Final Report - Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the Upper Long Island Sound Watershed

Prepared by JJ Environmental, LLC Prepared for NEIWPCC
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LOW COST RETROFITS FOR NITROGEN REMOVAL AT WASTEWATER TREATMENT PLANTS IN THE UPPER LONG ISLAND SOUND WATERSHED

Executive Summary

- The objectives of this Project were to perform a detailed and accurate evaluation of treatment plants in the Upper Long Island Sound Watershed, evaluate ability, on a conceptual basis, to configure existing tankage and pumps for nitrogen removal; estimate impact on operation and maintenance budgets; determine training needs for plant staff; recommend whether operational and/or low cost modifications will be practical; and quantify the reduction in effluent nitrogen concentrations and mass that is likely achievable.

- To achieve these objectives, the project was divided into several tasks including: preparation and approval of the Quality Assurance Project Plan (QAPP), kick-off meetings, initial site visits and data collection, special sampling by contract laboratory, preliminary modeling using an EXCEL-based nitrogen removal model, technical memorandum documenting WWTPs selected for further study, BioWin modeling, cost estimation and second site visits.

- Of the original 29 facilities studied, twenty were selected as possible candidates for low-cost retrofits; eleven from Massachusetts, four from New Hampshire and five from Vermont.

- Using BioWin simulations, a conceptual nitrogen design model was developed and the cost associated with the necessary retrofits was estimated. These costs were amortized over a 10-year and 20-year period. Potential increases in operation and maintenance costs were quantified.

- A combination of the capital cost and operation and maintenance (O&M) cost was used to calculate the cost per pound of incremental nitrogen removed. Incremental nitrogen removal is defined as the difference between what the plant is currently removing and what the model is predicting after the plant is retrofit.

- The results indicate that all twenty treatment plants could improve nitrogen removal using low-cost retrofits. The total predicted increased nitrogen removal is about 2,313 lbs/day or 844,525 lbs/yr. The capital cost for these retrofits is approximately $5 million. The greatest quantity of nitrogen removed is from Massachusetts facilities since there were more facilities in the study and for the most part are bigger facilities than the plants in New Hampshire and Vermont.

- The cost per pound of nitrogen removed ranged from $0.51 to $5.09 per pound of nitrogen removed for the 10-year term and $0.36 to $3.85 per pound of nitrogen removed for the 20-year term with one outlier at $170.92 and $153.00 respectively because of a high capital cost for a small amount of nitrogen removal.

- Littleton, NH and Lyndonville, VT were not listed for cost estimates or nitrogen removed because they began removing nitrogen midway through the project and they are seeing significant nitrogen removals.

- There are three plants in the study that use Rotating Biological Contactors (RBCs). Since these plants cannot be modeled, the potential nitrogen removal cannot be quantified without field studies so any cost and any nitrogen removal has been excluded from this report.

- The project was not intended to produce detailed designs but to evaluate the potential of low cost total nitrogen (TN) removal strategies and to produce a preliminary estimate of the associated costs of the conceptual retrofit for planning purposes. The costs do not include the cost for detailed design. In this study there was a very limited level of influent and primary effluent nitrogen data. The amount of data was sufficient to meet the project objectives but is considered less than desired. Furthermore, the nitrogen data received from many of the plants was not necessarily the species needed for the most comprehensive and detailed modeling. There is confidence that the model output for each plant is a good representation of what the plant can expect for TN discharge once modifications are made, but it cannot be guaranteed.

1.0 Background and Introduction

During the early 1980s, Long Island Sound showed significant water quality degradation, mostly in the form of hypoxia (low dissolved oxygen). In response to hypoxic conditions, Federal and state (New York and Connecticut) legislators supported monitoring, research and action plans to preserve and protect the waters of Long Island Sound through the Long Island Sound Study (LISS) National Estuary Program partnership. Their support resulted in the following:

- In 1985, Congress appropriated funds to both Connecticut and New York to monitor and research water quality.
- The Clean Water Act reauthorization in 1987 established a National Estuaries Program and Long Island Sound was designated an Estuary of National Significance.
- In 1994 the LISS Comprehensive Conservation Management Plan (CCMP) was developed by a management conference consisting of federal, state, interstate and local agencies, universities, environmental agencies, industry and the public.

The LISS CCMP is a significant document that identified several problems associated with the degradation of water quality in Long Island Sound, including:

- Hypoxia, or low dissolved oxygen (DO)
- Toxic contamination
- Pathogen contamination
- Floatable debris
- Habitat loss and its impact on living marine resources
- Land use and development practices which have contributed to degradation of natural habitat and water quality

The LISS Management Conference has focused its resources on the most pressing problem, hypoxia. Hypoxia is caused when excess amounts of nitrogen enter Long Island Sound by way of discharges from wastewater treatment plants, surface runoff and atmospheric deposition. Nitrogen is typically the limiting nutrient in marine waters for phytoplankton, a microscopic plant. When phytoplankton die, they sink to the bottom waters where the decay process uses oxygen in the water column which reduces the available amount of DO below critical levels. Hypoxia is defined as DO concentrations below 3.0 mg/L. Severe hypoxia, also known as anoxia, occurs when DO concentrations decrease to less than 2.0 mg/L. The CCMP concluded that the main objective for Long Island Sound corrective actions should focus on reducing the amount of nitrogen entering the Sound to increase DO concentrations.

