JYP-1303

Nutrient Removal at the Gardner Wastewater Treatment Facility

A Major Qualifying Project
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of
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By

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Abstract

The permit for the City of Gardner wastewater treatment facility (WWTF) National Pollution Discharge Elimination System (NPDES) will be revised in 2014. The purpose of this project was to analyze the quality of the facility's effluent and its receiving water body, the Otter River. Permitted parameters were tested and met requirements, with the exception of total phosphorus (TP) and metals. Due to discrepancies in sampling techniques and concentration limits of available laboratory equipment, these parameters require additional testing before conclusions can be made. However, nitrate levels in the WWTF effluent averaged 19.3 mg/L, much higher than average upstream (0.7 mg/L) and downstream (2.0 mg/L) conditions. Although total nitrogen is not regulated in the current NPDES permit, wastewater treatment facilities in the Connecticut River watershed have been subject to increasing pressure from the US Environmental Protection Agency to reduce nitrogen loading, in an effort to improve water quality in Long Island Sound. In anticipation of future discharge limits on total nitrogen, alternative denitrification treatment processes were evaluated. Design calculations were prepared to assess the feasibility of retrofitting the existing activated sludge process to accommodate a Modified-Ludzack Ettinger process.

Executive Summary

The Gardner wastewater treatment facility's (WWTF) National Pollution Elimination Discharge (NPDES) Permit is up for renewal in the fall of 2014. The facility has been subject to increasing pressure from the US Environmental Protection Agency (EPA) to reduce the nutrient loading on the Otter River, including a 0.12 mg/L limit on total phosphorus. A water quality study was conducted on the WWTF effluent and the Otter River to assess the ambient water quality of the river and impact of the facility's discharge of the river. The project group also evaluated design alternatives for the facility aimed at meeting possible future NPDES permit limits on total nitrogen. A design was proposed involving the retrofit of the existing activated sludge process to incorporate a Modified Ludzack-Ettinger (MLE) process.

Water quality sampling was conducted on a bi-weekly basis from April 2013 to October 2013. Grab samples were collected at the WWTF outfall pipe and at three locations along the Otter River, one upstream and two downstream of the facility. Samples were analyzed using ultraviolet-visible and atomic absorption spectroscopy for nutrients and permitted metals. Dissolved oxygen was measured at each location using a portable probe. Samples were also analyzed for *E. coli* using the IDEXX Colilert® and Quanti-Trays. Several statistical analyses were performed using the water quality data obtained from sampling, including an Analysis of Variance (ANOVA) and correlation tests. A mass balance was also developed to quantify the impact of the discharge on the Otter River.

From the testing results, the facility met NPDES permit requirements for all parameters tested with the exception of total phosphorus (TP) and metals. Average TP levels in the effluent from the facility were 0.268 mg/L P and the NPDES permit level is set at 0.12 mg/L. However, these results contradicted the facility's reported values over this same time period and may be attributed to differences in sampling technique (i.e. grab vs. composite). Furthermore, background concentrations of TP in the Otter River upstream of the facility averaged 0.221 mg/L P, which is higher than the established NPDES permit value. Three of the four metals tested, aluminum, cadmium, and copper exceeded permitted discharge limits on several occasions. However, the available laboratory equipment and methods were not able to reliably measure the minute concentrations of metals.

Nitrogen, particularly nitrate, was determined to be a concern for the facility. The average concentration of nitrate in the WWTF effluent was 19.3 mg/L. Downstream concentrations of nitrate in the Otter River were shown to be significantly affected by the discharge from the facility. Upstream values for nitrate averaged 0.7 mg/L and downstream values were on average greater than 2.0 mg/L. This was of particular concern for the facility, since the Otter River is part of the Connecticut River watershed. Wastewater treatment facilities operating in the lower Connecticut River watershed have been subject to increasing pressure from the EPA to reduce nutrient loading, specifically nitrogen loading, in an effort to improve water quality in Long

Island Sound. For this reason, the team chose to investigate alternative treatment processes that included denitrification.

The design effluent concentration of 8 mg/L total nitrogen (TN) was determined from regional trends and available technologies and would equate to a 55% reduction in nitrogen loading. Various advanced treatment processes were explored and a rating system was developed to assess these processes based on capital cost, operation cost, footprint, and scalability, among others factors. As a result of the rating system, the MLE process, a popular choice for retrofitting activated sludge processes in New England, was chosen for its simplicity and ease of operation.

The team chose to assess the feasibility of retrofitting the existing activated sludge aeration basins at the facility to accommodate an MLE process. The influent and effluent for the facility was characterized to determine the appropriate design parameters for the MLE process. The existing final clarifiers were assessed under critical loading conditions to determine the operation parameters of the MLE process. Design calculations for the nitrification and denitrification components of the MLE process were carried out using both theoretical and known values quantified from the facility data.

The team concluded that a simple retrofit was not feasible and that additional reactor volume would be required in order to achieve the desired level of treatment year round. Alternative design approaches aimed at improving efficiency and reducing the capital cost associated with the retrofit of an MLE process were recommended.

Acknowledgements

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Capstone Design

This Major Qualifying Project meets the criteria for Civil and Environmental Engineering capstone design at Worcester Polytechnic Institute by incorporating economic, manufacturability, sustainability, and environmental concerns applicable to engineering practice.

The Gardner Wastewater Treatment Facility (WWTF) is regulated by the National Pollutant Discharge Elimination System Permit, which is up for renewal in the fall of 2014. The facility expects permit limitations regarding the effluent water quality to become more stringent, so it is likely that improvements will need to be made to the treatment processes to accommodate these changes. The purpose of this project was to provide the WWTF with a comprehensive water quality analysis of the facility's wastewater effluent and its receiving water body, the Otter River by testing for physical, chemical, and microbial water quality parameters at various sampling locations. The team also provided the facility with recommendations to retrofit select treatment plant processes that will enable the facility to meet the new permit regulations. The water quality analysis provided insight on the effects the WWTF had on the river, and if any changes needed to be made to the facility's treatment processes to improve the WWTF effluent quality. The results showed total nitrogen and total phosphorus concentrations were relatively high compared to the other nutrients tested, so they were a focal point for treatment process design alterations. A variety of alternative retrofit designs were compared based on their ability to remove the nutrients, as well as the simplicity and cost of design and construction. Plant design parameters such as influent flow characteristics and process equipment specifics were utilized in the design calculations.

The team developed a list of criteria for biological nutrient removal processes and rated design alternatives to determine the best viable option. Ultimately, the team recommended that a Modified Ludzack-Ettinger design be implemented into existing processes within the facility. By implementing these upgrades, the facility can sustain future permit requirements and influent water quality changes. Finally, the higher quality effluent will help maintain the water quality standards of the Otter River set forth by the Environmental Protection Agency.

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ANOVA	Analysis of Variance
BAT	Best Available Technology
BNR	Biological Nitrogen Removal
BOD	Biological Oxygen Demand
CBOD	Carbonaceous Biological Demand
CCC	Criterion Continuous Concentration
CMC	Criterion Maximum Concentration
CWA	Clean Water Act
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
F/M	Food/Microorganisms
FS	Factor of Safety
I/I	Inflow/Infiltration
IR	Internal Recycle Rate
LISS	Long Island Sound Study
MassDEP	Massachusetts Department of Environmental Protection
MBR	Membrane Bioreactors
MDL	Method Detection Limit
MG	Million Gallons
MGD	Million Gallons per Day
MLE	Modified Ludzack-Ettinger
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Volatile Suspended Solids Concentration
MPN	Most Probable Number
MUG	Methylum-belliferyl- β-D-glucuronide
MWQC	Massachusetts Water Quality Criteria
NIST	National Institute of Standard Technology
NPDES	National Pollution Discharge Elimination System
ONPG	o-nitrophenyl- β-D-galactopyranoside
PCB	Polychlorinated biphenyl
RAS	Return Activated Sludge
SDNR	Specific Denitrification Rate
SOR	Surface Overflow Rate
SRT	Solids Retention Time
SSOs	Sanitary Sewer Overflows
SVI	Sludge Volume Index
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorous
USGS	United States Geological Survey
UV	Ultraviolet
WWTF	Wastewater Treatment Facility

1.0 Introduction

The Gardner wastewater treatment facility (WWTF) is a 5 million gallons per day (MGD) facility which serves populations of 20,000 in Gardner, 1,680 in Ashburnham, and 150 in East Templeton, MA. The WWTF utilizes activated sludge advanced treatment processes and produces over 4,400 metric tons of sludge each year. Effluent is discharged into a 4.4 mile portion of the Otter River (a Class B, warm water fishery, Segment MA35-07); therefore the facility is subject to permit requirements under the National Pollution Discharge Elimination System (NPDES) administered by the US Environmental Protection Agency (EPA).

The facility has complied with all outstanding requests made by the EPA in 2009, at the time of their last NPDES permit renewal. However, the Otter River is located within the Connecticut River Watershed, and may be subject to more stringent nutrient limits in the future. EPA stated at the time of the facility's last permit, "It is expected that future updates to the Long Island Sound TMDL [total maximum daily load] will most likely require significant reductions in the current nitrogen loads from wastewater facilities in the Connecticut River Watershed" (EPA, 2012).

In anticipation of more stringent discharge requirements, the purpose of this project was to aid the Gardner WWTF in their efforts to proactively review their effluent quality. Specifically, the objectives were to analyze the quality of the facility's effluent and its receiving water body, the Otter River, and to evaluate denitrification treatment options for retrofitting the current activated sludge process. The following chapters provide background on the facility, the Otter River and the current NPDES permit and nutrient pollution policies. Sampling methods and results are presented next. Lastly, retrofit design recommendations for adding denitrification to the existing facility.

2.0 Background

This chapter provides an overview of the Gardner WWTF, regulations on wastewater discharge and water quality standards. The Gardner WWTF requires specific operations and upholds responsibilities as a NPDES permit holder. This includes monitoring current water quality conditions of the receiving water body, Otter River, and upholding designated use requirements. With regard to nutrient pollution, this chapter describes national and state regulations on nitrogen and phosphorus loadings. An overview of current wastewater treatment processes used at the facility as well as a forecast of potential regulations is provided.

2.1 Gardner Wastewater Treatment Facility

The Gardner WWTF was designed in 1948. It was solely equipped with drying beds. In 1969, it was upgraded to a full wastewater treatment plant and in 1986 it was upgraded to what it consists of today. The 1986 upgrade included the renovation of the headworks building and chlorination building, the addition of the gravity-thickener sludge holding tank and improvements in the aeration treatment structure. It was designed to treat 5 MGD, but on average treats 3.9 MGD. The plant receives sewage from Templeton, Gardner and Hubbardston. It has one significant industrial user, whose contribution to the sewage is leachate from solid waste.

2.1.1 Operations

The Gardner WWTF utilizes preliminary treatment, primary treatment, secondary treatment and disinfection before discharge. The goal of preliminary treatment is to remove objects and particles that have the potential to cause the malfunction of plant equipment. Primary treatment reduces suspended solids and decreases the biological oxygen demand (BOD). Secondary treatment is composed of biological treatment to decrease BOD and suspended solids. The Gardner facility has an aerated sludge system for secondary treatment. Before the water is discharged into the Otter River, it is disinfected through chlorination**.** Figure 1 shows a schematic of the facility including from preliminary treatment to the Otter River discharge as well as sludge processing.

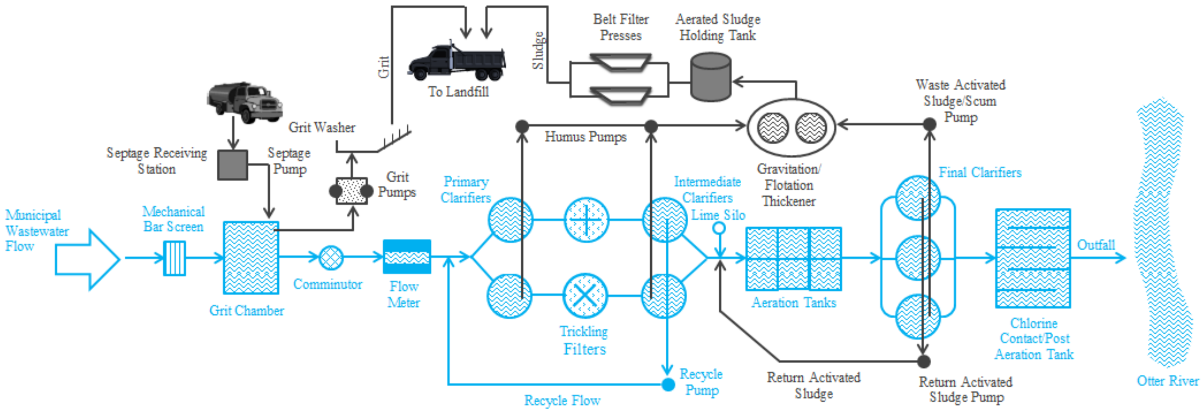

Figure 1: Gardner WWTF Process Flow Schematic

2.1.1.1 Preliminary Treatment

Treatment at the Gardner WWTF begins with preliminary treatment at the headworks (see Figure 2). The mechanical bar screen removes items such as rags, logs, and other coarse items. There are three types of screens or bar racks: trash screens, manually cleaned screens, and mechanically cleaned screens. Trash screens have large openings that range from 40 to 150 mm. The size of manually cleaned screens ranges from 25 to 50 mm and the size of mechanically cleaned screens ranges from 5 to 40 mm. Two sets of screens are usually installed to facilitate repair or cleaning. Gardner uses manually cleaned screens (Earnest, 2013). Phosphorus removal is also started during preliminary treatment with the addition of ferric chloride. This application is only performed for autumn, spring, and summer months, because during the winter, the presence of phosphorus in the effluent is insignificant (ASCE, WEF, 2009); (EPA, 2003).

Figure 2: Gardner WWTF Headworks
(Photo-credit: Mariel VanAtta, 2013)

The grit removal basin is located adjacent to the bar screens. Grit is dense material such as sand, silt, glass, gravel or putrescible organics such as coffee grounds, egg shells and fruit rinds. The processing of this material causes wear and tear to the pumps. Grit can settle in corners and bends of the system, reducing flow capacity and making the system less efficient. There are three common types of grit removal processes: aerated, velocity controlled flow and constant level short-term sedimentation basins. Gardner has a constant level short-term sedimentation basin (Earnest, 2013). Within this system the grit is washed to eradicate organic material. The basin does not have a flow stabilizer as the mechanical parts are above the water line. A hopper transports the grit from the basin to a container. The grit is processed as sludge, which is sent to a landfill. Preliminary treatment ends with a macerator or "muffin monster" which shreds solids that have passed the bar screens and grit tank. In Figure 2, the grit basin is located beneath the smaller of the two buildings and the hopper for the grit removal is located in the larger building in the photo. The bar racks and macerator are located beneath the grates (Droste, 1996); (Forster & Telford, 2003).

2.1.1.2 Primary Treatment

Primary treatment removes approximately 60% of the suspended solids and 35% of the BOD using primary and intermediate clarifiers and trickling filters. There are four types of clarifiers: rectangular, circular, stacked, and plate and tube settlers. The Gardner WWTF utilizes two primary circular clarifiers and two circular intermediate clarifiers. The facility has a total of three primary clarifiers as one serves as a backup clarifier (Earnest, 2013). No energy is used during this treatment process. Clarifiers threat the wastewater by sedimentation, the separation of suspended material from water with gravity. The primary clarifiers separate sewage and grease from the water that has flowed from the headworks. The intermediate clarifiers remove solids and humus, or trickling filter sludge after the water has been treated by the trickling filter. Figure 3 shows one of the settling tanks (ASCE, WEF, 2009); (Forster & Telford, 2003).

Figure 3: Gardner WWTF Primary Clarifier
(Photo-credit: Mariel VanAtta, 2013)

The plant contains two trickling filters. Originally the trickling filters were the core biological component of the plant. After the 1986 upgrades, they were considered as part of the primary treatment and the aerated sludge system became the core of biological secondary treatment (Earnest, 2013). In a typical wastewater treatment facility, trickling filters are considered part of secondary treatment. A trickling filter is a tank or bed containing media colonized by microorganisms that reduce the BOD though metabolic functions. The filter contains media, which can consist of angular stone, slag, gravel, or clinker. Two characteristics that the media must have is that it must have a high surface area for biological colonization and it must create substantial voids to allow downward flow of liquid and an upward flow of air. The media in the Gardner trickling filters are angular stones. A ventilation column allows air to come into the drainage zone from the base.

The wastewater flows through distributors onto the media. The most common distributors are rotary; four tubular distribution poles are attached to the center column. The poles at Gardner have outlets for pouring water, rather than jets or spray nozzles. This is seen in Figure 4, which provides an image of one of the trickling filters. The distributors move by the momentum created by the flowing wastewater. The biofilm in trickling filters is an intricate mixture of anaerobic and aerobic species ranging from bacteria to protozoa and higher predators. It takes about 24 months for the complexity of the biofilm to reach its maturity. Carbonaceous BOD (CBOD) and ammonia nitrogen are oxidized within the biofilm. The CBOD is oxidized in the upper levels due to the presence of heterotrophs in that section. If loading rates increase over time, the heterotrophs, which have a faster metabolism, will spread deeper into the biofilm with the abundance of carbonaceous material causing nitrification to decrease (Droste, 1996); (Forster & Telford, 2003).

Figure 4: Gardner WWTF Trickling Filter
(Photo-credit: Mariel VanAtta, 2013)

2.1.1.3 Secondary Treatment

Before the water enters secondary treatment, it is treated with hydrated lime to control the pH level. Secondary treatment is a bioprocess in which 85% of the remaining BOD can be removed. The Gardner WWTF utilizes an activated sludge process with six rectangular fine air diffused aeration basins and three final clarifiers. Fine air diffused aeration tanks utilize pumped air to mix the biomass, suspended solids, and settled sewage. Enough dissolved oxygen (DO) must be present in order for the microorganisms to aerobically degrade dissolved organics. Ceramic diffusers towards the bottom of the tank disperse the oxygen into the mixed liquor. This causes the production of bubbles with diameters of 2 to 5 mm. The creation of fine bubbles makes this process energy intensive. Figure 5 shows the technology used by Gardner for activated sludge treatment. The basin is divided into two lanes, each having three sections. The mixed liquor moves up the left lanes and right lanes. Sludge flows horizontally between the first chambers in the left and right lane. The maximum amount mixed liquor that can be processed at this stage is 7.117 MGD.

Figure 5: Gardner WWTF Activated Sludge Aeration Basins
(Photo-credit: Mariel VanAtta, 2013)

The facility is equipped with three final clarifiers. The final clarifiers, like the clarifiers in primary treatment, use sedimentation. Solids formed in the aeration tanks are settled during this stage. The water then flows from the final clarifiers to the chlorine contact-post aeration maze. Figure 6 shows the chlorine distribution unit and the mazes. There are two maze chlorine contact chambers and one maze post aeration chamber. In the chlorine contact chambers, the water is disinfected with liquid chlorine. The chlorine is applied through automated pulses; the pulse speed is relative to the amount of water flow passing through. This deactivates pathogens that may be present in the water before discharge. The beginning of chlorination or the start of the maze is at the chlorine distribution unit. After the chlorine reacts with the microorganisms, the water is dechlorinated with the addition of sodium bisulphate (Earnest, 2013). This ensures that excess chlorine is not discharged into the natural water body, which could harm aquatic organisms. Air is blown into the post aeration maze to increase the amount of oxygen in the water. This increases the ability of the water downstream to foster aquatic life (Forster & Telford, 2003). A summary of the design capacities of the plant is shown in Table 1.

Figure 6: Chlorine Contact Chamber
(Photo-credit: Mariel VanAtta, 2013)

Table 1: Gardner WWTF Design Capacity Data

Design Capacity	Plant Flow (MGD)	Mixed Liquor Flow (MGD)
Maximum	4.000	4.457
Minimum	0.580	0.799
Average	1.450	1.887
Hydraulic Peak	5.660	7.117

2.2 Otter River

The Otter River is located in Northern Worcester County, Massachusetts. The source of the Otter River is in the wetland areas of Hubbardston, Templeton, and Gardner. From these wetlands, the Otter River flows in a northwesterly path until its confluence with the Millers River, in Winchendon, MA. The Otter River watershed includes the towns of Ashburnham, Hubbardston, Gardner, Templeton, Westminster, and Winchendon. The watershed covers approximately 61.6 mi^2 and represents 19.8% of the Millers River watershed. The United States Geological Survey (USGS) operates a gaging station along the Otter River at the Turner Street Bridge in Templeton. The drainage area at the gage is 34.1 mi^2, which represents slightly more than half of the watershed. The gage monitors the height and discharge of the river at 15-minute intervals and has been operating since 1964 (USGS, 2013).

As previously noted, the Otter River is a tributary to the Millers River. The Millers River, in turn, is a tributary to the Connecticut River, the longest river in New England at roughly 410 miles long. Several organizations are involved with protecting water quality and promoting recreational opportunities in the Millers River watershed. Most notable is the Millers River Watershed Council, which is headquartered in Athol, MA. Although the majority of the Millers River watershed is occupied by forest and rural land, the portion through which the Otter River flows is the most developed. The Otter River sub-watershed is the mostly densely populated area within the Millers River watershed and has the greatest percentage of commercial and industrial land use. The population density of Gardner is the highest of all cities and towns in the watershed at 936 inhabitants per square mile. The next highest town is Athol at 347 inhabitants per square mile. Over 40% of commercial land use and over 50% of industrial land use within the Millers River watershed is located within the Otter River sub-watershed (MRPC & FRCOG, 2002).

2.2.1 Water Quality Classification

In accordance with Massachusetts state law, all surface waters are segmented and assigned a class. The three basic classes defined by the state are A, B, and C, with Class A being assigned to the highest quality waters in the state. Each class is identified by its most sensitive use to be achieved and protected and is assigned specific water quality criteria (314 CMR 4). The Otter River is broken up into the following three segments, as shown in Figure 7:

- Segment MA 35-06; from the source, Hubbardston (north of Pitcherville Road) to Gardner WWTP, Gardner/Templeton
- Segment MA 35-07; from the Gardner WWTP, Gardner/Templeton to the Seaman Paper Dam, Templeton
- Segment MA 35-08; from the Seaman Paper Dam, Templeton to the confluence with Millers River, Winchendon

The first segment of the Otter River (MA 35-06) is listed as Class B, Aquatic Life. This is a special designation under the Class B status, which is only given when background conditions prevent a “higher use” designation (e.g. cold/warm water fishery). In general, Class B waters are designated as a habitat for fish, other aquatic life, and wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation. In addition, Class B waters should have consistently good aesthetic value, which is judged by color, turbidity, taste, odor, and a lack of debris and nuisance species of aquatic life. For the Class B, Aquatic Life designation, the dissolved oxygen and temperature criteria of a Class C river apply. These criteria state that the DO shall not be less than 5.0 mg/L at least 16 hours of any 24-hour period and not less than 3.0 mg/L at any time and that the temperature shall not exceed 85°F (29.4°C) nor shall the rise due to a discharge exceed 5°F (2.8°C). The remaining two segments of the Otter River (MA 35-07 and MA 35-08) are both listed as Class B, Warm Water Fishery. For a Class B, Warm Water Fishery, the DO shall not be less than 5.0 mg/L and the temperature shall not exceed 83°F (28.3°C) (314 CMR 4).

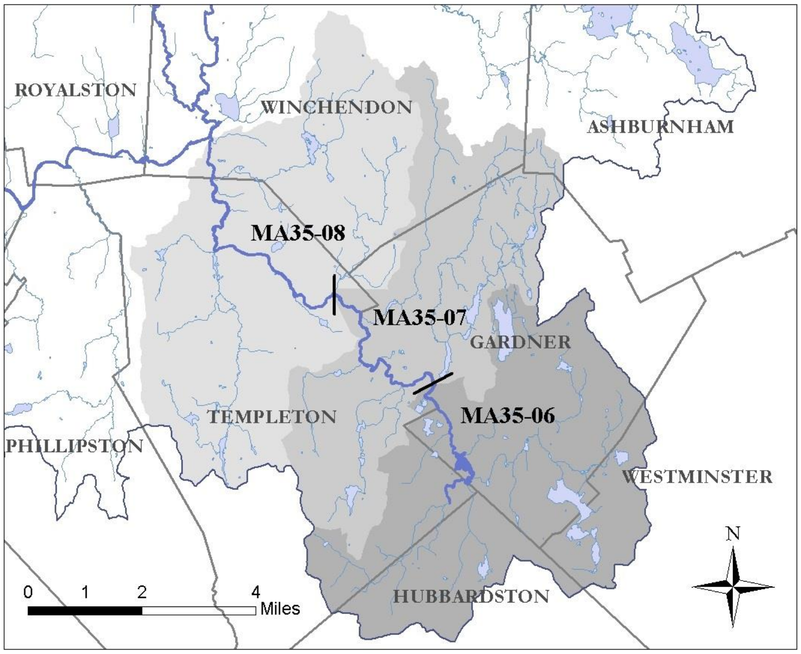

Figure 7: Otter River Watershed and State Designated Segments

The Massachusetts Department of Environmental Protection (MassDEP) conducted a comprehensive water quality assessment on the Millers River watershed in 2000 (Kennedy & Rojko, 2004). In this assessment, the individual segments of the watershed were assessed for their designated uses. The assessment included water quality testing for DO, temperature, turbidity, nutrients, and other parameters. The results of this assessment for the Otter River are summarized in Table 2.

Table 2: Results from the 2000 MassDEP Water Quality Assessment Report
(Adapted from Kennedy & Rojko, 2004)

River Segment	Aquatic Life	Fish Consumption	Primary Contact	Secondary Contact	Aesthetics
MA 35-06	N/A	Impaired	N/A	N/A	N/A
MA 35-07	Impaired	Impaired	Impaired	Impaired	Impaired
MA 35-08	Impaired	Impaired	Impaired	Impaired	Impaired

As shown in Table 2, all three segments of the Otter River were determined to be impaired, meaning they do not attain the water quality standards designated by the state. The most common source of impairment noted was turbidity. However, mercury and polychlorinated biphenyls were the cause of impairment for fish consumption in all three segments (Kennedy & Rojko, 2004). The source of PCB contamination in the river is contaminated sediments, which have been traced to discharges from the former Baldwinville Products, Inc. mill (Colman, 2001).

2.2.2 Pollution Sources

Pollution in a river can originate from point and nonpoint source pollution. Figure 8 shows the locations of NPDES permit holders and various land uses in the Otter River watershed. Point source pollution is traceable to a single identifiable source, such as a municipal discharge. In the Otter River watershed, there are three facilities which are permitted to discharge treated wastewater into the river. These include the Gardner WWTF (Municipal, 5.0 MGD), the Seaman Paper Company of Massachusetts (Industrial, 1.4 MGD), and the Templeton WWTF (Municipal, 2.4 MGD). The Gardner Water Treatment Facility also holds a NPDES permit to discharge effluent (0.47 MGD) from the treatment process through a storm drain system to Pond Brook, which feeds into the Otter River just before the Route 2 overpass. There are also numerous permitted storm water discharges in the watershed, although none are permitted to discharge directly into the Otter River (Kennedy & Rojko, 2004).

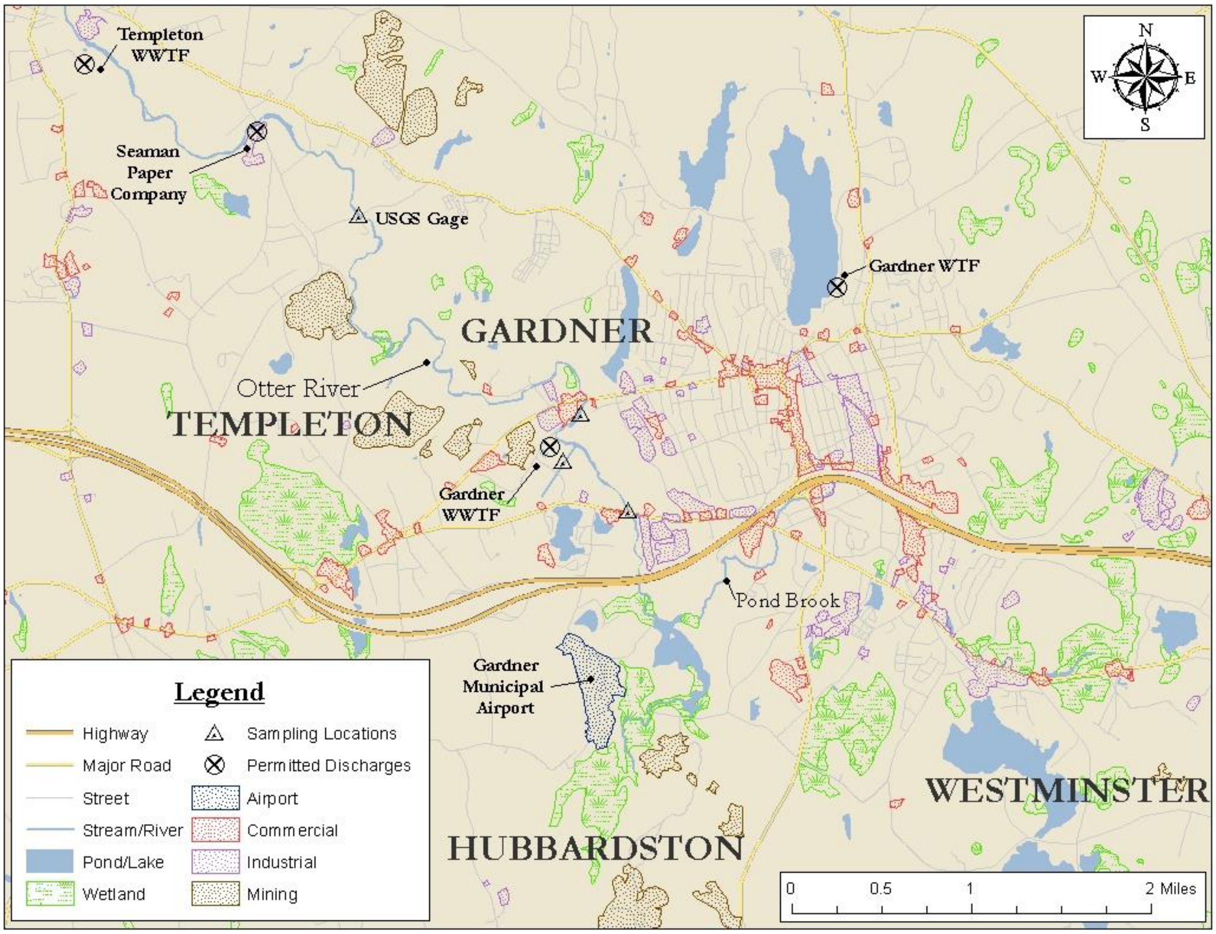

Figure 8: Map of Point Source and Nonpoint Source Pollution in the Otter River Watershed

Nonpoint source pollution, unlike direct discharges from municipal and industrial sources, is not traceable to a single source. Nonpoint source pollution can result from land runoff, precipitation, and atmospheric deposition (EPA, 2012). Several potential sources of nonpoint pollution have been identified in the Otter River watershed. There are numerous sand and gravel operations within the watershed, some of which extend up to the banks of the river itself. These operations can contribute to sediment loading (i.e. turbidity) and nutrient loading in neighboring water bodies (MassDEP, 2006). Urban runoff from commercial and industrial properties might adversely affect water quality in the watershed. The Gardner Municipal Airport, which lies adjacent to the extensive wetlands area at the headwaters of the Otter River, is another possible source of nonpoint source pollution. The impervious surface and vegetative control measures associated with airports can increase runoff and negatively impact water quality (MRPC & FRCOG, 2002).

