2017 study (Figure 8-14; *n*=20) and the values appear more stable than the values measured during the 2019 to 2021 study (Figure 8-15; n=65). The pH values collected during the 2019 to 2021 study (Figure 8-15) fluctuated considerably and ranged between ~pH 6.0 to pH 8.7. The consistent readings exhibited in Figure 8-15 for the *above* and *below* samples collected on the same sampling date suggest that there was no effect of influent ground water from the upper sand beds on tributary pH at the *below* (Dula Place) sampling site.

Specific conductance. A summary of *mean* values calculated for specific conductance at the Stewart Brook sampling sites *above* and *below* the ground water influence from the upper sand beds for the 2016 to 2017 and 2019 to 2021 studies is presented in Figure 8-17.

Figure 8-17.



There was a nine (9) percent decrease in the *mean* specific conductance at the *above* sampling site when comparing the two (2) studies (190>181 µS·cm @ 25C), whereas the *mean* specific conductance at the *below* station had a 32 percent increase (269>355 µS·cm @ 25C) when comparing the two (2) studies.

The annual cycles of specific conductance concentrations measured at the *above* and *below* sampling station during the two separate investigations are presented in Figures 8-18 and 8-19.

Figure 8-18.

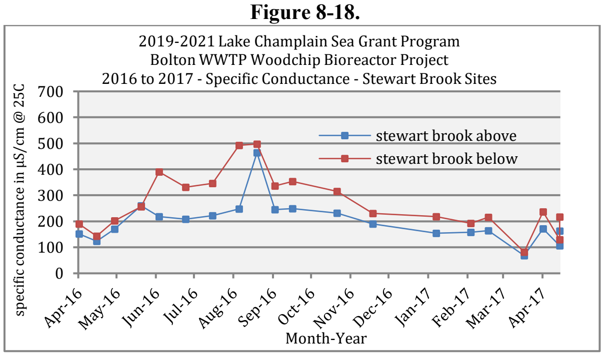
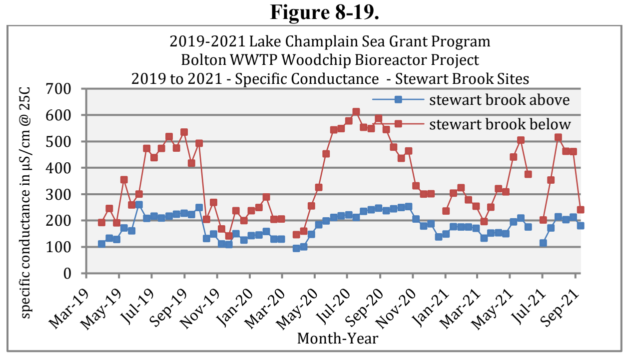


Figure 8-19.

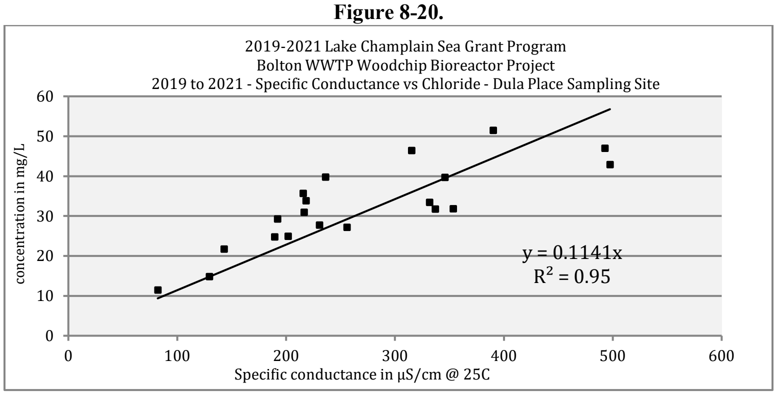


The annual pattern of specific conductance is the same at *above* and *below* sites, regardless of the investigation considered, although there are three (3) seasonal cycles clearly demonstrated in Figure 8-18. That is, the concentrations rise as tributary flow decreases during late spring, mid-summer, and early fall, then reach a point in late fall and early winter where flows begin to increase, and highway deicing products enter the tributary channel, raising the level of specific conductance.

Some of this increase in specific conductance at the *below* sampling site resulted from the almost continuous discharge of Bolton WWTP effluent to the upper sand beds from 2019 through 2021 and high chloride concentrations in the effluent. In addition, a portion of the high increase in *mean* conductance at this site also is due to winter deicing chloride stored in soils adjacent to Brook Street and Goodman Avenue which traverse the watershed between the two sampling sites and drain into Stewart Brook.

Although chloride was not one of the analytes measured during the 2019 to 2021 investigation, we can get an approximation of the concentration of chloride contributed by the Bolton WWTP. First, we examine the relationship between chloride and specific conductance at Dula Place during the 2016 to 2017 study as shown in Figure 8-20.

Figure 8-20.

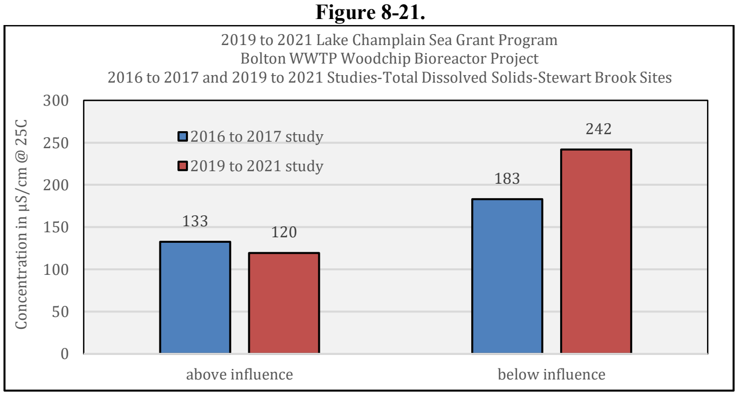


The R^2 for the relationship is highly significant at 0.95. According to the equation in Figure 8-20, the concentration of chloride at Dula Place can be calculated by multiplying specific conductance values at that site by 0.1141. So, while only an approximation, if we take the *mean* specific conductance value measured at SPDES Monitoring Well #3 during the 2019 to 2021 study (568 µS/cm @25C), and multiply that value by 0.1141, the result is 64.8 mg/L of chloride, an approximate value measured at MW #3 during the 31-month period of the 2019 to 2021 study,

Total dissolved solids (TDS). A standard definition for "dissolved solids" is that they must be small enough to pass through a 2-micron filter. In contrast, specific conductance contains any and all anions, cations, organic and inorganic particulates that enhance the ability of a solution to conduct an electrical charge. Based upon definition, therefore, TDS concentration always is less than the concentration measured for specific conductance and there usually is a specific relationship exhibited between the two (2) chemical analytes.

As shown in Figure 8-21, the relationship between the *above* and *below* sampling sites for TDS is similar to the relationship exhibited for specific conductance (Figure 8-17).

Figure 8-21.



At the *above* sampling site, there was a 10 percent decrease in TDS concentration between the 2016 to 2017 study and the 29019 to 2021 study. At the *below* sampling site, there was a 32 percent increase between the two investigations.

Furthermore, the annual pattern of individual measurements was the same for TDS as shown in Figures 8-18 and 8-19 for specific conductance, so those data are not summarized graphically here.

There was a strong relationship between TDS and specific conductance concentrations at both the *above* and *below* sampling stations on Stewart Brook during the 2019 to 2021 study as shown in Figures 8-22 and 8-23, respectively.

Figure 8-22.

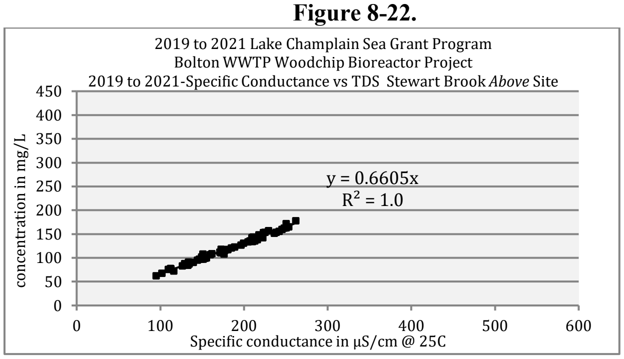
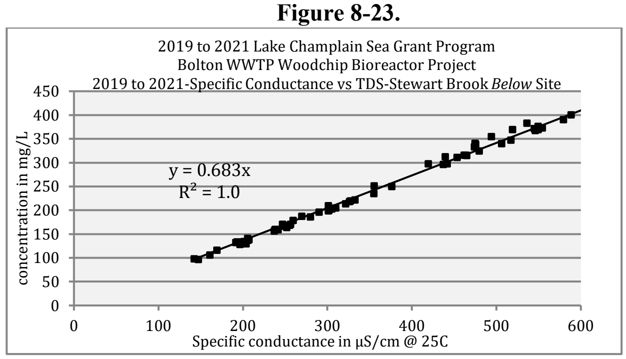


Figure 8-23.



The R^2 for both relationships (*above* and *below*) were 1.0; the wider range of TDS measurements at the *below* site clearly is shown in Figure 8-22, this wider range due to the addition of effluent from the disposal of Bolton WWTP effluent to the upper sand beds continuously during the 31-month period of the study.

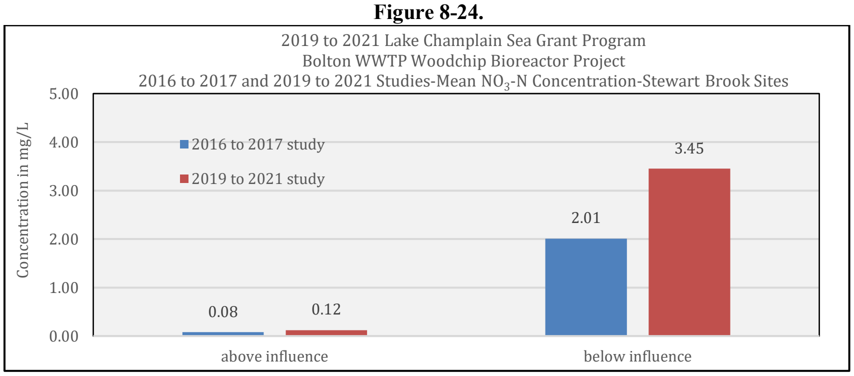
8.3.3 Nutrients

Nitrogen. An important nutrient used by phytoplankton and aquatic plants to produce biomass in lakes and ponds primarily in the form of nitrate-nitrogen (NO_3-N) and ammonia-nitrogen (NH_3-N) which are readily available for uptake and photosynthesis. The removal of nitrogen from wastewater is a three-step process that includes *ammonification*, *nitrification,* and *denitrification*.

Ammonification (mineralization) occurs in the processing, or septic, tank and converts the organic nitrogen in wastewater to *ammonia* by way of bacteria. *Nitrification* occurs in the soil absorption system and oxidizes *ammonia* dissolved in the wastewater to nitrate using a specialized group of bacteria that require an inorganic source of carbon such as carbonate or carbon dioxide. The last step involves a bacteria-mediated reduction of nitrate to nitrogen gas (*denitrification*), which requires an organic carbon food source for the bacteria and also can occur in anoxic micro-zones of the soil absorption system.

The *mean* values of **nitrate-nitrogen** (NO_3-N) measured *above* and *below* the area of ground water intrusion from the upper sand beds at the Bolton WWTP into Stewart Brook during the 2016 to 2017 and 2019 to 2021 studies are summarized in Figure 8-24.

Figure 8-24.

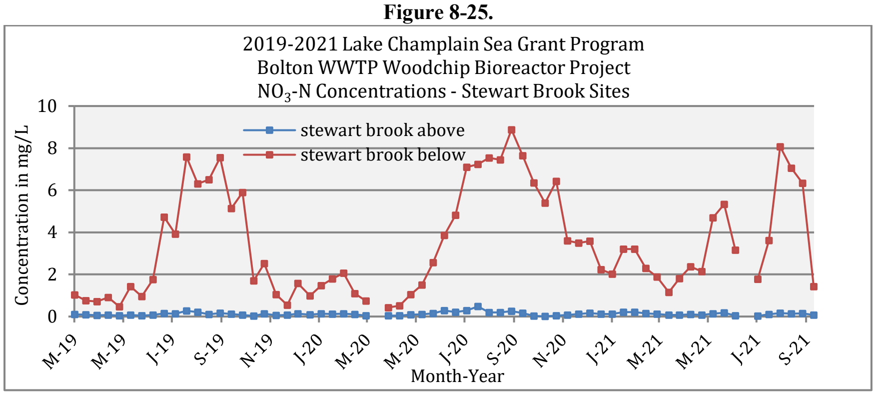


While there was a 50 percent increase in the *mean* nitrate-nitrogen concentration at the Stewart Brook *above* sampling site between the 2016 to 2017 study and the current 2019 to 2021 study (0.08 to 0.12 mg N·L), both values were low and within the range of concentration expected at this site which receives flow from higher elevations. In contrast to data from the *above* sampling station, there was a 72 percent increase in *mean* concentration at Dula Place when comparing the two studies, which was due to the continuous use of the upper sand beds for effluent disposal during the period summarized.