A Long Island Sound Total Maximum Daily Load (LIS TMDL) for nitrogen was approved by U.S. Environmental Protection Agency (EPA) in 2001. This TMDL specifies a 58.5% reduction in total nitrogen (TN) by 2014. Connecticut proposed to remove about 6,056 metric ton (6,670 US tons) per year of TN and New York proposed to remove about 15,570 metric tons (17,150 US tons) per year. Beginning in 2000, the waste load allocation for each treatment plant that discharges to LIS decreased annually through 2014. Wastewater treatment plants throughout

Connecticut and New York have adopted denitrification processes to meet the TMDL target load for nitrogen.

The LIS TMDL included a provision to re-evaluate and revise the TMDL at a later date. That process is currently underway by a workgroup comprised of representatives of the five watershed states (Connecticut, Massachusetts, New Hampshire, New York and Vermont), EPA, and NEIWPCC. The workgroup is considering many source categories for possible nitrogen reductions and is evaluating management strategies for achieving those reductions.

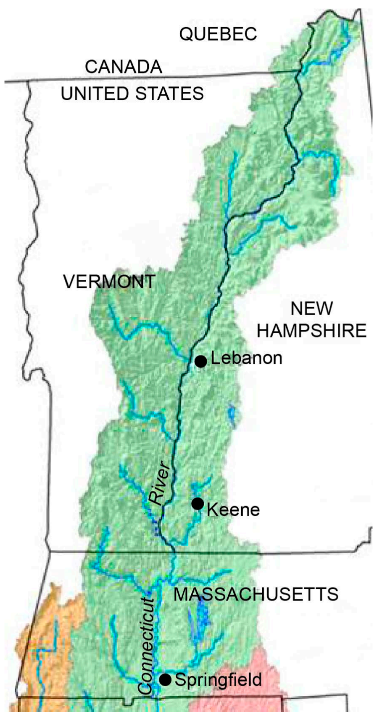

Figure 1 Upper Long Island Sound Watershed

There are three major river basins which contribute nitrogen to Long Island Sound; Connecticut, Housatonic and Thames. Of them, the Connecticut River is the largest. The Connecticut River begins near the Canadian border and passes through Vermont, New Hampshire, Massachusetts and Connecticut. The Housatonic River begins in western Massachusetts and the Thames River watershed includes areas in southern Massachusetts. About 37-50% of the nitrogen load (due to wastewater discharge, runoff and atmospheric deposition) from these three rivers to LIS was attributed to areas north of the Connecticut border according to the report "Estimated Nitrogen Loads from Selected Tributaries in Connecticut Draining to Long Island Sound, 1999–2009" (Mullaney and Schwartz, 2013). The drainage areas for these rivers north of the Connecticut/Massachusetts border constitute the Upper Long Island Sound Watershed (LISW) (Figure 1).

As a component of the evaluation and management strategies to reduce nitrogen in LIS, this Upper Basin (Massachusetts, New Hampshire, and Vermont) project was conducted to assess the feasibility and financial impact of installing low-cost biological nitrogen removal retrofits at select facilities in the Upper Connecticut River basin in Massachusetts (MA), New Hampshire (NH), and Vermont (VT) as well as facilities in the Housatonic and Thames River basins in Massachusetts.

2.0 Biological Nitrogen Removal

There are various species of nitrogen common in wastewater:

- Ammonia (NH_3 or NH_4)
- Organic Nitrogen
- Total Kjeldahl Nitrogen (TKN)
- Nitrate (NO_3)
- Nitrite (NO_2)

The species in raw wastewater are primarily ammonia nitrogen and organic nitrogen. A portion of organic nitrogen is hydrolyzed to ammonia nitrogen in the collection system thus the predominant form entering the treatment process is ammonia nitrogen. Typically there is little to no nitrate or nitrite nitrogen in treatment plant influent.