2.3 NPDES Permitting System

Point sources of discharge are regulated by the NPDES Permitting Program, which was the result of amendments made in 1972 to the National Clean Water Act (CWA or the Act). NPDES permits regulate all point sources such as pipes or man-made ditches that connect to municipal and industrial systems and discharge pollutants into United States surface water bodies (EPA, 2012).

The purpose of NPDES permits is to implement nutrient and contaminant limitations for effluent discharges, establish requirements for monitoring and reporting these discharges, and enforce acceptable treatment facility operations and management (O&M) practices. The discharge limitations established by the EPA are based upon accepted water quality standards of the receiving water body as well as capabilities of current treatment technologies. Technological abilities are the minimum level of control that the EPA uses to establish standards for municipal WWTF, which are mainly based upon secondary treatment requirements in the CWA. In Massachusetts, these secondary treatment requirements result from the water quality standards issued from the Massachusetts Surface Water Quality Standards. These standards regulate and control pollutants in state surface water bodies. Unless site-specific criteria are established by these standards, EPA water quality regulations must be followed.

Water quality standards are the main component for effluent limitations of NDPES permits to ensure that the quality of surface water bodies does not decline. The Massachusetts Anti-degradation Provisions were established for the CWA to ensure that discharge limits do not become more permissive and water quality standards remain high. Since the implementation of NPDES permits in 1972, the overall quality of surface waters nationwide has improved (EPA, 2012).

To continue improving water quality standards, NPDES permits also have the ability to limit pollutant discharges that may affect a certain water quality condition more readily than others. The permittee must determine if there is potential for this to happen, either by recognizing existing pollution controls, identifying a variation in the discharge concentrations, or acknowledging aquatic species that are sensitive to concentration changes of a particular constituent.

2.3.1 Gardner Permit

The Gardner WWTF discharges its treated effluent according to specifications outlined in NPDES permit into the Otter River via outfall No. 001. The permit authorizes discharges from this location, and other discharges at locations such as Sanitary Sewer Overflows (SSOs) are not included.

A renewed version of the permit became effective on December 1, 2009 and will expire November 30, 2014. The facility must follow the current effluent limitations, monitoring and reporting conditions set forth by the permit. The EPA and the MassDEP both equally and independently have the right to enforce these regulations. A copy of the permit can be found in Appendix A.

2.3.1.1 Effluent Limitations and Monitoring Requirements

The NPDES permit regulates a variety of effluent characteristics. The concentration limits of these characteristics vary during the summer and winter months, which range from April 1 to October 31 and November 1 to March 31, respectively. They may also have a maximum daily limit, average weekly limit, or average monthly limit. These limits are developed from toxicity tests of the water, chemical analyses, national water quality criteria pursuant to the CWA amendments and state water quality criteria, or other relatable data. Some parameters must be monitored and reported but do not have a limit. A summary of these parameters and their limits is shown in Table 3. A complete list of limited effluent characteristics and their monitoring and reporting requirements can be found in the full NPDES permit in Appendix A.

Table 3: Summary of NPDES Parameter Concentration Limits
(Adapted from NPDES Permit No. MA 0100994)

Parameter	Monitoring Requirement	Limit	
		Limit	Averaging Period
Effluent Flow	Record Continuously	5 MGD	Monthly
Biochemical Oxygen Demand (BOD)	24-hour Composite, 2/week	8.7 – 26.2 mg/L 8.7 – 39.3 mg/L	Monthly Weekly
Total Suspended Solids (TSS)	24-hour Composite, 2/week	17.4 – 26.2 mg/L 17.4 – 39.3 mg/L	Monthly Weekly
Dissolved Oxygen (DO)	Grab Sample, 1/day	No less than 6.0 mg/L	Any given time
E. coli	Grab Sample, 1/week	126 cfu/100mL 409 cfu/100mL	Monthly Daily Maximum
Total Residual Chlorine	Grab Sample, 1/day	15 ug/L 26 ug/L	Monthly Daily Maximum
Phosphorus	24-hour Composite, 1-2/week	0.12-1.0 mg/L	Monthly
Total Nitrogen	24-hour Composite, 1/week	Report	Monthly Daily Maximum
Nitrate + Nitrite	24-hour Composite, 1/week	Report	Monthly Daily Maximum
Metals	24-hour Composite, 1/month	0.5-8.7 ug/L	Monthly

The frequency of monitoring a component is dependent on its effect on the quality of the water. While some characteristics of the water such as flow rate are continuously monitored, others are sampled once a day via a grab sample. Some characteristics must be monitored by a 24-hour composite sample, and the testing is recorded biweekly, weekly, monthly or quarterly.

Whether or not the NPDES permit defines specific measurable limits for a constituent in the effluent, the effluent characteristics must not violate EPA water quality standards for the Otter River. These standards are described in more detail in Section 2.4. According to the NPDES permit, the effluent from the plant also must not contribute to any aesthetic problems in the river such as discoloration, foam, or floating solids. The facility cannot discharge toxic amounts of pollutants to the river, and is required to report any critical changes of pollutant amounts to the EPA.

The NPDES permit also regulates the Operations and Maintenance (O&M) practices of the treatment facility. An adequate maintenance staff must be provided, and a preventative maintenance program for the assets in the facility must be established to ensure that no overflows or failures of the infrastructure occur. Along with the preventative maintenance program, a separate inflow/infiltration (I/I) plan for the entire sewer system must be created and executed when necessary. The purpose of these O&M regulations is to prevent unauthorized discharges from the plant effluent.

Another component of the facility regulated by the NPDES permit is the condition of the sludge. The sludge utilization and disposal methods are required to comply with all federal and state requirements. Appropriate sludge conditions must be determined by the facility in accordance with specific criteria such as the effluent limitations outlined above.

2.3.1.2 Special Conditions of the Permit

In 2009, when the most recent NPDES permit was put into effect, the facility did not have the capability to comply with some of the limit requirements set forth by the EPA. Mr. Dane Arnold, Superintendent of the Gardner Department of Public Works, addressed this concern and requested that special provisions be made so that the WWTF could work towards compliance without facing fines. The EPA responded by adding a Special Conditions section to the permit.

The average monthly NPDES permit limit for TP is 0.12 mg/L from April 1 to October 31. The EPA calculated this permit level using a basic mass balance approach. The mass balance was constructed to ensure that the TP concentration would not exceed 0.1 mg/L in the Otter River under 7Q10 flow conditions. The background concentration of TP in the Otter River used in the mass balance represents the average of 12 samples collected over a two-month period in the summer of 1995 at the Route 2A bridge.

In 2009, at the time of the last permit renewal, the WWTF was not capable of consistently meeting the NPDES permit summer concentration limit of 0.12 mg/L for total phosphorus. Because of this, the facility was required to annually complete a formal evaluation of whether or not it was capable of meeting the effluent limits. An evaluation of the phosphorus concentration in the summer effluent was submitted to the EPA and MassDEP on December 1, 2010. The evaluation proved that the facility did not meet the requirements, so the TP section of the permit became effective on April 1, 2013. In the meantime, the facility had to submit a yearly report every February 1 that described in detail the measures being taken towards attaining the effluent goal.

Currently, the WWTF monitors average monthly/average weekly TP concentrations using, composite sampling over a 24 hour period. As shown in Table 4, the WWTF has met the permit level concentration of 0.12 mg/L for the past three years.

Table 4: Total Phosphorus Summer Concentration
(Adapted from: CDR Maguire, 2013)

Year	Influent Average (mg/L)	Effluent Average (mg/L)	Removal Rate
2011	2.27	0.08	96.5%
2012	4.72	0.06	98.7%
2013	3.70	0.06	98.4%

Similar to the phosphorous discharge evaluation requirement, an evaluation of the total nitrogen (TN) effluent was submitted. The NPDES permit required that the facility maintain a TN loading of 450 lbs/day, and suggested a 25% TN reduction to comply with the Long Island Sound TMDL. The TN evaluation also recommended alternative methods for optimizing nitrogen removal. These methods included possible operational changes that could improve seasonal and year-round nitrification, incorporation of anoxic zones in aeration basins, policies and procedures for receiving raw sewage, and side stream management options. In order to reduce nitrogen loading, it was recommended that the facility implement these changes right away. An annual report detailing the nitrogen removal efforts as well as annual trends of the nitrogen concentrations was also due on the first of each February until the nitrogen effluent limits were met (EPA, 2009). The average yearly concentrations for total nitrogen are shown in Table 5.

Table 5: Total Nitrogen Concentrations
(Adapted from: CDR Maguire, 2013)

Year	Influent Average (mg/L)	Effluent Average (mg/L)	Removal Rate (%)
2011	27.4	15.4	43.8
2012	37.0	16.2	56.1
2013	30.6	13.5	55.9

The results for TN were classified into the various forms of nitrogen: TN, total Kjeldahl nitrogen, total ammonia nitrogen, nitrite and nitrate. With the exception of nitrite and nitrate concentrations, the effluent of the TN concentrations and loadings was reduced from the influent to the effluent by an average of 50% in 2011 and 2012, as shown in Table 5. The permit states that the WWTF must not exceed annual TN loading of 450 lbs/day. The average effluent loading in 2011 and 2012 was 378 lbs/day, which is below the annual limit, however, the monthly average exceeded this limit for various months.

While the TN concentrations/loadings were reduced within the plant, the nitrite and nitrate concentrations actually increased between the wastewater influent and effluent. The average monthly concentrations of these nutrients in 2011 and 2012 are shown in Figure 9.

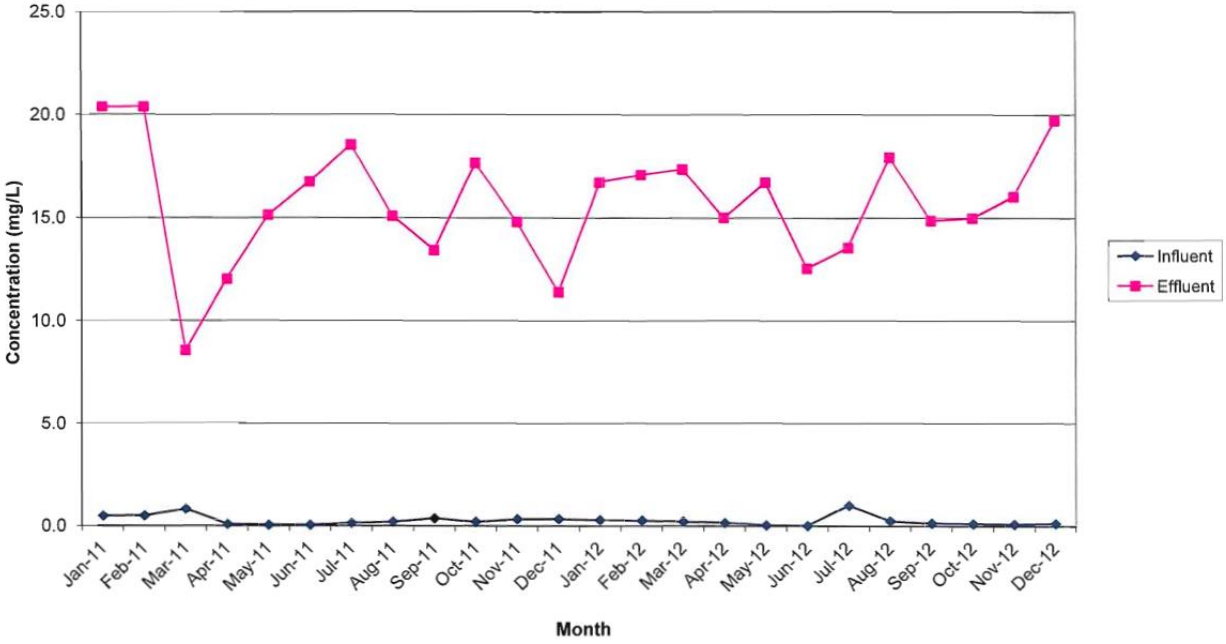

Figure 9: Gardner WWTF Nitrate-Nitrite Concentrations for Influent and Effluent
(Adapted from: CDR Maguire, 2013)

These results provide evidence that the treatment facility has been working to reduce the concentrations of these nutrients. While these trends show success with TN and TP removal, the effluent nitrate concentrations need to be reduced. Furthermore, the summer phosphorus effluent concentrations and TN loadings, while still primarily below permit levels, could be further reduced.

2.4 Nutrient Pollution Policies

From point sources, such as wastewater and industrial plants, to non-point sources, such as residential use of household chemicals, the increase in over-enrichment of surface waters is evident by rising pretreatment costs of drinking water, damaged water-based economies (i.e. fisheries and hatcheries), and the depletion of valuable plant and animal species (EPA, 2011). In response to the growth of nutrient pollution, policies have been developed on the national and local scale to address these issues. The following sections outline the progress that the EPA and Commonwealth of Massachusetts have made towards eliminating nutrient pollution.

2.4.1 EPA Policy

A 1996 National Water Quality inventory report by the EPA concluded that excess nutrients were one of the leading causes of water quality impairment in areas such as the Gulf of Mexico and East Coast states. Numerous events of hypoxia were leading to large-scale fish kills and recreational contact health risks (EPA, 1998). At that time, the only reference nutrient criteria were the listings in the 1976 *EPA Quality Criteria for Water*, otherwise known as the Red Book. The criterion for nitrate nitrogen was 10 mg/L (for the protection of water supplies) and the criterion for elemental phosphorous was 0.0010 mg/L (for the protection of marine and estuarine waters) (EPA, 1998). These criteria were outdated and insufficiently protecting waters from nutrient pollution as cultural eutrophication had significantly increased since late 1970's.

In 1998, the EPA introduced the National Nutrient Strategy, whose mission was to develop technical guidance documents that would serve as "user manuals" for assessing water-body trophic states. By establishing the EPA National Nutrient Team, the goal was to develop region-specific nutrient criteria to control areas of over-enrichment and prevent the spread of nutrient pollution (EPA, 1998).

Starting in 2000, the EPA released Technical Guidance Manuals for various surface water body types, outlining the process for identifying, monitoring and quantifying nutrient pollution in surface water. For rivers and streams, this guidance document outlined the upgrades to existing biannual testing criteria to include relationships between nutrient dispersion and algae growth (EPA, 2003).

In 2001, the EPA released their initial nutrient criteria recommendations, defined by ecoregion, "with the intent that they serve as a starting point for States and Tribes to develop more refined criteria…to reflect local conditions" (EPA, 2001). However, the EPA stressed that the criteria proposed are just a recommendation of how to approach the quantification of a nitrogen limit. The ultimate choice of water quality criteria for nutrients was distributed to State and Tribal entities.

For example, in the Northeast, Connecticut and New York implemented a joint TMDL for the Long Island Sound. Based on baseline studies, point and nonpoint sources contributed to impaired aesthetics, and to fishing and contact recreation use prohibition in the Long Island Sound. Excessive algal blooms and reduced dissolved oxygen levels created a dangerous environment for both animals and humans. In 2001, the EPA approved a plan put forth by the stakeholders of Connecticut and New York. They planned to achieve a 58.5% reduction in nitrogen loading by 2014 through the following objectives:

- Upgrading wastewater treatment plants
- Implementing a nitrogen trading program
- Reducing vehicle emissions
- Controlling storm water runoff

As of 2007, the Long Island Sound Study (LISS) found that the programs implemented had reduced nitrogen loadings by 25%. The State of Connecticut has implemented a robust nitrogen credit trading program for point sources along the Connecticut River, which has significantly helped meet nitrogen loading reductions. However, in order for further improvements to be made, additional restrictions are expected in coming years that will impact the Commonwealth of Massachusetts waterways.

2.4.2 Commonwealth of Massachusetts Policy

In 2003, the Commonwealth of Massachusetts determined their plan for development of nutrient criteria through the MassDEP. The main water quality goals sought by the Commonwealth were those already determined by the designated use categories (as defined in the State’s Water Quality Standards), therefore, the plan outlined methods for obtaining additional surface water quality data (MassDEP, 2005).

In 2003, the Commonwealth of Massachusetts set the “Nutrient Criteria Plan,” which outlined a plan for identifying polluted water bodies and created a timeline for addressing these polluted bodies (MassDEP, 2003). The plan also addressed the timeline for addressing such pollution problems through the creation of TMDLs to limit pollution and hold point sources accountable. According to Section 303(d) of the Clean Water Act and the EPA's Water Quality Planning and Management Regulations (40 CFR Part 130), states must develop TMDLs “for water bodies that are not meeting designated uses under technology-based controls” (EPA, 1998).

Priority water bodies identified by the Commonwealth in 2003 included coastal estuaries and polluted drinking water sources such as lakes and reservoirs (MassDEP, 2003). Based on their primary uses, water bodies were placed on the priority list for the EPA Ecoregion Nutrient Control Plan. In the most recent MassDEP Surface Water Quality update for FY2012, Otter River has been placed on the “in need of TMDL” list, but there has been no timeline to determine when a TMDL ruling can be expected (MassDEP, 2013).

However, the Connecticut River watershed (for which the Otter River is a minor tributary) has been prioritized by MassDEP for TMDL assessment (MassDEP, 2013). As mentioned in the EPA policy section, the Long Island Sound has already instated nitrogen and phosphorus TMDL’s. It is expected that as funding becomes available, the Millers’ River watershed will be placed on the assessment list for instituting a TMDL requirement for nitrogen and/or phosphorus.

3.0 Methodology

This chapter discusses the sampling methods and testing procedures used to analyze water quality constituents in the Otter River and the WWTF effluent. The data collected from these analyses were used to determine whether the effluent affects the river quality, and if changes are recommended to the WWTF to alter effluent quality.

3.1 Sample Collection

Grab samples were taken at three different locations along the Otter River and at the outfall pipe from the WWTF. A map displaying the location of these sampling sites is shown in Figure 10.

Figure 10: Sampling Locations

The upstream sampling was completed at the Route 2A bridge that passes over the Otter River approximately 1 km southeast of the treatment facility. Figure 13A shows a grab sample being taken on the bridge at this location. At all sample sites, water was taken from the middle of the river. A grab sample was taken at the outfall pipe from the WWTF, where the facility discharges into a trench before mixing with the Otter River. This sampling is shown in Figure 13B. Two downstream sites were also sampled. One site was located on Plant Road, 500 meters downstream of the effluent. A photograph of this sampling site is shown in Figure 13C. At the Plant Road site, sampling was carried out by standing on the concrete-reinforced pipe shown in the picture. The second downstream sample was taken at the USGS station on the bridge at Turner Road, approximately 5 km downstream of the effluent. This sampling location is shown in Figure 13D.

(A)
Route 2A Sampling Site

(B)
WWTF Effluent Sampling Site

(C)
Plant Road Sampling Site

(D)
USGS Station Sampling Site

Figure 11: Otter River Sampling Sites
(Photo-credit: Nicholas Noons, Kate Roosa, Mariel VanAtta, 2013)

Two grab samples were taken at each location in 1 L Nalgene bottles. The first bottle was cleaned and autoclaved, and the sample collected in this bottle was used for microbiological analysis. The second bottle was cleaned prior to sampling, and was used for all chemical analyses. The bottles were stored in a cooler with ice packs during the sampling event and while being transported to the laboratory. During the sampling events, the temperature and dissolved oxygen (DO) concentration at each site were recorded. The grab samples were then transported to the laboratory for further water quality analysis. The procedures for completing these analyses are described in Section 3.2. Samples were collected approximately every two weeks from April to the end of October 2013. Table 6 lists specific sampling dates.

Table 6: Sampling Dates

Season	# of Events	Dates
Spring	5	April 18 May 1 May 18 June 1 June 15
Summer	6	June 29 July 14 July 27 August 10 September 1 September 15
Fall	3	September 29 October 13 October 27

3.2 Water Quality Analysis

The river and WWTF effluent water samples were tested for physical, chemical, and microbial water quality parameters. The parameters selected were based on the NPDES Permit (See Appendix A), which specifies what must be reported and the concentration limits that must be met by the WWTF. Table 7 summarizes the parameters measured and the methods used to test them.

Table 7: Water Quality Parameters Monitored

Parameter	**Instrument**	**Method Description**	**Method Number**
Sample Collection and Preservation	1 Liter Nalgene Bottles	Collection of Samples	Standard Method 1060
Temperature	YSI Model 85	Temperature	Standard Method 2550
Dissolved Oxygen	YSI Model 85	Electrochemical Method	Standard Method 4500-O
Ammonia Nitrogen	HACH DR 6000 Spectrophotometer	Nessler Method	Hach Method 8038
Nitrate	HACH DR 6000 Spectrophotometer	Cadmium Reduction Method	Hach Method 8171
Nitrite	HACH DR 6000 Spectrophotometer	Diazotization Method	Hach Method 8507
Total Phosphorus	HACH DR 6000 Spectrophotometer	Acid Persulfate Digestion Method	Hach Method 8190
Orthophosphate	HACH DR 6000 Spectrophotometer	Ascorbic Acid Method	Hach Method 8048
Total Coliforms	Colilert Quanti Tray 2000	Enzyme Substrate Coliform Test	Standard Method 9223B
E. coli	Colilert Quanti Tray 2000	Enzyme Substrate Coliform Test	Standard Method 9223B
Aluminum	Perkin Elmer A Analyst 300	Flame Atomic Absorption	Standard Method 3111D
Cadmium	Perkin Elmer A Analyst 300	Flame Atomic Absorption	Standard Method 3111B
Copper	Perkin Elmer A Analyst 300	Flame Atomic Absorption	Standard Method 3111B
Lead	Perkin Elmer A Analyst 300	Electrothermo Atomic Absorption	Standard Method 3113

3.2.1 Dissolved Oxygen and Temperature

The NPDES permit requires the dissolved oxygen (DO) concentration in the effluent to be at least 6.0 mg/L at any given time. The DO concentration is an indicator of health for a body of water, and a sufficient concentration is important to support fish and other aquatic species. The permit requires this parameter to be tested only during the summer months. This is because DO can be higher in the winter months when the water is colder and therefore the saturation value of oxygen is higher. The moving water of the river dissolves oxygen, which is then consumed by microorganisms decomposing organic materials. If more oxygen is consumed than produced, the biology of the river can be negatively affected (EPA, 2012). Temperature, although not regulated by the permit, was also tested because it is inversely related to the DO saturation concentration of the water (EPA, 2012).

A Handheld Dissolved Oxygen, Conductivity, Salinity and Temperature System, YSI Model 85 (YSI Incorporation, Yellow Springs, OH), was used to measure the DO concentration and temperature at each location. The probe was calibrated prior to sampling by programming the altitude of the location into the instrument and allowing it to stabilize for 15 minutes. The probe remained on for the entirety of each sampling event. It was submerged in the center of the river where the flow was the greatest in order to obtain the most accurate reading and allowed to re-stabilize. The river flow must be at least 1 ft/s to obtain an accurate reading. The DO concentration and temperature were measured in mg/L and degrees Celsius, respectively.

3.2.2 Nitrogen

Nitrogen is present in numerous forms, and expressed as multiple values of nitrogen in the NPDES permit. According to parameters defined by the permit (see Appendix A), nitrogen was tested in three different forms: ammonia, nitrate and nitrite. For all tests, testing procedures were completed according to methodologies for Hach UV VIS Spectrophotometer - DR 6000 (Hach Company, 2011).

3.2.2.1 Ammonia Nitrogen

Ammonia nitrogen is an inorganic, dissolved form of nitrogen that encourages algae and plant growth. Ammonia is the most reduced form of nitrogen and it is found in waters with low dissolved oxygen content (University of North Carolina, 2013). Nessler's reagent, the principle reagent used for analysis, contains potassium iodide and mercury (II) chloride, which crystalizes in aqueous solution to form a pale yellow precipitate in the presence of ammonia nitrogen.

To measure ammonia nitrogen, 25 mL of each sample was measured in a graduated cylinder and transferred to a 25 mL sample cell. A 25 mL blank of deionized water was also measured in a graduated cylinder and transferred to a 25 mL sample cell. Three drops of Mineral Stabilizer (to compound hardness), three drops of Polyvinyl Alcohol Agent (to aid in color formation), and 1.0 mL of Nessler Reagent were added to each cell then mixed. After a one minute waiting period, the blank deionized sample zeroed the spectrophotometer. Then, the samples were read in the spectrophotometer at 425 nanometers (nm) (Hach Company, 2012). Appendix B-1 provides the detailed procedure for measuring ammonia nitrogen.

3.2.2.2 Nitrate

As the more stable soluble compound of organic nitrogen, nitrates are highly soluble and transport easily through water sources. To measure nitrate, cadmium is added to reduce the nitrate in the sample to nitrite. The nitrite ion reacts in an acidic medium with sulfanilic acid to form an intermediate diazonium salt. The salt couples with gentisic acid to form an amber colored solution, whose intensity is proportional to the original amount of nitrate. The amber solution is measured by use of an electronic spectrophotometer that measures the amount of light absorbed by the treated sample (EPA, 2012).

25 mL of each sample was measured in a graduated cylinder and transferred to a 25 mL sample cell. One NitraVer 5 Reagent Powder Pillow packet was added and the sample cell was shaken for one minute. After a five-minute waiting period, the spectrophotometer was zeroed with a sample blank, and then samples were read in the spectrophotometer at 400 nm (Hach Company, 2013). A detailed procedure is available in Appendix B-2.

3.2.2.3 Nitrite

Nitrites are also soluble compounds of organic nitrogen, but are considered less stable than nitrate compounds. Nitrites are usually low in concentration as they can be easily converted to atmospheric nitrogen. Therefore, the low range deionization method was chosen to assess nitrite concentration in the samples. Nitrite reacts with sulfanilic acid to form a diazonium salt. The salt combines with chomotrophic acid to produce a pink colored indicator, which determines the amount of nitrite present in the sample (Hach Company, 2013).

25 mL of each sample was measured in a graduated cylinder and transferred to a 25 mL sample cell. One NitriVer 3 Reagent Powder Pillow packet was added. After a twenty-minute waiting period, the sample blanks zeroed the spectrophotometer and then samples were recorded at 507 nm (Hach Company, 2013). A detailed procedure is available in Appendix B-3.

3.2.3 Phosphorus

Phosphorus naturally occurs as the phosphate molecule, PO_4. In aquatic environments, it is found as organic phosphate and inorganic phosphate. Organic phosphate contains the phosphate molecule and a carbon-based molecule while inorganic phosphate contains no organic material.

Phosphorus is an important nutrient in natural water bodies. A great amount of phosphorus can accelerate the development of algae blooms and plant growth. Some species can’t survive in an aquatic environment with more than the average amount of phosphorus. The average amount of phosphates in flowing waters not discharging into lakes is 0.005 to 0.05 mg/l (Osmond, 1976). Plants in water bodies utilize inorganic phosphorus and convert it into organic phosphorus. The sources of phosphorus could be soil, rocks or runoff from manure or fertilizers (EPA, 2012).

3.2.3.1 Reactive Phosphorus (Orthophosphate)

“Orthophosphate” is a term to describe the phosphate molecule by itself. “Reactive phosphorus” also refers to the phosphate molecule by itself, but it is a methods-based term describing what the test is measuring. Orthophosphate is a chemistry-based term. Orthophosphate can be measured using the ascorbic acid method. In this method, the orthophosphate reacts with molybdate in an acid, forming an antimony-phospho-molybdate complex. This molybdate complex is reacted with ascorbic acid. This reaction causes a blue hue in the sample measureable at 880 nm in the spectrophotometer. The intensity of the blue color is proportional to the amount of orthophosphate in the sample (EPA, 1978; EPA, 2012).

To measure orthophosphate, 25 mL of each sample was measured in a graduated cylinder and transferred to a 25 mL sample cell. One PhosVer 3 Reagent Powder Pillow packet was added, which contained molybdate and acid. After a two-minute waiting period, the sample blanks zeroed the spectrophotometer and then volumes in mg/L PO_4^{-3} were analyzed at 880 nm (Hach Company, 2013). A detailed procedure is available in Appendix B-4.

3.2.3.2 Total Phosphorus

Total phosphorus measures all of the different forms of phosphorus present in the sample. This includes orthophosphate, condensed phosphate and organic phosphate. Condensed phosphates are characterized by an extra phosphorus molecule attached to oxygen. This is compared to orthophosphate which has one phosphorus molecule. Organic phosphorus has a carbon-based molecule with the orthophosphate structure. Only orthophosphate forms a hue that can be read with the spectrophotometer, so this method encompasses the conversion of different forms into orthophosphate. This method for measuring total phosphorus is called the acid persulfate digestion method. The phosphorus conversion occurs through the hydrolysis of the different phosphorus forms and the formation of orthophosphate from the separated components from hydrolysis. Heat is used to break up the different forms of phosphorus present in the sample. Potassium persulfate is added to the sample before digestion and sodium hydroxide is added after digestion. This facilitates the break down and formation of phosphorus compounds. After digestion takes place, the ascorbic acid method is utilized to measure the amount of orthophosphate present in the sample.

25 mL of each sample was measured in a graduated cylinder and transferred to a test tube. Potassium persulfate was added to each tube and then the samples were digested for 30 minutes. After digestion, one PhosVer3 Reagent Powder Pillow packet was added and then allowed to react for two minutes. The spectrophotometer was zeroed and then the samples were analyzed and recorded at 880 nm (Hach Company, 2013). A detailed procedure is available in Appendix B-5.

3.2.4 Coliforms and *E. coli*

Coliforms and *E. coli* were enumerated using the IDEXX Colilert® reagent in conjunction with the IDEXX Quanti-Tray/2000. This method is approved by the EPA for detecting total coliforms and *E. coli* in water/wastewater samples and is included in Standard Methods (APHA, AWWA, WEF, 2005).

Colilert® uses two nutrient-indicators, o-nitrophenyl- β-D-galactopyranoside (*ONPG*) and 4-*methylum*-belliferyl- β-D-glucuronide (*MUG*). These indicators are the major sources of carbon in the reagent. ONPG can be metabolized by the coliform enzyme β-galactosidase and MUG can be metabolized by the *E. coli* enzyme β-glucuronidase. As coliforms metabolize ONPG, it changes from colorless to yellow. *E. coli* metabolize MUG to create a fluorescent byproduct. The yellow color and fluorescence are used to confirm the presence of coliforms and *E. coli*, respectively (IDEXX Laboratories, 2013).