Nitrate loading to Stewart Brook just above Dula Place has been a concern at least since the 2016 to 2017 study and was occurring prior to that time although there are no data to support this theory. The loading is in response to incomplete processing of nitrate-nitrogen via *denitrification* at the Bolton facility and the use of the upper sand beds for effluent disposal during the ice-free period of the year for several decades prior to construction of the woodchip bioreactor when effluent was disposed to the upper sand beds year-round. Nitrate loading also was shown to be problematic during the 2016 to 2017 study when effluent was disposed to lower sand beds #1 and #3 (see Sutherland and Navitsky 2017, Chapter 8).

The seasonal pattern of nitrate-nitrogen concentrations measured at the Brook Street and Dula Place sampling stations during the 2019 to 2021 study are shown in Figure 8-25.

Figure 8-25.



A pattern in the annual cycle of nitrate-nitrogen clearly is apparent with increasing concentrations in the late spring, summer and early fall each year when tourism in the area and the volume of wastewater increase, followed by lower concentrations during the winter months when tourism in the area and wastewater volumes decrease. The inability of the plant to achieve effective denitrification during periods of high volume clearly is evident from the data summarized in Figure 8-24.

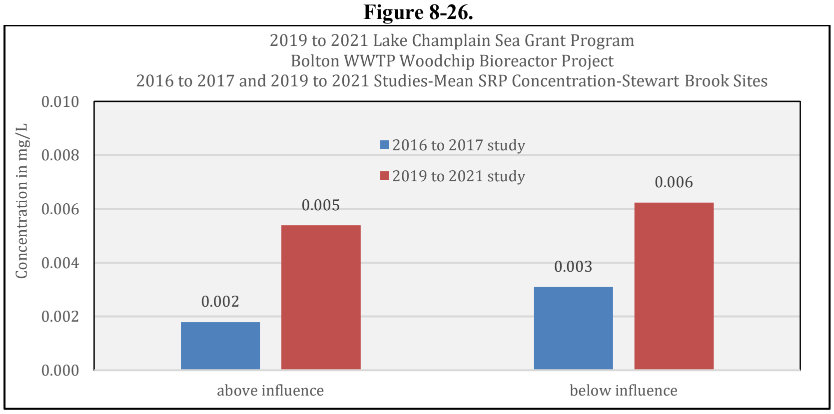
Although **ammonia-nitrogen** was one of the parameters measured in Stewart Brook during the current 2019 to 2021 study, the data are not summarized in Table 8-1 for two (2) reasons. First, most of the results reported for this parameter at the *above* and *below* sampling stations were below the lowest level of detection (0.050 mg N·L); in fact, only 12 of 65 total samples collected at each station were above the level of 0.050 mg N·L. The second reason is that **ammonia-nitrogen** was not one of the parameters measured during the 2016 to 2017 study.

Phosphorus. This nutrient has a key role in biological metabolism and often limits the amount of productivity in lakes and ponds since it is the least abundant of the major structural and nutritional components of the biota such as carbon, hydrogen, nitrogen, etc. Although phosphorus occurs as organic and inorganic forms, more than 90 percent of the phosphorus that occurs in lake water is bound organically with living material or associated with decaying material (Wetzel, 1975).

Soluble reactive phosphorus (**SRP**) is a form of this nutrient available for uptake by phytoplankton and attached aquatic vegetation in streams, ponds, and lakes. **SRP** was included in the test pattern of analytes for the current study based upon the results of the earlier 2016 to 2017 investigation where elevated levels of SRP were found entering the Mohican Road Tributary and Stewart Pond and were associated with the disposal of wastewater effluent to the lower sand beds at the Bolton facility. And while there was no indication of a similar phenomenon occurring with wastewater effluent disposal to the upper sand beds, it seemed prudent to track the concentrations of **SRP** in ground water moving down-gradient from the upper beds given that the upper beds were going to be used for effluent disposal on a year-round basis.

The *mean* values of **SRP** measured *above* and *below* the area of ground water intrusion from the upper sand beds at the Bolton WWTP into Stewart Brook during the 2016 to 2017 and 2019 to 2021 studies are summarized in Figure 8-26.

Figure 8-26.



The *mean* values shown above are misleading because the analytical laboratory, Phoenix Environmental Laboratories, Inc., for the 2019 to 2021 study, had a high lower detection limit for **SRP** (0.010 mg P·L) compared with the Darren Fresh Water Institute (DFWI) Laboratory, affiliated with Rensselaer Polytechnic Institute (Troy, New York), where we had samples from the previous 2016 to 2017 study analyzed and the **SRP** detection limit was 1.0 mg P·L.

As a result, only three (3) and four (4) of 65 samples were **above** detection at the *above* and *below* sampling stations, respectively, during the 2019 to 2021 study. In comparison, only five (5) and three (3) of SRP samples were **below** detection at the above and below sampling stations, respectively, during the 2016 to 2017 study and *mean* values for the earlier study were measured at 1.785 and 3.100 µg P/L.

Based upon the data summarized above, there was no problem demonstrated in the current study with **SRP** being introduced into Stewart Brook from the area of the upper sand beds. A more noteworthy problem was the 2.5-fold increase in the concentration of **SRP** measured at the *above* sampling station between the 2016 to 2017 study and the current investigation, which could have resulted from an increase in development in the upper region of the watershed. In fact, the individual results reported for SRP in the current 2019 to 2021 study for the *above* and *below* sampling stations were almost all below the level of detection (0.010 mg SRP·L) with only 3 values and 4 values above the level of detection, respectively, for a total of 65 samples collected at each station.

8.4 Summary of Findings

The following material presents important findings that have been realized as a result of the detailed analysis of data collected from the 2019 to 2021 investigation and a comparison of these data with similar data collected during the 2016 to 2017 investigation.

8.4.1 Flow

At the time of the 2016 to 2017 investigation and for several decades prior, Bolton WWTP effluent was pumped to the upper sand beds only during the ice-free period of the year (May through October) for disposal and not consistently during the time. The total time for disposal during those decades was highly variable as found when summarizing data from the 14-month 2016 to 2017 study when the upper sand beds were used on 119 days out of 245 days (49 percent) possible during the ice-free season.

Then, following start-up of the woodchip bioreactor during October 2018, installed at the site of one of the former upper sand beds, the facility effluent was pumped to the upper sand beds on an almost continuous basis. The total time of actual disposal in this upper sand bed area from March 19th 2019, when the 2019 to 2021 study began, through May 31st 2021 when the bioreactor was shut down due to plugging was 679 days out of 805 days possible (84 percent).

The contribution of ground water moving down gradient from the area of the upper sand beds from wastewater disposal on the total flow in Stewart Brook at the Dula Place sampling station varies depending upon the time of the year and factors such as tourism and patterns/amounts of precipitation that occur. It was evident from both investigations that there are times during the dry part of each year when ground water entering the Stewart Brook channel from the upper sand beds comprises most of the measurable flow.

A summary of flow data presented earlier in this chapter showed that the average flow discharged to the upper sand beds during the previous and current investigation was about the same, 0.180 and 0.182 mgd, respectively. These data and the total time the upper sand beds were used for effluent disposal will be used later to calculate nutrient loading to the tributary.

8.4.2 Temperature

The continuous emergence of ground water entering the Stewart Brook channel at an ambient temperature of about 13C has a significant effect on the tributary temperature down-gradient at the Dula Place sampling station, raising the temperature in the late fall, winter, and early spring, and cooling the temperature during the late spring, summer, and early fall. While this effect may appear not to be profound, it moderates the thermal environment for organisms, both plant and animal, in the channel down-gradient of the entrance point compared with the situation if no ground water at constant temperature was entering the channel.

8.4.3 Dissolved oxygen percent saturation

Ground water entering the Stewart Brook channel above the Dula Place sampling station has a lower dissolved oxygen percent saturation than water in the tributary channel flowing through the area as a result of bacterial metabolism that has occurred in the upper sand beds following the discharge of plant effluent. While the amount of dissolved oxygen removal was not measured in either investigation, its impact on the percent saturation in the tributary channel is noticeable when comparing the measured values for the *above* and *below* sampling stations. However, this phenomenon currently does not lead to any issues because the water in Stewart Brook at these sampling locations is supersaturated with oxygen (>100 percent) and the effect of the entering ground water is negligible,

8.4.4 Specific conductance and TDS

The primary sources of these analytes measured in Stewart Brook between the *upper* and *lower* sampling stations is chloride from road salt applied for winter deicing practices in the watershed and chloride as a residual from wastewater processing at the Bolton facility. Even though chloride was not measured during the 2019 to 2021 study, it was possible to estimate the concentration of chloride entering the Stewart Brook channel from specific conductance and chloride data collected during the 2016 to 2017 study. The result was estimated to be 65 mg Cl·L entering the Stewart Brook channel on a continuous basis from ground water moving down-gradient from the upper sand beds.

It is possible to use this estimate for chloride present in ground water entering Stewart Brook from the upper sand beds to calculate loading that occurred during the current investigation given the following:

- The duration of the Lake Champlain Sea Grant Program sponsored bioreactor monitoring from March 19th 2019 through September 30th 2021 was 927 days which did not include the number of days subtracted when plant effluent was not being pumped to the upper sand beds (126 days), for a revised total of 801 days,

- The *mean* flow calculated for the volume of plant effluent discharged to the upper sand beds during the period of the current 2019 to 2021 study was 0.182 mgd,
- The *mean* concentration of chloride contributed by the upper sand beds to Stewart Brook during the current 2019 to 2021 study was 64.8 mg Cl·L which was calculated in the section above describing specific conductance,

The loading for chloride now can be calculated using the *mean* values calculated for the upper sand beds that were presented above. The calculation for pounds of chloride discharged from the upper sand beds into Stewart Brook is as follows:

Cl^- from Upper Sand Beds = 64.8 mg Cl^-·L x 0.182 mgd x 8.34 lbs./gallon = 98.4 lbs./day of Cl^-

= 35,916 lbs./yr. of Cl^-

= 66,813.6 lbs. (33.4 tons) during 679-day duration of bioreactor operation

The above values represent estimates of the total load to Stewart Brook based upon the relationship determined to exist between specific conductance and chloride during the 2016 to 2017 study. Chloride present in water is not easily processed by vegetation or other organisms and enters Bolton Bay unmitigated and on a continuous basis. Chloride in Lake George has been described as a major water quality issue since long-term monitoring on the lake began in 1980 (Boylen et al. 2014).

8.4.5 Nitrate-nitrogen

A deficiency at the Bolton WWTP related to the removal of nitrogen from wastewater, and specifically the process of *denitrification*, is the reason that the woodchip bioreactor was constructed, and the current investigation proposed to evaluate any improvements in the process of nitrogen removal. A previous section in this chapter provided information on the input of nitrate-nitrogen to Stewart Brook from the upper sand beds during the previous and current investigation. However, there was no information provided on the contribution of the woodchip bioreactor to reducing the nitrate-nitrogen (NO_3-N) concentration entering Stewart Brook compared with untreated wastewater effluent discharged directly to the upper sand beds with no bioreactor treatment. The following is a summary of that important information:

- The *mean* concentration of NO_3-N leaving the Bolton WWTP during the 27-months of the woodchip bioreactor operation was 14.5 mg N·L, which also was the mean concentration of NO_3-N entering the influent chamber of the woodchip bioreactor,
- The *mean* concentration of NO_3-N leaving the effluent chamber of the bioreactor during the 27 months of woodchip bioreactor operation was 9.02 mg N·L, which was a 38 percent decrease compared with the concentration entering the bioreactor,
- The *mean* concentration of NO_3-N in bed effluent (plant effluent combined with woodchip bioreactor effluent) was 11.9 mg N·L, which was an 18 percent decrease compared with the effluent discharged from the wastewater treatment plant, and
- The woodchip bioreactor was operational a total of 679 days during the period of the 2019 to 2021 study reported herein.