Although the species are different, when determined by analytical methods, they are all calculated and reported as nitrogen (N); for example, NH_4-N (ammonia-nitrogen), NO_3-N (nitrate-nitrogen), etc. TKN measures both organic nitrogen and ammonia nitrogen. To calculate the total nitrogen (TN) for a treatment plant, the following formula is used:

$$TN = TKN + Inorganic\ Nitrogen$$

or

$$TN = TKN + NO_2 + NO_3$$

or

$$TN = NH_4 + OrgNitrogen + NO_2 + NO_3$$

The state of the art method for removal of nitrogen in wastewater is through biological nitrogen removal (BNR). BNR is accomplished through two steps-nitrification and denitrification. Nitrification is conversion of ammonia to nitrite (Eq 1) and then nitrite to nitrate (Eq 2).

$$2NH_4^{\ +} + 3O_2 \rightarrow 2NO_2^{\ -} + 4H^{\ +} + 2H_2O \qquad \text{Eq 1}$$

$$2NO_2^{\ -} + O_2 \rightarrow 2NO_3^{\ -} \qquad \text{Eq 2}$$

There are two groups of organisms responsible for this conversion. The first step (Eq 1) is carried out by ammonia oxidizing bacteria (AOBs) and the second step (Eq 2) by nitrite oxidizing bacteria (NOBs). These autotrophic organisms require aerobic conditions (typically DO concentrations of about 1.5 to 2.0 mg/L) and the presence of carbon dioxide. Nitrification uses alkalinity, so a treatment plant must have sufficient alkalinity entering the plant or have the ability to add it otherwise the pH will decrease and result in an inhibition of the nitrification process.

Denitrification is the biological conversion of nitrate to nitrogen gas (Eq 3) and requires an anoxic zone with DO concentrations less than 0.3 mg/L. Denitrification produces alkalinity which off-sets about 50% of the alkalinity requirement in the nitrification step. Nitrification must occur in order for denitrification to occur. If a treatment plant cannot nitrify because of process or influent characteristics, then it will unable to remove nitrogen to any appreciable amount.

$$2NO_3^{\ -} + 10\,e^{\ -} + 12\,H^{+} \rightarrow N_2 + 6H_20 \qquad \text{Eq 2}$$

Modified Ludzak-Ettinger (MLE) Process shown in Figure 2 is the most commonly used BNR process. MLE is a single-sludge, pre-denitrification process where denitrification and some biochemical oxygen demand (BOD) removal occurs in the anoxic zone (first zone) with additional BOD removal and nitrification occurring in the aerobic zone (second zone). BOD is removed in the anoxic zone because organic compounds are the electron donor for the facultative heterotrophic organisms used for denitrification.

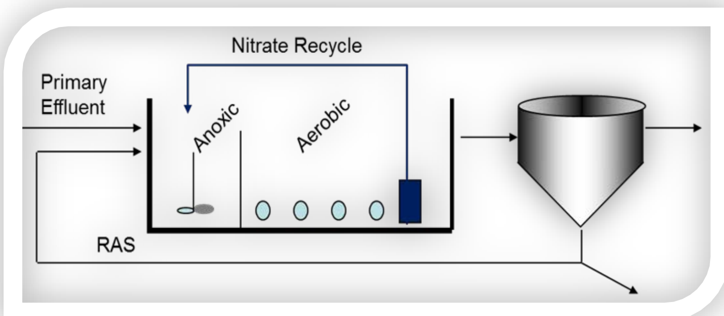

Figure 2 Modified Ludzak-Ettinger Process

Large capacity pumps are placed at the end of the aerobic zone to return nitrified wastewater to the anoxic zone for denitrification. This is called internal recycle, nitrate recycle, or mixed liquor recycle and is typically represented as NRCY (nitrate rich recycle). This is not to be confused with the standard return activated sludge (RAS) which must also be designed into the process. The anoxic zone must have DO concentrations <0.3 mg/L and must be well mixed for the best and most efficient nitrogen removal rate. Existing activated sludge plants can be modified for BNR by creating an anoxic zone from an existing aerated zone if there is sufficient reactor volume and clarifier capacity. The MLE process can typically achieve 6 to 10 mg/L effluent TN concentrations. To consistently achieve lower effluent concentrations, more complex and therefore more costly processes are required.

In addition to the MLE process, plants can remove nitrogen by cycling aeration system on and off to create alternating anoxic and aerobic zones if the equipment can sustain these cycles without damage. Additionally, a step feed system can also be employed if a treatment plant has the ability to add influent or primary effluent at various locations throughout the bioreactors and also have sufficient volume for the creation of anoxic zones. In general, the MLE process is easy to operate and control and produces a very stable effluent quality.

3.0 Project Description

3.1 Project Objectives

The objectives of the "Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the Upper Long Island Sound Watershed Project" are to:

1. Perform a detailed and accurate evaluation of the treatment plants including but not limited to existing and design capacity, expected near term future flows, seasonal flow and load variation, capacity of bioreactors and clarifiers and wastewater characteristics;
2. Evaluate ability to configure existing tankage and pumps for nitrogen removal;
3. Determine impact of nitrogen removal on operation and maintenance budgets;
4. Determine nitrogen removal training needs for plant staff;
5. Recommend whether operational and/or low cost modifications will be practical; and
6. Quantify the achievable reduction in effluent nitrogen concentrations and mass.