The Quanti-Tray/2000 is a semi-automated quantification method based on Standard Method 9221, the Most Probable Number (MPN) method. Each tray is composed of 49 large sample wells and 48 small sample wells and is designed for used with IDEXX reagents (e.g. Colilert®). After incubation, the number of positive wells is converted to MPN using a table provided by IDEXX (refer to Appendix C). The Quanti-Tray/2000 allows for counts from 1 to 2,419 for a 100 mL sample (IDEXX Laboratories, 2013)

3.2.4.1 Total coliforms and *E. coli* Procedure

The samples were collected in 1 L bottles that had been pre-sterilized using an autoclave. 100 mL of sample is required for quantification of coliforms/*E. coli* using the Quanti-Tray/2000. All transfers were completed aseptically in a laminar flow hood sprayed with a 95% ethanol solution. Each of the 1 L sample bottles was inverted several times to mix the contents. Then the required volume of sample was then transferred into sterilized, 250 mL intermediate bottles. Two replicate bottles were prepared for each sampling location.

Next, one packet of Colilert® reagent was added to each of the bottles. Each bottle was inverted several times and allowed to sit until the reagent dissolved. The Quanti-Tray Sealer was turned on and allowed to heat up. This device is a heated roller instrument used to seal the Quanti-Trays and evenly distribute the sample/reagent mixture amongst the wells. Two Quanti-Trays were prepared for each sampling location and labeled accordingly (e.g. Route 2A-1, Route 2A-2). Each bottle of sample/reagent mixture was then transferred to the corresponding Quanti-Tray. The tray was placed face down in the rubber insert for the Quanti-Tray Sealer and then fed through the automatic feeder. After the all of the trays were prepared, they were placed in an incubator at 35°C for 24 hours.

After the 24-hour incubation period, the trays were read. A Colilert® Quanti-Tray/2000 Comparator tray was used to distinguish threshold positive results from negative ones. A positive result for total coliforms was any well with a yellow color equal to or greater than the comparator. A positive result for *E. coli* was any well with fluorescence equal to or greater than the comparator. For fluorescence, the trays were exposed to an ultraviolet (UV) lamp in a dark room. The MPN/100 mL for the tray was obtained by taking the number of positive large wells and the number of positive small wells and comparing it to the MPN table provided by IDEXX (refer to Appendix C). Since two trays were prepared for each sampling location, the average MPN of the two trays was used to report the MPN/100 mL for that particular location.

3.2.5 Metals

The Gardner WWTF has permitted discharge limitations on five different metals: aluminum, cadmium, copper, lead, and mercury. The first four were tested; mercury was not tested because the laboratory did not possess the necessary equipment. All of the tests were carried out using the Perkin Elmer Analyst 300 Atomic Absorption Spectrophotometer with deuterium background correction. This analysis required special training and, therefore, the laboratory manager, Donald Pellegrino, performed all of the metals analyses. All of the analyses were conducted for total metals, since all NPDES permit limits are expressed in terms of total metals [40 CFR 122.45(c)]. The required sample preparation and analytical procedures are as follows.

The 1 L sample bottle was inverted several times to mix the contents, and then 50 mL of each sample was transferred into a 50 mL centrifuge tube and stored in a refrigerator until analysis.

To analyze each sample, they were first digested in the presence of a strong acid. The 50 mL sample was transferred into a 150 mL acid washed beaker. Exactly 0.5 mL of trace metals grade nitric acid was added to each sample. The samples were then digested for four hours at 175°F and left to stand overnight. Following this step, samples were brought back to 50 mL with the addition of deionized water.

After digestion, the samples were analyzed using the atomic absorption spectrophotometer. Samples were analyzed for Cd, Cu and Al using flame atomic absorption and for Pb using graphite furnace atomic absorption. A calibration curve was created for each element using NIST traceable standard solutions. Since the concentration of each metal was low, the method detection limit (MDL) was the first point (the lowest concentration standard solution) on the calibration curve.

3.3 Statistical Analyses

This section outlines the methodologies used to statistically analyze water quality data collected. Statistical tests were performed in Microsoft Excel 2013 using the plugin statistics tool.

3.3.1 One Way Analysis of Variance (ANOVA)

Analysis of variance tests were completed for each testing parameter. This statistical test was used to identify differences between sampling sites. For example, the mean nitrate concentrations were compared to each of the four sites (Plant Road, WWTF effluent, Route 2A and USGS station) to determine whether or not there was a statistical difference between the mean concentrations at the sites. A p-value less than 0.05 indicates statistically significant difference, meaning that the probability of the variance occurring by chance is unlikely.

3.3.2 Correlation

Pearson correlation tests were completed for each sampling site as well as a combined test for the sampling sites upstream and downstream from the effluent. These statistical analyses were completed to determine whether any of the various testing parameters were linearly correlated.

Some parameters such as temperature and dissolved oxygen are expected to be inversely correlated. Correlations were assessed by comparing the calculated correlation coefficient to the critical absolute value of 0.304. This value is the Pearson's Coefficient for a 95% confidence level. The critical value is based on the number of paired data points. For this project, "n" is equal to 14, the number of testing dates. Two testing parameters with a testing coefficient greater than or equal to the Pearson's Coefficient of 0.304 were assumed to be correlated.

4.0 Results and Discussion

This chapter presents the laboratory testing results of the DO, temperature, microbes, nutrients and metals from each sampling site. Grab samples were taken bi-weekly from April to October 2013 at one upstream location, Route 2A; the WWTF effluent outfall; and two downstream locations, Plant Road and the USGS station. Flow data for the river and the effluent were measured and compared with the testing results to find relationships between wet weather flows and concentrations of specific parameters.

4.1 River Flow Conditions

On each sampling date, precipitation, temperature and discharge data were collected, and weather and river flow conditions were observed. The precipitation data were obtained from the Fitchburg and Orange National Weather Service Station records, which provided 48-hour precipitation amounts for the eastern and western areas of the testing area (National Weather Service, 2013). The Fitchburg weather station is located approximately 15 miles east of the Gardner WWTF and the Orange weather station is located approximately 20 miles west of the Gardner WWTF. River flow data were obtained from the United States Geological Service (USGS) flow station at Turner Street Bridge along the Otter River, otherwise known as the USGS testing location (USGS, 2013). The discharge of the river increased following storm events, as shown in Figure 12.

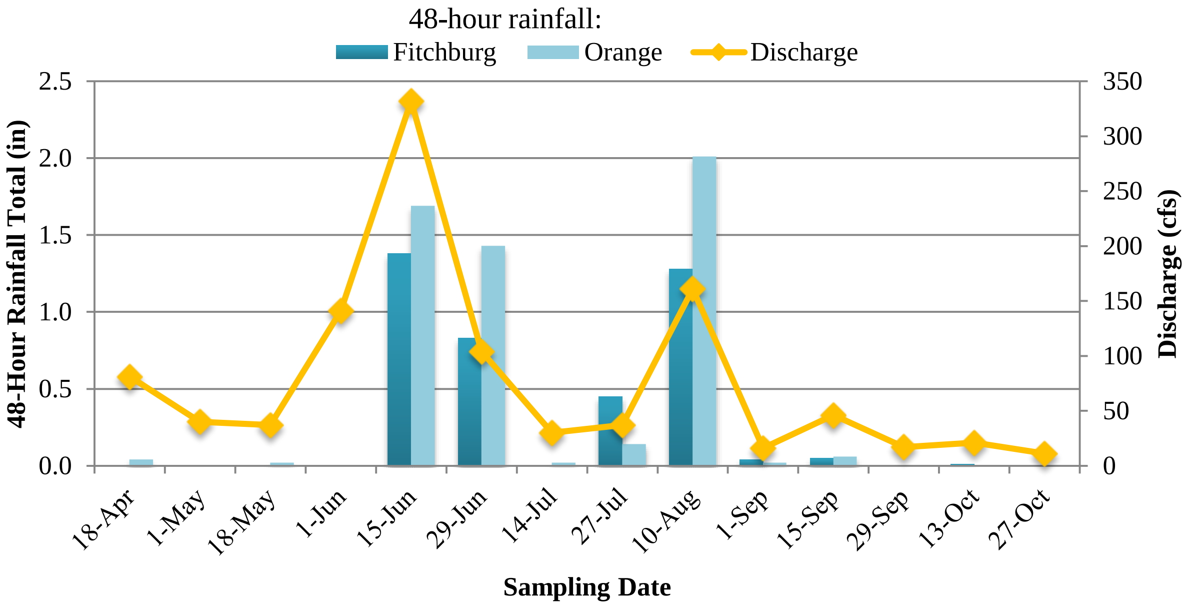

Figure 12: 48-Hour Rainfall Totals and Discharge

4.2 Effluent and River Water Quality

This section discusses the results from the water quality monitoring testing. Parameters in this section are regulated by the NPDES permit for the Gardner WWTF and/or regulated by the EPA as Ambient Water Quality Standards for the Otter River.

4.2.1 Dissolved Oxygen and Water Temperature

Dissolved oxygen (DO) and water temperature were measured at each sampling site (see Figure 13). DO for the effluent remained close to 8.0 mg/L and never fell below the WWTF NPDES permit level of 6.0 mg/L on any given testing day. The DO averaged 5.46 mg/L among all locations, but at Route 2A and Plant Road sites, 9 out of the 14 samples were below the Massachusetts Water Quality Criteria (MWQC) of 5.0 mg/L (MassDEP, 2008). The lowest DO concentration measured was 2.45 mg/L at the Plant Road sampling location on July 14. The USGS station DO average was expected to be greater than the other river conditions because there is a small weir located just above the sampling site and aeration is provided by the water movement. The DO average at USGS was 8.12 mg/L, with a high of 10.25 mg/L and low of 6.73 mg/L. The water temperature was below the MWQC limit of 28.3°C throughout the duration of the testing period (MassDEP, 2008).

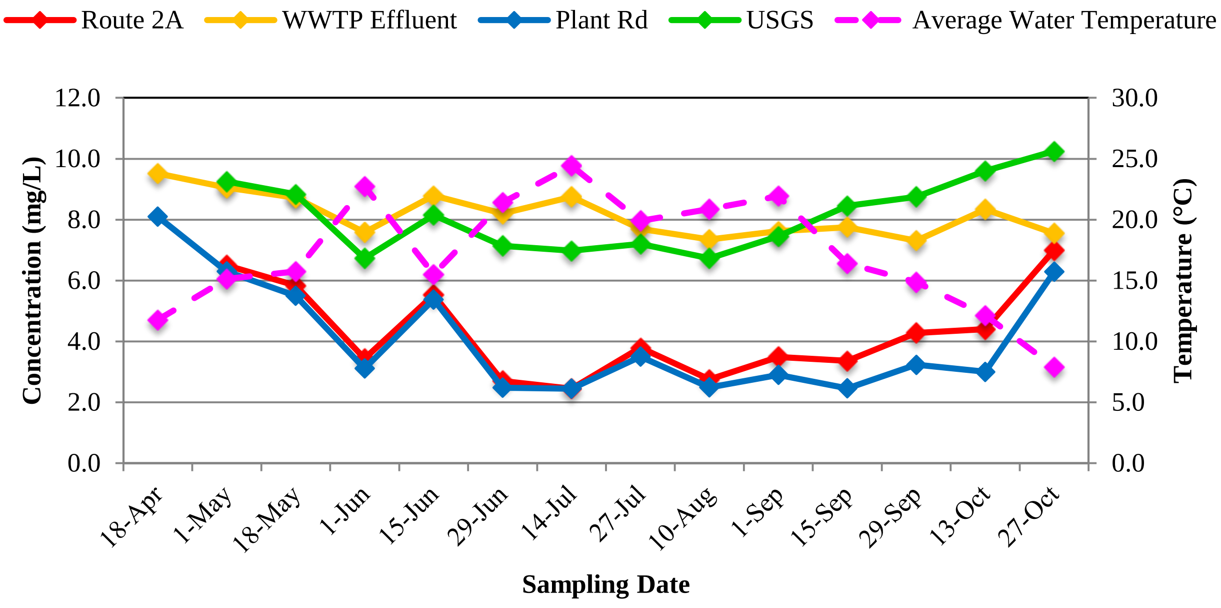

Figure 13: Results for Dissolved Oxygen and Temperature

4.2.2 Nitrogen

Nitrogen concentrations were measured in its three different forms: ammonia nitrogen, nitrate, and nitrite. Each form of nitrogen showed different trends and changes in concentration throughout the testing period, which are discussed in the following sections.

4.2.2.1 Ammonia Nitrogen

High levels of ammonia nitrogen in rivers are a cause for concern because the levels can become toxic to aquatic life at high pH and/or high temperature. The toxicity of ammonia results in biological changes such as physiological, behavioral, morphological, and organismal effects in aquatic wildlife. Examples of these effects are abnormal fish growth, gill conditions and organ weights, as well as hematocrit (Milne, 2000). According to the NPDES permit, the average monthly/average weekly requirement for the effluent concentration of ammonia nitrogen is 1.0 mg/L from June 1 to October 31. The average monthly/average weekly limit from November 1 to May 31 is 4.4 mg/L.

Figure 14 shows ammonia nitrogen concentration measurements in the effluent of the treatment plant and the three sampling locations up and downstream of the Otter River. These measurements were taken between April 18 and October 27. The average effluent concentration of ammonia nitrogen throughout the sampling period was 0.196 mg/L, which was well below the permit levels. In the river, the ammonia nitrogen levels ranged from 0.2 mg/L to 0.97 mg/L, with average values of 0.56 mg/L, 0.50 mg/L, and 0.48 mg/L at sites Route 2A, Plant Road, and the USGS Station, respectively.

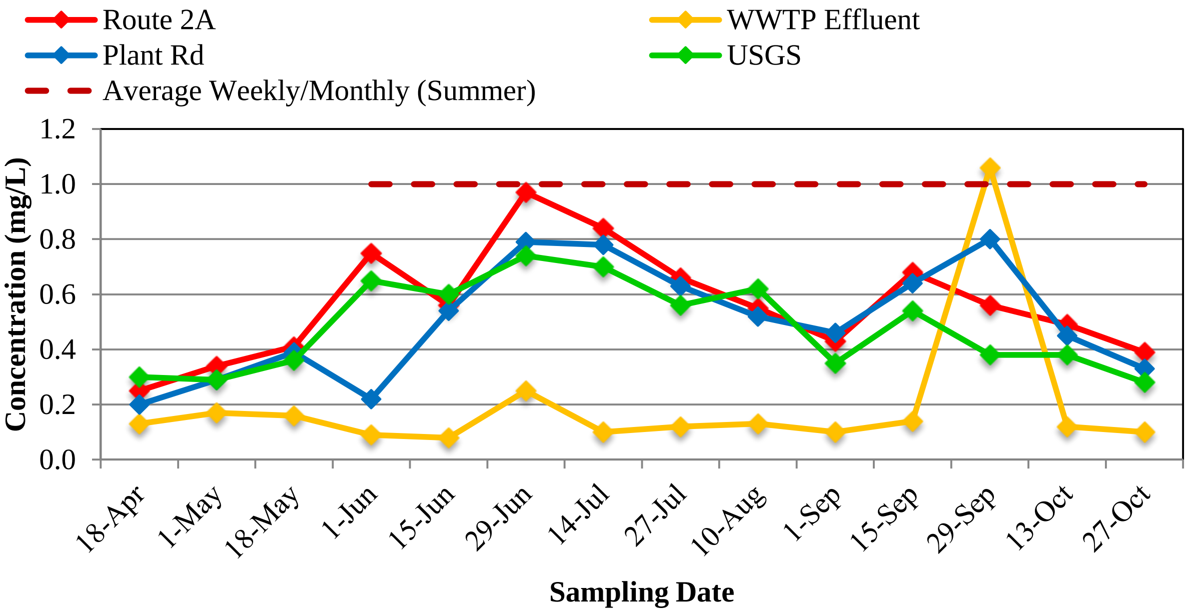

Figure 14: Results for Ammonia Nitrogen (with NPDES Permit Limitations)

Except on September 29, the samples in the river were consistently higher than the effluent samples, suggesting that the effluent does not negatively impact the ammonia concentrations in the river. In addition, downstream concentration levels were typically lower than upstream concentration levels, indicating potential decay mechanisms between the sampling sites or an improvement in river quality due to discharge.

4.2.2.2 Nitrate

Nitrate is a form of nitrogen that is an important aquatic plant nutrient but can hinder the quality of a water body in excess amounts. High nitrate concentrations can result in accelerated eutrophication, which subsequently affects DO concentrations and temperature in that body of water. Low DO concentrations can result in hypoxia, which is a very dangerous environment for aquatic wildlife.

There are currently no specific measurement limits for nitrate concentrations in the NPDES permit, and water quality standards for a Class B water body in Massachusetts do not provide recommendations of limits for nitrates. Figure 15 shows that the concentration of nitrate from the effluent is more than ten times greater than nitrate levels in the river. The average effluent concentration of nitrate throughout the sampling period was 19.3 mg/L. In the river, the nitrate levels ranged from 0.1 mg/L to 8.1 mg/L, with average values of 0.7 mg/L at Route 2A, 2.6 mg/L at Plant Road and 2.2 mg/L at the USGS Station, as shown in Appendix E.

With such high effluent concentrations, it would be expected that the nitrate concentration at the Plant Road location would also be high because it is located only a few hundred yards downstream. While the downstream concentrations are higher than the upstream concentrations, they are still significantly lower than the effluent. This indicates that the nitrate in the effluent is quickly diluted in the river. The data also show that the nitrate concentration in the effluent decreased from the spring to summer months, and then began increasing again at the end of summer and into the fall.

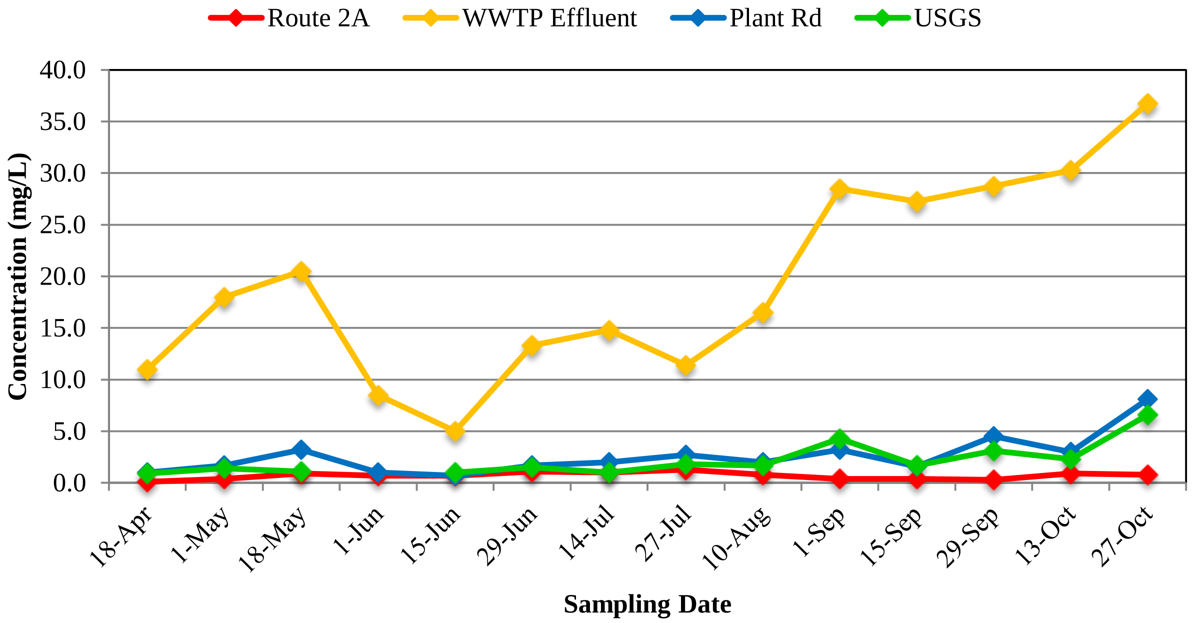

Figure 15: Results for Nitrate

4.2.2.3 Nitrite

Nitrite is the oxidized form of ammonia nitrogen, and although it is chemically similar to nitrate, it considerably more toxic to aquatic life than nitrate if excess concentrations are prevalent in water bodies (EPA, 2012). As shown in Appendix E, the average nitrite concentration in the effluent was 0.008 mg/L, while the average river concentration was 0.002 mg/L. It is evident from the data that the concentration of nitrite throughout the river is extremely low, and there were no noticeable changes throughout the seasons. Although all sampling locations proved to have diminutive concentrations, the effluent concentration of nitrite is relatively higher than at the river sites. There are no limit requirements from the NPDES permit or Class B water quality standards that the effluent from the WWTF must follow.

4.2.3 Phosphorus

Phosphorus concentrations were measured in two different forms: orthophosphate, and total phosphorus. Each form of phosphorus showed different trends and changes in concentration throughout the testing period, which is discussed in the following sections. Phosphorus can lead to uncontrollable growth of aquatic plants and the abundance of algal blooms. It can also impact the oxygen demand and reduce the efficiency of coagulation processes in water treatment facilities (Kaufman, 1975).

4.2.3.1 Reactive Phosphorus (Orthophosphate)

There is currently no permit limit for the concentration of orthophosphate in the WWTF effluent, but average orthophosphate is reported monthly. As shown in Figure 16, the concentration of dissolved orthophosphate in the WWTF effluent was greater than the concentration in the river sites for the majority of the sampling dates. The highest effluent value was 0.34 mg/L in June and the lowest value was 0.21 mg/L in October. However, the effluent values remained higher than the average river values throughout testing. The highest river value was 0.18 mg/L, and the lowest river value was 0.07 mg/L. It should be noted that a testing error was suspected on July 27, when the group used a new spectrophotometer which had a different methodology for phosphorus testing.

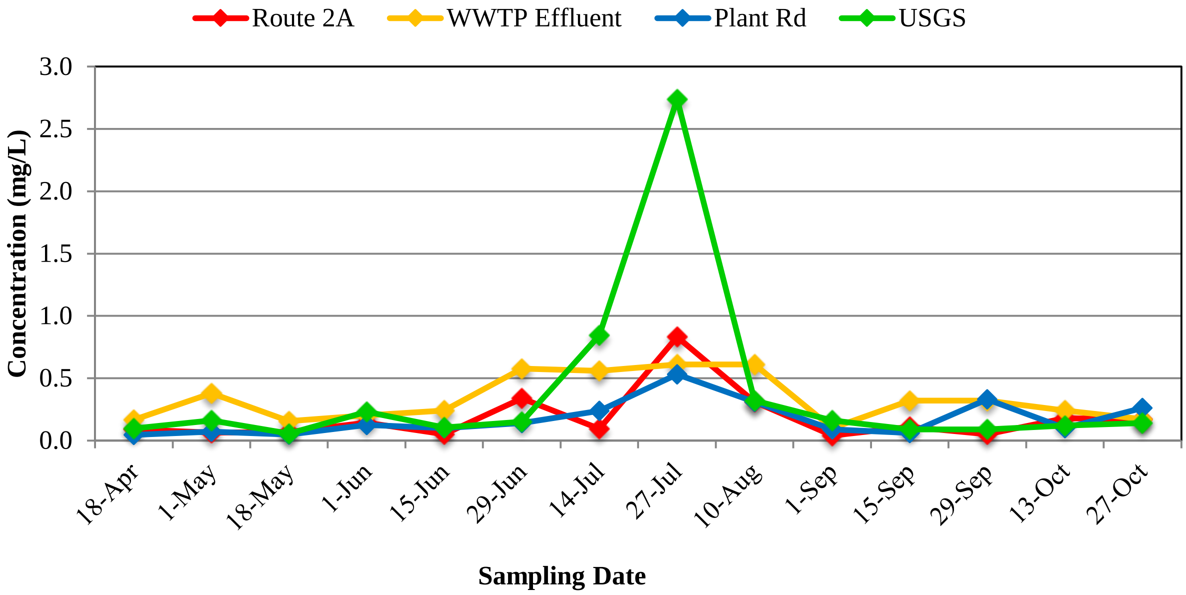

Figure 16: Results for Dissolved Orthophosphate

4.2.3.2 Total Phosphorus

According to the NPDES permit, the average monthly/average weekly requirement for effluent concentration of TP is 0.12 mg/L from April 1 to October 31. The average monthly/average weekly limit from November 1 to March 31 is 1.0 mg/L. Figure 17 shows TP in the effluent of the treatment plant and the three sampling locations up and downstream of the Otter River.

The average effluent concentration of TP throughout the sampling period was 0.27 mg/L, with levels ranging from 0.08 mg/L to 0.54 mg/L, which were higher than the permit level. In the river, the TP levels ranged from 0.08 mg/L to 0.56 mg/L, with average value of 0.22 mg/L.

In general, the results indicate that the amount of phosphorus in the WWTF's effluent was greater than the phosphorus in the river. However, the project team's measured background level (upstream, Route 2A site) of TP was significantly higher than the background level used in the determination of the NPDES permit level. As mentioned in Section 2.3, the background level used by the EPA in the mass balance was approximately 0.06 mg/L (Kennedy & Rojko, 2004). The average TP concentration at the Route 2A sampling location for the duration of the water quality sampling was 0.22 mg/L. This suggests that the permit level calculated was inaccurate for the current conditions of the Otter River.

Over the sampling period, there were discrepancies between the results from the measured data and the WWTF data for TP. The WWTF reported that between April and October 2013, they exceeded NPDES permit level of 0.12 mg/L 5 out of a total of 58 sampling times, or approximately 9%. This is a very small fraction of samples compared to the 12 out of 14 samples, or approximately 86% of samples, that exceeded the permit level from the project team's water quality testing results. This discrepancy could be due to the differences in sampling methodologies. The WWTF collected 24-hour composite samples approximately four times per month, while the project team collected grab samples twice a month, usually at the same time of day.

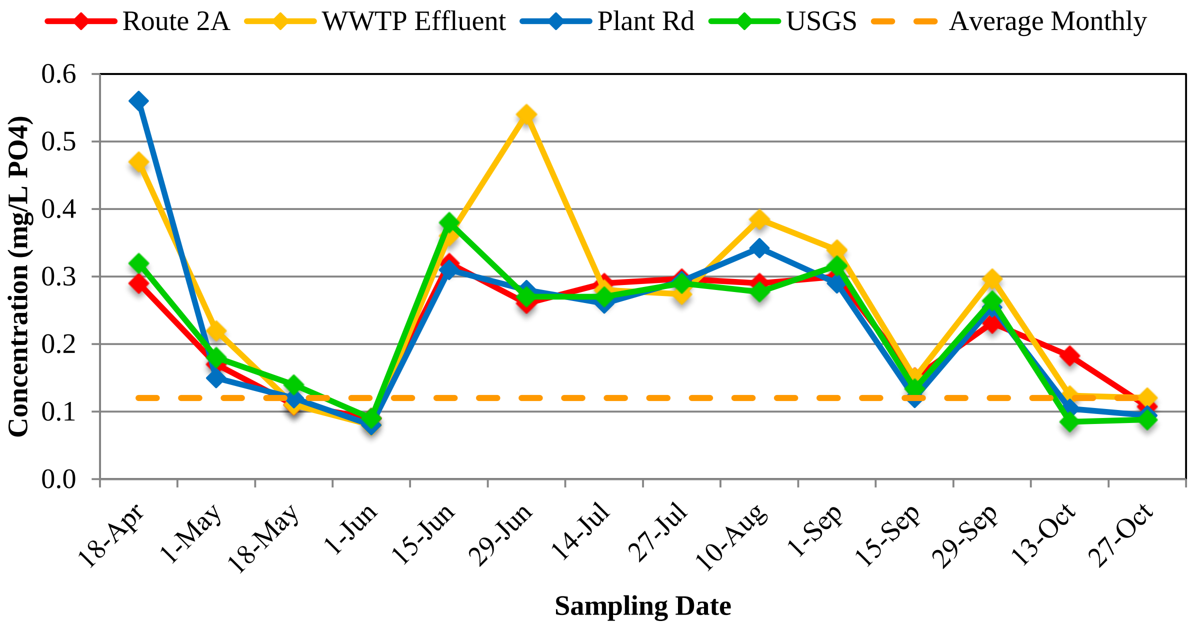

Figure 17: Results for Total Phosphorus

4.2.4 Coliforms

Total coliforms and *E. coli* are indicator organisms whose presence can indicate the presence of pathogens in water. Only the *E. coli* data were considered for analysis because it is most specific indicator of microbiological drinking water quality (EPA, 2012) and addressed in the NPDES permit. *E. coli* is measured in colony forming units (cfu) per 100 milliliters.

Figure 20 shows *E. coli* data collected from plant effluent and river, NPDES permit requirements, and EPA recreational water quality criteria. The NPDES permit maximum daily requirement is 409 MPN/100 mL and the average monthly requirement is 126 MPN/100 mL. For recreation, primary contact criteria is 235 MPN/100 mL and secondary contact criteria is 630 MPN/100 mL. Considering the effluent range of 0 to 59 cfu/100 mL, 13 of 14 samples were 5 cfu/100 mL or less and all samples met the permit requirements. Considering the river data range of 2 to 300 cfu/100 mL, the values were lowest in spring (<100 cfu/100 mL) and increased during the summer (highest value on July 14, 300 cfu/100 mL), remaining elevated in the fall (average 55 cfu/100 mL). All of the measured *E. coli* concentrations in the river were below the daily permit level of 409 MPN/ 100 mL and met the EPA recreational water quality criteria for primary contact and secondary contact recreation with the exception of Plant Road and USGS sites on July 14.

Speculation concerning the reasoning for the September 1 increase in both total coliform and *E. coli* results at each site has been accredited to the presence of beavers in the river. The group noticed beavers and dams that were not previously there on that sampling date, which could be the reason for the increase in *E. coli*.