The loading for nitrate-nitrogen now can be calculated using the *mean* values calculated above The calculation for pounds of nitrate-nitrogen discharged from the upper sand beds into Stewart Brook is as follows:

NO_3N from Upper Sand Beds = 11.9 mg N·L x 0.182 mgd x 8.34 lbs./gallon = 18.1 lbs./day of NO_3N

= 6,607 lbs./yr. of NO_3N

= 12,290 lbs. (6.1 tons) during 679 days of woodchip bioreactor operation

The above values represent the total load to Stewart Brook based upon the operation of the woodchip bioreactor and its successful removal of a significant concentration of nitrate-nitrogen during the period of the study. Had the woodchip bioreactor not been operating during the 679-day period, there would have been an additional 2,648 lbs. (1.3 tons) of nitrate-nitrogen loaded to Stewart Brook

8.4.6 Soluble reactive phosphorus

Not much can be said regarding any findings related to soluble reactive phosphorus because the analytical laboratory (Phoenix Environmental Laboratories, Inc) did not have a low enough detection limit to measure accurate concentrations of this important nutrient.

8.5 Recommendations

The following recommendations have been compiled following review and evaluation of the data collected during the monitoring program described herein. These recommendations are not stated in any particular order except recommendation #1 for obvious reasons. These recommendations are as follows:

(1) The existing woodchip bioreactor located at the Bolton WWTP which has been inoperable since May 31st 2021 should be restored to operating condition as soon as possible by removing "plugged" woodchips and re-filled with new woodchips to minimize the impact of the Bolton WWTP effluent on the water quality of Stewart Brook and Lake George without the bioreactor in operation,

(2) The Town of Bolton should proceed with the installation of two (2) new woodchip bioreactors adjacent to the bioreactor already installed in the upper sand bed disposal area; adding these new unit processors will allow a larger capacity of the daily wastewater flow through the facility to be treated by this "green technology", thus reducing the load of nitrate-nitrogen,

(3) The Lake George Association should extend the current Bolton Bay Water Quality Assessment Program through at least December 2022 and add the Dula Place sampling station to this Program; implementing this recommendation will allow the collection of sufficient water quality data and facilitate the evaluation of SRP concentrations entering the Stewart Brook watershed from the region of the upper sand disposal beds which was not possible during the current investigation due to insensitivity of phosphorus analytical techniques.

(4) The Town of Bolton should consider installing a new SPDES Permit monitoring well on Bolton WWTP property in the region of the upper sand disposal beds between bed #9 and Stewart Brook; none of the current SPDES wells in that region lie in a direct line between the bed infiltration area and the Stewart Brook channel.

8.6 Literature Cited

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2019 to 2021 Lake Champlain Sea Grant Program

A Monitoring Program to Evaluate the Efficacy of a Woodchip Bioreactor Installed at the Bolton Wastewater Treatment Plant, Lake George (Warren County), New York

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Final Report

Chapter 9

Woodchip Bioreactors as Treatment Technology for Low Volume Wastewater Treatment Plants: An Economic Analysis of Nitrate-nitrogen Removal

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9.0 Woodchip Bioreactors in Agriculture and Aquaculture

Nutrient pollution can have significant negative impacts on our ecosystem and ecology by feeding microscopic plants or algae resulting in rapid growth or algae blooms. These blooms can clog waterways and prevent recreational use such swimming or boating. Specific algae can produce harmful toxins, referred to as Harmful Algae Blooms (HABs), that can affect humans, pets and wildlife. After the bloom stage, algae can die off and as they decay, decomposition removes oxygen from the water producing more ecological problems where fish and aquatic animals lack oxygen creating a "dead zone". Perhaps the most-recognized dead zone forms in the Gulf of Mexico where nutrient loading from the Mississippi River basin is discharged (Christianson 2016a).

A large source of nutrient loading is runoff from drainage networks associated with agricultural use where a 1985 study estimates there are close to 80 million acres in the Midwest (Iowa, Illinois, Indiana, Ohio, Michigan, Minnesota, Missouri, and Wisconsin) that have some degree of subsurface drainage (University of Illinois Urbana-Campaign, Illinois Extension, 2017). To improve agricultural water quality, researchers turned to a natural process for denitrification that relies on bacteria found in soil to convert nitrates to nitrogen gas, which is environmentally benign and comprises more than 75 percent of the atmosphere. Woodchips placed subsurface in saturated conditions to create what is referred to as a bioreactor help facilitate the denitrification process performed by these bacteria by providing a carbon source.

The woodchip bioreactor is a simple process that includes digging a trench, placing woodchips within a protective liner and routing water from farm fields into the bioreactor. This technology was proven to be cost effective as there was limited material cost, no equipment except for inlet and outlet control structures, and no loss of land from production. Research found the process effective for nitrate removal and through studies and data analysis determined effective design characteristics such as media type, dimensional criteria and treatment time. Estimates for construction for agricultural installations range from $8,000 to $12,000 for bioreactors 20 feet wide and 100 feet long with costs depending on contractor labor costs and woodchip availability and transport (Christianson et al. 2012a).

Benefits of selecting woodchip bioreactors over other denitrification technologies include their small ecological footprint due to low or no energy requirements, enhancement of a natural process and relatively low installation and maintenance costs. Similarly, this technology was applied for wastewater treatment in the aquacultural industry for wastewater with higher total suspended solids (TSS) and chemical oxygen demand (COD)(Lepine et al. 2016).

9.1 Exclusive Nature of the Bolton WWTP Woodchip Bioreactor Project

The Town of Bolton Wastewater Treatment Plant (Bolton WWTP) has been operating for six decades and for much of this time the facility has performed within its design capability. The original wastewater treatment plant and the collection system were designed and constructed in the late 1950s, employing the best available technology at the time. However, like the Village of Lake George WWTP, the Bolton facility was plagued by its inability to denitrify. Final effluent nitrate-nitrogen concentrations (permitted at 20 mg N·L) and ground water monitoring well sample results (permitted at 10 mg N·L) periodically exceeded the permitted limits, which was documented in a 2016 to 2017 study (Sutherland and Navitsky). The discharged effluent enters the ground water and emerges down-gradient as surface seepage streams, which then enter tributaries to Lake George, causing recreational use impairment along shoreline segments.

As part of the Town's initiative to improve the Bolton WWTP operational efficiency, the Town Supervisor and Town Board during the summer of 2018 authorized the installation of a woodchip bioreactor proposed by the Town of Bolton consulting engineer in one of the infiltration sand beds previously used for the discharge of the treatment plant effluent. The Town of Bolton prepared a demonstration engineering project proposal for a woodchip bioreactor project which was submitted to the New York State Department of

Environmental Conservation and approved in July 2018. That same month, The FUND for Lake George (now the Lake George Association), awarded a Water Quality and Clarity Grant of $50,000 to the Town of Bolton for complete funding of the bioreactor construction. The construction was completed by the Town's operational staff, a local contractor (who donated local woodchips, representing "green" locally-sourced and sustainable raw materials used for the project), the Town's DPW staff, the Town consulting engineer and the Town Supervisor, all of whom were engaged in the field activities for the bioreactor installation. The Bolton woodchip bioreactor officially went online October 10, 2018.

To our knowledge, this is one of, if not, the first full-size denitrifying woodchip bioreactors designed in this style for treating municipal wastewater in the United Stated and in the world.

The project specifically addresses the non-point source input of nitrate-nitrogen in the Lake George drainage basin, which likely is now, or will become, problematic within the Lake Champlain Basin with respect to community wastewater treatment systems up-gradient of the lake (6 percent of current runoff to the lake) and particularly with agricultural runoff which contributes an estimated 38 percent of total runoff into the lake. Regardless of the nitrate-nitrogen source, it is highly mobile in soils and inevitably will leach into down-gradient water bodies where it can promote eutrophication, alter ecosystem productivity and biodiversity, and is linked to several health-related effects including thyroid dysfunction, colon cancer, methemoglobinemia and ovarian cancer in humans (Inoue-Choi et al. 2015, EWG Tap Water Database 2017, Powlson et al. 2008, Sadeq et al. 2008).

9.2 Full Scale Bioreactor Design

The Bolton WWTP woodchip bioreactor was installed in former sand infiltration bed #10, which was not utilized in routine dispersal of treated effluent for many years due to the inoperability of the #10 bed valve. The woodchip bioreactor is 20 feet wide and 100 feet long, which easily fit within the existing sand infiltration bed with dimensions of 120 feet by 80 feet, and held to the recommendations of Midwest researchers that the bioreactors tend to be long and narrow (i.e., high L:W ratio)(Christianson et al. 2012a)

The bioreactor media was 4 feet of hardwood and softwood chips ranging in size from 0.5-inch to 2 inches, with some chips being larger. Tree species such as willow and poplar are not acceptable, nor are any greens from post-leaf out trees. This design was compliant with the recommended design standards developed over the years by university researchers and in-field installations, which would be the most appropriate and effective design for this project.

The influent and discharge headers are 20 feet long, 6" PVC pipe with ¾" holes drilled around the entire circumference of the pipe. The influent flow is controlled by a standard gate valve on the 6" PVC line from the 2000-gallon reservoir to the bioreactor influent structure. The 2000-gallon concrete storage reservoir is filled from the existing tertiary effluent pump station at the WWTP campus and was constructed above grade and backfilled around the outside to be able to provide gravity discharge to the bioreactor. The pump station historically has been used to pump wastewater effluent to the upper six (6) sand infiltration beds, typically during the summer months. For this demonstration project, this pumped effluent flow was intercepted by the 2000-gallon concrete reservoir to provide a continuous wastewater supply to the bioreactor, with any excess wastewater bypassing the woodchip bioreactor and directly discharged to the original sand infiltration beds.

The flow control into and out of the bioreactor requires easily controlled inlet and outlet structures. The current favored water level control structure is manufactured by Agri Drain of Adair, Iowa. Flow monitoring was initially through a V-notch weir within the Agri Drain structure, which is a 3-chamber control structure with an influent chamber, controlled flow into the bioreactor and excess flow by-pass. The design flow capacity of the Bolton WWTP demonstration bioreactor allows for treatment of between one-third and two thirds of the tertiary effluent. A 2-chamber control structure is used for the outlet flow with controlled flow from the bioreactor chamber and discharge pipe. The controlled flooding of the woodchip bioreactor is achieved by controlling the height of the outlet "log" within the flow control structure, like flash boards on a dam outlet. Flow rate and detention time within the bioreactor are factors of the "log" setting and are under the operator control. The desired retention time through the bioreactor is variable and depends upon a number of environmental criteria including water temperature, influent nitrate-nitrogen concentration, dissolved oxygen concentration and accessible carbon source.

As stated, initial bioreactor flow was being gauged by a V-notch weir in the bioreactor influent Agri Drain structure, which is a standard flow measurement mechanism that utilized a calibration curve for the V-notch weir that resulted in a flow formula for various depths of water over the weir. Measurement of flow over the weir is generally done with a measuring tape. For this demonstration project, a more definitive flow measurement method was required. As part of the original bioreactor design and installation, a sampling manhole was installed downstream of the effluent Agri Drain flow control structure. Flow through the bioreactor was controlled by a number of 6-inch stop logs placed in the influent and discharge Agri Drain flow control structures. The number of stop logs used is manually determined and adjusted by Bolton WWTP operations staff, in discussion with the Town's engineering consultant and is dependent upon the season and unit processes upstream of the bioreactor. For more definitive flow measurements, a Greyline in-pipe flow meter was installed in the 6-inch discharge pipe from the effluent Agri Drain flow control structure into the sampling manhole.

9.3 Capital Expenditure Cost Itemization of Full Scale Design

9.3.1 Initial Capital Expenditures: Materials and Installation

The construction of the demonstration woodchip bioreactor project was initiated in July 2018 and completed in October 2018. The installation was performed in-house by Town WWTP staff, Town DPW staff, a local contractor, Town consulting engineer (KS) and the Town Supervisor to keep project cost down with a design build approach. Table 9-1 details the material and cost summary for the original bioreactor:

Table 9-1.