To achieve these objectives, the project was divided into several tasks including:

- Preparation and approval of the Quality Assurance Project Plan (QAPP) (Appendix A)
- Kick-off meetings
- Initial site visits and data collection
- Special sampling by contract laboratory
- Preliminary modeling using an EXCEL-based nitrogen removal model
- Technical memorandum documenting WWTPs selected for further study (Appendix B)
- BioWin modeling and second site visits
- Development of recommended modifications to achieve low cost nitrogen removal
- Comparative cost analysis based on dollars per pound of nitrogen removed

3.2 Project Team

The team included the project manager, project lead, project officer, technical advisory committee and contract laboratory. The project organization is shown in Figure 3. The following is a detailed list of project participants and their responsibilities:

Project Manager: Emily Bird, NEIWPCC, was responsible for overseeing implementation of the project work plan, reviewing draft reports, approving final report, managing the project budget, selecting and contracting directly with a Contract Laboratory for analysis of wastewater samples, providing necessary information to the Project Lead, processing invoices and meeting any obligations with the U.S. EPA project officer.

Project Lead: Jeanette Brown, President JJ Environmental, LLC, was responsible for all agreed upon tasks as outlined in the contract and approved statement of work including collecting and analyzing existing plant data, plant designs, performing site visits, developing nitrogen removal projections and costs, organizing project meetings, preparing cost estimates, writing reports, coordinating with Contract Laboratory, preparing the QAPP and preparing the final report. Two subcontractors, Stacy Passaro, Passaro Engineering and Dr. David Stensel, University of Washington, assisted JJ Environmental, LLC with the above tasks.

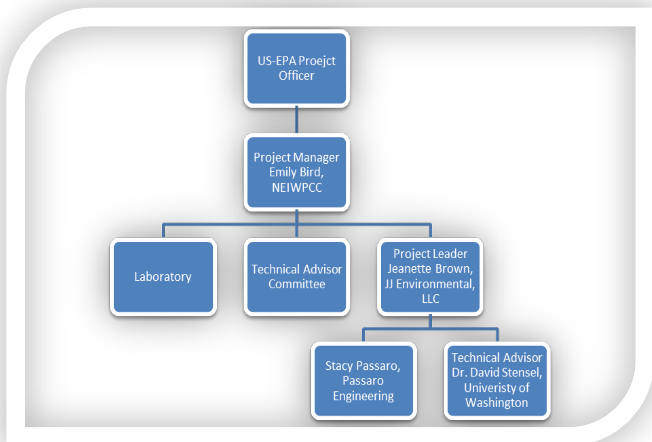

Figure 3: Organization Table

Project Officer: Leah O'Neill, U.S. EPA Region 1 was responsible for reviewing reports and other administrative requirements.

Technical Advisory Committee: The Technical Advisory Committee was responsible for providing general guidance and advice on all technical aspects of the project, including: reviewing the QAPP, reviewing draft reports, reviewing draft recommendations, reviewing final recommendations and reviewing and approving final report.

Contract Laboratory: The Contract Laboratory, Chemserve, was responsible for laboratory testing of specific analytes required for this project. They were responsible for adhering to all approved methodology and the approved QA/QC procedures, adhering to approved disposal procedures and adhering to the project schedule.

3.3 QAPP

This project was funded by the U.S. EPA and distributed and managed through the New England Interstate Water Pollution Control Commission (NEIWPCC). Since this project included collection and evaluation of data, NEWIPCC required a detailed document describing the quality control and assurance program. No data collection or evaluation could begin until the QAPP was approved.

The following is a direct quote from the Guidance Document describing the QAPP (NEIWPCC, March 2006) which explains the QAPP and its importance: "A QA Project Plan is a planning document that provides a "blueprint" for obtaining the type, quantity and quality of data needed to support environmental decision making. More simply, a QA Project Plan is a written document describing the procedures that a project will use to ensure that the data or information collected and analyzed will meet project requirements. The QA Project Plan documents all quality assurance (QA), quality control (QC) and technical activities and procedures associated with planning, implementing and assessing all environmental data operations. The phrase "environmental data operation" refers to activities involving the collection, generation, compilation, management, analysis, evaluation and/or use of environmental data. Environmental data can be generated from direct measurement activities (such as fish or bird surveys, water quality monitoring, or microbial source tracking), collected from other sources (such as previous studies, surveys, or evaluations), or compiled from computerized databases and information systems (such as state or federal databases or computer models)."

3.4 Special Sampling Program

Although several of the treatment plants included in this project had effluent nitrogen data, few had influent nitrogen data. Additionally, for the computer modeling phase, parameters such as soluble chemical oxygen demand (SCOD), soluble Kjeldahl nitrogen (SKN) and influent alkalinity were necessary.