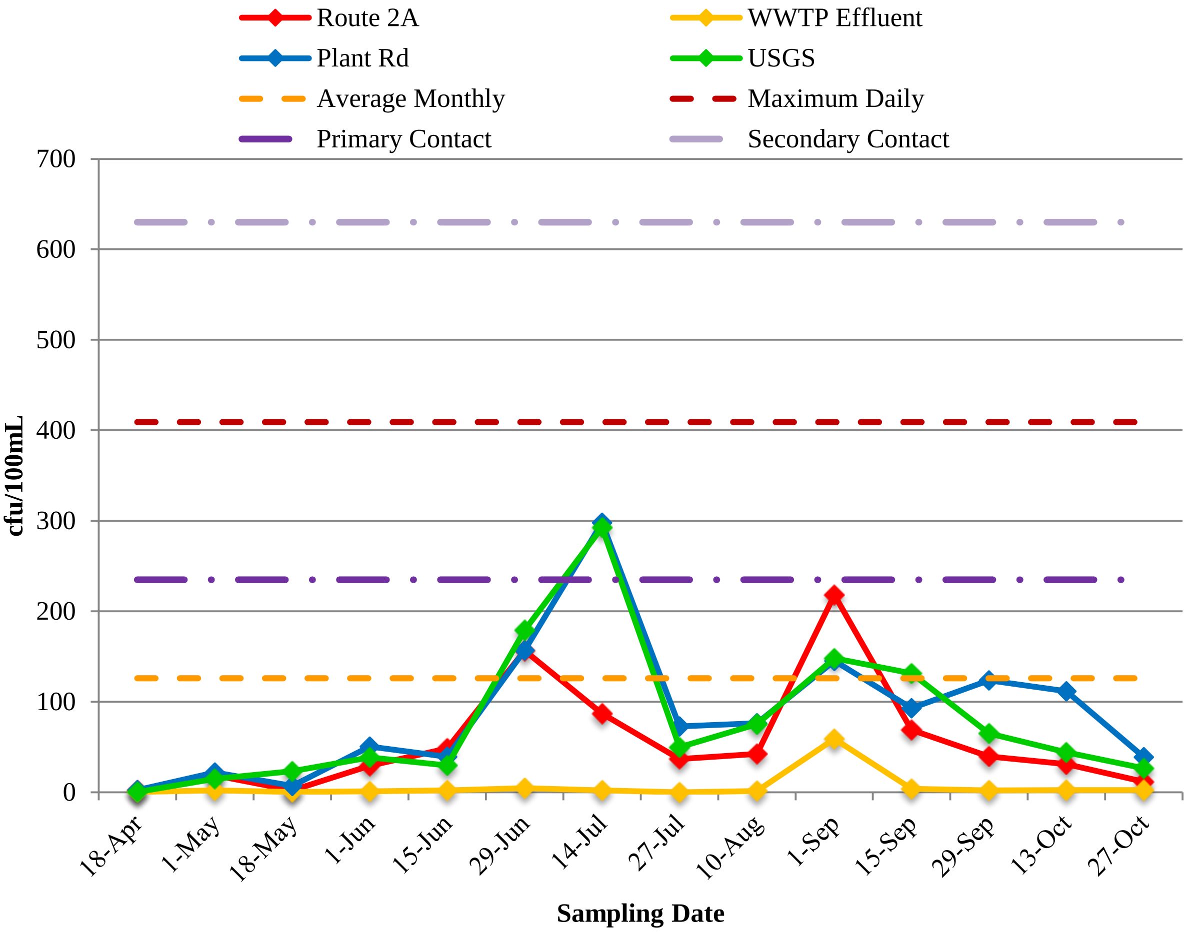

Figure 18: *E. coli* for the Otter River (with EPA Recreational Water Quality Criteria)

4.2.5 Metals

The testing for metals was completed using atomic absorption spectroscopy. As discussed in the methodology, this testing required a calibration curve to relate absorbance to concentration. The lowest standard concentration used to construct the calibration curve is the method detection limit (MDL), specific to each test. It should be noted that for each metal, the NPDES permit level fell below the MDL, which affects interpretation of the results.

Table 8: NPDES Permit Levels and Method Detection Limits for Metals Tested

Parameter	NPDES Permit Level(s) [ppb]	Method Detection Limit [ppb]
Aluminum	87, Monthly	500
Cadmium	0.5, Monthly	50
Copper	13.6, Monthly; 22.0, Daily	100
Lead	4.4, Monthly	10

4.2.5.1 Aluminum

Aluminum is considered toxic to aquatic life, but is not of health concern to humans (EPA). The average monthly NPDES permit level for aluminum is 87 ppb and the MDL is 500 ppb. As indicated in Figure 19, on all but three occasions (May 18, October 13, October 27), the concentration of aluminum in the Gardner WWTF effluent exceeded the NPDES permit level for the average monthly value. However, effluent samples were above the MDL on only two occasions: August 21 and September 1. All river samples were below the MDL except for four occasions between July 14 and September 1.

For aquatic life, the EPA lists the criterion maximum concentration (CMC) for aluminum as 750 ppb and the criterion continuous concentration (CCC) as 87 ppb (EPA, 2013). Aquatic life exposed to these concentrations for a short duration (acute) will likely experience adverse effects. On several occasions the aluminum concentration measured in at the river locations exceeded the CMC. This may suggest a problem with the river itself or it could be the result of sediment in the water column. Clay particles may contribute to total recoverable aluminum, but are not likely to be toxic to aquatic life (EPA, 2012). A possible source of aluminum is the Gardner Water Treatment Facility at Crystal Lake. High concentrations of aluminum ranging from 87 to 410 ppb were measured in the effluent in 2003 (Kennedy & Rojko, 2004).

As previously noted in Section 2.2.2, the effluent from the Gardner water treatment facility at Crystal Lake is not discharged directly into the Otter River, but is discharged through storm drains to Pond Brook. This stream joins with the Otter River in the wetlands area upstream of the Route 2A sampling location. Therefore, the water treatment facility contributions would show up at all river sampling locations. Furthermore, the concentration in the WWTF effluent never exceeded the concentration measured at any of the three locations on the Otter River on any given date.

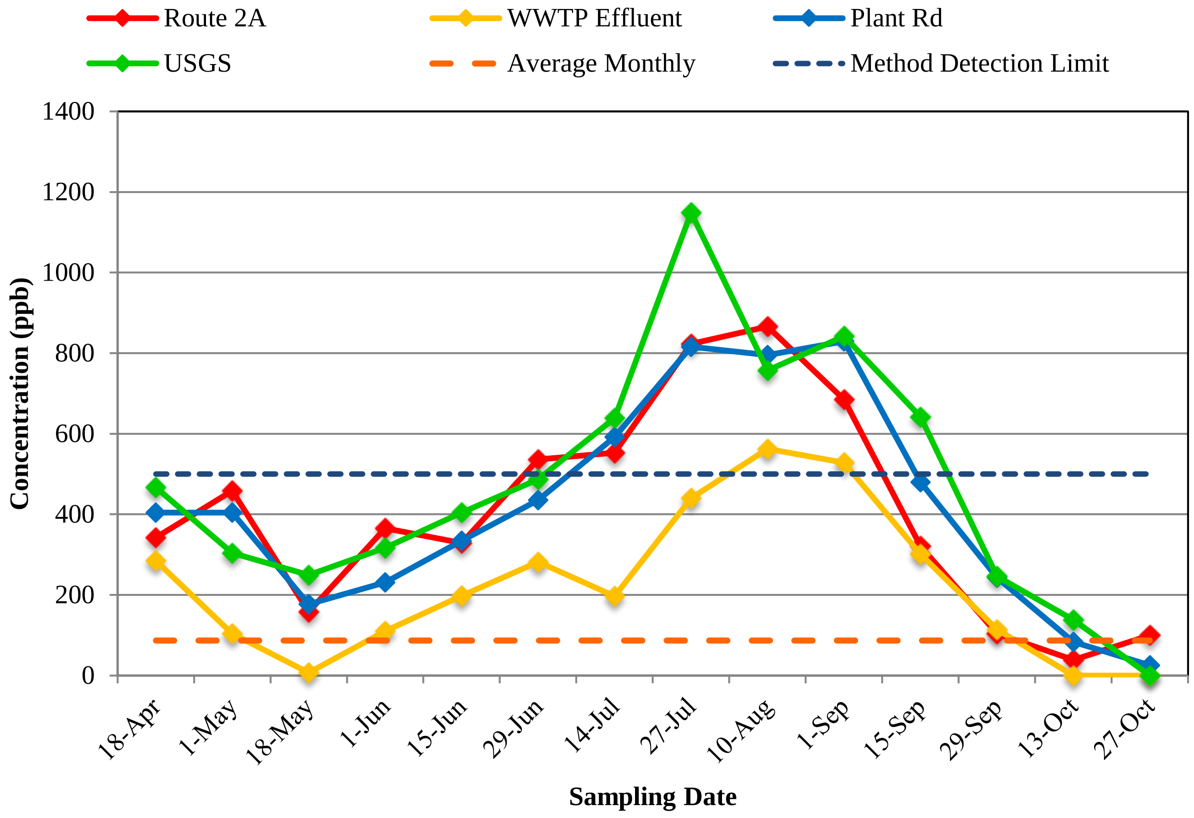

Figure 19: Results for Aluminum (with NPDES Permit Limitations and MDL)

4.2.5.2 Cadmium

Cadmium is a metal found in natural deposits and can be caused by corrosion of galvanized pipes, erosion of natural deposits and runoff from waste batteries and paints. If ingested above the maximum contaminant level, cadmium could cause kidney damage in humans (EPA, 2014). The average monthly NPDES permit level is 0.5 ppb and the MDL is 50 ppb. All samples were below the MDL, ranging from 0 to 30 ppb, as shown in Figure 20.

With regard to water quality criteria, the CMC and CCC for cadmium are based on dissolved metals, not total metals. As a result, the effect that the observed concentrations would have on aquatic life cannot be determined from the available data. The concentrations of cadmium in the effluent were comparable to those of the river on any given date.

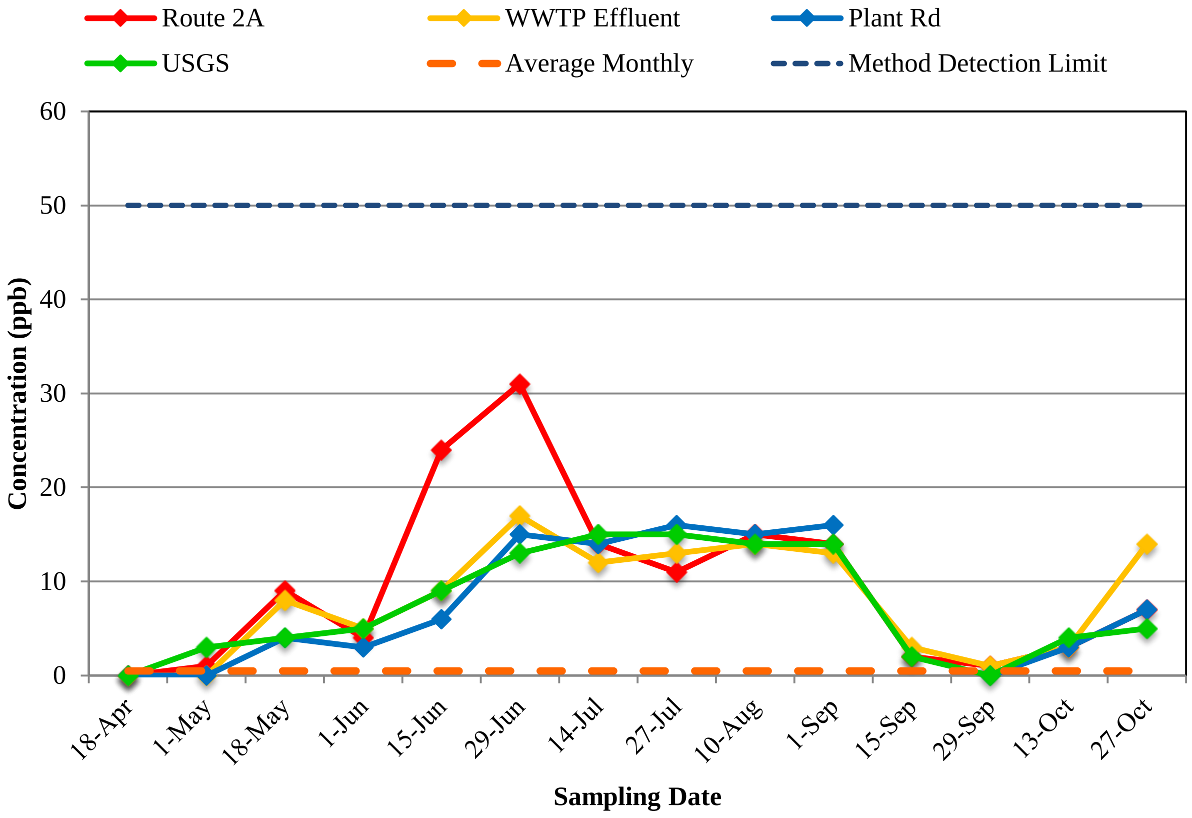

Figure 20: Results for Cadmium (with NPDES Permit Limitations)

4.2.5.3 Copper

Copper is found in natural deposits and commonly in household plumbing. In humans, if exposed short term above the maximum contaminant level, copper can cause gastrointestinal distress. If exposed long term, copper can cause liver or kidney damage (EPA, 2014). The average monthly NPDES permit level is 13.6 and the maximum daily value is 22 ppb. The MDL is 100 ppb and all samples were below the MDL, ranging from 0 to 80 ppb, as shown in Figure 21.

Half of the effluent results were less than or equal to the maximum daily value. Effluent results were below the average monthly permit level on 4 of 14 sampling dates. On average, the concentration of copper in the effluent was greater than the concentrations at the three river locations and the concentrations at the downstream locations were higher than the concentration at the Route 2A location. This suggests that the facility may be contributing to the copper loading in the Otter River. As with cadmium, the EPA water quality criteria for copper are based on dissolved metals. Therefore, the effect that the observed concentrations would have on aquatic life cannot be determined from the available data.

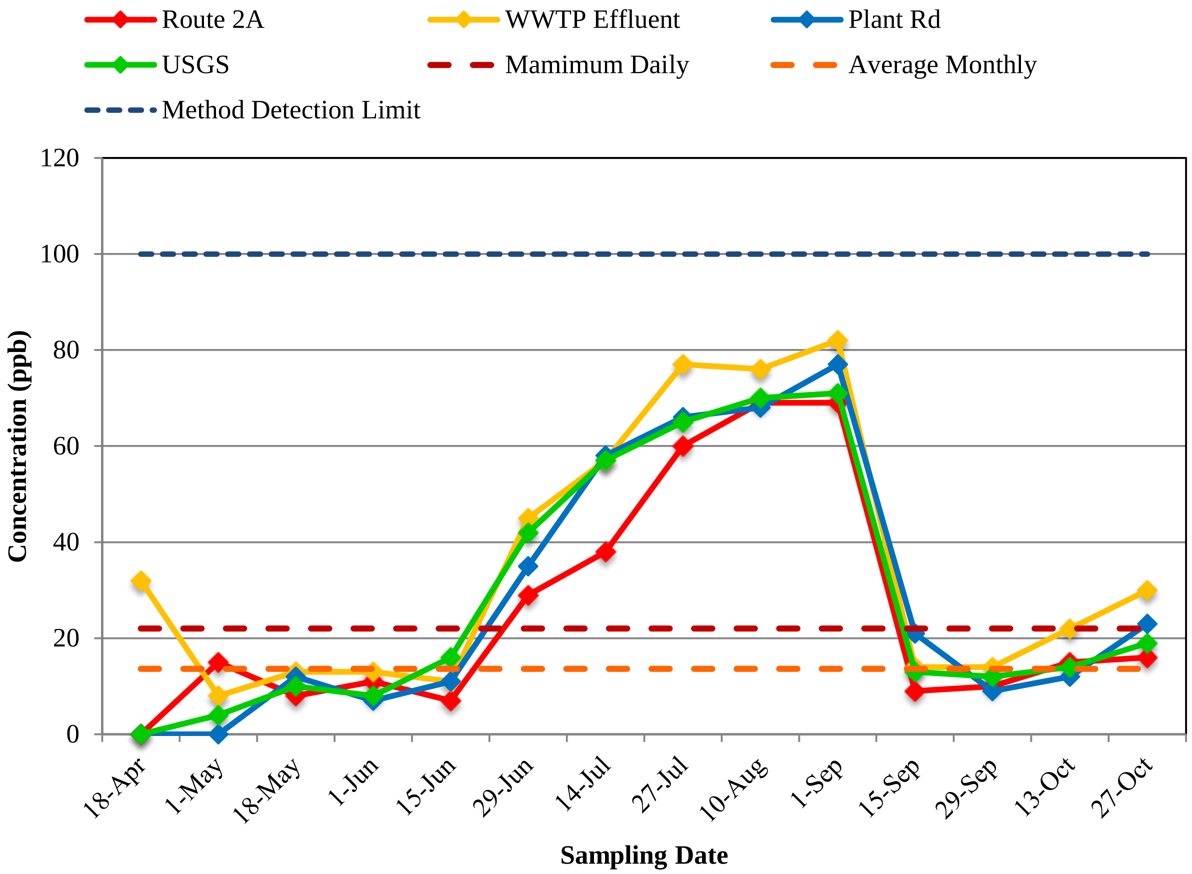

Figure 21: Results for Copper (with NPDES Permit Limitations)

4.2.5.4 Lead

Lead is found in natural deposits and commonly used in household plumbing materials. Lead exposure in infants and children above the action level can result in developmental problems while exposure in adults can increase blood pressure and lead to kidney problems (EPA, 2014). The average monthly NPDES permit level is 4.4 ppb and the MDL is 10 ppb. All samples were below the MDL, ranging from 0 to 8 ppb, as shown in Figure 22. The concentrations of lead in the effluent did not exceed the average monthly value on any of the sampling dates.

On average, the concentration of lead in the effluent was lower than at the concentration at the three river locations and the concentrations at the downstream locations were lower than the concentration at Route 2A. This suggests that the discharged effluent may help to reduce lead loading in the Otter River. With regards to water quality criteria, the CMC and CCC are 65 and 2.5 ppb respectively. As a result, the effect that the observed concentrations would have on aquatic life cannot be determined from the available data. The concentrations of lead in the effluent were comparable to those of the river on any given date.

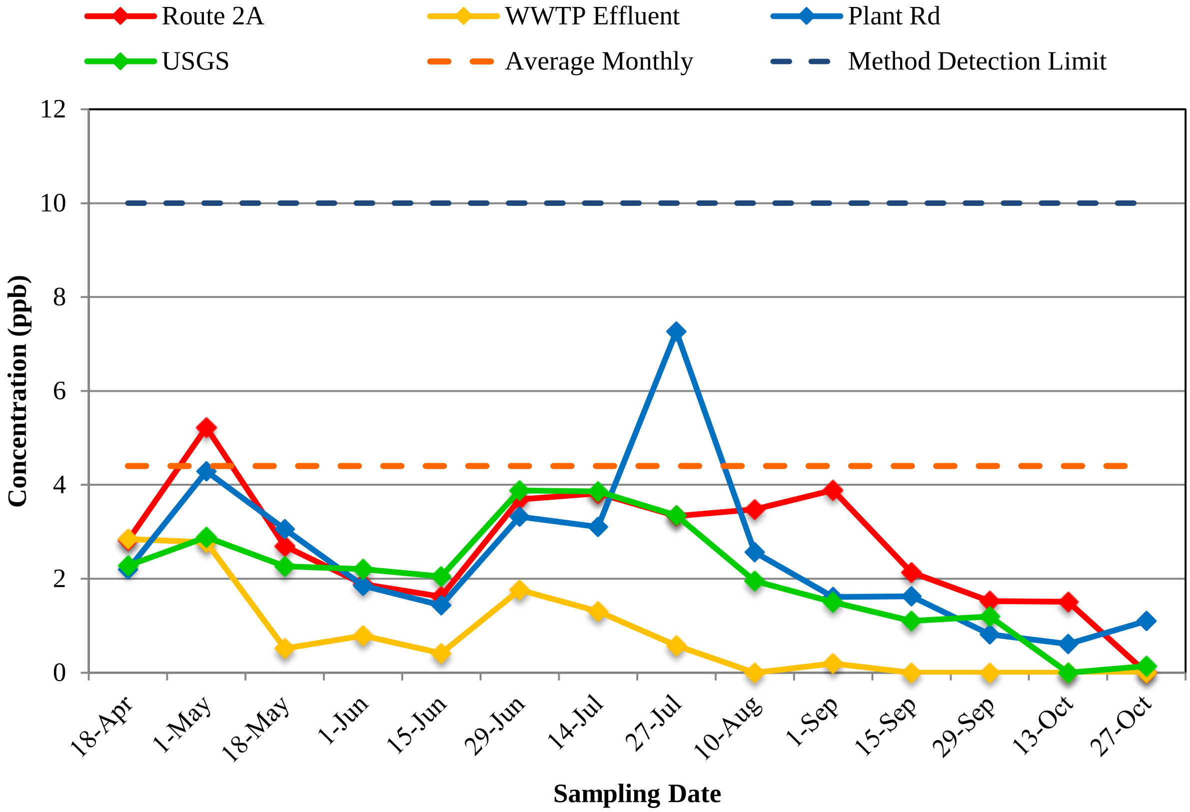

Figure 22: Results for Lead (with NPDES Permit Limitations)

4.3 Data Analysis

This section contains results from descriptive and analytical statistical analyses and mass balance summary, computed in Excel, to determine significance of findings. A summary of parameter descriptive statistics can be found in Table 15 in Appendix E.

4.3.1 One Way Analysis of Variance (ANOVA)

ANOVA tests were also completed for each testing parameter to determine whether or not there were variances by site. A p-value lower than 0.05 (95% confidence) indicates that there is statistical significance between locations. Table 16 in Appendix E displays the p-values for each parameter tested. All three nitrogen parameters, *E. coli* and dissolved oxygen were statistically different by location. Total phosphorus, dissolved orthophosphate, and temperature had p-values greater than 0.05 and thus did not vary by location. Changes in nitrogen concentration by location can indicate an impact of the WWTF discharge on river water quality and/or the reaction of nitrogen species over time. Similarly, changes in DO concentration by location may indicate an impact of the WWTF discharge on river water quality, the reaction of DO overtime, and/or reaeration. Changes in *E. coli* concentration by location may indicate an impact of the WWTF discharge on river water quality, the death of the organisms over time and/or naturally occurring variations related to biota.

4.3.2 Correlation Analysis

Each water quality parameter, excluding metals, was analyzed for statistical correlations between the other testing parameters for all testing locations. Out of 36 possible correlations, 6 direct and 4 inverse correlations were found. An absolute value greater than or equal to the Pearson's Coefficient of 0.304 indicated that there was a correlation, either directly or inversely. A positive value indicates a direct correlation, while a negative value indicates an indirect correlation. Table 17 in Appendix E provides correlation comparison values for each parameter. As expected, there was an inverse correlation between the temperature in the river and the dissolved oxygen (DO), because as temperature increases, the amount of oxygen available in the water decreases (EPA, 2012). Similarly, there was an inverse correlation between dissolved oxygen and ammonia nitrogen. This may be related to the fact that ammonia exerts a biochemical oxygen demand on receiving waters. There was a direct correlation between total coliforms and *E. coli*, which makes sense considering that *E. coli* are a subset of total coliforms. There were several other correlations present in our testing data, but there are no explanations for them.

4.3.3 Conservation of Mass

A mass balance was used to predict water quality in the river at the point of mixing of the Gardner WWTF effluent and the Otter River. The values obtained from water quality testing from Route 2A (upstream) and the Gardner WWTF effluent were used in the calculation, and predictions were compared to values obtained from Plant Road (downstream). Figure 23 shows a more detailed, orthographic map of the specific sampling locations and the point of mixing for the WWTF effluent and the Otter River.

Figure 23: Orthographic Map with Sampling Locations and Point of Mixing for Mass Balance

Daily flow data were obtained for the Gardner WWTF for sampling dates from the chief operator. If daily flow data were not available on a particular date, the daily flow from closest available date was used. Flow data for the Otter River were obtained at the approximate time of sampling (10:00 A.M.) from the USGS Gaging station (01163200) downstream. The flow rate upstream of the facility was adjusted to account for the contribution from the WWTF according to Equation 1.

$$Q_{\text{Upstream}} = Q_{\text{USGS}} - Q_{\text{WWTF}} \qquad \text{(Equation 1)}$$

Where Q represents the volumetric flow rate in cubic feet per second (cfs). The mass balance for the Gardner WWTF effluent and the Otter River is shown in Equation 2.

$$Q_{\text{USGS}}C_{\text{Predicted}} = Q_{\text{Upstream}}C_{\text{Route 2A}} + Q_{\text{WWTF}}C_{\text{Effluent}} \qquad \text{(Equation 2)}$$

Where C represents the concentration in mg/L or temperature in °C. The mass balance was rearranged to solve for concentration in order to predict the value of each testing parameter at the point of mixing (Equation 3).

$$C_{\text{Predicted}} = \frac{Q_{\text{Upstream}}C_{\text{Route 2A}} + Q_{\text{WWTF}}C_{\text{Effluent}}}{Q_{\text{USGS}}} \qquad \text{(Equation 3)}$$

The predicted value was then compared to the actual value obtained from testing at the Plant Road location, which is approximately 0.3 miles downstream. The percent difference was calculated using Equation 4. The percent difference was also calculated neglecting the absolute value to illustrate whether the predicted values were, on average, higher (positive value) or lower (negative value) than the Plant Road values.

$$\text{Percent difference} = \frac{|C_{\text{Predicted}} - C_{\text{Plant Rd}}|}{C_{\text{Predicted}}} \times 100\% \qquad \text{(Equation 4)}$$

The average percent difference obtained for each parameter for all of the testing dates is reported in Table 9. The calculations and graphs (Predicted vs. Actual) for each parameter are located in Appendix F.

Table 9: Average Percent Error for Mass Balance Parameters

Parameter	Average Percent Difference (%)	Average Percent Difference (Absolute Value) (%)
Temperature	−0.5	1.9
Dissolved Oxygen	20.6	20.6
Ammonia Nitrogen	2.7	13.7
Nitrate	14.4	26.0
Total Phosphorus	0.3	16.8
Dissolved Orthophosphate	−8.9	56.8

The average percent difference was lowest for temperature (1.9%), compared to the chemical parameters (13.7-56.8%). This is understandable considering that temperature is the only conservative water quality in the mass balance and can be expected to remain relatively constant. However, the other water quality parameters in this mass balance are reactive and, therefore, are subject to change. The distance between sampling locations and the associated travel times may explain the higher average percent difference, since it would allow time for biological reactions to occur. Furthermore, it would explain why the predicted values were, on average, higher for these parameters (with the exception of dissolved orthophosphate).

DO values at the Plant Road site were consistently lower than the value predicted by the mass balance. This may be related to the utilization of DO by microorganisms to break down organic matter present in the water. Although the effluent contained high levels of DO, its influence appeared to be outweighed by the depletion of DO in the river. Ammonia nitrogen values in the effluent were consistently lower than those upstream. As a result, the predicted downstream values were lower than those upstream. This may indicate that the dilution effect of the WWTF effluent lowers ammonia concentrations in the river and/or it may be the result of nitrification taking place over this stretch of the river. Nitrate values in the effluent were consistently and significantly higher than upstream values. The predicted downstream values were necessarily higher and were consistent with actual testing results. This seems to suggest that the WWTF contributes to nitrate loading in the Otter River. Total phosphorus values in the effluent were generally comparable to the values obtained both upstream and downstream of the facility. Therefore, no conclusions related to the impact of the WWTF on phosphorus loading can be drawn from the mass balance alone. Dissolved orthophosphate values in the effluent were typically higher than those upstream. However, predicted downstream values were, on average, higher than actual testing results. This makes it difficult to assess the impact of the effluent on the river. This may attributed to additional inputs of dissolved orthophosphate into the river (e.g. runoff).

4.4 Summary

The Gardner WWTF met NPDES permit requirements for all parameters tested with the exception of total phosphorus and metals. Average TP levels in the effluent from the facility were 0.268 mg/L and the NPDES permit level is set at 0.12 mg/L (average monthly). However, these results contradicted the facility's reported values over this same time period and may be attributed to differences in sampling technique (i.e. grab vs. composite). Furthermore, background concentrations of TP in the Otter River upstream of the facility averaged 0.221 mg/L P, which is higher than the established NPDES permit value. Three of the four metals tested, aluminum, cadmium, and copper exceeded permitted discharge limits on several occasions. However, the available laboratory equipment and methods was not able to reliably measure the minute concentrations of metals.

Nitrogen, particularly nitrate, was determined to be a concern for the facility. The average concentration of nitrate in the WWTF effluent was 19.3 mg/L. Downstream concentrations of nitrate in the Otter River were shown to be significantly affected by the discharge from the facility. Upstream values for nitrate averaged 0.7 mg/L and downstream values were on average greater than 2.0 mg/L. Although nitrogen is not typically of concern in freshwater systems, the EPA has been increasing pressure on WWTFs in the Connecticut River watershed to reduce nitrogen loading.

ANOVA testing revealed that values obtained for dissolved oxygen, *E. coli*, and all three nitrogen species were statistically different by location. These differences may indicate an impact of the WWTF on river water quality and/or they may be the result of natural phenomenon. The Correlation analysis did not yield any unexpected results. Inverse correlations between dissolved oxygen concentration and water temperature and between dissolved oxygen and ammonia nitrogen were observed. A direct correlation between *E. coli* and total coliforms was also observed. These correlations were logical and related to natural processes, but several other correlations present in the testing data could not be explained. The mass balance was constructed to determine if the facility had an impact on water quality in the Otter River. The mass balance results showed that the WWTF may be contributing to nitrogen loading in the river.

5.0 Nutrient Removal Design

This section explores various advanced treatment processes aimed at reducing nitrogen in the Gardner WWTF effluent. It includes a detailed design of a retrofit option for the facility that may meet target effluent TN concentrations that may be expected in future NDPES permits.

5.1 Target Effluent Goals

In an effort to help the facility meet future NPDES permit limits regarding nutrients, potential process modifications and alternative treatment processes for the facility were evaluated. The water quality monitoring conducted by our project group and by the facility show that the facility is contributing a significant amount of nitrogen (compared to other characteristics in the effluent), in the form of nitrate, to the Otter River. As described in Chapter 4, on periods of low flow days, the effluent significantly impacted the water quality of the Otter River. In terms of total phosphorus, grab samples collected by the project team were as high as 0.54 mg/L, however, the facility's 24-hour composite samples have consistently met the permit level of 0.12 mg/L over the past two years. For this reason, TN was prioritized in the design of an advanced nutrient removal process and phosphorus was not be considered at this time.

MassDEP advises permitted facilities to assume best available technology (BAT) target nutrient goals; which vary from 5 to 8 mg/L for TN. The 2-year average effluent TN concentration through 2012 and 2013 was 14.5 mg/L. Our design assumed a target goal of 8 mg/L TN in the effluent, which is approximately a 55% reduction from historical discharge levels.

5.2 Advanced Treatment Options

There are many advanced wastewater treatment technologies available for the removal of nitrogen. The team examined treatment processes including membrane bioreactors (MBR), four-stage Bardenpho process, filtration units, Modified Ludzack-Ettinger (MLE) and cyclic aeration processes.

In order to determine the best nitrogen removal retrofit alternative, a review and assessment of each process was conducted and options were ranked based on specific selection criteria. The decision factors that were considered in the design selection included the capital and operating costs, the ease of operation, process scalability, site footprint, and whether or not piping and pumping is needed. Alternatives were ranked 1-5, with 1 being the least desirable and 5 being the most. The alternative with the highest total score was determined to be the optimal recommendation.

Relative capital and O&M costs were based on estimates and case studies from Volume 1 of the Municipal Wastewater Technologies Reference Document by the EPA (Kang, 2008). Capital costs include cost of process equipment and necessary construction for new basins, construction within basins, and additional piping and recycle streams. O&M costs include costs of additional carbon sources, chemicals, and sludge. This cost also takes into consideration increased energy and electricity consumption and increased labor costs. Alternatives with lower costs have more favorable criteria rankings. Table 10 displays the estimated costs for each treatment process.