Material Description/ Construction Activity	Cost
Woodchips (300 CY) (KLC Property Enhancement)	$7,800
Woodchip installation (Labor & Equipment) [1]	-------
45-mil pond liner & appurtenances	$4,716
Agri Drain structures (2)	$2,075
Precast Concrete structures (2,000 gal reservoir & sampling manhole)	$3,865
Geotextile Cover	$370
New piping, valves, connectors, etc[2]	$12,315
Construction tools	$930
Lumber for bioreactor sidewall support	$2,235
Engineering Fees	$4,500
GreyLine flow meter[3]	-------
General Labor & Equipment[4]	-------
Total Cost	**$43,085**

[1]Labor & Equipment donated by KLC Property Enhancement
[2]New piping from bioreactor to existing sand infiltration beds was required.
[3]Meter donated by KSPE (Town Engineer)
[4]Labor and equipment provided by Town DPW and WWTP staff

As shown by the costs associated with the demonstration project, the overall project was very cost effective for a denitrifying process at a municipal WWTP. However, it must be realized that the project costs do not include labor or equipment, which were provided through the Town or donated. Additionally, the design for the demonstration project did not incorporate structural supportive sidewalls, which were found to be necessary for future long-term installations. Therefore, the costs associated with this demonstration project should not be used for future project plans or budgetary decisions as they will not represent actual costs.

9.3.2 Capital Cost – Proposed Additional Bioreactor Cells

The Town of Bolton has applied to the New York State Department of Environmental Conservation for the installation of two additional woodchip bioreactor cells at the Bolton WWTP. Table 9-2 details the estimated construction cost for the proposed two bioreactor cells that have incorporated recommendations for improved long-term operation. These recommendations have resulted in substantial project cost increases and should be utilized for future project considerations.

Table 9-2.

Material Description/ Construction Activity	Estimated Cost
General Excavation and Grading (Estimated 1,000 CY)	$32,500
Reinforced Concrete walls (Inlet & Outlet ends) (340 CY @ $650/CY)	$221,000
Reinforced Concrete Walls (Concrete ThoroSeal)	$2,800
Pipe Connections, Fittings & Valves (Supply and Install)	$12,000
Piping (Supply & install 700 lf 6" PVC)	$15,000
Woodchips (Supply and install 700 CY)	$21,000
3,000-gallon Precast Concrete Water Reservoir (Supply and install)	$2,000
Precast Monitoring Manhole (Supply and install)	$750
Pressure Treated Plywood and bracing material (Supply 240 sf ¾" plywood)	$2,000
45 mil Pond Liner and penetration materials (2 total (40'x60'))	$6,000
Agri Drain flow structures (4 total)	$4,500
In House Items (Materials/Construction Activities)	
Clear and Grub Infiltration Bed #10	-------
Repurpose existing 2,000-gallon reservoir	$500
Plywood, Pond Liner and Agri Drain structures (Install)	------
GreyLine Precision Flow Meters (Purchase and install)	$10,000
Influent Control Valves (Purchase and install)	$12,000
Topsoil & Seed (Purchase and install)	------
Preliminary Construction Cost	**$342,050**
Engineering and Construction Oversight and Certification to NYSDEC	$15,000
Sampling Equipment and Start-up Monitoring Costs	$9,500
Contingency	$12,500
TOTAL COST	**$379,050**

9.3.3 Recurring Expenditures: Woodchip Replacement and Operational Maintenance

The operation and maintenance cost gives the annual cost component associated with running and maintaining the proposed woodchip bioreactors. As shown in Table 9-3, most of the components for Operations and Maintenance are within the daily duties of the Bolton WWTP operation staff.

Table 9-3.

Component/Activity	O&M Cost
Labor supplied by BLWWTP Staff[1]	------
Water Sampling Cost for Permitting/Monitoring[2]	$5,000
Normal Operational Maintenance (By BLWWTP staff)[1]	-------
Woodchip Replacement [3]	$900
Maintenance for Flow Meter	------
TOTAL COST	**$5,900**

[1]Normal operational duties for Bolton WWTP staff
[2] Based upon estimated sample sites; to be determined after design with possible grant funding from the Lake George Association
[3]Estimate woodchip front end replacement every two years for $1,800

9.3.4 Annual N Removal Calculations

The woodchip bioreactor was proposed for the Bolton WWTP for the removal of nitrogen from wastewater, and specifically the process of *denitrification*, that would reduce the input of nitrate-nitrogen to Stewart Brook tributary to Lake George, which would result in certain water quality, ecosystem and economic benefits. This information was previously discussed and detailed in Section 8.4.5. and the following is a summary of that information:

- The *mean* concentration of nitrate-nitrogen leaving the Bolton WWTP during the 31-month period of the 2019 to 2021 study was 14.5 mg N·L, which also was the mean concentration of nitrate-nitrogen entering the influent chamber of the woodchip bioreactor,
- The *mean* concentration of nitrate-nitrogen leaving the effluent chamber of the bioreactor during the 31-month period of the 2019 to 2021 study was 9.02 mg N·L, which was a 38 percent decrease compared with the concentration entering the bioreactor,
- The *mean* concentration of NO_3-N in bed effluent (plant effluent combined with woodchip bioreactor effluent) was 11.9 mg N·L, which was an 18 percent decrease compared with the effluent discharged from the wastewater treatment plant, and
- The woodchip bioreactor was operational a total of 679 days during the period of the 2019 to 2021 study reported herein.

The loading for nitrate-nitrogen now can be calculated using the *mean* values calculated above The calculation for pounds of nitrate-nitrogen discharged from the upper sand beds into Stewart Brook is as follows:

NO_3N from Upper Sand Beds = 11.9 mg N·L x 0.182 mgd x 8.34 lbs./gallon = 18.1 lbs./day of NO_3N
= 6,607 lbs./yr. of NO_3N
= 12,290 lbs. (6.1 tons) during 679-day duration of 2029 to 2021 study

The above values represent the total load to Stewart Brook based upon the operation of the woodchip bioreactor and its successful removal of a significant concentration of nitrate-nitrogen during the period of the study. Had the woodchip bioreactor not been operating during the 679-day period, there would have been an additional 3,007 lbs. (1.5 tons) of nitrate-nitrogen loaded to Stewart Brook, the difference between 14.5 mg/L and 11.9 mg/L or a **total of 1,440 lbs. of nitrate-nitrogen per year**.

9.4 Economic Evaluation

9.4.1 Benefits of Nitrate-nitrogen Reduction to Ecosystem Services

"Ecosystem services" represent the human benefits that healthy ecosystems provide including water purification, flood protection, enhanced fisheries, carbon sequestration and improved tourism and recreational opportunities. These services can be impacted negatively by increased pollution and nutrients that can have significant community impacts.

As detailed in earlier sections, the original Bolton WWTP lacked processes necessary for complete nitrification/denitrification resulting in high nitrate-nitrogen loading to adjacent watersheds and ultimately Lake George. Nitrate-nitrogen is highly mobile in soils and inevitably will leach into down-gradient water bodies where it can promote eutrophication, alter ecosystem productivity and biodiversity, and is linked to several health-related effects including thyroid dysfunction, colon cancer, methemoglobinemia and ovarian cancer in humans (Inoue-Choi et al. 2015, EWG Tap Water Database 2017, Powlson et al. 2008, Sadeq et al. 2008). In fact, the Jefferson Project at Lake George 2019 Algae Tile Study results indicated that Bolton Bay was the most productive bay on Lake George, supporting the negative impacts to the Lake George ecosystem, and that nitrate-nitrogen loading is a contributing factor.

A process to implement corrective actions to enhance the treatment efficiencies at the Bolton WWTP regarding denitrification was the installation of a woodchip bioreactor demonstration project. The Town of Bolton and The FUND for Lake George submitted a proposal to the Lake Champlain Sea Grant (LCSG) Program for funding to study the Bolton WWTP woodchip bioreactor as a potential technique for wastewater treatment in the northeastern US where high concentrations of nitrate entering ground and surface water is an issue. The LCSG awarded a $58,656 grant for the study, which began in March 2019. The study monitored the efficiency of the woodchip bioreactor for nitrate-nitrogen removal, monitored the wastewater effluent discharged to the WWTP infiltration beds by sampling groundwater in monitoring wells and monitored surface water in Stewart Brook, a tributary that is influenced by the ground water discharge of the Bolton WWTP.

The woodchip bioreactor was shown to have reduced the nitrate-nitrogen concentrations in the wastewater effluent discharged to the WWTP infiltration beds from 14.5 mg/L to 11.9 mg/L, a 2.6 mg/L reduction (18 percent). The total annual reduction of loading was 1,424 lbs. of nitrate-nitrogen per year.

The benefits to ecosystem services by the reduction of nitrate-nitrogen loadings would be a reduction in algae growth and a reduction in the productivity of the Bolton Bay and Lake George. As can be seen from the Figure 9-1, the algae growth in Bolton Bay is excessive and can alter the natural ecosystem.

Figure 9-1.

Although there may be no market value for the native submerged aquatic vegetation, it has ecosystem services because it provides habitat for valuable fish populations, among other things. Other ecosystem services include the recreational enjoyment of Lake George, which has a water quality classification by the New York State Department of Environmental Conservation of Class AA-Special meaning that its primary use is for contact recreation. But as seen in Figure 9-2, this primary use is being impacted in Bolton Bay by excessive algae that can wash up on beaches impacting swimming enjoyment.

Figure 9-2.

Improving water quality supports increased biological diversity and increases water clarity, which is tied to algae growth and enhances recreational benefits that improve business opportunities. A 2015 study found that improved water clarity is associated with increased numbers of visits to lakes and that lake users were willing to incur greater costs to visit cleaner lakes. Lake users were willing to travel 56 minutes further for every one-meter increase in water clarity in Minnesota and Iowa lakes (Keller et al. 2015).

9.4.2 Economic Benefits of Nitrate-nitrogen Reduction

As with many types of pollution, the economic damages associated with water quality impairments are difficult to quantify but datum does exist. A Cape Cod study showed that an average price reduction in sales prices of single-family homes of 0.61 percent for each 1 percent increase in nitrogen concentration (Ramachandran 2015). Based upon these data and the 18 percent decrease in nitrate-nitrogen was measured at the WWTP, nitrate concentrations should be measured in the tributaries closer to Lake George for more definitive assessment.

Dettmann et al. (2004) modeled the effects of nitrogen loading on chlorophyll-***a*** concentrations and found that nitrogen reductions would result in chlorophyll-***a*** reductions increasing water clarity. An Ontario study found buyers of lake-front properties were willing to pay about 2% more for each 1-foot increase in water clarity as measured by Secchi disc depth (Clapper-Caudil 2014).

The study performed here documented significant localized nitrate-nitrogen reductions but it is unsure if these localized reductions will be recognized in the larger water body such as Lake George, especially in quantities that may result in the economic benefits detailed. Historical water quality monitoring on Lake George has shown that nutrient concentrations do not vary in mid-lake with only slight variations in very near shore locations.

9.5 Recommendations

The following recommendations have been developed after careful consideration of the water quality data collected during the current 31-month study reported herein. These recommendations are not presented in any particular order of importance except for the first recommendation which acknowledges that facility upgrades are required and essential to the future of development in the Bolton community in order to maintain stewardship with regard to the water quality of Lake George.

(1) The Town of Bolton, WWTP operations staff and the Town's engineering consultant (KS) should move forward with excavation of the plugged woodchips from the existing bioreactor and get the existing unit up and running as soon as possible.

(2) The Town of Bolton, WWTP operations staff and the Town's engineering consultant (KS) should move forward with installation of two (2) new woodchip bioreactor units in the area of the upper sand beds and adjacent to the existing unit so that virtually all of the daily flow through the plant can be treated by this "green technology".

(3) There should be water quality monitoring in Bolton Bay near the tributary mouths and the near-shore littoral zone to determine if there are any detectible changes in nitrate-nitrogen and/or chlorophyll-***a*** concentrations that can be attributed to the woodchip bioreactor.

(4) According to the most recent 2012 Lake Champlain Basin Program (LCBP) State of the Lake Report, six (6) percent and 38 percent of the phosphorus load to Lake Champlain is generated by WWTPs and agriculture, respectively. In reviewing a series of recent technical reports dealing with Lake Champlain, it became clear that there is very little, if any, data available on nitrate-nitrogen from these sources; most of the nitrogen data was reported bas TN (total nitrogen). We strongly advise the LCBP to investigate the nature of the nitrate-nitrogen problem in the drainage basin. It likely is a bigger issue than currently understood based upon a lack of appropriate data collected.