Table 1 Final List of Facilities in First Phase

Facility Name	State	Facility Name	State
Amherst	MA	Claremont WWTF	NH
Athol	MA	Hanover WWTF	NH
Belchertown	MA	Hinsdale WWTF	NH
Easthampton	MA	Keene WWTF	NH
Gardner	MA	Littleton WWTF	NH
Great Barringtor	MA	Bellows Falls	VT
Lenox	MA	Town of Springfield	VT
Montague	MA	Town of Windsor	VT
Orange	MA	Town of St. Johnsbur	VT
Palmer	MA	Village of Ludlow	VT
Pittsfield	MA	Village of Lyndonvill	VT
South Hadley	MA		
Southbridge	MA		
Spencer	MA		
Ware	MA		
Warren	MA		
Webster	MA		
Winchendon	MA		

NEIWPCC contracted with a laboratory (Chemserve) to process special samples. The special sampling program was explained to plant personnel at each initial site visit including a review of proper sampling procedures and identification of sample locations to ensure these samples would be representative and reflect the influent characteristics entering the biological system. Furthermore, plant personnel were instructed to take sample after sidestreams such as digester supernatant, septic waste, filtrate or centrate from thickening or dewatering operations entered the treatment plant. Furthermore, if plants only dewatered on certain days or received septic on certain days, they were asked to include one of those days as part of the special sampling period to ensure any increased loadings were captured in the data. Additionally, instructions were provided for proper storage and transfer of samples to Chemserve and use of the chain of custody form.

The special sampling program included three consecutive days of sampling. The personnel at each treatment plant took samples of influent or primary effluent for determination of six analytes (BOD_5, sCOD, NH_4-N, TKN, TSS/VSS and Alkalinity and final effluent for five analytes (BOD_5, sCOD, NH_4-N, sKN and NO_x).

Samples were immediately refrigerated until transferred by the plant staff to a Chemserve courier, placed in a cooler and delivered to the laboratory. A chain of custody form was used for the sample transfer. The results of this special sampling program were used, in part, for initial selection of plants for further study and for the modeling phase.

3.5 Project Facilities

At project start, there were thirty-two treatment plants included in the study. Four of the initial thirty-two plants were designated for cost estimates only based on a study performed by another consultant ("Engineering Feasibility and Cost Analysis of Nitrogen Reduction from Selected POTWS in Massachusetts", CDM 2007). Those plants were Easthampton, Palmer, South Hadley and Ware. However, there was insufficient information in that report to determine if low cost nitrogen removal was possible and if so how it could be accomplished. After discussion with NEIWPCC and Massachusetts Department of Environmental Protection staff, those four plants were included for the full study program.

Additionally, some plants from the original list were deleted because they were under design or construction of nitrogen removal processes or chose not to participate in the study. The final list for facilities included in the first phase of the study is shown in Table 1.

Table 2 Facilities Selected for Further Study

FACILITY NAME	STATE
Athol Wastewater Treatment Plant	MA
Belchertown Water Reclamation Facility	MA
Claremont WWTF	NH
Gardner Wastewater Treatment Plant	MA
Great Barrington Wastewater Treatment Facility	MA
Hanover Wastewater Treatment Reclamation Facility	NH
Hinsdale Wastewater Treatment Plant	NH
Littleton Wastewater Treatment Reclamation Facility	NH
Ludlow Wastewater Treatment Facility	VT
Lyndonville Wastewater Treatment Pant	VT
Palmer Wastewater Treatment Plant	MA
Pittsfield Wastewater Treatment Plant	MA
South Hadley Wastewater Treatment Plant	MA
Spencer Wastewater Treatment Plant	MA
Springfield Wastewater Treatment Plant	VT
St. Johnsbury Wastewater Treatment Facility	VT
Warren Wastewater Treatment Plant	MA
Webster Wastewater Treatment Facility	MA
Winchendon Wastewater Pollution Control Facility	MA
Windsor	VT

3.6 Facility Selection for Further Study

During the first site visit, various plant records were collected including two years of operating data, plant schematics and plant design criteria. Additional data from the site visits included wet weather-cold weather operational problems, number and capacity of various pumps and blowers or aerators, sizes of tanks and types of sidestreams and the locations where they enter the process. Additionally, each plant was sent an information request which asked for the average of all influent, primary effluent and final effluent monitoring parameters for a two-year period and other pertinent information. This information along with the results of the special sampling was used to determine which plants would be included for further study which includes BioWin modeling for all activated sludge plants, conceptual designs for all plants including biofilm plants (Rotating Biological Contactors-RBCs), and cost estimation.