Table 10: Capital and O&M Cost Estimates for Treatment Process Alternatives

Cost	MBR	4-Stage Bardenpho	Denitrification Filter	MLE	Cyclic Aeration
Capital ($ per GPD)	7-20	2.45	0.95	1.75	0.20
O&M ($ per MGD)	1770	500	310	110	111

The ease of operation is a subjective decision factor that takes into consideration operation techniques used for the specific process. A treatment process that can be automated could potentially be ranked highly in this category, while another process that requires continuous monitoring could be ranked low.

Whether or not a process can be adjusted with changing seasons and flow capacities is another aspect of the design alternatives that were taken into consideration. The ease of scalability is an important aspect for the Gardner WWTF, considering that NPDES Permit limitations could become more stringent in the future and processes would have to be adjusted accordingly. A design option that can be effectively upgraded to meet future requirements would score a high ranking, while another option that is costly to upgrade would receive a low ranking.

The goal of retrofitting a design process is to minimize or eliminate footprint additions from constructing new features of the plant. Most design alternatives did not increase the footprint of the plant, and therefore received the highest score. The exception was the 4-Stage Bardenpho process because it requires multiple basins to be constructed. The same ranking applied for additional pumping and pumping required, however most alternatives required additional piping and pumping, so received a score of one. The exception was the cyclic aeration process, which only requires an additional mixer in the anoxic zone.

Table 11 shows the analysis for each alternative based on the decision-making criteria described above. From these rankings, the total rank for each alternative was determined. Details on each alternative are provided in the following sections

Table 11: Alternative Design Analysis

Selection Criteria	Alternative				
	MBR	4-Stage Bardenpho	Denitrification Filter	MLE	Cyclic Aeration
Relative Capital Cost	1	2	4	3	5
Relative Operating Cost	1	2	3	5	4
Ease of Operation	4	3	2	5	1
Process Scalability	2	4	3	5	1
Limited Site Footprint	5	1	5	5	5
Piping/Pumping Required	1	1	1	1	5
Total Score	14	13	18	24	21
Ranking	4	5	3	1	2

5.2.1 Membrane Bioreactors

A membrane bioreactor (MBR) is a combination biological-physical process, which combines a suspended growth biological reactor with filtration to remove solids. Due to its ability to improve treatment in a smaller space, its implementation has become more popular within the past ten years. In an MBR, water passes through a membrane (called permeate) while the membrane traps waste constituents (called retentate) (EPA, 2007). Membrane filters, including micro-porous, track-etched, ultrafiltration and reverse-osmosis filters, are constructed of cellulose or other polymer materials with various pore sizes for various sized particles.

Usually pores are a size of 1 micron for membrane filters, which allows for efficient solids removal. However, particles that escape in the permeate must be removed through an additional advanced process, which are usually removed in a subsequent process.

Flow considerations are important when considering implementation of an MBR system, as the membrane requires a certain level of water maintained in the membrane and is sensitive to high flow conditions. Due to the physical properties of the membrane, it is especially important that peak design flows be no more than 2 times the average design flows. If there is the possibility of flow exceeding this limit, additional units must be installed to accommodate the additional flow. The installation of an equalization basin could also be considered, but flow must remain at the specified level in order to retain the efficiency of the membrane. Membranes are usually installed immersed in the biological reactor or as a separate vessel, allowing for a reduced footprint for the process (Atac Solutions Ltd., 2011). The membrane filter comes after the anoxic and aerobic basins in the process. These configurations are displayed in Figures 28 and 29, respectively.

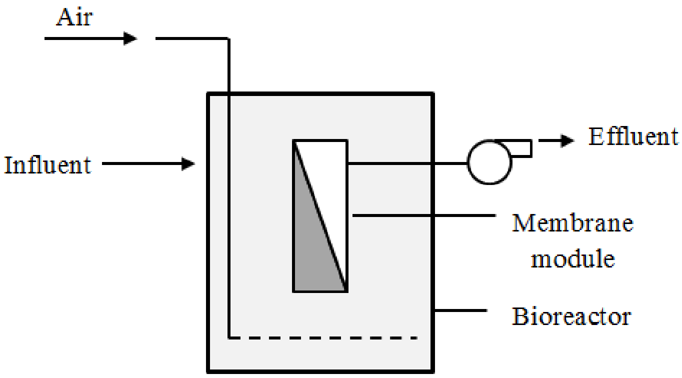

Figure 24: Internal MBR Configuration

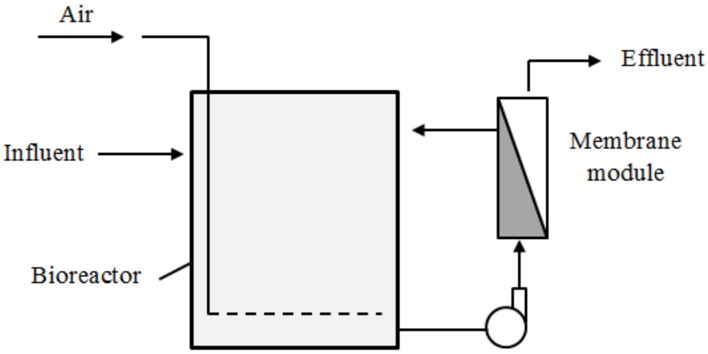

Figure 25: External MBR Configuration

Advantages of MBR systems include better effluent quality, smaller footprint and ease of operation and maintenance through use of automation. Bacteria, suspended solids, BOD, nitrogen and phosphorus can be reduced up to 90% in membrane effluent (EPA, 2007). Membranes also produce less sludge due to their longer solids retention time. In terms of process footprint, MBRs operate with a lower hydraulic retention time, which requires less space than a conventional activated sludge system. Once an MBR system is installed, most operation can be automated which allows for reduced oversight by facility operators.

Disadvantages of MBR systems include typically higher capital and operating costs than conventional systems. In terms of capital cost, the initial purchase of the membrane unit is the most expensive aspect with installed costs of $7-$20 per gallon treated. Over the lifespan of the membrane, costs are incurred through energy use and chemicals used for cleaning. While higher operating costs are usually offset by the reduced sludge hauling costs, the average operating cost of an MBR unit is $1.77 per 1,000 gallons treated (EPA, 2007).

Overall, the MBR process is not feasible for the plant mainly due to its ranking for capital and O&M costs. It would also be difficult and costly to adjust the process to changes in flow rates, which therefore lowers its scalability rating. Although MBR processes offer high effluent qualities and require small footprints, these advantages are not enough to choose this process over the other alternatives.

5.2.2 Four-stage Bardenpho Process

The four-stage Bardenpho process is a biological treatment process. A Bardenpho process is used for plants to attain a low effluent TN. It can achieve removal rates of 90% and concentrations in the range of 3 - 5 mg/L TN. Like the MBR process, it has an anoxic and an aerobic zone, but it also has a second anoxic tank and an aeration tank. The majority of denitrification takes place in the first anoxic tank. The denitrification process is directly related to the fraction of mixed liquor suspended solids recycle. The nitrates from the first aerobic zone that were not recycled to the first anoxic zone are removed in the second anoxic zone. Following the second anoxic zone, the second aerobic zone removes nitrogen, in the gaseous form, from the water. Figure 26 shows the process schematic for a four-stage Bardenpho process.

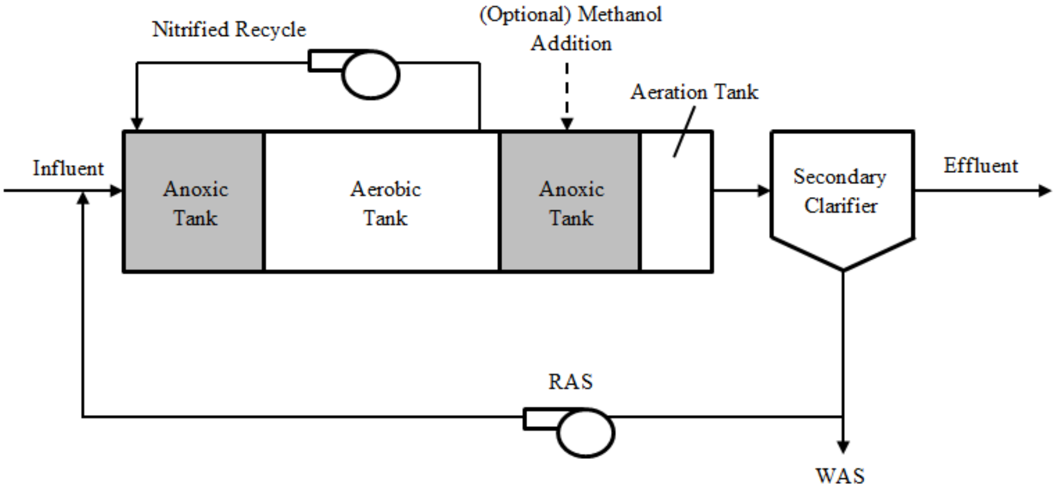

Figure 26: Four-Stage Bardenpho Process Schematic

A carbon source, such as methanol, might be needed for the second anoxic zone to conduct denitrification; this would increase O&M costs. The process requires four tanks, making retrofit options difficult and the need for much construction. Along with this construction, additional piping, pumps, and electricity are needed. The major disadvantage of the Bardenpho process is the capital cost in the construction of the different tanks or zones. Also, the detention times of each tank have to be strictly monitored and adjusted to ensure that nitrification and denitrification processes occur to the fullest extent. The advantage of the Bardenpho process is the high removal rates that can be achieved (Kang, 2008).

This process had the worst rating compared to the other alternatives. Because it is very difficult to retrofit this process into existing facilities because of its large footprint and need for excess equipment, piping, and pumping, the capital and O&M costs would be very high, and other criteria would be negatively affected.

5.2.3 Denitrification Filter

Denitrification filtration incorporates a chemical, physical, and biological process. Denitrification filters are a chemical process because of the addition of a biodegradable organic compound; in other words, the carbon source. Common chemicals used are methanol and acetic acid. This aids the growth of microorganisms, which carry out denitrification. The use of microorganisms gives it the biological treatment classification and the removal of suspended solids by filtration gives it the physical treatment classification. The ideal loading rate for this technology is 2-3 gallons per minute per square foot (Kang, 2008). These filters are implemented directly after the secondary clarifier, before treated wastewater leaves the effluent. Figure 27 shows the general process schematic for denitrification filters.

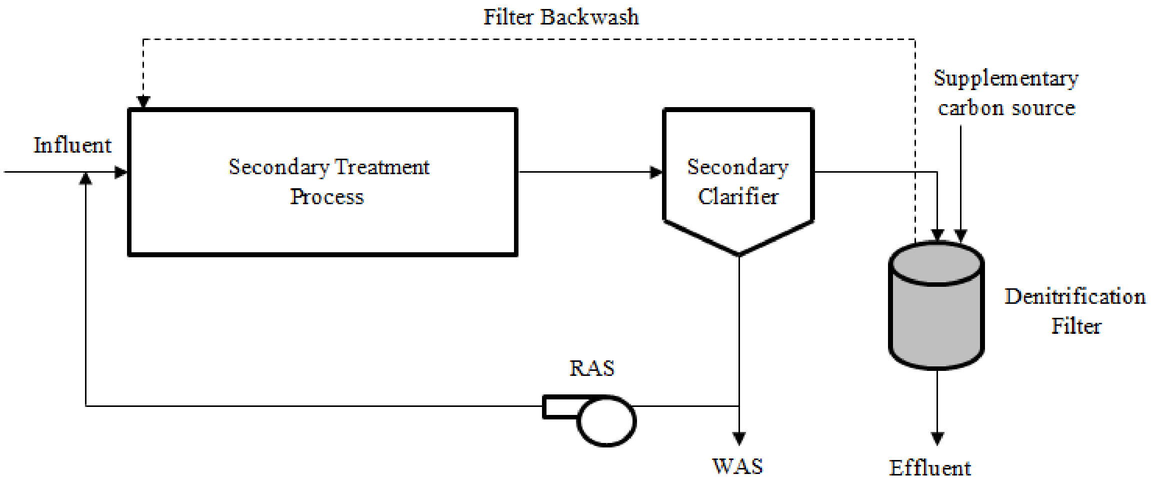

Figure 27: Denitrification Filter Process Schematic

There are two types of denitrification filters: down flow filters and up-flow continuous backwash filters. Down flow filters have a media and support gravel. Water flows through the filter over weirs along the filter bed. Because water flows in a downward direction, nitrogen can become entrapped in the media grains, and therefore, a periodic "bumping" process must be carried out in which water or air is directed upwards through the media, releasing the trapped gas. Less periodic controlled backwashing is also completed for this type of filter.

In up-flow filters, water flows upward to the filter bed, against the flow of the influent. Continuous automatic backwashing takes places in timed controlled cycles in order for nitrate to be broken down into nitrogen gas. The wastewater enters the filter via a pipe, where the biodegradable organic compound can be added. As water moves through either type of filter, the filter media moves downward towards the middle of the filter. Compressed air is applied through an airlift pipe, to reposition media throughout the filter. The wastewater then rises above a divider and smaller suspended solids are removed. Figure 28 displays this process.

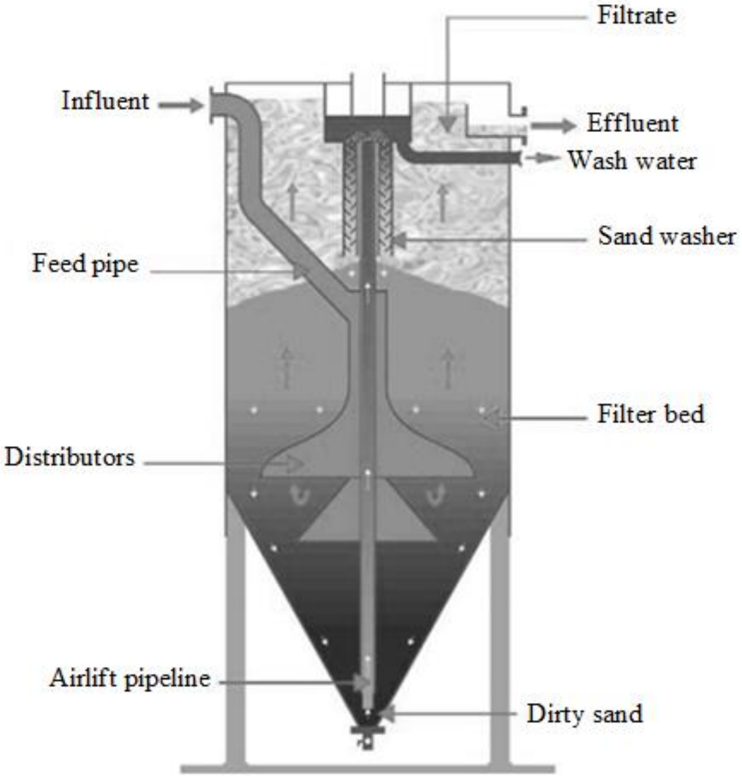

Figure 28: Upflow Filter Process (EPA, 2007)

Backwash supply pumps are not needed for the system because the water is transported by head differential, but pumps are needed in transporting the water to and from the system. Depending on the size of the system, it is more probable that the DO concentration will increase if the head differential increases. An increase of DO reduces the ability of the filter to remove nitrate causing a greater amount of biodegradable organic matter in the effluent.

Capital costs for denitrification filters consist of the system itself, piping, and valves. Operation and maintenance costs for the system include the cost of energy and the cost of the carbon source. Energy costs stem from backwashing, air scouring, and nitrogen release cycles. The amount of carbon source utilized is dependent on the system head differential and efficiency control systems for implementation to ensure that the right amount is used. While operation and maintenance costs are a disadvantage of the systems compared to others, its advantages are that it has a small footprint and its ability to accomplish both denitrification and effluent filtration within one system (EPA, 2007).

Overall, denitrification filters ranked average among the other treatment process alternatives. With its relatively small retrofit footprint, and average capital and O&M costs, it would seem to be a viable alternative. However, it would require additional operating tasks such as timing for backwashing and use of necessary amounts of carbon utilized and head distribution. These parameters vary based on specific design requirements for the Gardner WWTF.

5.2.4 Modified Ludzack-Ettinger Process

The Modified Ludzack-Ettinger (MLE) design is a biological nitrogen removal (BNR) process. The process begins with primary treated wastewater being fed to an anoxic zone, where denitrification occurs, which is represented as the influent for the process schematic. Typical retention times in the anoxic zone last between two and four hours. The MLE process is a relatively simple design that can be retrofitted to existing aeration tanks, provided that the tank volume is an acceptable size for splitting into two tanks. Figure 29 shows the MLE process schematic.

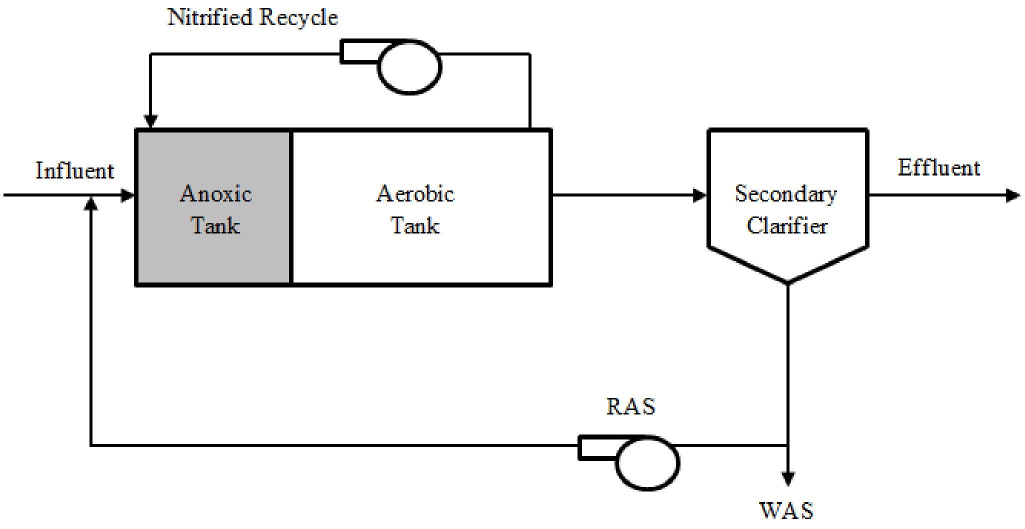

Figure 29: Modified Ludzack-Ettinger Process Schematic

Additional modifications can be made to enhance nitrification and denitrification processes. Such modifications include additional recycles and anoxic and/or aerobic basins. In some cases, the anoxic zone can be divided into three or four stages in series. The RAS mixes with the anoxic zone wastewater, and an increase in the recycle rate increases the denitrification rates. Only recycled nitrate can be denitrified, therefore the wastewater cannot be completely denitrified.

The next step in the process involves the wastewater moving to an aerobic zone where nitrification occurs and nitrate is formed. It then travels to the clarifiers where the wastewater moves to the next stage of treatment, and the sludge is settled and clarifier effluent is discharged. Nitrate is returned to the anoxic zone in two ways. It is returned via return activated sludge (RAS) from the clarifier, as well as an internal recycle of mixed liquor directly from the aerobic zone to the anoxic zone. The advantage to adding two recycles is the increase in both the nitrate and the nitrogen removal efficiency. The nitrate returned from the aeration zone is used in lieu of oxygen for the breakdown of organic compounds in the anoxic zone, while the RAS conveys the heterotrophic bacteria that use the nitrate and organics for cell growth and reproduction. The original influent wastewater in the anoxic zone provides the carbon source for bacteria.

Typical internal recycle flow ratios are determined by dividing the influent flow rate by the recycle flow rate and range from 2:1 to 4:1 (with a typical ratio of 4:1). The effluent nitrate concentration from MLE systems treating domestic wastewater can typically reach 4-7 mg/L, provided there is a sufficient influent BOD and anoxic contact time (Metcalf & Eddy, 2003).

A major advantage of retrofitting the existing process to a MLE design is the relatively small capital and O&M costs. Because the existing aeration basins can be converted to the anoxic and aerobic zones, limited construction is needed aside from additional piping for the nitrified recycle feed. The process design can also be scaled to fit various flows and denitrification rates. An increase in the mixed liquor recycle flow rate increases denitrification, however, the denitrification rate may be limited by other factors including carbon source availability, process kinetics, and anoxic and aerobic basin volumes (Kang, 2008). These parameters must be taken into consideration when designing for the Gardner WWTF.

As discussed in Section 2.1, the facility currently employs a two-step biological treatment process consisting of both trickling filters and activated sludge aeration basins. Under the current configuration, the trickling filters remove the majority of BOD present in the wastewater and the aeration basins provide nitrification. Since denitrification processes consume organic carbon, the trickling filter effluent would not have a sufficient amount of BOD to reduce the desired amount of nitrogen. In order to avoid (or limit if necessary) the addition of supplementary carbon to the MLE process, the trickling filters and intermediate clarifiers could be taken off-line.

5.2.5 Cyclic Aeration Process

Cyclic aeration is a biological process that utilizes blower cycling in the aeration basin to produce anoxic and aerobic zones for denitrification. Case studies have demonstrated that cycling the blowers in an aeration basin can remove TN by up to 80% (Hao, 1996). This treatment process is considered a unique denitrification alternative because it requires little capital investment and improves energy efficiency. However, planning and implementation of these type systems are considered challenging, as they require regular monitoring.

The process consists of turning the aeration blower off for a period of time, creating an anoxic zone, and then turning the blowers on to create an aerobic zone. In order to determine the blower timing, there are several operational factors that are required. If over-aeration occurs in the process, the plant becomes less energy efficient but the treatment level is not compromised. However, if there is under-aeration, then the treatment efficiency is compromised.

While there is no set procedure at this time for setting the anoxic/aerobic blower timing, there are several factors that can be monitored to determine the best timing scenario. One of these indicators is the oxidation-reduction potential (ORP) that correlates the trends of nitrate and ammonia during cyclic aeration. This can be measured by monitoring the ammonia and nitrate over time in the aeration basin. When all ammonia is consumed, the “ammonia breakpoint” is reached and this point in time indicates an aerobic phase sufficient enough to complete nitrification. When nitrate is completely consumed, the “nitrate knee” is reached and denitrification is complete. If the nitrate knee does not appear, then it is an indicator the anoxic phase is too short. As shown in Figure 30, pH can also indicate timing. Figure 30 represents a pH profile for a 3-hour anoxic and aerobic cyclic aeration program.

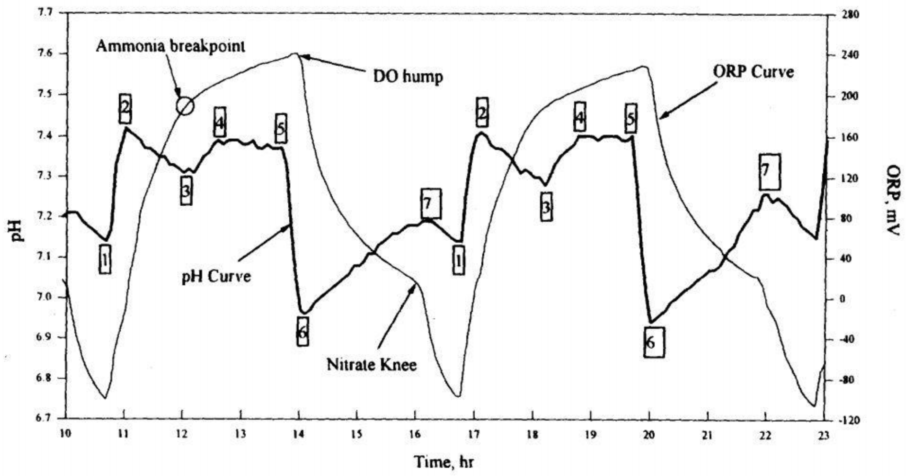

Figure 30: pH Profile for a Cyclic Aeration Program
Adapted from: (Hao, 1996)

During nitrification, alkalinity is consumed in conversion of ammonia to nitrate. This causes the pH to reach a plateau, and then plummet at start of denitrification. During denitrification, alkalinity is produced as nitrate is converted to nitrogen gas. At the “nitrate apex” (similar to nitrate knee), aeration should commence to oxygenate the water and raise pH.

Two ratios that are critical to cyclic aeration are the aeration factor (AF), which is the ratio of aeration time during aerobic phase to the total cycle time, and cycle time ratio (CTR), which is the ratio of the cycle time to HRT. In order for cyclic aeration to be possible, AF should be 0.50 and the CTR should be a minimum of 0.07 and can be increased to optimize denitrification. The relationship between timing the AF and CTR are dependent on the amount of flexibility given within the current process (Ruddy, 2009). By adjusting given timing parameters, the sludge processing and other cycle timing effects could be affected and need to be approached with caution. Therefore, in order to consider this process at the Gardner WWTF, further study and evaluation would be necessary. Other operational requirements include DO (less than 0.1 mg/L during the anoxic phase and about 2 mg/L to 2.5 mg/L during the aerobic phase), SRT (minimum 10 days), and COD to TKN ratio (3.6 to 4.9) (Ruddy, 2009).

Advantages of using this process include the potential removal of 90% ammonia, 90% COD, and >80% TN. In order to achieve these removal results, optimum time rotation must be determined, but operating the blowers and mixers on intervals will also result in significant energy savings. Potential capital upgrades to retrofit Gardner WWTF include the installation of a mixer in the aeration basin for the anoxic zone processing. However, no other features of the current treatment process would need to be changed significantly and, therefore, upgrade costs would be reduced. Another advantage of this process is the natural alkalinity recovery that takes place within the aeration basin, which may save money when purchasing lime chemicals for the facility.

Due to the complicated nature of timing, one disadvantage of this process would be the operational constraints of developing a timing plan for the Gardner WWTF. While automated monitoring and blower operation would assist greatly, the changing daily inflow variation and seasonal temperature difference in New England would require operators at the facility to constantly monitor the process and change the timing as seasons change. Additionally, one disadvantage of this process is that it has not been studied extensively for use in plants greater than 1 MGD. Challenges that arise as a result include the effect on facility SVI, sludge settling and back-intrusion effects. It is recommended that further research be completed before recommending this treatment be implemented at the Gardner WWTF. However, it may be the most cost effective and the easiest to implement immediately in the event a nitrogen limit is implemented in November 2014.

5.2.6 Process Selection Summary

The cyclic aeration process and MLE design were the top-rated design alternatives that were considered. Cyclic aeration scored highest in the capital cost category, and required very little pumping and piping investment. The MLE process scored highest in the remaining categories including the relative operating cost, ease of operation, process stability, and limited site footprint. Based on these criteria, it was decided that the MLE process the best design alternative.

5.3 Process Design

This section focuses on the analysis of current plant operations and assesses the feasibility of dividing the existing aeration basin to accommodate an MLE process. Design requirements such as clarifier characteristics, influent and effluent wastewater characteristics, and other design conditions were addressed.

5.3.1 Retrofit Design Requirements

The first step in designing a retrofit of the activated sludge process at the facility was to evaluate the existing secondary (final) clarifiers to determine the optimum operating MLSS to ensure proper sludge removal under critical loading conditions. This was determined by calculating the surface overflow rate (SOR) (GPD/ft^2) of the clarifiers at critical loading using the design characteristics outlined in

Table 12. The peak hourly flow rate at the facility is 21.35 MGD (Churchill, 1987).

Table 12: Existing Final Clarifier Characteristics

Attribute	Value
Diameter (ft.)	75
Depth (ft.)	14
Individual Surface Area (ft^2)	4,418
Individual Volume (gal.)	465,000

There are a total of three final clarifiers at the facility. The SOR for all three clarifiers was calculated using Equation 5, where Q_p is the peak flow rate in MGD, and SA is the surface area of a single clarifier in ft^2.

$$SOR = \frac{Q_p \times 10^6}{3 \cdot (SA)} \qquad \text{(Equation 5)}$$

The SOR at the Gardner WWTF was calculated to be 1,611 GPD/ft^2. The current sludge volume index (SVI) observed at the facility is approximately 100 mL/g. This value represents the two-year average for 2012 and 2013 and was calculated from data obtained from the WWTF. The addition of an anoxic selector (i.e. anoxic zone) to an activated sludge process has been shown to improve sludge settleability and SVI (Griborio, *et. al.*, 2009). Therefore, it is reasonable to use the current observed SVI. Using the calculated SOR and an SVI of 100 mL/g, the mixed liquor suspended solid (MLSS) concentration was determined using Figure 31.

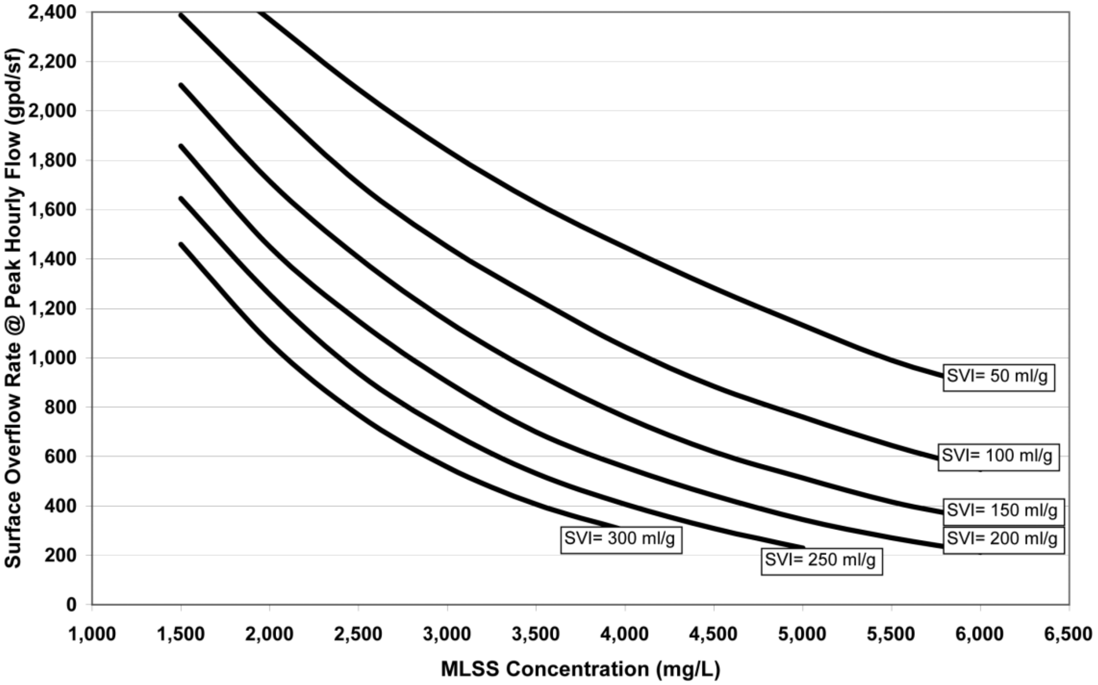

Figure 31: Secondary Clarifier Peak Hourly Flow SOR vs. MLSS Concentration & SVI at Critical Loading Rate
(NEIWPCC, 2011)

The appropriate MLSS concentration at critical loading was determined to be approximately 2,700 mg/L. This concentration was then used to determine the return activated sludge (RAS) rate from Figure 32.