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2019 to 2021 Lake Champlain Sea Grant Program

A Monitoring Program to Evaluate the Efficacy of a Woodchip Bioreactor Installed at the Bolton Wastewater Treatment Plant, Lake George (Warren County), New York

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Final Report

Chapter 10

Background, Documentation of Water Quality Problems, An Innovative Pathway Toward Water Quality Solutions, Summary of 2019 to 2021 Woodchip Bioreactor Performance, Conclusions, and Recommendations

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10.0 Background

The Bolton WWTP was constructed during 1959 to 1960 on the west side of Lake George, within the Town of Bolton, on a series of plateaus comprised of delta sand deposits, left by receding glaciers, in order to utilize the sand as an infiltration area for treated wastewater effluent. This geographic and geologic arrangement is similar to the Village of Lake George Wastewater Treatment Plant (Sutherland and Navitsky 2015). Soils in the region of the Bolton treatment plant and surrounding area consist of Woodstock-Rock outcrop complex and Udorthents, which are moderately to excessively drained soils.

Concurrent with construction of the Bolton WWTP was the development of excessive wet conditions experienced by residents along the north side of Mohican Road in the form of seepage emerging from the slope of the hill. The source of the emerging ground water was from higher elevations to the north and west of the area, in the direction of the Bolton WWTP.

The late Paul F. Donahue, Sr., Esq. had accumulated an extensive file of documents and communications with the Town of Bolton concerning the matter (dating to the 1960s) in an effort to resolve the problem. Mr. Donahue described the problem as originating just after construction of the Bolton WWTP when plant effluent was discharged to the lower sand beds for disposal. In effect, the plant location up-gradient of Mohican Road provided an additional source of ground water that had not existed previously in the area.

10.1 Documentation of Water Quality Problems

Aulenbach and Fillip (1983) conducted a dye tracer study during the early 1980s at the Bolton WWTP and determined that ground water from the upper sand beds “has the effect of increasing the nitrate and chloride content and associated conductivity of the water in the (Stewart) Brook”. However, the pond down-gradient had the effect of lowering the nitrate and elevated phosphorus levels from runoff, while the chloride and conductivity levels remained elevated. It was concluded that further studies were necessary over a longer period below (Stewart) Pond downstream to Lake George before conclusions could be made regarding any water quality impacts to Bolton Bay.

Other studies conducted since the early 1970s suggested that the Bolton WWTP has had a significant impact on the water quality of local tributaries and Bolton Bay, and that further studies were warranted:

- Fuhs (1972) conducted a 12-month study of 18 tributaries, one of which was tributary #55 flowing through the Bixby property. He describes tributary #55 as a “trickle which must be considered mostly seepage from the irrigation field of the Bolton Landing Sewage Treatment Plant (primary treatment only). Between the sampling station and the lake, it feeds a pond which bears heavy blooms of algae.” This tributary consistently had higher levels of nitrate-nitrogen, ammonia-nitrogen, total nitrogen, and silica than other study streams and was consistently referenced as a “polluted” tributary in the report. In a subsequent report, Wood and Fuhs (1979) acknowledge that the Bolton WWTP may contribute 7 percent of the external phosphorus loading to Lake George.
- Coates et al. (1983) studied the influence of the curtain drain on Stewart Brook and determined that nitrate-nitrogen and conductivity levels were substantially higher down-gradient of the discharge from the curtain drain.
- Sutherland et al. (2001) reported measurements of base-flow similar to the Fuhs study 30 years earlier; however, the mean concentrations of conductivity, calcium, magnesium, and chloride were noticeably higher than reported by Fuhs. Data collected during this study suggested that soils below the Bolton WWTP sand beds were saturated and contributing increased concentrations of chloride and calcium during periods of increased flow. These contaminants were impacting the small pond on the Bixby Estate and its outflow into Lake George. Further investigation of problems at this site was suggested.

- Stearns and Wheler (2001) determined that the total phosphorus loading to ground water is far greater from the Bolton WWTP than from the Village of Lake George WWTP, even though the former has substantially less flow.
- Keppler et al. (2008) and Keppler (2009) collected physical, chemical, and biological data from Stewart Brook, the Mohican Road tributary, and offshore sites located in Bolton Bay. They determined that (1) total nitrogen (TN) and total phosphorus (TP) were high in both tributaries, exceeding US EPA's recommended nutrient level criteria, (2) both nutrients were more concentrated down-stream of the Bolton WWTP curtain drain in Stewart Brook, (3) the majority of the (TP) was in soluble reactive form, which is readily available for uptake by algae and plants, and (4) both tributaries were found to be biologically impacted, with the Mohican Road tributary being most impacted.
- Sutherland and Navitsky (2017) conducted the most comprehensive study to date, collecting data from six (6) wells, three (3) seepage streams, two (2) sites on the Mohican Road Tributary and three (3) sites along the channel of Stewart Brook. The sampling sites were selected to correspond with sites from previous investigations. The average NO_3-N concentration measured in effluent discharged from the Bolton WWTP to the sand beds was 17.54 mg $N{\cdot}L^{-1}$. Neither the upper or lower sand beds at the facility were capable of 'polishing' effluent with this high concentration, so ground water down-gradient of the beds was transporting high concentrations of NO_3-N to receiving waters including the Mohican Road Tributary, Stewart Brook, and Stewart Pond. The average monthly concentration of TP measured in effluent discharged from the treatment plant during the study was 0.29 mg P·L (290 µg P·L), while the average monthly concentration measured in effluent since January 2008 when the DMRs were reviewed was 0.45 mg P·L (450 µg P·L) .

10.2 An Innovative Pathway Toward Water Quality Solutions

Coincident with the release of the 2017 Sutherland and Navitsky report, the Town of Bolton consulting engineer for the wastewater facility (Kathleen Suozzo PE) submitted a process and facility review analysis to evaluate the plant's performance within its design parameters and pursuant to the regulatory standards of the New York State Department of Environmental Conservation. The report also offered a series of short-term and long-term recommendations to upgrade the performance ability of the plant. One of the short-term recommendations in the report was to "*conduct a demonstration project involving the repurposing of one of the infiltration sand basins as a woodchip bioreactor for treatment of nitrate*." The installation of a woodchip bioreactor also was one of the recommendations included in the 2017 Sutherland and Navitsky report.

The Town of Bolton accepted the recommendation for installation of a woodchip bioreactor based upon the low cost of construction, the fact that the bioreactor could be constructed within the footprint of the existing WWTP, and potential benefit of reducing the nitrate-nitrogen concentrations leaving the plant in effluent discharged to local ground water.

The bioreactor for the Bolton WWTP was designed by Kathleen Suozzo PE, PLLC. Sand infiltration bed #10, which had been inactive for a considerable period of time and is the southernmost bed in the upper region of the WWTP property, was chosen for the site of bioreactor installation. The details of bioreactor installation including a timeline and step-by-step photographs are provided in Chapter 4 of this report. The woodchip bioreactor began treating Bolton WWTP tertiary effluent on October 10th, 2018, under a variety of environmental and operational conditions.

The Bolton WWTP woodchip bioreactor was designed to specifically address the non-point source input of nitrate-nitrogen in the Lake George drainage basin. At the time, we realized that a similar scenario was, or could become, problematic within the Lake Champlain Basin with respect to community wastewater treatment systems up-gradient of the lake (6 percent of current runoff into the lake) and particularly agricultural runoff which contributes an estimated 38 percent of total runoff into the lake.

Therefore, a successful demonstration of the pilot program would have widespread application within the Lake Champlain basin and beyond and was a technology that would relate directly to the *Lake Champlain Sea Grant Strategic Plan* focus and relevant goals including:

- *Resilient Communities and Economies–Goal 1*: Water resources are sustained and protected to meet emerging needs of the communities, economies, and ecosystems of the Lake Champlain basin.
- *Healthy Coastal Ecosystems–Goal 5:* Habitat, ecosystems, and the services they provide are protected, enhanced, and/or restored.
- *Healthy Coastal Ecosystems–Goal 6:* Land, water, and living resources are managed by applying sound science, tools, and services to sustain ecosystems.

Installation of the woodchip bioreactor at Lake George, and within the Lake Champlain Drainage Basin, provided the perfect opportunity to submit a grant proposal to the Lake Champlain Sea Grant Program for funding to evaluate the efficacy of this technology in the variable, seasonal climate of the northeastern region of the United States.

A proposal prepared and submitted for funding to the Lake Champlain Sea Grant Program during fall 2018 received positive reviews and received an award of $58,656, which with match ($38,971) resulted in a project total amount of $97,627. The details of the grant award are explained elsewhere (Chapter 5). Initially, the grant was awarded for a two-year period. Subsequent problems occurred when the COVID-19 pandemic interfered with Project sampling and a no-cost time extension was granted.

The Project began in March 2019 and the Final Report due December 31st, 2021. This Final Report describes the results of the 31-month investigation on the Bolton WWTP woodchip bioreactor.

10.3 Summary of 2019 to 2021 Woodchip Bioreactor Performance

As previously stated in Chapter 5, the goal of this Project was to conduct a thorough investigation of a woodchip bioreactor at the Bolton WWTP to reduce nitrate-nitrogen from the final wastewater effluent prior to a groundwater discharge. The Project's Null Hypothesis (H_O) being tested was:

> ***The woodchip bioreactor will not reduce the nitrate-nitrogen concentrations that currently occur in the tertiary effluent discharged from the BLWWTP to existing sand infiltration beds and ultimately the local groundwater.***

Based upon the results of this current study, the above-stated Null Hypothesis (H_O) can be rejected in favor of the alternative hypothesis, that…. ***the woodchip bioreactor did reduce the nitrate-nitrogen concentrations that currently occur in the tertiary effluent discharged from the Bolton WWTP to existing sand infiltration beds and ultimately the local groundwater***.

Furthermore, in addition to dis-proving the null hypothesis, the Project described herein was able to realize successful completion of all original and primary objectives as well as additional objectives that were identified as the Project entered the second year of data collection.

Project Objective (1) included characterizing and comparing the Bolton WWTP effluent with particular emphasis on the chemistry of the specific analytes in denitrified and non-denitrified portions of the effluent stream. Chapter 6, Section 6.1.3 characterizes the chemistry of the Bolton WWTP effluent, with particular emphasis on nitrate, ammonia and soluble reactive phosphorus of the effluent stream being denitrified through the bioreactor and side-by-side, the stream not denitrified.

Project Objective (2) referenced monitoring the improvement in ground water nitrate levels moving down-gradient from the Bolton WWTP upper sand disposal beds during the study period. Chapter 7 in its entirety detailed the performance of the Bolton WWTP during the period of the 2019 to 2021 woodchip bioreactor Project and also examined facility SPDES permit data extending back to 2008. The data mining back to 2008 was an effort to properly evaluate any trends within the plant and also in the ground water moving away from the upper sand beds which were used exclusively for plant effluent disposal when operation of the woodchip bioreactor went online. The latter sections of Chapter 7 focus on the improvements in ground water quality related to nitrate as exhibited in SPDES Monitoring Well #3 through the analysis of samples collected as part of the 2019 through 2021 monitoring program. In a similar manner, the final sections of Chapter 8 describe and identify the amount of nitrate loading to Stewart Brook that was alleviated because the woodchip bioreactor was able to reduce nitrate concentrations entering the ground water beneath the upper sand disposal beds.

Project Objective (3) was to define the means and methods of characterizing the operation and efficiency of a full-scale woodchip bioreactor which was the overall emphasis of material presented in Chapter 6. And although this chapter provided extensive analysis and discussion of specific variables, it is difficult to isolate a single variable, especially in this on-site field application, where all variables must be considered at the same time.

Project Objective (4) is directly related to **Project Objective (3)** and the complexity of the effect of different environmental variables makes it extremely difficult, if not impossible, to separate the two (2) objectives because they are so completely interrelated. Perhaps the complexity of the interaction among all of the parameters examined in this investigation is best realized when viewing the Operational Metrics Table (Table 6-3) which compares all of these variables at the same time.