Various graphical and statistical methods were used in analyzing data from each plant. Flow and BOD loading variability, temperature, and influent/effluent nitrogen species, if available, were analyzed. Flow is a critical factor since nitrogen removal requires sufficient plant capacity of process units such as bioreactors and clarifiers. Flow data were analyzed using histograms (frequency distribution) to compare current average flow to design flow and 80% of the design flow. This is important because if the plant is currently receiving flows close to 80% of design flow, it might be an indicator that low-cost nitrogen removal is not appropriate for that facility since typically that is the threshold for communities to limit future sewer connections. Additional statistical analysis used to make assessments of the treatment plants included mean, standard deviation, linear regression and correlation for all important parameters such as flow, wastewater temperature, BOD, TSS and nitrogen concentrations (if available).

In addition to this analysis, a desk top nitrogen removal model was used to evaluate the treatment plants. The model is based on the International Association on Water Quality (IAWQ) Activated Sludge model. This is a steady state model using average conditions. Inputs include, flow, BOD, COD, nitrogen species concentrations, temperature (average of winter months) and desired permit conditions. Inputs also include default kinetic coefficients corrected for temperature. It is a "go/no go" model since it does not have the sophistication of the BioWin model used for the second phase of the project. The output from the model is the total volume of the bioreactors and the distribution of this volume between anoxic and aerobic zones. Additionally, it calculates clarifier capacity. Neither this model nor the BioWin model has been developed for biofilm processes using rotating biological contactors (RBC's) so an empirical method is used for evaluating the RBC plants and is explained in the discussion for the individual plants.

In selecting facilities for further study (BioWin modeling, conceptual design and cost estimation), several things were taken into consideration such as flow, loading, temperature, sCOD to TKN ratio, effluent SKN, nitrate/nitrite concentration and total nitrogen. In many cases, if the plant was already achieving total annual effluent nitrogen concentrations of less than 10 mg/L, typically they were not selected since the assumption was made they were already doing low-cost nitrogen removal. Table 2 is the list of plants selected for further study. A detailed explanation of each plant and the reasons for including or not including it for further study is reported in the project technical memo (Appendix B). One additional plant was selected for evaluation, Orange, MA, but not modeling, conceptual design or cost estimation. The Orange plant has been nitrifying and denitrifying well except for certain times. The evaluation for Orange was simply to determine, if possible, why sometimes their performance declined.

3.7 BioWin Modeling

The BioWin model was selected for this project because it is a wastewater treatment process simulator that ties together biological, chemical and physical process models and is used world-wide to design, upgrade and optimize wastewater treatment plants of all types. It is considered one of the industry standard models. One drawback of this model as well as other wastewater models is that Rotating Biological Contactor (RBC) processes cannot be simulated, so potential nitrogen removal at those plants was based on theoretical and empirical method.

The modeling process employed two steps. First, a baseline model was created. The baseline model was developed to reasonably replicate current plant conditions and was configured to match the number and dimension of the various unit processes typically used by the treatment facility. The baseline model was then calibrated. Calibration means adjusting the parameters of the model to have good agreement between model predictions and measured data. Calibration of the model is one of the most important and critical steps in this process. In general, steady state predictions from the model calibration should match actual data within 5 to 20%. For this project, the model was calibrated using the averages from plant data typically between the period of mid-2011 to mid-2014 and gives a level of confidence that the model represents the specific treatment plant and correlates as closely as possible to the current effluent BOD, TSS and TN concentrations discharged from the treatment plant. It is important to note that most plants had no influent nitrogen data and many had limited effluent nitrogen data. In many cases, the only nitrogen data available were those obtained from the project special sampling. In those cases, only that data was used because of the absence of historical or monitoring plant data. The calibrated model is called the "Baseline Model". Once the model was calibrated, various design alternatives and changes in process control parameters were evaluated to determine which alternative resulted in the lowest possible effluent total nitrogen called the "Conceptual Design". Sensitivity testing of the model was performed by reducing the temperature to the wintertime average and rerunning the model. In addition, the model was run with an increased flow comparable to 80% of the design flow at the wintertime temperatures. Wintertime average temperatures were obtained from the treatment plants and represented the average temperature from January to March.

As stated above, BioWin modeling software is accepted as an industry standard, being utilized by many environmental engineering design firms and has a proven level of success. However, modeling regardless of the model used, is only as good as the available data. In this study there was a very limited level of influent and primary effluent nitrogen data. The amount of data was sufficient to meet the project objectives but is considered less than desired. Furthermore, the nitrogen data received from many of the plants was not necessarily the species needed for the most comprehensive and detailed modeling. There is confidence that the model output for each plant is a good representation of what the plant can expect for TN discharge once modifications are made, but it cannot be guaranteed. It is important to note that monitoring influent, effluent and primary effluent nitrogen species on a regular basis is critical and is highly recommended. Having these data available is important for plants, consultants and regulators to help make decisions and recommendations concerning future nitrogen upgrades.