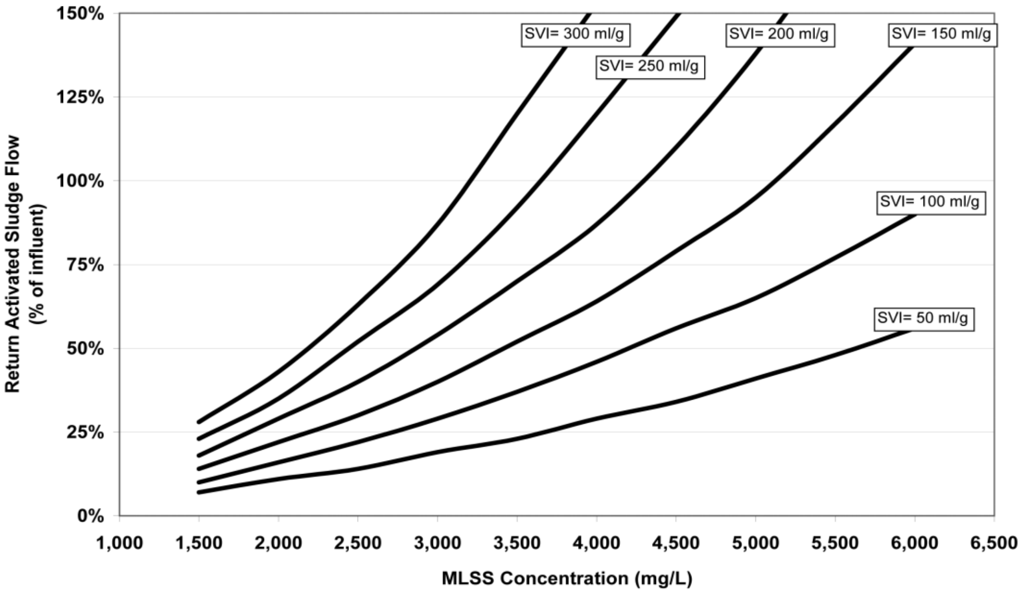

Figure 32: RAS Rate vs. MLSS Concentration & SVI at Critical Loading
(NEIWPCC, 2011)

As with the previous calculation, an SVI of 100 mL/g was assumed. Using the MLSS concentration obtained from Figure 31, the appropriate recycle ratio at critical loading was determined to be approximately 25%.

5.3.2 Influent/Effluent Characteristics

In order to design for the desired conditions of the wastewater effluent, influent and effluent wastewater characteristics must be identified, specifically BOD and TN concentrations. Table 13 lists the influent and effluent characteristics used for the design of the MLE process.

Table 13: Influent and Effluent Characteristics for MLE Design

Wastewater Stage	Parameter	Value (mg/L)	Comments
Influent	BOD	210	2-year average
	TN	51.4	Maximum monthly
Primary Effluent	BOD	147	Assuming 30% reduction
	TN	36.0	Assuming 30% reduction
Effluent	BOD	-	Dependent on operation
	TN	8	Target effluent goal
	TSS	2.65	2-year average

As previously discussed, the design effluent concentration for the Gardner WWTF was determined to be 8 mg/L. The influent values in the table represent the influent to the facility and the primary effluent values are equivalent to the influent to the MLE process. The two-year average BOD concentration in the influent to the facility for 2012 and 2013 was 210 mg/L. Assuming 30% of BOD is removed in the primary clarifier, the BOD concentration entering the anoxic zone would be approximately 147 mg/L. For this design, the maximum monthly TN concentration in the influent to the facility is 51.4 mg/L. This value was obtained from the average of 5 samples taken over a 30-day period in the fall of 2013 (Sept 25, 2013 to Oct 24, 2013). Assuming a 30% reduction in TN in the primary clarifiers, the TN concentration entering the anoxic zone is 36.0 mg/L. The effluent BOD concentration is dependent upon the operation of the MLE process. In general, nearly all of the soluble BOD will be completely consumed in the activated sludge process and the majority of the effluent BOD will be contained in the biodegradable portion of the effluent TSS. The effluent TSS concentration is also dependent upon the operation of the MLE process and the effectiveness of the final clarifiers. The two-year average TSS concentration in the effluent leaving the facility was 2.65 for 2012 and 2013.

5.3.3 Nitrification Process Design

The unit processes at the WWTF were designed to accommodate the maximum monthly flow at the facility, which is the average daily value over for 30-day period with maximum wastewater flow. Using the available data, the maximum monthly flow was calculated to be 5.0 MGD over the period starting on May 23, 2013 and ending on June 21, 2013. Although this coincides with the permitted average monthly flow for the facility, the facility operates well below this capacity on average. The two-year average daily flow at the facility for 2012 and 2013 was 2.8 MGD. In addition, the population of Gardner, which contributes over 90% of the customer base, has been stagnant over the past 20 years. From 1990 to 2010, the population of Gardner only grew from 20,125 to 20,228, a 0.5% increase. The design temperature at the facility was chosen to be 8°C because average temperature for the winter of 2012 (Dec 21, 2012 to March 20, 2013) was approximately 46.8°F (8.2°C).

The specific growth rate for the nitrifying bacteria in the activated sludge process, or the increase in cell mass per unit time, was estimated using typical values for activated-sludge nitrification kinetic coefficients (Metcalf & Eddy, 2003). The kinetic coefficients are for operation at 20°C and were adjusted for the design operating temperature of 8°C using Equation 6. Table 14 lists the kinetic coefficients used in the estimation. The target effluent ammonia concentration was set at 0.5 mg/L, which is below the NDPES permit level of 1.0 mg/L (June 1 – Oct 31). In addition, 0.5 mg/L will ensure a small contribution to TN in the effluent and a reasonable design SRT (10-20 days).

$$C_T = C_{20}\theta^{T-20} \qquad \text{(Equation 6)}$$

Where C_T is the coefficient at any temperature T, C_{20} is the coefficient value at 20 degrees Celsius, θ is the temperature coefficient, and T is the temperature in degrees Celsius. The temperature coefficients associated with each kinetic coefficient are also listed in Table 14.

Table 14: Kinetic Coefficients for Activated-Sludge Nitrification

Kinetic Coefficient	Units	θ	Value (20°C)	Value (8°C)
Maximum specific growth rate, $\mu_{n,m}$	(g new cells/g cells · d)	1.07	0.75	0.33
Half-velocity constant, K_n	(mg/L)	1.053	0.74	0.40
Endogenous decay coefficient, k_{dn}	(1/d)	1.04	0.08	0.05

The specific growth rate was calculated using Equation 7, where μ_n represents the specific growth rate of nitrifying bacteria in grams new cells/ grams cells · day, and N is the target effluent ammonia concentration in mg/L. Using the kinetic coefficients in Table 14 for 8°C, the specific growth rate was calculated to be 0.117.

$$\mu_n = \left(\frac{\mu_{n,m} \cdot N}{K_n + N}\right) - k_{dn} \qquad \text{(Equation 7)}$$

The mean cell residence time, or solids retention time (SRT), is the average amount of time that the microorganism will spend in the activated-sludge process. A factor of safety (FS) was included to ensure the desired level of nitrification was achieved. The factor of safety was calculated from the average and peak Total Kjeldahl Nitrogen (TKN) measured in the influent to the facility using Equation 8. The two-year average TKN for 2013 and 2013 was 33.6 mg/L and the maximum value reported during that time period was 58.3 mg/L. The design SRT for the nitrification process was calculated using Equation 9.

$$\mathrm{FS} = \frac{\mathrm{TKN_{peak}}}{\mathrm{TKN_{average}}} + 0.5 \qquad \text{(Equation 8)}$$

$$\text{Design SRT} = \mathrm{FS} \cdot \frac{1}{\mu_n} \qquad \text{(Equation 9)}$$

The factor of safety for the facility was calculated to be 2.24 and the design SRT for operation at 5°C was calculated to be 16.5 days. The required aerobic volume is calculated using the design SRT. In order to calculate the aerobic volume, the amount of sludge produced per day must be calculated. Under steady state conditions, the amount of sludge produced is equal to the amount of sludge wasted or the waste activated sludge (WAS). The observed sludge yield (Y_{obs}) must first be estimated in order to proceed with the calculations. The observed sludge yield was estimated using Equation 9 and the sludge production was calculated using Equation 10.

$$Y_{obs} = \frac{0.67}{1 + k_d \cdot SRT} \qquad \text{(Equation 10)}$$

$$\text{WAS (lbs VSS/day)} = Y_{obs} \cdot (S_o - S) \cdot Q \cdot 8.34 \qquad \text{(Equation 11)}$$

In Equation 10, Y_{obs} is the observed sludge yield in mg VSS/mg BOD, k_d is the endogenous decay coefficient (from Table 14) in days^{-1}, and SRT is the design SRT in days. The value in the numerator represents the stoichiometric relationship between BOD consumed and VSS produced. The observed yield adjusts this relationship to account for the effect of endogenous decay. In Equation 11, S_o is the influent concentration of BOD in mg/L, S is the effluent concentration of BOD in mg/L, and Q is the flow rate in MGD. As discussed previously, the concentration of BOD in the effluent is subject to operation and performance of the MLE process and cannot be directly quantified. The facility currently discharges <1 mg/L BOD on average and, therefore, the concentration in the effluent is neglected for the purposes of design. In other words, it was assumed that all of the influent BOD will be converted to biomass. The observed sludge yield and the WAS were calculated to be 0.367 mg VSS/mg BOD and 2,251 lbs/day respectively. The required aeration volume was then calculated using Equation 12.

$$\mathrm{SRT} = \frac{\text{VSS in system, lbs}}{\text{VSS wasted, lbs/day}} = \frac{X_v \cdot V_{aerobic} \cdot 8.34}{\mathrm{WAS}} \qquad \text{(Equation 12)}$$

Where SRT is the design SRT in days, X_v is the MLVSS in the aeration basin in mg/L, $V_{aerobic}$ is the volume of the aeration basin in MG, and WAS is the sludge production/wasted sludge in lbs VSS/day. For the purposes of this design, the volatile fraction of the MLSS was assumed to be 70% (Price, 1991). The equation was then rearranged to solve for $V_{aerobic}$.

The aeration volume required to achieve the desired level of nitrification was calculated to be approximately 2.36 MG. The total volume of the current aeration basins is approximately 1.01 MG. Therefore, without any further calculation, it is already clear that a retrofit of the current aeration basins to accommodate an MLE process is not possible without expansion. The required aerobic volume could be reduced by increasing the operating MLVSS. However, this would require the expansion and/or addition of final clarifiers to ensure proper operation under critical loading (refer to Section 5.3.1).

At its present configuration, the facility is able to achieve near complete (< 0.1 mg/L) nitrification of its wastewater. However, it is not feasible to achieve the same level of treatment if the existing basins are retrofit for an MLE process. The reason for this discrepancy is related to the sludge handling. The facility currently operates as a two-sludge system; the majority of BOD is removed by the trickling filters and associated sludge is removed in the intermediate clarifiers, while activated sludge process removes only a small quantity of BOD and produces sludge primarily through the oxidation of ammonia (nitrification), which is associated with lower sludge yields (Metcalf & Eddy, 2003). In order to avoid the addition of a supplementary carbon source for denitrification, the trickling filters would have to be bypassed in order to provide sufficient BOD for denitrification. As a consequence, the sludge produced through the reduction of BOD would now be produced in the aeration basin. Since the aeration basins were only designed to handle the sludge produced from nitrification, the excess sludge negatively impacts the SRT in the basin. In order to achieve the desired level of treatment in this scenario, additional aerobic reactor volume is required.

5.3.4 Denitrification Process Design

The goal of the denitrification process is to achieve an effluent nitrate concentration of 6 mg/L, which is lower than the design effluent concentration of 8 mg/L in order to account for the contribution from other nitrogen species (e.g. ammonia). The design of the anoxic basin was carried out using the specific denitrification rate (SDNR) approach. First, the SDNR was estimated using Equation 13 (New York State Department of Environmental Conservation, 2014).

$$SDNR = (6.4 \times 10^{10}) \cdot e^{-\frac{15880}{R \cdot T}} \qquad \text{(Equation 13)}$$

Where SDNR is the specific denitrification rate in lbs NO_3/ (lbs VSS · day), R is a thermodynamic constant equal to 1.987 kcal/ (mole · K), and T is the temperature in Kelvin. For the design temperature of 8°C, the SDNR is estimated to be 0.285 lbs NO_3/ (lbs VSS · day). Since the MLSS is known, the required anoxic zone volume can be calculated. First the amount of nitrate to be treated on a daily basis was calculated using Equation 14.

$$NO_x = Q \cdot (N_o - N) \cdot 8.34 \qquad \text{(Equation 14)}$$

Where NO_x is the amount of nitrate in lbs/day, Q is the design flow rate in MGD, N_o is the influent TN concentration under maximum monthly loading (i.e. the primary effluent TN in Table 13) in mg/L, and N is the target nitrate concentration in mg/L. Using the design values, the amount of nitrate to be treated was calculated to be 1250 lbs/day. Next, the required volume of the anoxic zone was calculated using Equation 15.

$$V_{anoxic} \cdot X_v \cdot SDNR \cdot 8.34 = NO_x \qquad \text{(Equation 15)}$$

Where V_{anoxic} is the required anoxic volume in MG, X_v is the MLVSS in mg/L, and SDNR is the estimated specific denitrification rate in lbs NO_3/ (lbs VSS · day). The equation was rearranged and solved for V_{anoxic}, which was calculated to be 2.79 MG.

This value is very high, especially when considering that the recommended ratio of aerobic to anoxic volume for an MLE process is 3:1 (Metcalf & Eddy, 2003). The large amount of anoxic volume required can be attributed to the SDNR and the high value for influent TN concentration. Designing a process to achieve a consistent level of treatment year round is difficult in cold climates because the SDNR is highly temperature dependent. An important point to note is that the influent TN value of 36.0 mg/L used in this design value may be too high. Actual influent data for the aeration basins under current operating conditions was not available, but the effluent TN values reported under current operating conditions average 14.5 mg/L with a maximum monthly value of approximately 20.5 mg/L (calculated from Nov 13, 2013 to Dec 11, 2013). Since the facility does not currently denitrify, this may be a better estimation of the TN concentration in the influent. Using the maximum monthly value of 20.5 mg/L, the required anoxic zone was calculated to be 1.35 MG.

As with the nitrification process, the efficiency of this process would be improved by increasing the operating MLVSS. However, as stated before this would require the expansion of final clarifier capacity. Another option would be to use supplementary carbon source, such as methanol, instead of the primary effluent. Although this would require a capital investment and result in higher operational costs, it would also result in a higher SDNR, since methanol is a more efficient electron donor (Metcalf & Eddy, 2003).

6.0 Conclusions and Recommendations

The water quality monitoring conducted by our project group and by the facility show that the facility is contributing a significant amount of nitrogen (compared to other characteristics in the effluent), in the form of nitrate, to the Otter River. MassDEP advises permitted facilities to assume best available technology (BAT) target nutrient goals which vary from 5 to 8 mg/L for TN. The group examined retrofit design options to reach a target effluent goal of 8 mg/L in order to help prepare for the possibility of TN requirements to the facility NPDES permit.

6.1 Conclusions

The following conclusions can be made from the sampling data collected and design options examined.

1. Denitrification should be the priority component of any planned treatment upgrades.

Nitrate was present in consistently high values in the effluent throughout water quality testing in comparison to all other nutrient values, which makes nitrogen an area of concern for the upcoming NPDES permit renewal period. Denitrification needs to be considered as upcoming treatment upgrades are considered. Additionally, as the EPA stated in the current NPDES permit issued to Gardner, "it is strongly recommended that any [facility upgrades] should consider alternatives for further enhancing nitrogen reduction" (EPA, 2012).

2. According to the assessment rubric, the MLE process is the most sustainable implementation option for the Gardner WWTF.

The MLE process is the most viable option for denitrification due to the simplicity of design and implementation as well as ease of operation. As stated in Chapter 5, the MLE process has the lowest relative capital and O&M costs and offers the flexibility to add additional treatment regimens as regulations become more stringent. Additionally, the facility would require neither a supplemental carbon source nor additional chemicals.

3. A simple retrofit by dividing the aeration basin into two zones is not possible.

Retrofitting the current aeration basin to accommodate a single-sludge MLE process is not feasible due to the increased sludge production from migrating over from the current two-sludge system. However, utilizing the current aeration basins in a future upgrade would minimize additional reactor volume required to operate an MLE process at the facility.

4. Trickling filter(s) could be repurposed to serve as an anoxic zone for a two-sludge MLE system

The trickling filters and intermediate clarifiers are associated with BOD removal in the current configuration. Repurposing the trickling filters may avoid the construction of additional aeration basins because the BOD loading to the aeration basin would be comparable to the loading under current conditions.

6.2 Recommendations

The following points are considered the next steps that the City of Gardner may consider as they continue on their journey to system upgrades.

1. Further investigate alternative design options discussed in Chapter 5.

Although the MLE design was chosen as the best option for the Gardner WWTF, the team recommends further research on other alternatives such as cyclic aeration and denitrification filters. These process designs were ranked second and third on the alternative rubric, respectively. Cyclic aeration, although in its early design stages, requires minimal alterations of the physical mechanisms of the plant, and could possibly be a completely automated process. This could potentially reduce O&M costs and reduce capital costs. Although denitrification filters have a higher capital cost than the MLE and cyclic aeration processes, this alternative could potentially be the easiest to implement and operate. Because the filters are a single unit, construction costs would be minimal and implementation would be quick. Denitrification filters also have an automated feature, therefore reducing O&M time and costs.

2. The full-scale cost analysis should include considerations of operation, maintenance and life-cycle costs.

In the scope of this project, a complete cost analysis was unable to be completed because there are limited data available for cost analysis of retrofitting existing facilities. When researching cost estimation techniques for wastewater treatment facilities, most literature sources recommended a cost estimation software program (CAPDETWorks 2.5) to compute a complete retrofit cost analysis. For typical retrofits, case by case cost estimates may be needed.

3. Investigate long term ambient water quality and nutrient impacts in the Otter River, specifically phosphorus.

The background level of TP measured by the project group was significantly higher than the background level used in the determination of the NPDES permit level. The average TP concentration at the Route 2A sampling location for the duration of the water quality sampling was 0.22 mg/L. The background level used by the EPA in the mass balance equation used to determine the current permit level was approximately 0.06 mg/L (Kennedy & Rojko, 2004). As per the EPA’s direction, “If the City decides to conduct such sampling, it should submit its proposed sampling program to EPA and MassDEP prior to initiation to ensure appropriate QA/QC measures are follow” (EPA, 2012).

4. Consider alternative methods for phosphorus removal as part of future upgrades

In order to sustain WWTF improvements long term, phosphorus removal should be accounted for in process development. While our design investigation did not focus on phosphorus removal, it was a nutrient that was assessed throughout water quality testing. Considering the differences between the grab-sample results that the project team collected and the 24-hour composite results from the plant, additional testing recommended. Additionally, as the cost of purchasing ferric chloride chemical rises, the ability to keep up with more stringent phosphorus limits may become difficult. We recommend the investigation of biological phosphorus removal in addition to the ferric chloride chemical application.

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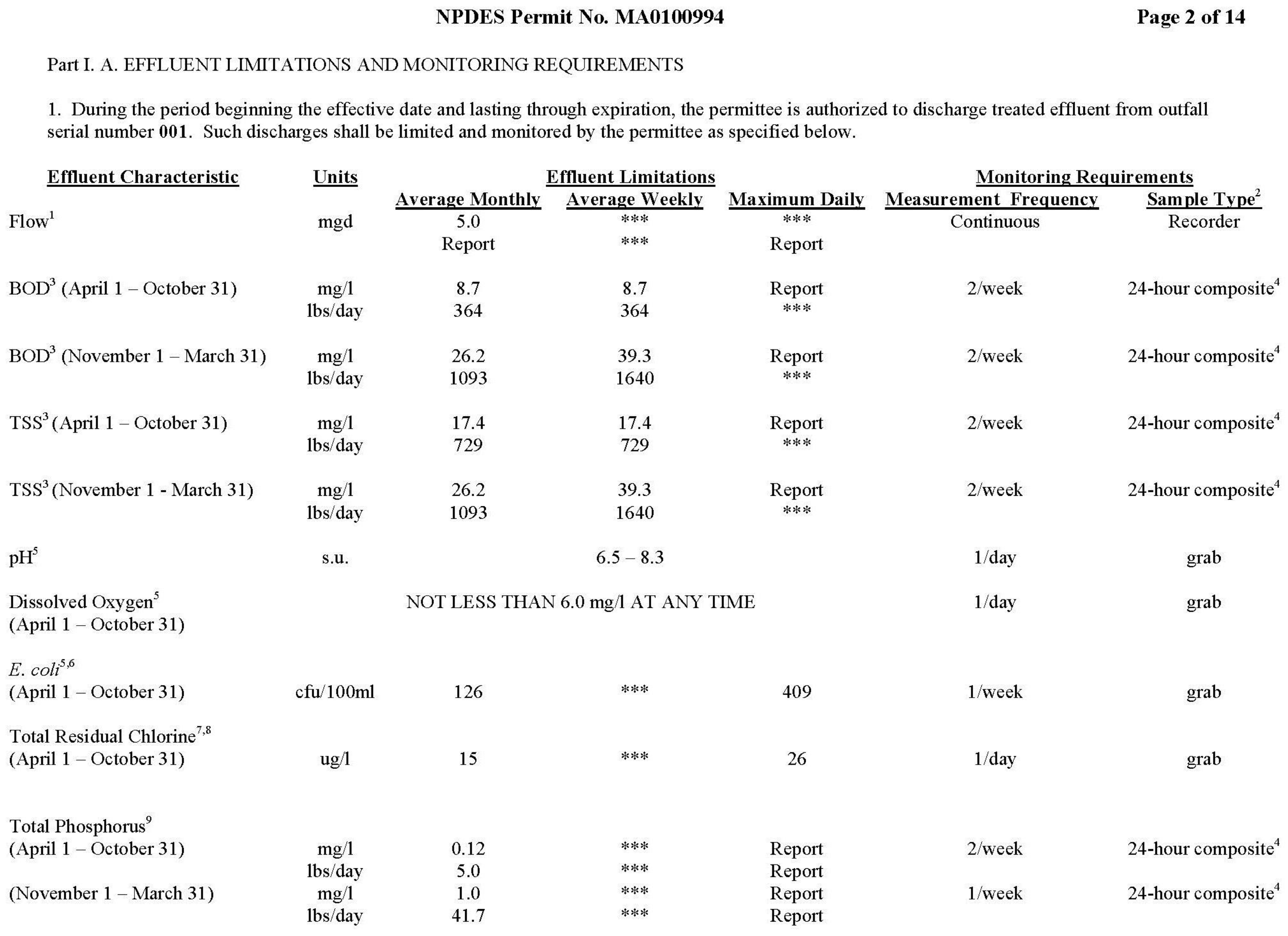
Appendix A: NPDES Permit Part I. A.



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Part I. A. EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS

1. During the period beginning the effective date and lasting through expiration, the permittee is authorized to discharge treated effluent from outfall serial number **001**. Such discharges shall be limited and monitored by the permittee as specified below.

Effluent Characteristic	Units	Effluent Limitations			Monitoring Requirements	
		Average Monthly	Average Weekly	Maximum Daily	Measurement Frequency	Sample Type[2]
Flow[1]	mgd	5.0	***	***	Continuous	Recorder
		Report	***	Report		
BOD[3] (April 1 – October 31)	mg/l	8.7	8.7	Report	2/week	24-hour composite[4]
	lbs/day	364	364	***		
BOD[3] (November 1 – March 31)	mg/l	26.2	39.3	Report	2/week	24-hour composite[4]
	lbs/day	1093	1640	***		
TSS[3] (April 1 – October 31)	mg/l	17.4	17.4	Report	2/week	24-hour composite[4]
	lbs/day	729	729	***		
TSS[3] (November 1 - March 31)	mg/l	26.2	39.3	Report	2/week	24-hour composite[4]
	lbs/day	1093	1640	***		
pH[5]	s.u.	6.5 – 8.3			1/day	grab
Dissolved Oxygen[5] (April 1 – October 31)		NOT LESS THAN 6.0 mg/l AT ANY TIME			1/day	grab
E. coli[5,6] (April 1 – October 31)	cfu/100ml	126	***	409	1/week	grab
Total Residual Chlorine[7,8] (April 1 – October 31)	ug/l	15	***	26	1/day	grab
Total Phosphorus[9] (April 1 – October 31)	mg/l	0.12	***	Report	2/week	24-hour composite[4]
	lbs/day	5.0	***	Report		
(November 1 – March 31)	mg/l	1.0	***	Report	1/week	24-hour composite[4]
	lbs/day	41.7	***	Report		

Effluent Characteristic	Units	Effluent Limitations			Monitoring Requirements	
		Average Monthly	Average Weekly	Maximum Daily	Measurement Frequency	Sample Type[2]
Dissolved orthophosphate (November 1 –March 31)	mg/l	Report	***	***	1/week	24-hour composite[4]
Total Nitrogen[3,10]	mg/l	Report	***	Report	1/week	24-hour composite[4]
	lbs/day	Report	***	Report		
Total Kjeldahl Nitrogen[3]	mg/l	Report	***	Report	1/week	24-hour composite[4]
Total Ammonia Nitrogen[3]						
(June 1 – October 31)	mg/l	1.0	1.0	***	1/week	24-hour composite[4]
	lbs/day	Report	Report	***		
(November 1 – May 31)	mg/l	4.4	4.4	***	1/week	
	lbs/day	Report	Report	***		
Nitrate + Nitrite[3]	mg/l	Report	***	Report	1/week	24-hour composite[4]
Aluminum	ug/l	87	***	Report	1/month	24-hour composite[4]
Cadmium[11]	ug/l	0.5	***	Report	1/month	24-hour composite[4]
Copper[12]	ug/l	13.6	***	22.0	1/month	24-hour composite[4]
Lead[13]	ug/l	4.4	***	Report	1/month	24-hour composite[4]
Mercury[14]	ug/l	1.3	***	2.3	1/month	24-hour composite[4]
Whole Effluent Toxicity[15,16,17]	%		Acute LC50 ≥100%		1/quarter	24-hour composite[4]
			Chronic NOEC ≥ 72%			

Appendix B: Detailed Methodologies

This section includes references to methodology supplies, procedure numbers and product catalog numbers for supplies used for water quality monitoring as described in the methodology.

Table 9: Testing Summary

Test	HACH Methods Number	EPA Methods Number	Specific Reagents Required (Hach Product Number)
Ammonia, Nitrogen	8083	SM 4500-NH3 C	Nessler Reagent (2119449) Mineral Stabilizer (2376626) Polyvinyl Alcohol Dispersing Agent (2376526)
Nitrate, Nitrogen	8171	N/A	NitraVer® 5 Reagent Powder Pillows (2106169)
Nitrite, Nitrogen	8507	353.2	NitriVer® 3 Nitrite Reagent Powder Pillows (2107169)
Phosphorus Reactive	8048	365.1	PhosVer 3 Phosphate Reagent (212599)
Total Phosphorus	8190	365.3	Phosphate Acid Reagent Vials (2742645) PhosVer 3 Phosphate Reagent (2106046) Deionized Water (27242) Potassium Persulfate (2084766) Sodium Hydroxide Solution (2743042)

Table 10: General Equipment List

Material Name	Amount	Hach Catalog Number
Water, deionized	25 mL	27256
Cylinder, graduated	25-mL	2088640
Pipette, TenSette® 0.1 - 1.0 mL each	1	1970001
Pipette Tips, for TenSette Pipet 1970001	1	2185628
Sample Cells, 1-inch, 25-mL	1 + 1 per sample	2495402
Stopper, Neoprene, solid, size #1	1 + 1 per sample	1480801

B.1 Ammonia, Nitrogen

1. Configure the Spectrophotometer to the correct wavelength settings by choosing stored program “380 N, Ammonia, Ness.”
2. Fill a graduated cylinder to the 25-mL mark with deionized water. Pour deionized water into 25mL sample cell. This cell will serve as the blank.
3. After collection bottle has adjusted to room temperature, fill a graduated cylinder to the 25-mL mark with sample. Pour sample into 25mL sample cell.
4. Add three drops of Mineral Stabilizer to each cylinder. Stopper and invert three times to mix.
5. Add three drops of Polyvinyl Alcohol Dispersing Agent to each cylinder. Stopper and invert three times to mix.
6. Pipet 1.0 mL of Nessler Reagent into each cylinder. Stopper and invert three times to mix.
7. Repeat steps 3-6 for all samples.
8. Start a stopwatch for one-minute reaction period.
9. When the timer expires, insert the blank into the cell holder.
10. Zero the instrument.
11. Wipe the prepared sample and insert it into the cell holder.
12. Read the results in mg/L NH3 –N.
13. Repeat steps 11-12 for all samples.
14. Dispose of all samples in an appropriately labeled hazardous waste bottle and store in hazardous waste cabinet.

Ammonia Nitrogen Chemical Reaction

$$NH_4^+ + 2[HgI_4]^{2-} + 4OH^- \rightarrow HgO(Hg(NH_2)I) + 7I^- + 3H_2O$$

B.2 Nitrate, Nitrogen

1. Configure the Spectrophotometer to the correct wavelength settings by choosing stored program “353 N, Nitrate MR PP.”
2. After collection bottle has adjusted to room temperature, fill a graduated cylinder to the 25-mL mark with sample. Pour sample into 25mL sample cell.
3. Add one NitraVer 5 Nitrate Reagent Powder Pillow and stopper.
4. Start a stopwatch for one-minute reaction period and shake cell vigorously until timer expires.
5. When the stopwatch expires, reset and start again for five-minute waiting period.
6. When timer expires, fill a second cell with 25mL of sample. This will serve as the blank sample.
7. Wipe blank and insert it into the cell holder.

8. Zero the instrument.
9. Wipe the prepared sample and insert it into the cell holder.
10. Read the results in mg/L N03 –N.
11. Repeat steps 2-10 for all samples.
12. Dispose of all samples in an appropriately labeled hazardous waste bottle and store in hazardous waste cabinet.