Project Objective (5) involved using the 2019 to 2021 Bolton WWTP on-site investigation to identify means and methods to optimize nitrate removal efficiency of a woodchip bioreactor throughout four (4) seasons of the year in a newly constructed on-site theoretical unit processor. Once again, Chapter 6 contains a wealth of valuable information provided for future consideration in this regard including the following:

- Provide a method of continual and fairly consistent delivery of flow to the bioreactor unit utilizing gravity, a more discrete control device than an Agri Drain unit and a flow meter,
- An effluent flow meter also is a necessary monitoring device for a woodchip bioreactor in constant use,
- A variety of in-reactor monitoring wells at several locations and depths across the *influent* and *effluent* faces of the bioreactor greatly aid in assessing conditions within the woodchip matrix,
- There is the inevitable need for recharging the woodchips within the bioreactor matrix, and based upon the experience encountered with the Bolton WWTP woodchip bioreactor, an *influent* "sacrificial front end" and *effluent* "sacrificial back end" sections are both design considerations for future woodchip bioreactors,
- Replacement of the permeable filter fabric surface cover of the unit processor with an impermeable membrane to prevent the biological activity observed in the demonstration project reported herein.

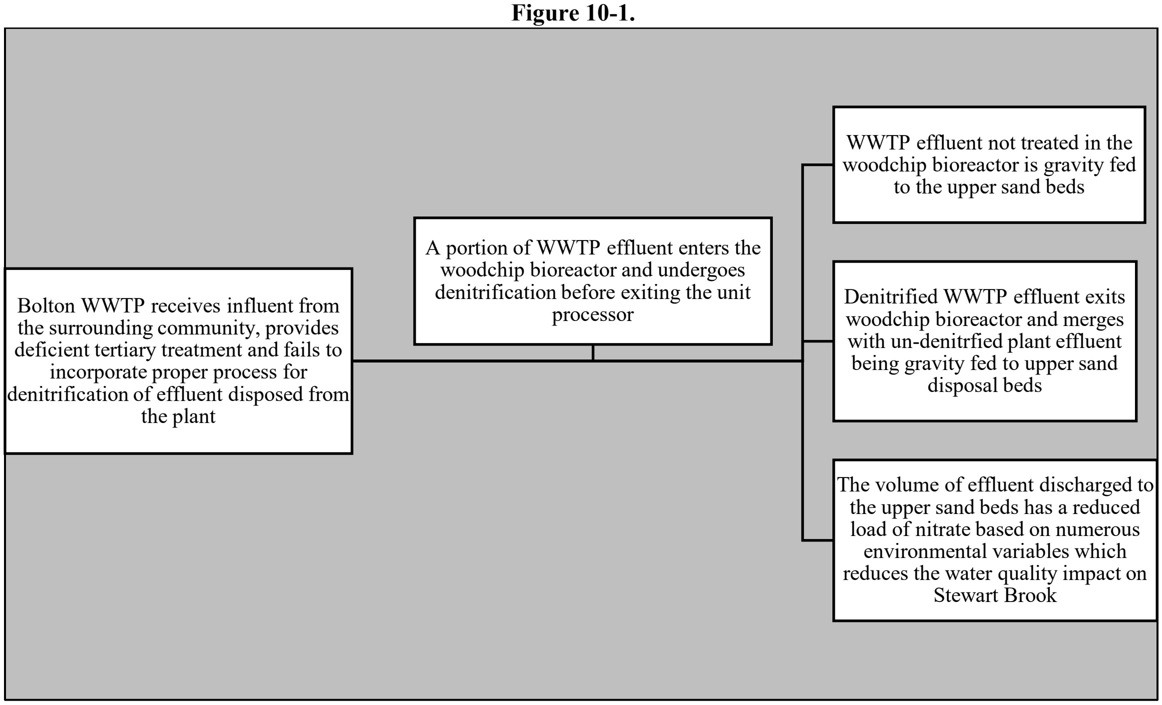
As a final consideration to adjust the current Bolton WWTP unit processor system to achieve greater nitrate removal in facility effluent on a year-round basis, the Town of Bolton, and the Town engineering consultant (KS) have designed two (2) new woodchip bioreactor units for installation at the Bolton facility during 2022.

Project Objective (6) specified advancing collaboration with other researchers and field practitioners to further knowledge in the woodchip bioreactor field. In this regard, there were numerous examples of Project outreach to Dr. Laura Christianson and collaborators at SUNY Strong Brook to discuss intricacies of the Bolton WWTP woodchip bioreactor and determine whether the experience of others conducting research in the bioreactor field could aid us with certain decisions and also facilitate improvements on the system under investigation.

As detailed above, the investigation and evaluation of the Bolton WWTP woodchip bioreactor (1) disproved the Null Hypothesis stated at the onset of the Project, (2) satisfactorily fulfilled all of the Project Objectives stated in the original conceptual proposal, and (3) realized completion of additional established objectives for this “green” technology subsequent to the start of the Project.

The conceptual diagram in Figure 10-1 defines the linkage between Bolton WWTP effluent and eventual water quality impacts on the Stewart Brook when the installed “green technology” woodchip bioreactor is processing some portion of the total daily effluent volume released from the facility.

Figure 10-1.



10.4 Conclusions

The following conclusions have been formulated following careful consideration of the data collected and the results received during the recently completed 31-month study of the woodchip bioreactor installed at the Bolton WWTP.

(1) The investigation reported herein provided compelling evidence that the woodchip bioreactor was capable of reducing the nitrate-nitrogen concentrations that occurred in the tertiary effluent discharged from the Bolton WWTP by about 41 percent, which decreased from the beginning of the study when compared with tertiary effluent that was untreated following discharge from the treatment facility and disposal to the upper sand beds

(2) While the reduction in nitrate-nitrogen was shown throughout the duration of this demonstration project, the variability of removal depends upon a myriad of environmental factors including the concentration of influent nitrate, the temperature of the wastewater, the measure of dissolved oxygen in the wastewater as it traverses the woodchip matrix, the retention time of the wastewater within the bioreactor, the availability of a carbon source for the denitrifying bacteria, wastewater pH, and the flow characteristics of the wastewater through the woodchip matrix.

(3) This “green technology” would perform in a similar effective and efficient manner in geographical and environmental situations comparable to Bolton Landing on the west side of Lake George (New York) in the northeastern United States with more effective nitrate removal during the summer months and less effective nitrate removal during the winter months.

(4) The key to successful operation of this “green technology” regardless of the location is the interest and dedication of the wastewater plant operator(s) who are required to pay attention to system details on a daily basis and use their knowledge to fine tune the system when necessary. The success of the Bolton WWTP demonstration project rested on the shoulders of Plant Operators Matt Coon and Justin Persons, while Kathleen Suozzo always was available and “on call” for technical assistance.

(5) Wastewater *denitrification* through this passive environmentally compatible technology continues to move beyond concept into actual full-scale field applications. Future installations will benefit from the lessons already learned at the Bolton WWTP woodchip bioreactor facility, with additional bioreactor units there providing additional treatment capacity, further options for process optimization, and continued learning opportunities.

(6) The installation and operation of the woodchip bioreactor in the region of the upper sand disposal beds had a significant effect on reducing the nitrate load to Stewart Brook through ground water moving down gradient from the disposal area.

10.5 Recommendations

The following recommendations have been developed after careful consideration of the water quality data collected during the current 31-month study reported herein. These recommendations are not presented in any particular order of importance except for the first recommendation which acknowledges that facility upgrades are required and essential to the future of development in the Bolton community in order to maintain stewardship with regard to the water quality of Lake George.

(1) The Town of Bolton, WWTP operations staff and the Town’s engineering consultant (KS) should move forward with excavation of the plugged woodchips from the existing bioreactor and get the unit up and running as soon as possible.

(2) The Town of Bolton, WWTP operations staff and the Town’s engineering consultant (KS) should move forward with installation of 2 new woodchip bioreactor units in the area of the upper sand beds and adjacent to the existing unit so that virtually all of the daily flow through the plant can be treated by this “green technology”.

(3) According to the most recent 2012 Lake Champlain Basin Program (LCBP) State of the Lake Report, six (6) percent and 38 percent of the phosphorus load to Lake Champlain is generated by WWTPs and agriculture, respectively. In reviewing a series of recent technical reports dealing with Lake Champlain, it became clear that there is very little, if any, data available on nitrate-nitrogen from these sources; most of the nitrogen data was reported bas TN (total nitrogen). We strongly advise the LCBP to investigate the nature of the nitrate problem in the drainage basin. It likely is a bigger issue than currently understood based upon a lack of appropriate data collected.

(4) The Town of Bolton may want to consider providing an updated and more robust "Sewer Use Ordinance" to protect the existing infrastructure from wastewater characteristics that could upset plant operation. With the continual growth of the Bolton community, more stress is being put on the existing collection system and treatment system, which is 60 years old. Pretreatment standards for various wastewater constituents (i.e., organic loadings, pH ranges, oil and grease

concentrations, inhibitory compounds), and routine monitoring of dischargers would benefit the operation of the Bolton WWTP.

The following programs are suggested in an effort to further document and evaluate the long-term effect of the repaired woodchip bioreactor and the two (2) new bioreactor units to be constructed during 2022:

- The Lake George Association should extend the current Bolton Bay Water Quality Assessment Program through December 2022 and beyond and add the Dula Place sampling station to this Program; implementing this program will allow the collection of sufficient water quality data and facilitate the evaluation of SRP concentrations entering the Stewart Brook watershed from the region of the upper sand disposal beds which was not possible during the current investigation due to insensitivity of phosphorus analytical techniques.
- There should be water quality monitoring in Bolton Bay near the tributary mouths and the near-shore littoral zone to determine if there are any detectible changes in nitrate-nitrogen and/or chlorophyll-***a*** concentrations that can be attributed to the woodchip bioreactor.

10.6 Literature Cited

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2019 to 2021 Lake Champlain Sea Grant Program

A Monitoring Program to Evaluate the Efficacy of a Woodchip Bioreactor Installed at the Bolton Wastewater Treatment Plant, Lake George (Warren County), New York

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Final Report

Attachments

Attachment #1 – Bolton WWTP SPDES Permit for Facility Operation

Attachment #2 – Bolton WWTP Original Woodchip Bioreactor Design Plans

Attachment #3 – Bolton WWTP Woodchip Bioreactor Gaps in Operation - 2019 to 2021 Study

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Attachments

Attachment #1 – Bolton WWTP SPDES Permit for Facility Operation

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91-20-5 (3/97)

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION
State Pollutant Discharge Elimination System (SPDES)
NOTICE / RENEWAL APPLICATION / PERMIT

Please read **ALL** instructions on the back before completing this application form. Please **TYPE** or **PRINT** clearly in ink.

PART 1 - NOTICE 02/14/2012

Permittee Contact Name, Title, Address

BOLTON (T)
SUPERVISOR
PO BOX 698
BOLTON LANDING NY 12814

Facility and SPDES Permit Information

Name: BOLTON (T) WASTEWATER TREATMENT P
Ind. Code: 4952 County: WARREN
DEC No.: 5-5220-00155/00002
SPDES No.: NY 009 3688
Expiration Date: 12/31/2012
Application Due By: 07/04/2012

Are these name(s) & address(es) correct? if not, please write corrections above.

The State Pollutant Discharge Elimination System Permit for the facility referenced above expires on the date indicated. You are required by law to file a complete renewal application **at least 180 days prior to expiration of your current permit**. **Note the "Application Due By" date above.**

CAUTION: This short application form and attached questionnaire are the only forms acceptable for permit renewal. Sign Part 2 below and mail only this form and the completed questionnaire using the enclosed envelope. *Effective April 1, 1994 the Department no longer assesses SPDES application fees.*

If there are changes to your discharge, or to operations affecting the discharge, then in addition to this renewal application, you must also submit a separate permit modification application to the Regional Permit Administrator for the DEC region in which the facility is located, as required by your current permit. See the reverse side of this page for instructions on filing a modification request.

PART 2 - RENEWAL APPLICATION

CERTIFICATION: I hereby affirm that under penalty of perjury that the information provided on this form and all attachments submitted herewith is true to the best of my knowledge and belief. False statements made herein are punishable as a Class A misdemeanor pursuant to section 210.45 of the Penal Law.

Ronald F. Conover — Supervisor
Name of person signing application (see instructions on back) — **Title**

[signature] — 2-15-12
Signature — **Date**

PART 3 - PERMIT (Below this line - Official Use Only)

Effective Date: 1 / 1 / 13 **Expiration Date:** 12 / 31 / 22

Stuart Fox
Permit Administrator

Address: NYSDEC - Division of Environmental Permits
Bureau of Environmental Analysis
625 Broadway, Albany, NY 12233-1750

Stuart M. Fox — AUG - 3 2012
Signature — **Date**

This permit together with the previous valid permit for this facility issued 1 / 1 / 08 and subsequent modifications constitute authorization to discharge wastewater in accordance with all terms, conditions and limitations specified in the previously issued valid permit, modifications thereof or issued as part of this permit, including any special or general conditions attached hereto. Nothing in this permit shall be deemed to waive the Department's authority to initiate a modification of this permit on the grounds specified in 6NYCRR §621.14, 6NYCRR §754.4 or 6NYCRR §757.1 existing at the time this permit is issued or which arise thereafter.