3.8 Conceptual Design

The project was not intended to produce detailed designs, but to evaluate the potential of low cost TN removal strategies and produce a preliminary estimate of the associated costs of the conceptual retrofit for planning purposes. The conceptual design for each facility is based on the model output or calculated nitrogen removal potential and the equipment or modifications necessary to achieve that concentration. These modifications (mostly MLE-type processes) are practical and have proven successful at many treatment facilities. They are cost effective and are relatively easy to operate and control.

Depending on the existing plant configuration and process, the design might include addition of nitrate recycle pumps, creation of anoxic and or swing zones (swing zones can be used as aerobic or anoxic zones depending on either seasonal or flow changes at a particular treatment plant) and/or mixers. In some cases, the design includes the addition of variable frequency drives (VFDs), piping modifications and/ or addition of isolation valves. In all cases, conceptual designs include instrumentation. The instrumentation recommended and included in the cost estimates are the typical units currently used at treatment plants; pH, DO, nitrate/nitrite, ammonia. The instrumentation can be located and read locally or through a computer-based data acquisition system (SCADA). The instruments are easy to operate and maintain. Both the DO and ammonia probes are capable of controlling DO concentration in the bioreactors if the plant has variable drive blowers and automatic air controlled valves which would be determined during design of the retrofit. The exact location of the instruments and whether the readout will be local or both locate and remote data acquisition system (SCADA) should be made when the system is designed.

3.9 Cost Estimate

A pro forma construction estimate for each facility was prepared based on the conceptual design for that specific facility. The cost estimate is broken down into categories:

- Contractor labor
- Contractor material
- Contractor equipment

The contractor material category includes items such as mixers and pumps, piping, baffles, instrumentation and/or chemical feed systems which are necessary to achieve the predicated effluent nitrogen concentration as well as the installation costs associated with them. The contractor material costs are based on estimates obtained from manufacturers. The contractor equipment category includes whatever equipment needed to install the pumps, mixers, etc. such as forklifts and cranes. Labor costs were calculated using prevailing wage rates for the State of Connecticut, Central Valley Region. Since each state and region has different labor rates, using one specific labor rate normalized the cost estimates and allowed comparisons from plant to plant and state to state. The cost estimates are budgetary for planning purposes only and will vary depending on the plant location, site conditions and equipment. Furthermore, the estimate does not include any cost for detailed design or other engineering services, but does include a 15% contractor markup on materials and equipment. Additionally, annual increases or decreases in operating cost (primarily electrical) were estimated and included in the project cost. The reduction in oxygen due to the reduction of BOD from denitrification and therefore, the reduction in electrical cost for aeration, was not taken into account as an avoided cost. A rate of $0.10 per kilowatt-hour (kWh) was used for estimating electrical costs. Capital costs were calculated using 3% interest over a term of 10 years and 20 years. The annual capital cost plus the annual operation and maintenance (O&M) cost were used to calculate the cost per pound of nitrogen removed. Nitrate recycle pumps were sized at 4 times the current influent flow (4Q) with variable frequency drives to allow them to operate at lower flows. One redundant pump was specified for each plant. The number of pumps varied from plant to plant depending on what appeared most beneficial for the plant operators.

The number of instruments varied based on the number of tanks in service and where best to monitor particular parameters.

3.10 Training Needs

It is important that operators understand the theory and practice of nitrogen removal including process control and monitoring. As part of this project, a nitrogen training course will be made available to all plant operators within this study.

3.11 Explanation of Comparison Table

There is a "Baseline Model Comparison to Conceptual Design" table for each treatment plant. The column labelled "Plant Influent Data" represents the actual two-year average influent values for the data sets supplied by each treatment plant using the most current two-years. The "Baseline Model Effluent" column represents the data from the calibrated model and in general is within $\pm$ 10% of the actual two-year average effluent values determined from the data sets supplied by the treatment plants. In general, steady state predictions from the model calibration should match actual data within $\pm$5 to 20%, but the goal of this project was to be within $\pm$ 10% as often as possible. The two parameters that consistently fell outside of this range were effluent BOD and TKN. In general, the model predicted lower effluent BOD concentrations and higher effluent TKN concentrations. This is most likely due to the inability to fully characterize influent carbon and TKN fractions due to sampling budget constraints.

The column labelled "Design Model Effluent" represents the predicted effluent quality at average conditions from the nitrogen conceptual design model. These are the expected values if the design is implemented. The last column labelled "Compare Baseline to Model Design" is the comparison of the current effluent values achieved by the treatment facility to the expected values for the conceptual design. The purpose of this is to give credit to the treatment plant for their current level of nitrogen removal and also to show that expected effluent permit parameters are met.

4.0 Individual Plant Discussions

The following section briefly describes each of the treatment facilities selected for further study, their current operation, the conceptual nitrogen design and the cost per pound of nitrogen removed. The plant discussions are organized by state beginning with Massachusetts and then followed by New Hampshire and Vermont.