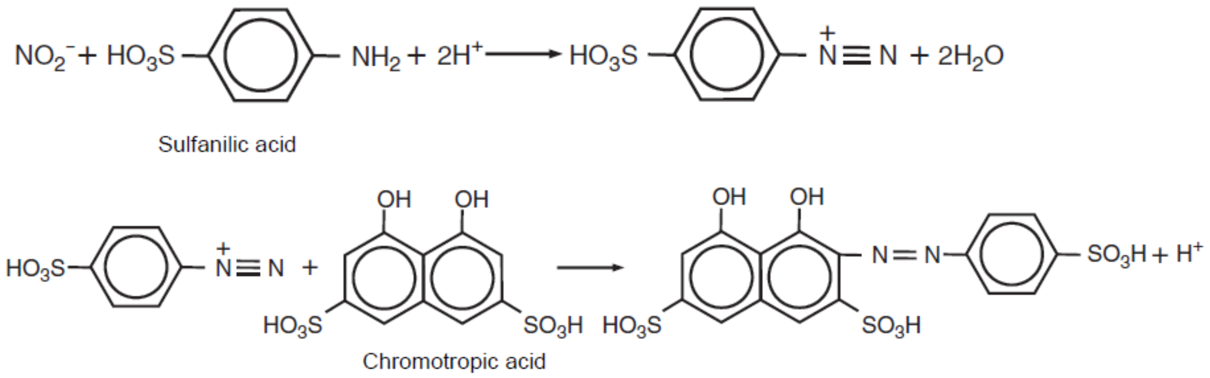
Nitrate Chemical Reaction

$$\mathrm{NO_3 + H_2O + C_6H_7NO_3S^{4-} + Cd^0 \rightarrow NO_2^- + 2OH^- + Cd(C_6H_7NO_3S)^{2-}}$$

B.3 Nitrite, Nitrogen

1. Configure the Spectrophotometer to the correct wavelength settings by choosing stored program “371 N, Nitrite LR PP.”
2. After collection bottle has adjusted to room temperature, fill a graduated cylinder to the 25-mL mark with sample. Pour sample into 25mL sample cell.
3. Add one NitraVer®3 Nitrite Reagent Powder Pillow and stopper. Swirl cell to dissolve.
4. Start a stopwatch for twenty-minute reaction period.
5. When timer expires, fill a second cell with 25mL of sample. This will serve as the blank sample.
6. Wipe blank and insert it into the cell holder.
7. Zero the instrument.
8. Wipe the prepared sample and insert it into the cell holder.
9. Read the results in mg/L N02 –N.
10. Repeat steps 2-9 for all samples.
11. Dispose of all samples in an appropriately labeled hazardous waste bottle and store in hazardous waste cabinet.

Nitrite Chemical Reaction



B.4 Orthophosphate, Phosphorus Reactive

1. Configure the spectrophotometer to the correct stored program. The program number using the HACH DR 6000 is 490 P React PP.
2. Using a graduated cylinder, measure 25 mL of the sample, and fill a sample cell. Repeat this step for each sample. In between measuring different samples, rinse the graduated cylinder with deionized water.
3. Add the powder pillow packet, PhosVer3, to each sample cell and shake vigorously for thirty seconds.
4. After the thirty second shake period has expired, allow for a two minute reaction period.
5. During this two minutes, prepare a blank for each sample measured by repeating step 2.
6. When the two minute reaction period has expired, clean the blank with a KimWipe® and insert into spectrophotometer.
7. Push "Zero" and the display will show 0.00 mg/L $PO_4{}^{3-}$
8. Clean the prepared sample with a KimWipe® and insert it into the spectrophotometer
9. Push "Read" and record the result.
10. Repeat 6-9 for the remaining samples and corresponding blanks.

Orthophosphate Chemical Reaction

Orthophosphate (in water) + Sodium Molybdate → Phosphomolybdic Acid

Phosphopmolybdic Acid + Ascorbic Acid → Reduced Phosphomolybdate complex

- The phosphomolybdate complex results in an intense blue color with a measurement wavelength of about 880 nm.
- Also present in the reaction is potassium pyrosulfate to ensure complete dissolution and stability of the reaction

B.5 Total Phosphorus

1. Turn on the tube reactor and preheat at 150 Celsius for fifteen minutes.
2. Configure the spectrophotometer to the correct stored program. The program number using the HACH DR 6000 is 536 P Total/AH PV TNT
3. After the time for preheat has extinguished, using a pipette, add 5.0 mL of the sample into a Total and Acid Hydrolyzable Test Vial. Repeat for each sample.
4. Add 1 Potassium Persulfate powder pillow to each prepared sample vial.
5. Heat the vial(s) for thirty minutes at 150 Celsius.
6. After the thirty minutes has extinguished, remove the vial(s) from the reactor and place in a test tube rack. Allow the vials to cool to room temperature.
7. Using a pipette, add 2.0 mL of 1.54 N Sodium Hydroxide Standard Solution to the vial.
8. Wipe the outside of the vial with a damp KimWipe® followed by a dry one.
9. Place the vial into the machine with the proper shape holder.

10. Push “Zero” and the display will show 0.00 mg/L PO_4^{3-}
11. Add the powder pillow packet, PhosVer3, to the sample vial and shake vigorously for thirty seconds.
12. After the thirty second shake period has expired, allow for a two minute reaction period.
13. When the two minute reaction period has expired, clean the vial with a Kimwipe® and insert into spectrophotometer.
14. Push “Read” and record the result.
15. Repeat 7-14 for the remaining samples.

Total Phosphorus Chemical Reaction

Organic Phosphates (in water) + Potassium Persulfate + heat→ Orthophosphates (in water)

Orthophosphate (in water) + Sodium Molybdate → Phosphomolybdic Acid

Phosphopmolybdic Acid + Ascorbic Acid → Reduced Phosphomolybdate complex

- The digestion or heating of the water and potassium persulfate allows the hydrolysis of the condensed inorganic forms. This promotes the conversion into orthophosphates

Appendix C: IDEXX Quanti-Tray/2000 MPN Table

IDEXX Quanti-Tray®/2000 MPN Table *(per 100ml)*

# Large Wells Positive	# Small Wells Positive																								
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
0	<1	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.1	15.1	16.1	17.1	18.1	19.1	20.2	21.2	22.2	23.3	24.3
1	1.0	2.0	3.0	4.0	5.0	6.0	7.1	8.1	9.1	10.1	11.1	12.1	13.2	14.2	15.2	16.2	17.3	18.3	19.3	20.4	21.4	22.4	23.5	24.5	25.6
2	2.0	3.0	4.1	5.1	6.1	7.1	8.1	9.2	10.2	11.2	12.2	13.3	14.3	15.4	16.4	17.4	18.5	19.5	20.6	21.6	22.7	23.7	24.8	25.8	26.9
3	3.1	4.1	5.1	6.1	7.2	8.2	9.2	10.3	11.3	12.4	13.4	14.5	15.5	16.5	17.6	18.6	19.7	20.8	21.8	22.9	23.9	25.0	26.1	27.1	28.2
4	4.1	5.2	6.2	7.2	8.3	9.3	10.4	11.4	12.5	13.5	14.6	15.6	16.7	17.8	18.8	19.9	21.0	22.0	23.1	24.2	25.3	26.3	27.4	28.5	29.6
5	5.2	6.3	7.3	8.4	9.4	10.5	11.5	12.6	13.7	14.7	15.8	16.9	17.9	19.0	20.1	21.2	22.2	23.3	24.4	25.5	26.6	27.7	28.8	29.9	31.0
6	6.3	7.4	8.4	9.5	10.6	11.6	12.7	13.8	14.9	16.0	17.0	18.1	19.2	20.3	21.4	22.5	23.6	24.7	25.8	26.9	28.0	29.1	30.2	31.3	32.4
7	7.5	8.5	9.6	10.7	11.8	12.8	13.9	15.0	16.1	17.2	18.3	19.4	20.5	21.6	22.7	23.8	24.9	26.0	27.1	28.3	29.4	30.5	31.6	32.8	33.9
8	8.6	9.7	10.8	11.9	13.0	14.1	15.2	16.3	17.4	18.5	19.6	20.7	21.8	22.9	24.1	25.2	26.3	27.4	28.6	29.7	30.8	32.0	33.1	34.3	35.4
9	9.8	10.9	12.0	13.1	14.2	15.3	16.4	17.6	18.7	19.8	20.9	22.0	23.2	24.3	25.4	26.6	27.7	28.9	30.0	31.2	32.3	33.5	34.6	35.8	37.0
10	11.0	12.1	13.2	14.4	15.5	16.6	17.7	18.9	20.0	21.1	22.3	23.4	24.6	25.7	26.9	28.0	29.2	30.3	31.5	32.7	33.8	35.0	36.2	37.4	38.6
11	12.2	13.4	14.5	15.6	16.8	17.9	19.1	20.2	21.4	22.5	23.7	24.8	26.0	27.2	28.3	29.5	30.7	31.9	33.0	34.2	35.4	36.6	37.8	39.0	40.2
12	13.5	14.6	15.8	16.9	18.1	19.3	20.4	21.6	22.8	23.9	25.1	26.3	27.5	28.6	29.8	31.0	32.2	33.4	34.6	35.8	37.0	38.2	39.5	40.7	41.9
13	14.8	16.0	17.1	18.3	19.5	20.6	21.8	23.0	24.2	25.4	26.6	27.8	29.0	30.2	31.4	32.6	33.8	35.0	36.2	37.5	38.7	39.9	41.2	42.4	43.6
14	16.1	17.3	18.5	19.7	20.9	22.1	23.3	24.5	25.7	26.9	28.1	29.3	30.5	31.7	33.0	34.2	35.4	36.7	37.9	39.1	40.4	41.6	42.9	44.2	45.4
15	17.5	18.7	19.9	21.1	22.3	23.5	24.7	25.9	27.2	28.4	29.6	30.9	32.1	33.3	34.6	35.8	37.1	38.4	39.6	40.9	42.2	43.4	44.7	46.0	47.3
16	18.9	20.1	21.3	22.6	23.8	25.0	26.2	27.5	28.7	30.0	31.2	32.5	33.7	35.0	36.3	37.5	38.8	40.1	41.4	42.7	44.0	45.3	46.6	47.9	49.2
17	20.3	21.6	22.8	24.1	25.3	26.6	27.8	29.1	30.3	31.6	32.9	34.1	35.4	36.7	38.0	39.3	40.6	41.9	43.2	44.5	45.9	47.2	48.5	49.8	51.2
18	21.8	23.1	24.3	25.6	26.9	28.1	29.4	30.7	32.0	33.3	34.6	35.9	37.2	38.5	39.8	41.1	42.4	43.8	45.1	46.5	47.8	49.2	50.5	51.9	53.2
19	23.3	24.6	25.9	27.2	28.5	29.8	31.1	32.4	33.7	35.0	36.3	37.6	39.0	40.3	41.6	43.0	44.3	45.7	47.1	48.4	49.8	51.2	52.6	54.0	55.4
20	24.9	26.2	27.5	28.8	30.1	31.5	32.8	34.1	35.4	36.8	38.1	39.5	40.8	42.2	43.6	44.9	46.3	47.7	49.1	50.5	51.9	53.3	54.7	56.1	57.6
21	26.5	27.9	29.2	30.5	31.8	33.2	34.5	35.9	37.3	38.6	40.0	41.4	42.8	44.1	45.5	46.9	48.4	49.8	51.2	52.6	54.1	55.5	56.9	58.4	59.9
22	28.2	29.5	30.9	32.3	33.6	35.0	36.4	37.7	39.1	40.5	41.9	43.3	44.8	46.2	47.6	49.0	50.5	51.9	53.4	54.8	56.3	57.8	59.3	60.8	62.3
23	29.9	31.3	32.7	34.1	35.5	36.8	38.3	39.7	41.1	42.5	43.9	45.4	46.8	48.3	49.7	51.2	52.7	54.2	55.6	57.1	58.6	60.2	61.7	63.2	64.7
24	31.7	33.1	34.5	35.9	37.3	38.8	40.2	41.7	43.1	44.6	46.0	47.5	49.0	50.5	52.0	53.5	55.0	56.5	58.0	59.5	61.1	62.6	64.2	65.8	67.3
25	33.6	35.0	36.4	37.9	39.3	40.8	42.2	43.7	45.2	46.7	48.2	49.7	51.2	52.7	54.3	55.8	57.3	58.9	60.5	62.0	63.6	65.2	66.8	68.4	70.0
26	35.5	36.9	38.4	39.9	41.4	42.8	44.3	45.9	47.4	48.9	50.4	52.0	53.5	55.1	56.7	58.2	59.8	61.4	63.0	64.7	66.3	67.9	69.6	71.2	72.9
27	37.4	38.9	40.4	42.0	43.5	45.0	46.5	48.1	49.6	51.2	52.8	54.4	56.0	57.6	59.2	60.8	62.4	64.1	65.7	67.4	69.1	70.8	72.5	74.2	75.9
28	39.5	41.0	42.6	44.1	45.7	47.3	48.8	50.4	52.0	53.6	55.2	56.9	58.5	60.2	61.8	63.5	65.2	66.9	68.6	70.3	72.0	73.7	75.5	77.3	79.0
29	41.7	43.2	44.8	46.4	48.0	49.6	51.2	52.8	54.5	56.1	57.8	59.5	61.2	62.9	64.6	66.3	68.0	69.8	71.5	73.3	75.1	76.9	78.7	80.5	82.4
30	43.9	45.5	47.1	48.7	50.4	52.0	53.7	55.4	57.1	58.8	60.5	62.2	64.0	65.7	67.5	69.3	71.0	72.9	74.7	76.5	78.3	80.2	82.1	84.0	85.9
31	46.2	47.9	49.5	51.2	52.9	54.6	56.3	58.1	59.8	61.6	63.3	65.1	66.9	68.7	70.5	72.4	74.2	76.1	78.0	79.9	81.8	83.7	85.7	87.6	89.6
32	48.7	50.4	52.1	53.8	55.6	57.3	59.1	60.9	62.7	64.5	66.3	68.2	70.0	71.9	73.8	75.7	77.6	79.5	81.5	83.5	85.4	87.5	89.5	91.5	93.6
33	51.2	53.0	54.8	56.5	58.3	60.2	62.0	63.8	65.7	67.6	69.5	71.4	73.3	75.2	77.2	79.2	81.2	83.2	85.2	87.3	89.3	91.4	93.6	95.7	97.8
34	53.9	55.7	57.6	59.4	61.3	63.1	65.0	67.0	68.9	70.8	72.8	74.8	76.8	78.8	80.8	82.9	85.0	87.1	89.2	91.4	93.5	95.7	97.9	100.2	102.4
35	56.8	58.6	60.5	62.4	64.4	66.3	68.3	70.3	72.3	74.3	76.3	78.4	80.5	82.6	84.7	86.9	89.1	91.3	93.5	95.7	98.0	100.3	102.6	105.0	107.3
36	59.8	61.7	63.7	65.7	67.7	69.7	71.7	73.8	75.9	78.0	80.1	82.3	84.5	86.7	88.9	91.2	93.5	95.8	98.1	100.5	102.9	105.3	107.7	110.2	112.7
37	62.9	65.0	67.0	69.1	71.2	73.3	75.4	77.6	79.8	82.0	84.2	86.5	88.8	91.1	93.4	95.8	98.2	100.6	103.1	105.6	108.1	110.7	113.3	115.9	118.6
38	66.3	68.4	70.6	72.7	74.9	77.1	79.4	81.6	83.9	86.2	88.6	91.0	93.4	95.8	98.3	100.8	103.4	105.9	108.6	111.2	113.9	116.6	119.4	122.2	125.0
39	70.0	72.2	74.4	76.7	78.9	81.3	83.6	86.0	88.4	90.9	93.4	95.9	98.4	101.0	103.6	106.3	109.0	111.8	114.6	117.4	120.3	123.2	126.1	129.2	132.2
40	73.8	76.2	78.5	80.9	83.3	85.7	88.2	90.8	93.3	95.9	98.5	101.2	103.9	106.7	109.5	112.4	115.3	118.2	121.2	124.3	127.4	130.5	133.7	137.0	140.3
41	78.0	80.5	83.0	85.5	88.0	90.6	93.3	95.9	98.7	101.4	104.3	107.1	110.0	113.0	116.0	119.1	122.2	125.4	128.7	132.0	135.4	138.8	142.3	145.9	149.5
42	82.6	85.2	87.8	90.5	93.2	96.0	98.8	101.7	104.6	107.6	110.6	113.7	116.9	120.1	123.4	126.7	130.1	133.6	137.2	140.8	144.5	148.3	152.2	156.1	160.2
43	87.6	90.4	93.2	96.0	99.0	101.9	105.0	108.1	111.2	114.5	117.8	121.1	124.6	128.1	131.7	135.4	139.1	143.0	147.0	151.0	155.2	159.4	163.8	168.2	172.8
44	93.1	96.1	99.1	102.2	105.4	108.6	111.9	115.3	118.7	122.3	125.9	129.6	133.4	137.4	141.4	145.5	149.7	154.1	158.5	163.1	167.9	172.7	177.7	182.9	188.2
45	99.3	102.5	105.8	109.2	112.6	116.2	119.8	123.6	127.4	131.4	135.4	139.6	143.9	148.3	152.9	157.6	162.4	167.4	172.6	178.0	183.5	189.2	195.1	201.2	207.5
46	106.3	109.8	113.4	117.2	121.0	125.0	129.1	133.3	137.6	142.1	146.7	151.5	156.5	161.6	167.0	172.5	178.2	184.2	190.4	196.8	203.5	210.5	217.8	225.4	233.3
47	114.3	118.3	122.4	126.6	130.9	135.4	140.1	145.0	150.0	155.3	160.7	166.4	172.3	178.5	185.0	191.8	198.9	206.4	214.2	222.4	231.0	240.0	249.5	259.5	270.0
48	123.9	128.4	133.1	137.9	143.0	148.3	153.9	159.7	165.8	172.2	178.9	186.0	193.5	201.4	209.8	218.7	228.2	238.2	248.9	260.3	272.3	285.1	298.7	313.0	328.2
49	135.5	140.8	146.4	152.3	158.5	165.0	172.0	179.3	187.2	195.6	204.6	214.3	224.7	235.9	248.1	261.3	275.5	290.9	307.6	325.5	344.8	365.4	387.3	410.6	435.2

09-63235-01

IDEXX Quanti-Tray®/2000 MPN Table *(per 100ml)*

 # Small Wells Positive

# Large Wells Positive	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
0	25.3	26.4	27.4	28.4	29.5	30.5	31.5	32.6	33.6	34.7	35.7	36.8	37.8	38.9	40.0	41.0	42.1	43.1	44.2	45.3	46.3	47.4	48.5	49.5
1	26.6	27.7	28.7	29.8	30.8	31.9	32.9	34.0	35.0	36.1	37.2	38.2	39.3	40.4	41.4	42.5	43.6	44.7	45.7	46.8	47.9	49.0	50.1	51.2
2	27.9	29.0	30.0	31.1	32.2	33.2	34.3	35.4	36.5	37.5	38.6	39.7	40.8	41.9	43.0	44.0	45.1	46.2	47.3	48.4	49.5	50.6	51.7	52.8
3	29.3	30.4	31.4	32.5	33.6	34.7	35.8	36.8	37.9	39.0	40.1	41.2	42.3	43.4	44.5	45.6	46.7	47.8	48.9	50.0	51.2	52.3	53.4	54.5
4	30.7	31.8	32.8	33.9	35.0	36.1	37.2	38.3	39.4	40.5	41.6	42.8	43.9	45.0	46.1	47.2	48.3	49.5	50.6	51.7	52.9	54.0	55.1	56.3
5	32.1	33.2	34.3	35.4	36.5	37.6	38.7	39.9	41.0	42.1	43.2	44.4	45.5	46.6	47.7	48.9	50.0	51.2	52.3	53.5	54.6	55.8	56.9	58.1
6	33.5	34.7	35.8	36.9	38.0	39.2	40.3	41.4	42.6	43.7	44.8	46.0	47.1	48.3	49.4	50.6	51.7	52.9	54.1	55.2	56.4	57.6	58.7	59.9
7	35.0	36.2	37.3	38.4	39.6	40.7	41.9	43.0	44.2	45.3	46.5	47.7	48.8	50.0	51.2	52.3	53.5	54.7	55.9	57.1	58.3	59.4	60.6	61.8
8	36.6	37.7	38.9	40.0	41.2	42.3	43.5	44.7	45.9	47.0	48.2	49.4	50.6	51.8	53.0	54.1	55.3	56.5	57.7	59.0	60.2	61.4	62.6	63.8
9	38.1	39.3	40.5	41.6	42.8	44.0	45.2	46.4	47.6	48.8	50.0	51.2	52.4	53.6	54.8	56.0	57.2	58.4	59.7	60.9	62.1	63.4	64.6	65.8
10	39.7	40.9	42.1	43.3	44.5	45.7	46.9	48.1	49.3	50.6	51.8	53.0	54.2	55.5	56.7	57.9	59.2	60.4	61.7	62.9	64.2	65.4	66.7	67.9
11	41.4	42.6	43.8	45.0	46.3	47.5	48.7	49.9	51.2	52.4	53.7	54.9	56.1	57.4	58.6	59.9	61.2	62.4	63.7	65.0	66.3	67.5	68.8	70.1
12	43.1	44.3	45.6	46.8	48.1	49.3	50.6	51.8	53.1	54.3	55.6	56.8	58.1	59.4	60.7	62.0	63.2	64.5	65.8	67.1	68.4	69.7	71.0	72.4
13	44.9	46.1	47.4	48.6	49.9	51.2	52.5	53.7	55.0	56.3	57.6	58.9	60.2	61.5	62.8	64.1	65.4	66.7	68.0	69.3	70.7	72.0	73.3	74.7
14	46.7	48.0	49.3	50.5	51.8	53.1	54.4	55.7	57.0	58.3	59.6	60.9	62.3	63.6	64.9	66.3	67.6	68.9	70.3	71.6	73.0	74.4	75.7	77.1
15	48.6	49.9	51.2	52.5	53.8	55.1	56.4	57.8	59.1	60.4	61.8	63.1	64.5	65.8	67.2	68.5	69.9	71.3	72.6	74.0	75.4	76.8	78.2	79.6
16	50.5	51.8	53.2	54.5	55.8	57.2	58.5	59.9	61.2	62.6	64.0	65.3	66.7	68.1	69.5	70.9	72.3	73.7	75.1	76.5	77.9	79.3	80.8	82.2
17	52.5	53.9	55.2	56.6	58.0	59.3	60.7	62.1	63.5	64.9	66.3	67.7	69.1	70.5	71.9	73.3	74.8	76.2	77.6	79.1	80.5	82.0	83.5	84.9
18	54.6	56.0	57.4	58.8	60.2	61.6	63.0	64.4	65.8	67.2	68.6	70.1	71.5	73.0	74.4	75.9	77.3	78.8	80.3	81.8	83.3	84.8	86.3	87.8
19	56.8	58.2	59.6	61.0	62.4	63.9	65.3	66.8	68.2	69.7	71.1	72.6	74.1	75.5	77.0	78.5	80.0	81.5	83.1	84.6	86.1	87.6	89.2	90.7
20	59.0	60.4	61.9	63.3	64.8	66.3	67.7	69.2	70.7	72.2	73.7	75.2	76.7	78.2	79.8	81.3	82.8	84.4	85.9	87.5	89.1	90.7	92.2	93.8
21	61.3	62.8	64.3	65.8	67.3	68.8	70.3	71.8	73.3	74.9	76.4	77.9	79.5	81.1	82.6	84.2	85.8	87.4	89.0	90.6	92.2	93.8	95.4	97.1
22	63.8	65.3	66.8	68.3	69.8	71.4	72.9	74.5	76.1	77.6	79.2	80.8	82.4	84.0	85.6	87.2	88.9	90.5	92.1	93.8	95.5	97.1	98.8	100.5
23	66.3	67.8	69.4	71.0	72.5	74.1	75.7	77.3	78.9	80.5	82.2	83.8	85.4	87.1	88.7	90.4	92.1	93.8	95.5	97.2	98.9	100.6	102.4	104.1
24	68.9	70.5	72.1	73.7	75.3	77.0	78.6	80.3	81.9	83.6	85.2	86.9	88.6	90.3	92.0	93.8	95.5	97.2	99.0	100.7	102.5	104.3	106.1	107.9
25	71.7	73.3	75.0	76.6	78.3	80.0	81.7	83.3	85.1	86.8	88.5	90.2	92.0	93.7	95.5	97.3	99.1	100.9	102.7	104.5	106.3	108.2	110.0	111.9
26	74.6	76.3	78.0	79.7	81.4	83.1	84.8	86.6	88.4	90.1	91.9	93.7	95.5	97.3	99.2	101.0	102.9	104.7	106.6	108.5	110.4	112.3	114.2	116.2
27	77.6	79.4	81.1	82.9	84.6	86.4	88.2	90.0	91.9	93.7	95.5	97.4	99.3	101.2	103.1	105.0	106.9	108.8	110.8	112.7	114.7	116.7	118.7	120.7
28	80.8	82.6	84.4	86.3	88.1	89.9	91.8	93.7	95.6	97.5	99.4	101.3	103.3	105.2	107.2	109.2	111.2	113.2	115.2	117.3	119.3	121.4	123.5	125.6
29	84.2	86.1	87.9	89.8	91.7	93.7	95.6	97.5	99.5	101.5	103.5	105.5	107.5	109.5	111.6	113.7	115.7	117.8	120.0	122.1	124.2	126.4	128.6	130.8
30	87.8	89.7	91.7	93.6	95.6	97.6	99.6	101.6	103.7	105.7	107.8	109.9	112.0	114.2	116.3	118.5	120.6	122.8	125.1	127.3	129.5	131.8	134.1	136.4
31	91.6	93.6	95.6	97.7	99.7	101.8	103.9	106.0	108.2	110.3	112.5	114.7	116.9	119.1	121.4	123.6	125.9	128.2	130.5	132.9	135.3	137.7	140.1	142.5
32	95.7	97.8	99.9	102.0	104.2	106.3	108.5	110.7	113.0	115.2	117.5	119.8	122.1	124.5	126.8	129.2	131.6	134.0	136.5	139.0	141.5	144.0	146.6	149.1
33	100.0	102.2	104.4	106.6	108.9	111.2	113.5	115.8	118.2	120.5	122.9	125.4	127.8	130.3	132.8	135.3	137.8	140.4	143.0	145.6	148.3	150.9	153.7	156.4
34	104.7	107.0	109.3	111.7	114.0	116.4	118.9	121.3	123.8	126.3	128.8	131.4	134.0	136.6	139.2	141.9	144.6	147.4	150.1	152.9	155.7	158.6	161.5	164.4
35	109.7	112.2	114.6	117.1	119.6	122.2	124.7	127.3	129.9	132.6	135.3	138.0	140.8	143.6	146.4	149.2	152.1	155.0	158.0	161.0	164.0	167.1	170.2	173.3
36	115.2	117.8	120.4	123.0	125.7	128.4	131.1	133.9	136.7	139.5	142.4	145.3	148.3	151.3	154.3	157.3	160.5	163.6	166.8	170.0	173.3	176.6	179.9	183.3
37	121.3	124.0	126.8	129.6	132.4	135.3	138.2	141.2	144.2	147.3	150.3	153.5	156.7	159.9	163.1	166.5	169.8	173.2	176.7	180.2	183.7	187.3	191.0	194.7
38	127.9	130.8	133.8	136.8	139.9	143.0	146.2	149.4	152.6	155.9	159.2	162.6	166.1	169.6	173.2	176.8	180.4	184.2	188.0	191.8	195.7	199.7	203.7	207.7
39	135.3	138.5	141.7	145.0	148.3	151.7	155.1	158.6	162.1	165.7	169.4	173.1	176.9	180.7	184.7	188.7	192.7	196.8	201.0	205.3	209.6	214.0	218.5	223.0
40	143.7	147.1	150.6	154.2	157.8	161.5	165.3	169.1	173.0	177.0	181.1	185.2	189.4	193.7	198.1	202.5	207.1	211.7	216.4	221.1	226.0	231.0	236.0	241.1
41	153.2	157.0	160.9	164.8	168.9	173.0	177.2	181.5	185.8	190.3	194.8	199.5	204.2	209.1	214.0	219.1	224.2	229.4	234.8	240.2	245.8	251.5	257.2	263.1
42	164.3	168.6	172.9	177.3	181.9	186.5	191.3	196.1	201.1	206.2	211.4	216.7	222.2	227.7	233.4	239.2	245.2	251.3	257.5	263.8	270.3	276.9	283.6	290.5
43	177.5	182.3	187.3	192.4	197.6	202.9	208.4	214.0	219.8	225.8	231.8	238.1	244.5	251.0	257.7	264.6	271.7	278.9	286.3	293.8	301.5	309.4	317.4	325.7
44	193.6	199.3	205.1	211.0	217.2	223.5	230.0	236.7	243.6	250.8	258.1	265.6	273.3	281.2	289.4	297.8	306.3	315.1	324.1	333.3	342.8	352.4	362.3	372.4
45	214.1	220.9	227.9	235.2	242.7	250.4	258.4	266.7	275.3	284.1	293.3	302.6	312.3	322.3	332.5	343.0	353.8	364.9	376.2	387.9	399.8	412.0	424.5	437.4
46	241.5	250.0	258.9	268.2	277.8	287.8	298.1	308.8	319.9	331.4	343.3	355.5	368.1	381.1	394.5	408.3	422.5	437.1	452.0	467.4	483.3	499.6	516.3	533.5
47	280.9	292.4	304.4	316.9	330.0	343.6	357.8	372.5	387.7	403.4	419.8	436.6	454.1	472.1	490.7	509.9	529.8	550.4	571.7	593.8	616.7	640.5	665.3	691.0
48	344.1	360.9	378.4	396.8	416.0	436.0	456.9	478.6	501.2	524.7	549.3	574.8	601.5	629.4	658.6	689.3	721.5	755.6	791.5	829.7	870.4	913.9	960.6	1011.2
49	461.1	488.4	517.2	547.5	579.4	613.1	648.8	686.7	727.0	770.1	816.4	866.4	920.8	980.4	1046.2	1119.9	1203.3	1299.7	1413.6	1553.1	1732.9	1986.3	2419.6	>2419.6

09-63235-01

Appendix D: USGS Stream Gage Data

This section includes USGS data collected during water quality monitoring period.

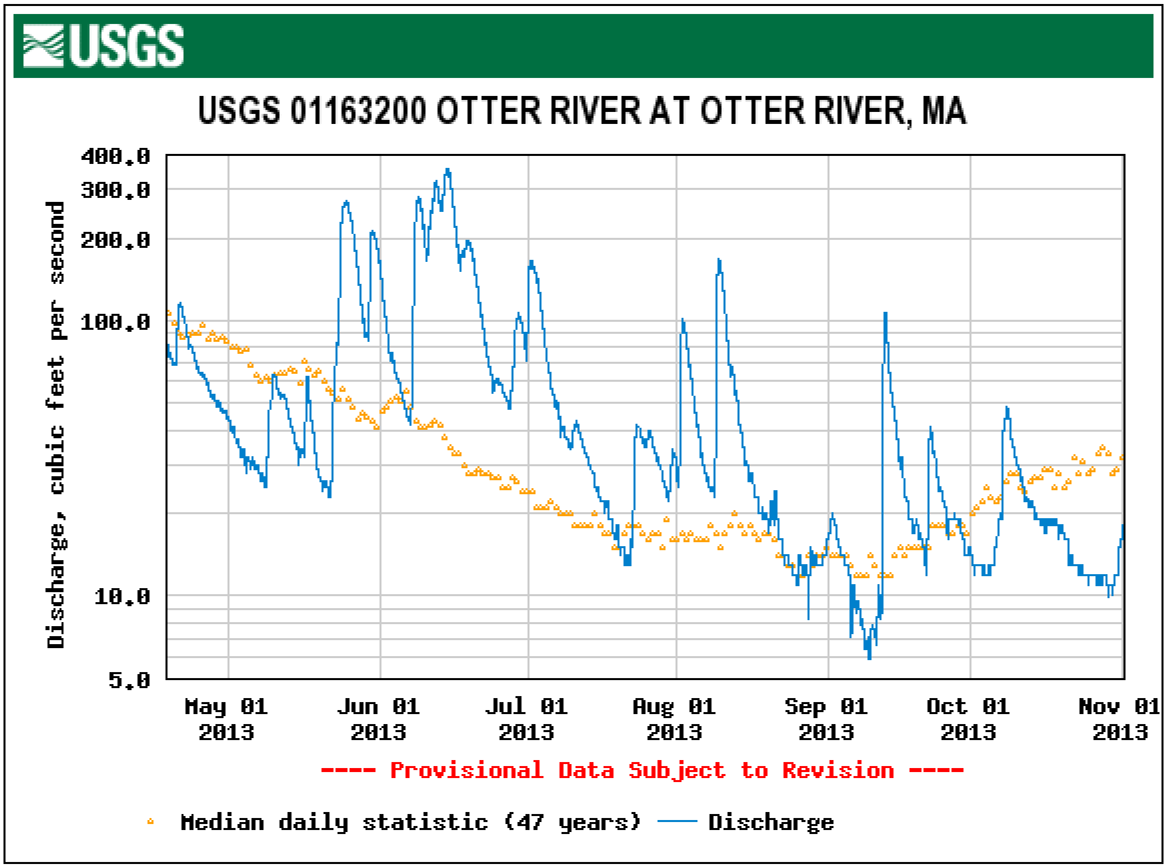


Figure 33: Raw USGS Stream Gage Data for Otter River

Appendix E: Statistical Summary of Results

This section includes statistical data from analysis of water quality data.