~~Attachments: General Conditions dated ___ / ___~~

RECEIVED NYSDEC 12 FEB 16 PM 12: 13

91-20-2 (1/89)

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION

State Pollutant Discharge Elimination System (SPDES)
DISCHARGE PERMIT
Special Conditions (Part I)

Industrial Code: 4952	SPDES Number: NY - 0093688
Discharge Class (CL): 07	DEC Number: 5-5220-00155/00002
Toxic Class (TX): N	Effective Date (EDP): January 1, 1998
Major Drainage Basin: 10	Expiration Date (ExDP): January 1, 2003
Sub Drainage Basin: 06	Modification Date(s): April 5, 2001
Water Index Number: Groundwater	Attachment(s): General Conditions (Part II) Date: 11/90
Compact Area:	

This SPDES permit is issued in compliance with Title 8 of Article 17 of the Environmental Conservation Law of New York State and in compliance with the Clean Water Act as amended, (33 U.S.C. Section 1251 et. seq.)(hereafter referred to as "the Act").

PERMITTEE NAME AND ADDRESS Attention: Deanne Rehm, Supervisor

Name: Town of Bolton
Street: Town Hall, Lakeshore Drive, P.O. Box 698
City: Bolton Landing State: NY Zip Code: 12814

is authorized to discharge from the facility described below:

FACILITY NAME AND ADDRESS

Name: Town of Bolton WWTP
Location (C,T,V): Bolton (T) County: Warren
Facility Address: Town Hall, Lakeshore Drive, PO Box 698
City: Bolton Landing State: NY Zip Code: 12814
NYTM - E: 608 · 165 NYTM - N: 4823 · 268
From Outfall No.: 001 at Latitude: 43° 33′ 20″ & Longitude: 73° 34′ 39″
into receiving waters known as: Groundwater Class: GA

and; (list other Outfalls, Receiving Waters & Water Classifications)

In accordance with the effluent limitations, monitoring requirements and other conditions set forth in Special Conditions (Part I) and General Conditions (Part II) of this permit.

DISCHARGE MONITORING REPORT (DMR) MAILING ADDRESS

Mailing Name: Town of Bolton WWTP
Street: Town Hall, Lakeshore Drive, PO Box 698
City: Bolton Landing State: NY Zip Code: 12814
Responsible Official or Agent: Albert Huck Phone: (518) 644-2212

This permit and the authorization to discharge shall expire on midnight of the expiration date shown and the permittee shall not discharge after the expiration date unless this permit has been renewed, or extended pursuant to law. To be authorized to discharge beyond the expiration date, the permittee shall apply for a permit renewal no less than 180 days prior to the expiration date shown above.

DISTRIBUTION:

Anita Gabalski
Robert Hannaford
William Wasilauski

Deputy Regional Permit Administrator: Walter L. Haynes
Address: 232 Hudson St., PO Box 220, Warrensburg NY 12885-0220
Signature: Walter L. Haynes Date: April 5, 2001

91-20-2b (1/89)

SPDES No.: NY 0093688

Part 1, Page 2 of 5

EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS

During the period beginning EDP and lasting until completion of construction Phase I upgrade the discharges from the permitted facility shall be limited and monitored by the permittee as specified below:

LIMITATIONS APPLY: [x] All Year [ ] Seasonal from ______ to ______

Outfall Number 001

EFFLUENT LIMITATIONS

[x] Flow	30 day arithmetic mean	0.3	[x] MGD	[ ] GPD
[ ] BOD, 5 - Day	30 day arithmetic mean	____ mg/l and	____	lbs/day(1)
[ ] BOD, 5 - Day	7 day arithmetic mean	____ mg/l and	____	lbs/day
~~[ ] UOD(2)~~		~~mg/l and~~		~~lbs/day~~
[ ] Solids, Suspended	30 day arithmetic mean	____ mg/l and	____	lbs/day(1)
[ ] Solids, Suspended	7 day arithmetic mean	____ mg/l and	____	lbs/day

[ ] Effluent disinfection required: [ ] All Year [ ] Seasonal from ______ to ______

[ ] Coliform, Fecal	30 day geometric mean shall not exceed 200/100 ml		
[ ] Coliform, Fecal	7 day geometric mean shall not exceed 400/100 ml		
[ ] Chlorine, Total Residual	Daily Maximum		mg/l
[x] pH	Range	6.5 - 8.5	SU
[x] Solids, Settleable	Daily Maximum	0.3	ml/l
[x] Nitrogen, Nitrate (as N)	Daily Maximum	20 mg/l as N (4)	
[x] Nitrogen, Nitrate (as N)	Daily Maximum	10 mg/l as N (5)	
[ ]			
[ ]			
[ ]			
[ ]			

MONITORING REQUIREMENTS

Parameter	Frequency	Sample Type	Sample Location Influent	Effluent
Effluent				
[x] Flow, [ ] MGD [ ] GPD	continuous	Recorder	x	
[x] BOD, 5 - Day, mg/l (6)	monthly	6 hr. comp.	x	x
[x] Solids, Suspended, mg/l (6)	monthly	6 hr. comp.	x	x
[ ] Coliform, Fecal, No./100 ml(3)				
[ ] Nitrogen, TKN (as N), mg/l				
[ ] Ammonia (as NH_3), mg/l				
[x] pH, SU (standard units)	daily	grab	x	x
[x] Solids, Settleable, ml/l	daily	grab	x	x
[ ] Chlorine, Total Residual, mg/l(3)				
[x] Phosphorus, Total (as P), mg/l (4)	monthly	6 hr. comp.		x
[ ] Temperature, Deg.__				
[x] Nitrogen, Nitrate (as N), mg/l (4)	monthly	6 hr. comp.		x
[x] Phosphorus, Total (as P), mg/l (5)	monthly	grab		x
[x] Nitrogen, Nitrate (as N), mg/l (5)	monthly	grab		x
[ ]				

NOTES: (1) and effluent value shall not exceed ____ % and ____ % of influent values for BOD_5 & TSS respectively.

(2) Ultimate Oxygen Demand shall be computed as follows:

UOD = 1 1/2 x $CBOD_5$ + 4 1/2 x TKN (Total Kjeldahl Nitrogen)

(3) Monitoring of these parameters is only required during the period when disinfection is required.

(4) Final treated effluent prior to discharge to percolation beds.

(5) At monitoring wells.

(6) Percent removal shall be calculated and reported.

91-20-2b (1/89)

SPDES No.: NY 0093688

EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS

During the period beginning completion of construction of Phase I upgrade and lasting until ExDP
the discharges from the permitted facility shall be limited and monitored by the permittee as specified below:

LIMITATIONS APPLY: [x] All Year [ ] Seasonal from ______ to ______

Outfall Number 001

EFFLUENT LIMITATIONS

[x] Flow	30 day arithmetic mean	0.3	[x] MGD	[ ] GPD
[ ] BOD, 5 - Day	30 day arithmetic mean		mg/l and	lbs/day(1)
[ ] BOD, 5 - Day	7 day arithmetic mean		mg/l and	lbs/day
~~[ ] UOD(2)~~			~~mg/l and~~	~~lbs/day~~
[x] Solids, Suspended	30 day arithmetic mean	30	mg/l and	lbs/day(1)
[x] Solids, Suspended	7 day arithmetic mean	45	mg/l and	lbs/day
[ ] Effluent disinfection required: [ ] All Year [ ] Seasonal from			to	
[ ] Coliform, Fecal	30 day geometric mean shall not exceed 200/100 ml			
[ ] Coliform, Fecal	7 day geometric mean shall not exceed 400/100 ml			
[ ] Chlorine, Total Residual	Daily Maximum			mg/l
[x] pH	Range	6.5 - 8.5		SU
[x] Solids, Settleable	Daily Maximum	0.3		ml/l
[x] ~~Nitrogen, Nitrate (as N)~~	~~Daily Maximum~~	20 mg/l as N (4)		
[x] ~~Nitrogen, Nitrate (as N)~~	~~Daily Maximum~~	~~10 mg/l as N~~ (5)		
[x] ~~Phosphorus, Total (as P)~~	~~Daily Maximum~~	~~1.0 mg/l~~ (4)		
[ ]				
[ ]				
[ ]				

MONITORING REQUIREMENTS

Parameter Effluent	Frequency	Sample Type	Sample Location Influent	
[x] Flow, [ ] MGD [ ] GPD	continuous	recorder	x	
[x] BOD, 5 - Day, mg/l (6)	monthly	6 hr. comp.	x	x
[x] Solids, Suspended, mg/l (6)	monthly	6 hr. comp.	x	x
[ ] Coliform, Fecal, No./100 ml(3)				
[ ] Nitrogen, TKN (as N), mg/l				
[ ] Ammonia (as NH_3), mg/l				
[x] pH, SU (standard units)	daily	grab	x	x
[x] Solids, Settleable, ml/l	daily	grab	x	x
[ ] Chlorine, Total Residual, mg/l(3)				
[x] Phosphorus, Total (as P), mg/l (4)	~~monthly~~	~~6 hr. comp.~~		~~x~~
[ ] Temperature, Deg.				
[x] Nitrogen, Nitrate (as N), mg/l (4)	monthly	6 hr. comp.		x
[x] Phosphorus, Total (as P), mg/l (5)	monthly	grab		x
[x] Nitrogen, Nitrate (as N), mg/l (5)	monthly	grab		x
[ ]				

NOTES: (1) and effluent value shall not exceed ____ % and ___ % of influent values for BOD_5 & TSS respectively.
(2) Ultimate Oxygen Demand shall be computed as follows:
UOD = 1 1/2 x $CBOD_5$ + 4 1/2 x TKN (Total Kjeldahl Nitrogen)
(3) Monitoring of these parameters is only required during the period when disinfection is required.
(4) Final treated effluent prior to discharge to percolation beds.
(5) At monitoring wells.
(6) Percent removal shall be calculated and reported.

DEFINITIONS OF DAILY AVERAGE AND DAILY MAXIMUM

The daily average discharge is the total discharge by weight or in other appropriate units as specified herein, during a calendar month divided by the number of days in the month that the production or commercial facility was operating. Where less than daily sampling is required by this permit, the daily average discharge shall be determined by the summation of all the measured daily discharges in appropriate units as specified herein divided by the number of days during the calendar month when measuements were made.

The daily maximum discharge means the total discharge by weight or in other appropriate units as specified herein, during any calendar day.

MONITORING LOCATIONS

The permittee shall take samples and measurements, to comply with the monitoring requirements specified in this permit, at the location(s) indicated below: (Show sampling locations and outfalls with sketch or flow diagram as appropriate)

Final effluent samples shall be collected after the last treatment unit but prior to discharge to the percolation beds.

Groundwater samples shall be collected from the five monitoring wells located around the plant site.

RECORDING, REPORTING AND ADDITIONAL MONITORING REQUIREMENTS

a) The permittee shall also refer to the General Conditions (Part II) of this permit for additional information concerning monitoring and reporting requirements and conditions.

b) The monitoring information required by this permit shall be summarized, signed and retained for a period of three years from the date of the sampling for subsequent inspection by the Department or its designated agent. **Also;**

[x] (if box is checked) monitoring information required by this permit shall be summarized and reported by submitting completed and signed Discharge Monitoring Report (DMR) forms for each 1 month reporting period to the locations specified below. Blank forms are available at the Department's Albany office listed below. The first reporting period begins on the effective date of this permit and the reports will be due no later than the 28th day of the month following the end of each reporting period.