Table 15: Descriptive Statistic Summary

		Route 2A	WWTF Effluent	Plant Road	USGS
Ammonia Nitrogen	Mean+/- σ	0.563 +/- 0.201	0.196 +/- 0.252	0.503 +/- .205	0.482 +/- 0.164
	Minimum	0.250	0.080	0.200	0.280
	Maximum	0.970	1.060	0.800	0.740
Nitrate	Mean+/- σ	0.700 +/- 0.340	19.321 +/- 9.532	2.600 +/- 1.898	2.185 +/- 1.637
	Minimum	0.1	5.0	0.7	0.9
	Maximum	1.3	36.8	8.1	6.6
Nitrite	Mean+/- σ	0.001 +/- 0.001	0.008 +/- 0.007	0.002 +/- 0.004	0.002 +/- 0.003
	Minimum	0.000	0.003	0.000	0.000
	Maximum	0.005	0.028	0.012	0.012
Total Phosphorus	Mean+/- σ	0.221 +/- 0.083	0.268 +/- 0.142	0.233 +/- 0.132	0.212 +/- 0.092
	Minimum	0.090	0.080	0.080	0.085
	Maximum	0.320	0.540	0.560	0.320
Dissolved Orthophosphate	Mean+/- σ	0.181 +/- 0.208	0.332 +/- 0.184	0.175 +/- 0.141	0.379 +/- 0.708
	Minimum	0.040	0.100	0.045	0.055
	Maximum	0.830	0.610	0.530	2.740
E. coli	Mean+/- σ	56.6 +/- 61.332	6.00 +/- 15.312	88.4 +/- 75.853	79.9 +/- 81.202
	Minimum	2.0	0.0	2.6	0.5
	Maximum	218.1	59.1	298.1	292.7
Dissolved Oxygen	Mean+/- σ	4.27 +/- 1.44	8.16 +/- 0.68	4.09 +/- 1.79	8.12 +/- 1.12
	Minimum	2.45	7.31	2.45	6.73
	Maximum	7.00	9.52	8.10	10.25
Temperature	Mean+/- σ	17.3 +/- 4.87	16.75 +/- 3.02	17.51 +/- 4.51	16.76 +/- 4.56
	Minimum	7.00	10.60	8.70	8.00
	Maximum	24.60	21.20	25.20	23.50

Table 16: Analysis of Variance for Water Quality by Site (p-Values <0.05)

ANOVA	P-Value
Ammonia Nitrogen	**0.0001**
Nitrate	**0.0000**
Nitrite	**0.0001**
Total Phosphorus	0.5969
Dissolved Orthophosphate	0.3930
E. coli	**0.0062**
Dissolved Oxygen	**0.0000**
Temperature	0.9571

Table 17: Correlation Statistical Analysis Data

	Temp.	DO	Ammonia Nitrogen	Nitrate	Nitrite	TP	Dissolved OrthoP.	Total Coliform	E. coli
Temp.	1								
DO	**-0.52**	1							
Ammonia Nitrogen	**0.598**	**-0.529**	1						
Nitrate	-0.267	0.209	-0.164	1					
Nitrite	**-0.307**	0.224	-0.126	**0.358**	1				
TP	0.255	-0.135	0.154	-0.242	0.085	1			
Dissolved OrthoP	0.199	0.045	0.197	0.034	-0.051	0.188	1		
Total Coliform	-0.145	-0.053	0.003	**0.409**	0.163	-0.092	-0.117	1	
E. coli	**0.599**	**-0.31**	**0.524**	0.056	-0.154	0.217	0.089	**0.407**	1

Pearson’s Coefficient = 0.304

Appendix F: Conservation of Mass Data

Table 18: Conservation of Mass Data for Temperature

Date	Otter River Flow (cfs)	Otter River Adjusted (cfs)	WWTF (MGD)	WWTF (cfs)	2A	WWTF Effluent	Predicted Value	Plant Road	Percent Difference	Absolute Value Percent Difference
18-Apr	81	75.12	3.8	5.88	12.10	10.60	11.99	12.00	-0.1	0.1
1-May	40	35.05	3.2	4.95	15.50	12.50	15.13	15.60	-3.1	3.1
18-May	37	32.82	2.7	4.18	16.50	14.40	16.26	15.90	2.2	2.2
1-Jun	141	134.50	4.2	6.50	23.00	15.70	22.66	22.80	-0.6	0.6
15-Jun	332	321.94	6.5	10.06	15.60	14.90	15.58	15.40	1.1	1.1
29-Jun	104	97.50	4.0	6.19	21.60	17.70	21.37	21.30	0.3	0.3
14-Jul	30	25.82	2.7	4.18	24.60	19.70	23.92	25.20	-5.4	5.4
27-Jul	37	32.82	2.7	4.18	20.10	19.20	20.00	20.40	-2.0	2.0
10-Aug	161	156.05	3.2	4.95	20.90	20.10	20.88	20.90	-0.1	0.1
1-Sep	16	12.13	2.5	3.87	22.60	21.20	22.26	21.70	2.5	2.5
15-Sep	46	42.29	2.4	3.71	16.40	18.70	16.59	16.90	-1.9	1.9
29-Sep	17	13.60	2.2	3.40	14.40	18.50	15.22	15.80	-3.8	3.8
13-Oct	21	17.60	2.2	3.40	11.90	17.30	12.78	12.60	1.4	1.4
27-Oct	11	8.06	1.9	2.94	7.00	14.00	8.87	8.70	1.9	1.9
Average	76.7	71.8	3.2	4.9	17.30	16.75	17.39	17.51	-0.5	1.9

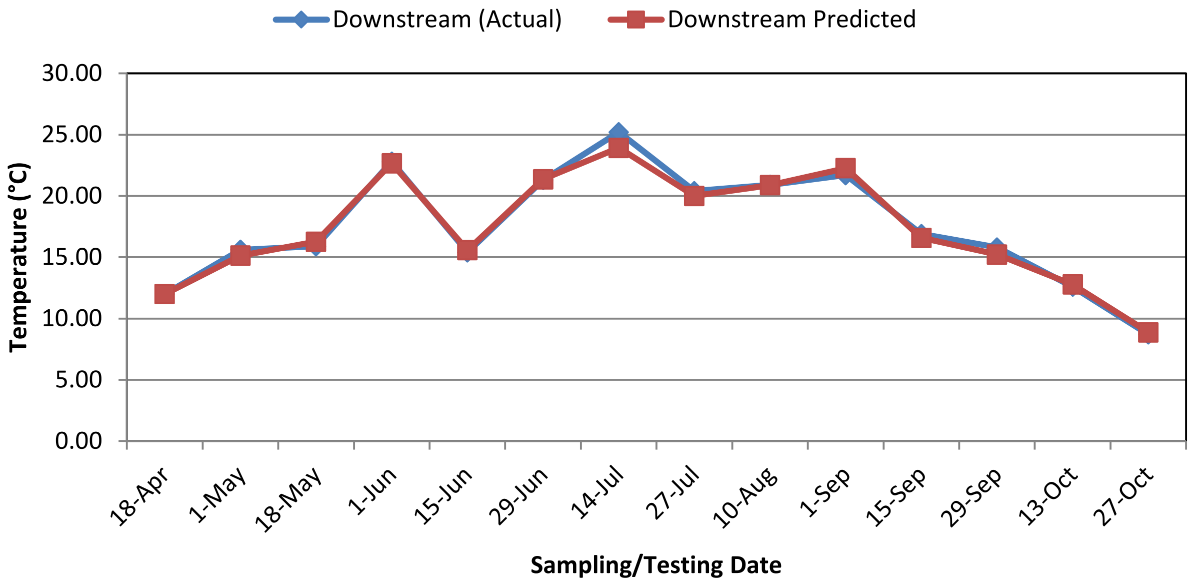


Figure 34: Conservation of Mass for Temperature

Table 19: Conservation of Mass Data for Dissolved Oxygen

Date	Otter River Flow (cfs)	Otter River Adjusted (cfs)	WWTF (MGD)	WWTF (cfs)	2A	WWTF Effluent	Predicted Value	Plant Road	Percent Difference	Absolute Value Percent Difference
18-Apr	81	75.12	3.8	5.88	N/A	N/A	N/A	N/A	N/A	N/A
1-May	40	35.05	3.2	4.95	6.50	9.05	6.82	6.30	7.6	7.6
18-May	37	32.82	2.7	4.18	5.83	8.72	6.16	5.50	10.7	10.7
1-Jun	141	134.50	4.2	6.50	3.43	7.58	3.62	3.11	14.1	14.1
15-Jun	332	321.94	6.5	10.06	5.53	8.79	5.63	5.38	4.4	4.4
29-Jun	104	97.81	4.0	6.19	2.70	8.20	3.03	2.48	18.1	18.1
14-Jul	30	25.82	2.7	4.18	2.45	8.75	3.33	2.45	26.4	26.4
27-Jul	37	32.82	2.7	4.18	3.79	7.70	4.23	3.50	17.3	17.3
10-Aug	161	156.05	3.2	4.95	2.75	7.35	2.89	2.49	13.9	13.9
1-Sep	16	12.13	2.5	3.87	3.49	7.62	4.49	2.90	35.4	35.4
15-Sep	46	42.29	2.4	3.71	3.36	7.75	3.71	2.46	33.8	33.8
29-Sep	17	13.60	2.2	3.40	4.28	7.31	4.89	3.23	33.9	33.9
13-Oct	21	17.60	2.2	3.40	4.40	8.34	5.04	3.00	40.5	40.5
27-Oct	11	8.06	1.9	2.94	7.00	7.55	7.15	6.29	12.0	12.0
Average	76.7	71.8	3.2	4.9	4.27	8.05	4.69	3.78	20.6	20.6

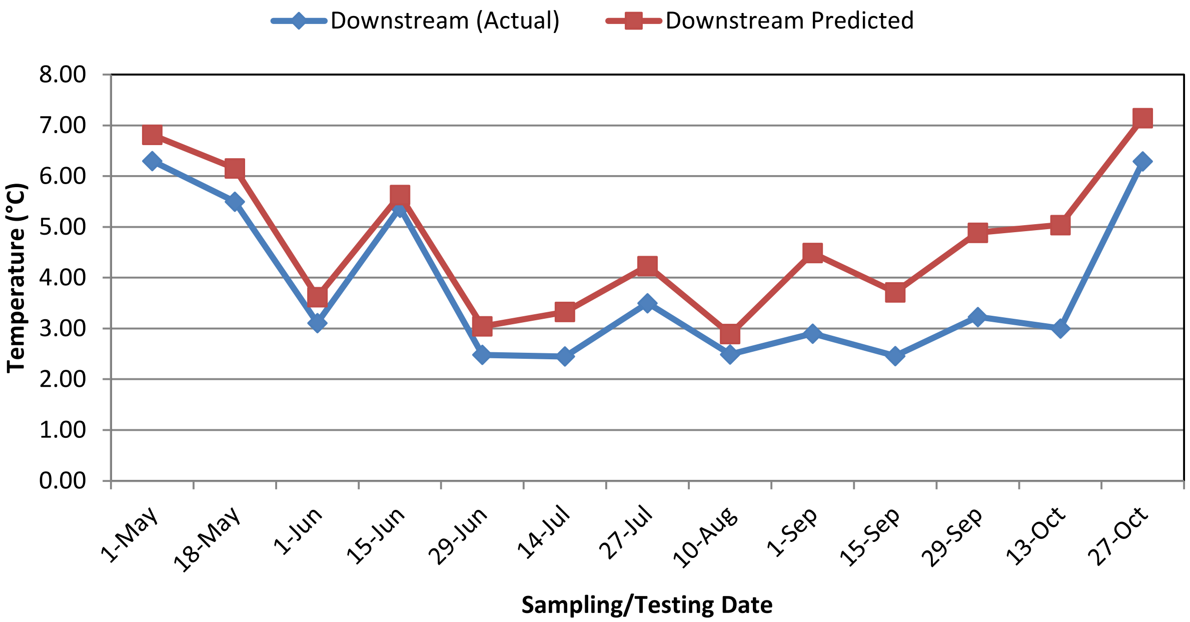


Figure 35: Conservation of Mass for Dissolved Oxygen

Table 20: Conservation of Mass Data for Nitrate

Date	**Otter River Flow (cfs)**	**Otter River Adjusted (cfs)**	**WWTF (MGD)**	**WWTF (cfs)**	**2A**	**WWTF Effluent**	**Predicted Value**	**Plant Road**	**Percent Difference**	**Absolute Value Percent Difference**
18-Apr	81	75.12	3.8	5.88	0.10	11.00	0.89	1.00	-12.2	12.2
1-May	40	35.05	3.2	4.95	0.40	18.00	2.58	1.70	34.1	34.1
18-May	37	32.82	2.7	4.18	0.90	20.50	3.11	3.20	-2.8	2.8
1-Jun	141	134.50	4.2	6.50	0.70	8.50	1.06	1.00	5.6	5.6
15-Jun	332	321.94	6.5	10.06	0.70	5.00	0.83	0.70	15.7	15.7
29-Jun	104	97.81	4.0	6.19	1.10	13.30	1.83	1.70	6.9	6.9
14-Jul	30	25.82	2.7	4.18	1.00	14.80	2.92	2.00	31.5	31.5
27-Jul	37	32.82	2.7	4.18	1.30	11.40	2.44	2.70	-10.6	10.6
10-Aug	161	156.05	3.2	4.95	0.80	16.50	1.28	2.00	-55.9	55.9
1-Sep	16	12.13	2.5	3.87	0.40	28.50	7.19	3.20	55.5	55.5
15-Sep	46	42.29	2.4	3.71	0.40	27.25	2.57	1.60	37.7	37.7
29-Sep	17	13.60	2.2	3.40	0.30	28.75	6.00	4.50	25.0	25.0
13-Oct	21	17.60	2.2	3.40	0.90	30.25	5.66	3.00	47.0	47.0
27-Oct	11	8.06	1.9	2.94	0.80	36.75	10.41	8.10	22.2	22.2
Average	76.7	71.8	3.2	4.9	0.70	19.32	3.50	2.60	14.4	26.0

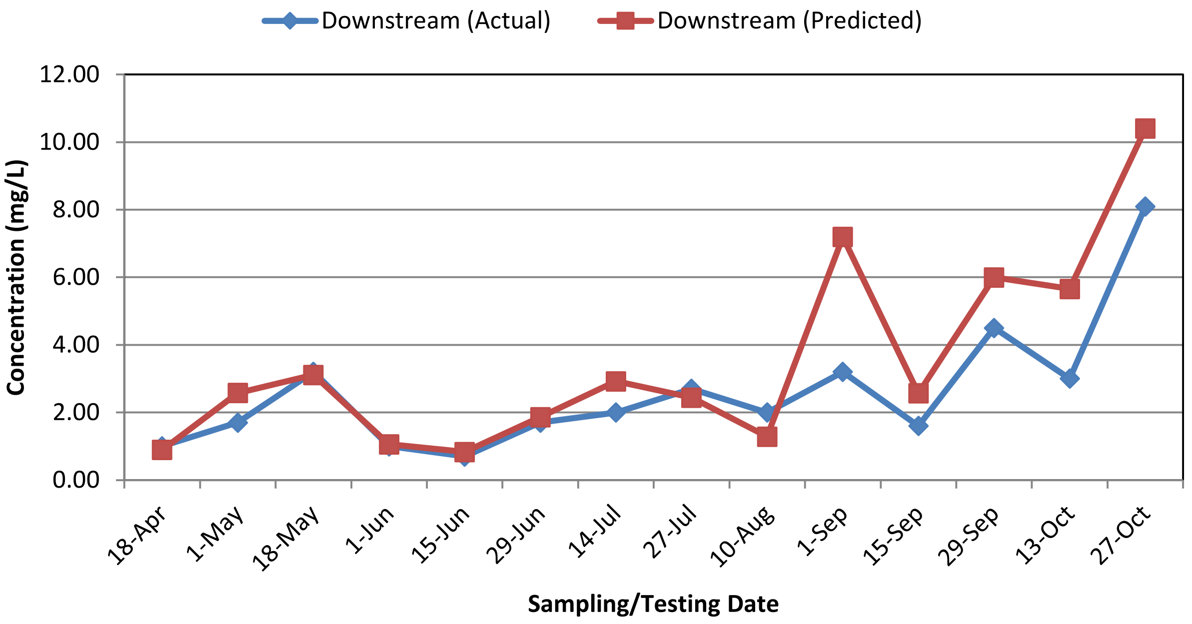


Figure 36: Conservation of Mass for Nitrate

Table 21: Conservation of Mass Data for Ammonia Nitrogen

Date	Otter River Flow (cfs)	Otter River Adjusted (cfs)	WWTF (MGD)	WWTF (cfs)	2A	WWTF Effluent	Predicted Value	Plant Road	Percent Difference	Absolute Value Percent Difference
18-Apr	81	75.12	3.8	5.88	0.25	0.13	0.24	0.20	17.1	17.1
1-May	40	35.05	3.2	4.95	0.34	0.17	0.32	0.29	9.1	9.1
18-May	37	32.82	2.7	4.18	0.41	0.16	0.38	0.39	-2.2	2.2
1-Jun	141	134.50	4.2	6.50	0.75	0.09	0.72	0.22	69.4	69.4
15-Jun	332	321.94	6.5	10.06	0.56	0.08	0.55	0.54	1.0	1.0
29-Jun	104	97.81	4.0	6.19	0.97	0.25	0.93	0.79	14.8	14.8
14-Jul	30	25.82	2.7	4.18	0.84	0.10	0.74	0.78	-5.8	5.8
27-Jul	37	32.82	2.7	4.18	0.66	0.12	0.60	0.63	-5.2	5.2
10-Aug	161	156.05	3.2	4.95	0.55	0.13	0.54	0.52	3.2	3.2
1-Sep	16	12.13	2.5	3.87	0.43	0.10	0.35	0.46	-31.3	31.3
15-Sep	46	42.29	2.4	3.71	0.68	0.14	0.64	0.64	-0.6	0.6
29-Sep	17	13.60	2.2	3.40	0.56	1.06	0.66	0.80	-21.2	21.2
13-Oct	21	17.60	2.2	3.40	0.49	0.12	0.43	0.45	-4.6	4.6
27-Oct	11	8.06	1.9	2.94	0.39	0.10	0.31	0.33	-5.6	5.6
Average	76.7	71.8	3.2	4.9	0.56	0.20	0.53	0.50	2.7	13.7

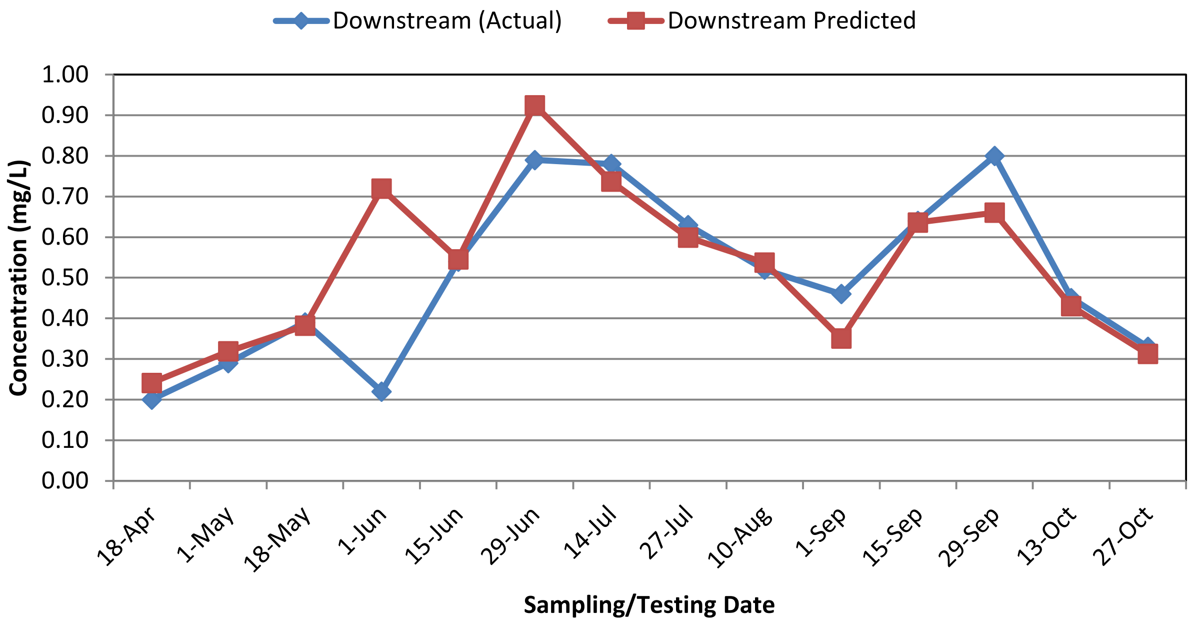


Figure 37: Conservation of Mass for Ammonia Nitrogen

Table 22: Conservation of Mass Data for Total Phosphorus

Date	Otter River Flow (cfs)	Otter River Adjusted (cfs)	WWTF (MGD)	WWTF (cfs)	2A	WWTF Effluent	Predicted Value	Plant Road	Percent Difference	Absolute Value Percent Difference
18-Apr	81	75.12	3.8	5.88	0.29	0.47	0.30	0.56	-84.8	84.8
1-May	40	35.05	3.2	4.95	0.17	0.22	0.18	0.15	14.9	14.9
18-May	37	32.82	2.7	4.18	0.11	0.11	0.11	0.12	-9.1	9.1
1-Jun	141	134.50	4.2	6.50	0.09	0.08	0.09	0.08	10.7	10.7
15-Jun	332	321.94	6.5	10.06	0.32	0.36	0.32	0.31	3.5	3.5
29-Jun	104	97.81	4.0	6.19	0.26	0.54	0.28	0.28	-1.2	1.2
14-Jul	30	25.82	2.7	4.18	0.29	0.28	0.29	0.26	9.9	9.9
27-Jul	37	32.82	2.7	4.18	0.30	0.27	0.29	0.29	0.2	0.2
10-Aug	161	156.05	3.2	4.95	0.29	0.38	0.29	0.34	-16.8	16.8
1-Sep	16	12.13	2.5	3.87	0.30	0.34	0.31	0.29	6.2	6.2
15-Sep	46	42.29	2.4	3.71	0.15	0.15	0.15	0.12	19.6	19.6
29-Sep	17	13.60	2.2	3.40	0.23	0.30	0.24	0.25	-4.0	4.0
13-Oct	21	17.60	2.2	3.40	0.18	0.12	0.17	0.10	39.7	39.7
27-Oct	11	8.06	1.9	2.94	0.11	0.12	0.11	0.09	14.9	14.9
Average	76.7	71.8	3.2	4.9	0.22	0.27	0.22	0.23	0.3	16.8

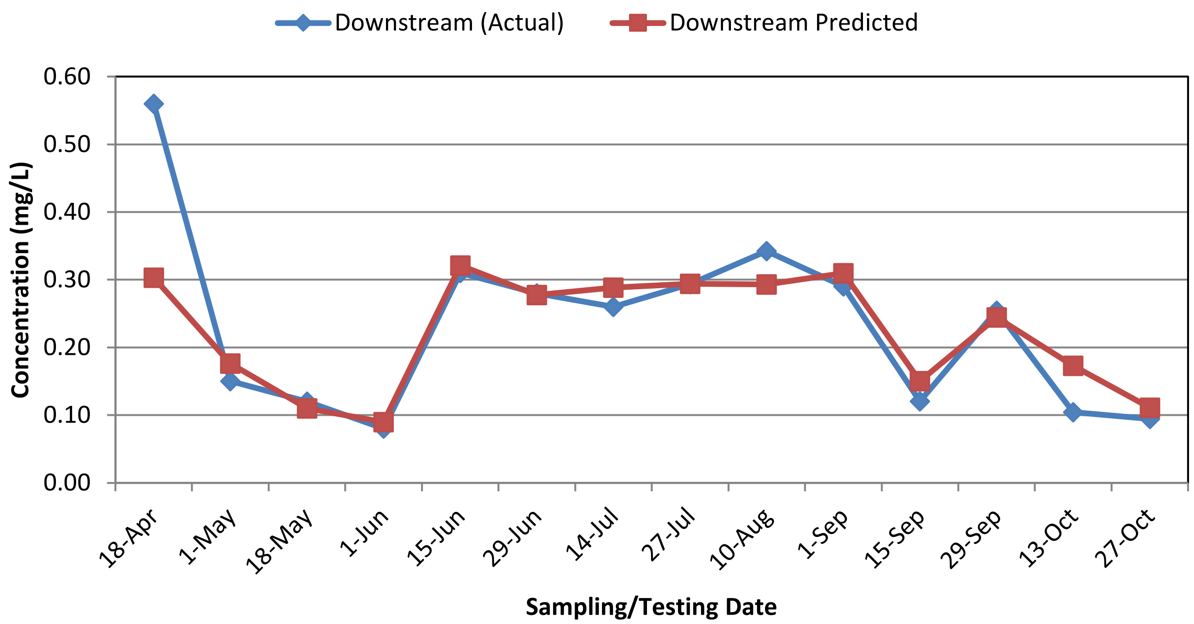


Figure 38: Conservation of Mass for Total Phosphorus

Table 23: Conservation of Mass Data for Dissolved Orthophosphate

Date	Otter River Flow (cfs)	Otter River Adjusted (cfs)	WWTF (MGD)	WWTF (cfs)	2A	WWTF Effluent	Predicted Value	Plant Road	Percent Difference	Absolute Value Percent Difference
18-Apr	81	75.12	3.8	5.88	0.09	0.17	0.10	0.05	52.9	52.9
1-May	40	35.05	3.2	4.95	0.06	0.38	0.10	0.07	31.4	31.4
18-May	37	32.82	2.7	4.18	0.07	0.16	0.08	0.05	40.3	40.3
1-Jun	141	134.50	4.2	6.50	0.14	0.20	0.14	0.13	13.7	13.7
15-Jun	332	321.94	6.5	10.06	0.05	0.24	0.06	0.10	-76.3	76.3
29-Jun	104	97.81	4.0	6.19	0.34	0.58	0.35	0.14	60.1	60.1
14-Jul	30	25.82	2.7	4.18	0.10	0.56	0.16	0.24	-48.4	48.4
27-Jul	37	32.82	2.7	4.18	0.83	0.61	0.81	0.53	34.2	34.2
10-Aug	161	156.05	3.2	4.95	0.31	0.61	0.32	0.31	2.9	2.9
1-Sep	16	12.13	2.5	3.87	0.04	0.10	0.05	0.09	-65.1	65.1
15-Sep	46	42.29	2.4	3.71	0.11	0.32	0.13	0.06	52.7	52.7
29-Sep	17	13.60	2.2	3.40	0.05	0.32	0.10	0.33	-217.1	217.1
13-Oct	21	17.60	2.2	3.40	0.18	0.24	0.19	0.10	47.3	47.3
27-Oct	11	8.06	1.9	2.94	0.17	0.17	0.17	0.26	-52.9	52.9
Average	76.7	71.8	3.2	4.9	0.18	0.33	0.20	0.17	-8.9	56.8

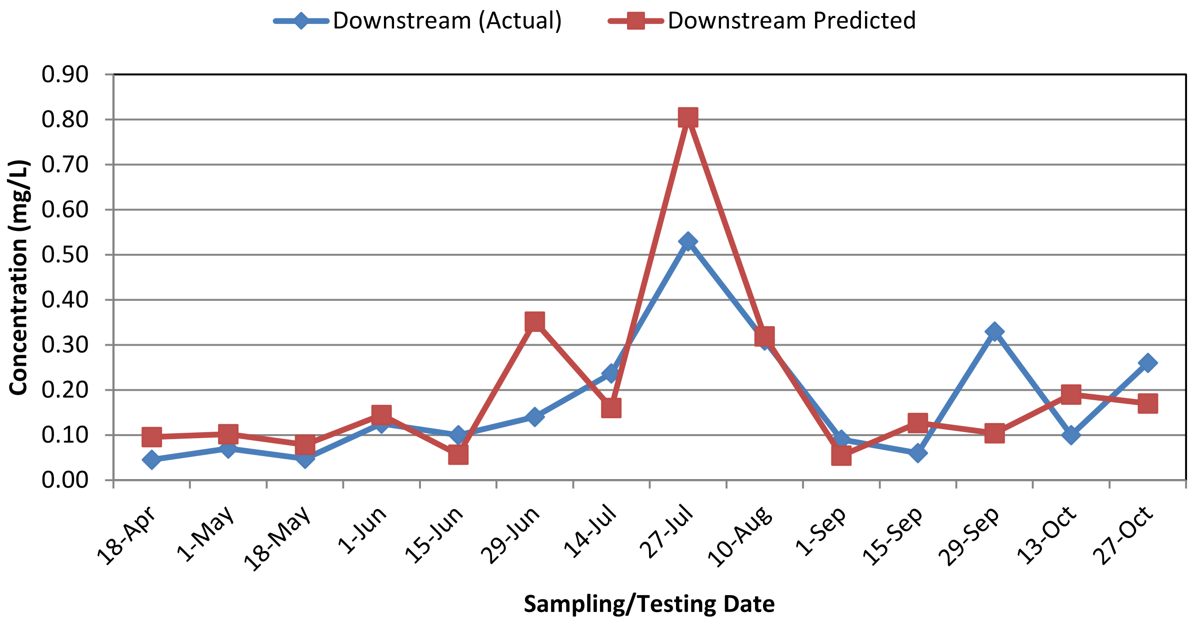


Figure 39: Conservation of Mass for Dissolved Orthophosphate