Send the **original** (top sheet) of each DMR page to:

Department of Environmental Conservation
Division of Water
Bureau of Watershed Compliance Programs
50 Wolf Road
Albany, New York 12233-3506

Phone: (518) 457-3790

Send the **first copy** (second sheet) of each DMR page to:

Department of Environmental Conservation
Regional Water Engineer
232 Hudson St., P.O. Box 220
Warrensburg, NY 12885-0220

c) A monthly "Wastewater Facility Operation Report..." (form 92-15-7) shall be submitted (if box is checked) to the [X] Regional Water Engineer and/or [ ] County Health Department or Environmental Control Agency listed above.

d) **Noncompliance** with the provisions of this permit shall be reported to the Department as prescribed in the attached General Conditions (Part II).

e) Monitoring must be conducted according to test procedures approved under 40 CFR Part 136, unless other test procedures have been specified in this permit.

f) If the permittee monitors any pollutant more frequently than required by this permit, using test procedures approved under 40 CFR Part 136 or as specified in this permit, the results of this monitoring shall be included in the calculations and recording on the Discharge Monitoring Reports.

g) Calculations for all limitations which require averaging of measurements shall utilize an arithmetic mean unless otherwise specified in this permit.

h) Unless otherwise specified, all information recorded on the Discharge Monitoring Report shall be based upon measurements and sampling carried out during the most recently completed reporting period.

i) Any laboratory test or sample analysis required by this permit for which the State Commissioner of Health issues certificates of approval pursuant to section five hundred two of the Public Health Law shall be conducted by a laboratory which has been issued a certificate of approval. Inquiries regarding laboratory certification should be sent to the Environmental Laboratory Accreditation Program, New York State Health Department Center for Laboratories and Research, Division of Environmental Sciences, The Nelson A. Rockefeller State Plaza, Albany, New York 12201.

TABLE 1

EXISTING WASTEWATER TREATMENT PLANT
Basis of Design (1959)

Flow & Loading

Year round design population	1200 at 90 gpd	=	108,000 gpd
Tourist Seasonal loading	5,000 at 45 gpd	=	225,000 gpd
		Design 1	333,000 gpd

Process Loading

Summer:	BOD	200 mg/l x 0.333 MGD x 8.34	=	555 lb/day
	TSS	250 mg/l x 0.333 MGD x 8.34	=	694 lb/day
Winter:	BOD	200 mg/l x 0.108 MGD x 8.34	=	180 lb/day
	TSS	250 mg/l x 0.108 MGD x 8.34	=	225 lb/day

Grit Chamber

Velocity controlled settling chamber
Lenght 12'
Maximum width 2'-8"
Sump width 9"
Manually Cleaned

Influent Flow Meter

6" Parshall flume with flow transmitter.

Primary Settling/Sludge Digestion

Imhoff Tank 36' diameter

Primary Settling Area - Total - Gas Vent	1017 - 230	=	787 sq. ft.
Surface Settling Rate	423 gal/day/sf (at 0.333 MGD)		
	137 gal/day/sf (at 0.108 MGD)		

Sludge Digestion Compartment (unheated)

Weighted Population Equivalent

Year Round	1,200
Tourist 5,000 @ 1/4 Factor	1,250
Total Equivalent	2,450

Volume of Compartment	=	11,900 C.F.
Volume per population Equivalent	=	4.9 C.F./capita

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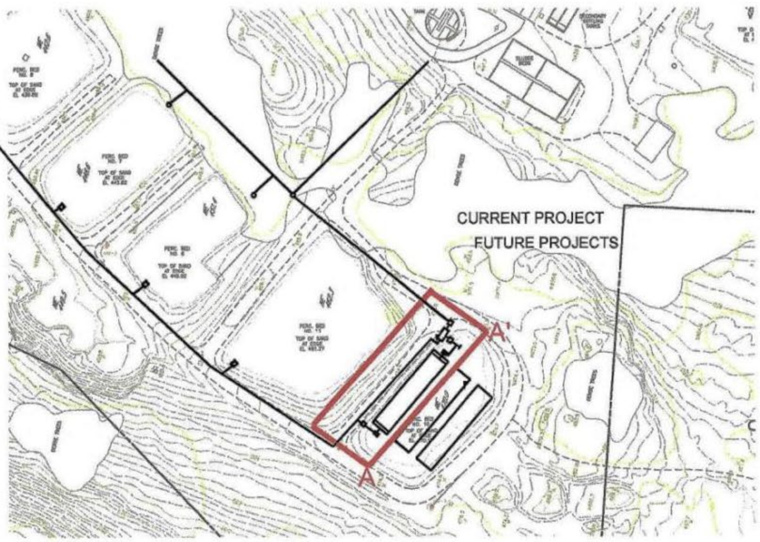
Attachments

Attachment #2 – Bolton WWTP Original Woodchip Bioreactor Design Plans



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NOTES

LIMITS OF CONSTRUCTION

REQUIRED EQUIPMENT

FOR INLET STRUCTURE
1 - 2000 GALLON PRECAST CONCRETE SEPTIC TANK
2 6" CAST IRON GATE VALVES, MJ X MJ, INCLUDING RISER STEM & HAND OPERATOR
40 FT 6" SDR 21 PRESSURE PIPE
2 SCH 40 6" X 6" X 6" TEE
40 FT 6" SDR 21 PIPE, 1 6" END CAP, 8 6" COUPLINGS
60 FT 6" SDR 21 PIPE, 4 6" QUARTER BENDS
1 3-CHAMBER INLET CONTROL STRUCTURE FROM AGRI DRAIN W/V-NOTCH WEIR FLOW MONITORING
6"X4"X4" SCH 40 TEE TO 20 FT. 4" PERFORATED PIPE

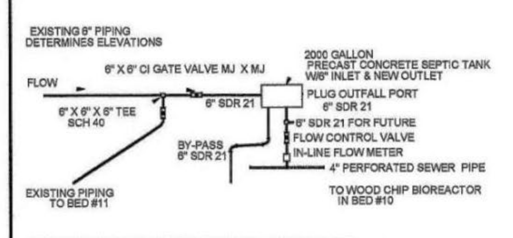
FOR BYPASS PIPING
60 FT 6" SCH 40 PIPE,8 6" COUPLINGS AND 4 6" QUARTER BENDS
2 6" X 6" X 6" SCH 40 TEE

FOR WOOD CHIP BIOREACTOR CELL
4800 SF 45 MIL EPDM POND LINER W/APPURTENANCES
400 CUBIC YARDS OF HARDWOOD/SOFTWOOD CHIPS (1/4" -2" SIZE)
FILTER FABRIC TO COVER WOOD CHIPS
MINIMUM 12" TOPSOIL OVER BIOREACTOR BED, NATIVE VEGETATION
6 2" PVC SCREENED SAMPLING WELL POINTS, EACH 6 FT LONG FOR BIOFILTER THREE WELL POINTS AT BOTTOM OF BED; 3 MID DEPTH

FOR OUTLET STRUCTURE
1 2-CHAMBER OUTLET CONTROL STRUCTURE FROM AGRIDRAIN
6"X4"X4" SCH 40 TEE FROM 20 FT. 4" PERFORATED PIPE
60 FT. SDR 21 GASKETED SEWER PIPE
1 4 FT. X 4 FT. X 6 FT DEEP MANHOLE WITH COVER, 2 6" OPENINGS (DRILLED IN FIELD)

DETAIL OF INFLUENT STRUCTURES

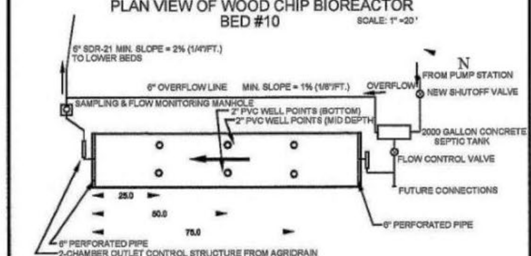
NTS



NON-PRESSURIZED PIPING TO HAVE MINIMUM 1/4"/1 FT. SLOPE
PRESSURIZED PIPING CAN BE TRANSITIONED TO SDR 21 AT HUB (FIELD DETERMINED)

PLAN VIEW OF WOOD CHIP BIOREACTOR BED #10

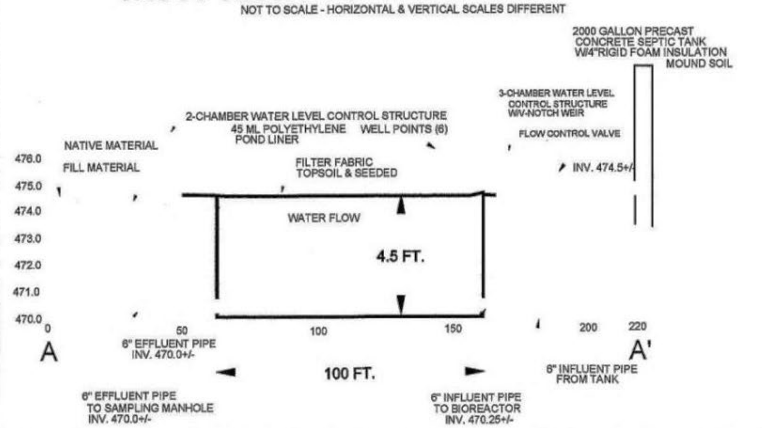
SCALE: 1" =20'



ALL 6" SDR-21 PRESSURE PIPE W/SCH 40 FITTINGS

CROSS SECTION OF BIOREACTOR

NOT TO SCALE - HORIZONTAL & VERTICAL SCALES DIFFERENT



REVISIONS

NO	DATE	DESCRIPTION
1	7/5/18	PURSUANT TO NYSDEC COMMENTS
2	8/13/18	PURSUANT TO FIELD REVISIONS
3	8/17/18	PURSUANT TO FIELD REVISIONS
4	9/20/18	PURSUANT TO FIELD REVISIONS
5	10/5/18	AS-BUILT DRAWING

KSPE
KATHLEEN SUOZZO PE, PLLC
4607 LAKE SHORE DRIVE
PO BOX 653
BOLTON LANDING, NY 12814
contact@kspepllc.com // 518-240-6293

DRAWING TITLE:
TOWN OF BOLTON WASTEWATER TREATMENT PLANT
WOOD CHIP BIOREACTOR PILOT PROGRAM

CLIENT:
TOWN OF BOLTON, WARREN COUNTY
WASTEWATER TREATMENT PLANT
BROOK STREET EXTENSION

DESIGNED BY:	DRAWN BY:	REVIEWED BY:	CHECKED BY:	APPROVED BY:	GRAPHIC SCALE	SCALE:	DATE:	FILENAME:	SHEET NO.
KAS	KAS	KAS	MJS		0 20	AS SHOWN	9/2018	BLWWTP-1	G-1

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Attachments

Attachment #3 – Bolton WWTP Woodchip Bioreactor Gaps in Operation - 2019 to 2021 Study

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The table below summarizes the periods during the 2019 to 2021 study when the bioreactor was shut down for various reasons explained in the table.

Date Bioreactor Down	Date Bioreactor Online	Total Days Offline	Reason
April 30, 2019	May 13, 2019	14	Snow melt & heavy rain shut down pump sta.
August 16, 2019	August 26, 2019	10	Breach influent face due to plugged woodchips
September 17, 2019	September 19, 2019	3	Concern regarding WWTP influent characteristics
November 13, 2019	November 14, 2019	2	
November 30, 2019	November 30, 2019	1	
December 10, 2019	December 10, 2019	1	Meter down
December 31, 2019	January 1, 2020	2	Dead battery
February 6, 2020	February 12, 2020	6	Dead battery – charging
February 20, 2020	February 20, 2020	1	Wiring issue; unplugged from meter
February 29, 2020	March 3, 2020	4	Meter down
March 27, 2020	March 31, 2020	4	Flow meter issue; recharging battery
April 8, 2020	April 9, 2020	2	Charging battery
May 3, 2020	May 5, 2020	3	Charging battery
June 10, 2020	June 13, 2020	4	Meter down
July 17, 2020	August 2, 2020	16	Battery out; system flushed; Pump to bioreactor down
August 26, 2020	August 26, 2020	1	Flushing bioreactor
September 6, 2020	September 6, 2020	1	Loose wire on flow meter
September 15, 2020	September 23, 2020	8	Flow meter issues
October 8, 2020	October 8, 2020	1	
October 27, 2020	November 23, 2020	27	Flow meter sent out for repair
November 30, 2020	November 30, 2020	1	Dead battery
December 8, 2020	December 10, 2020	3	Battery charging
December 31, 2020	December 31, 2020	1	Dead battery
February 10, 2021	February 10, 2021	1	Flushing bioreactor
April 2, 2021	April 5, 2021	3	Dead battery, Cord issue
May 3, 2021	May 9, 2021	6	Flow meter not recording, wire issue
June 1, 2021			Bioreactor shut down due to surface ponding, plugging