4.1 Massachusetts

As stated earlier, there were eleven Massachusetts treatment plants selected for BioWin modeling and cost estimation. Another plant, Orange, MA, appears to nitrify and denitrify very well except for some occasional problems and was not selected for modeling or cost estimation but we were asked to evaluate their data to determine potential causes for these problems.

Athol, MA

Plant Description

The Athol, MA Wastewater Treatment Plant (Figure A-1) is an activated sludge plant. The plant's design flow is 1.75 MGD and the plant is currently treating an average of 0.75 MGD or about 43% of design flow. The plant has no primary treatment. The secondary system is made up of four biological reactors which can operate either in series or in parallel. Flow from the biological system is then conveyed to two secondary clarifiers.

Figure A-1 Aerial View, Athol, MA Facility

Secondary effluent is disinfected using ultraviolet light, reaerated and then is discharged to Millers River, which is a tributary to the Connecticut River (Figure A-2). Permit limits for Athol, MA, are shown in Table A-1. Along with these permit limits; they are required to monitor various nitrogen species once per month.

Table A-1 Current Permit Limits, Athol, MA

	Monthly	Weekly	Annual Goal
TSS, mg/L	30	45	X
BOD, mg/L	30	45	X
TN, lbs/d	X	X	199

Currently the plant is operating the biological reactors in series with the first reactor anoxic and the rest aerobic. Plant personnel recently installed four mixers in the first reactor to ensure sufficient mixing under anoxic conditions. The model was configured using the current operation.

BioWin Model and Conceptual Design

Average influent concentrations and an average influent temperature of 15.5^{o} C (Table A-2) were used for calibration of the model using a steady-state simulation. Model output was compared to average effluent data.

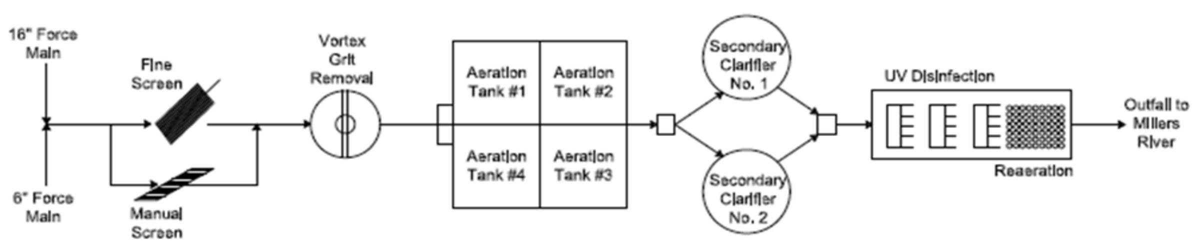

Figure A-2 Athol, MA Process Flow Diagram

The model was considered calibrated if the output typically matched effluent BOD5, TSS and total nitrogen within +/- 10% of the actual values in the data sets.   For Athol, the exception to this was that the model predicted a lower effluent BOD5 concentration by 3% and a higher effluent TKN (50%) than the actual data. Once the model was calibrated, various design alternatives and changes in process control parameters were evaluated to determine which alternative resulted in the lowest possible effluent total nitrogen. Sensitivity testing was also performed by reducing the temperature to 10^{o} C and increasing the flow to 80% of the design at 10^{o} C.

Table A-2 Baseline Model Comparison to Conceptual Design, Athol, MA

Plant Influent Data			Baseline Model Effluent		Design Model Effluent		Compare Baseline to Model Design	
Parameters	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d
Volatile suspended solids	186	1163	2.2	13	2.3	14	-0.1	-0.8
Total suspended solids	233	1456	3.5	22	3.7	23	-0.2	-1.3
Total Kjeldahl Nitrogen	34	213	2.0	13	2.1	13	-0.1	-0.6
Total Carbonaceous BOD	203	1267	1.0	6	1.1	7	-0.1	-0.7
Total N	34	213	11.9	74	5.3	33	6.6	41.2
pH	7.2		6.6		6.8	42		
Ammonia N	22.4	140	0.1	1	0.1	1	0.0	-0.1
Nitrate N	0	0	9.8	61	3.1	20	6.7	41.8
Parameter								
Temperature, ^{o}C	15.5		15.5		15.5			
Flow, MGD	0.75		0.75		0.75			

This plant can be operated in both a parallel and series mode with plant personnel currently operating the plant in series with the first tank anoxic. The series configuration with a pre-anoxic zone was used for both the baseline and conceptual design models. The baseline model was configured (Figure A-3) and calibrated (Table A-2 Baseline Model Column). Average annual flow and temperature (0.75 MGD and 15.5^{o} C) obtained from plant data were used for both the baseline and nitrogen design models.

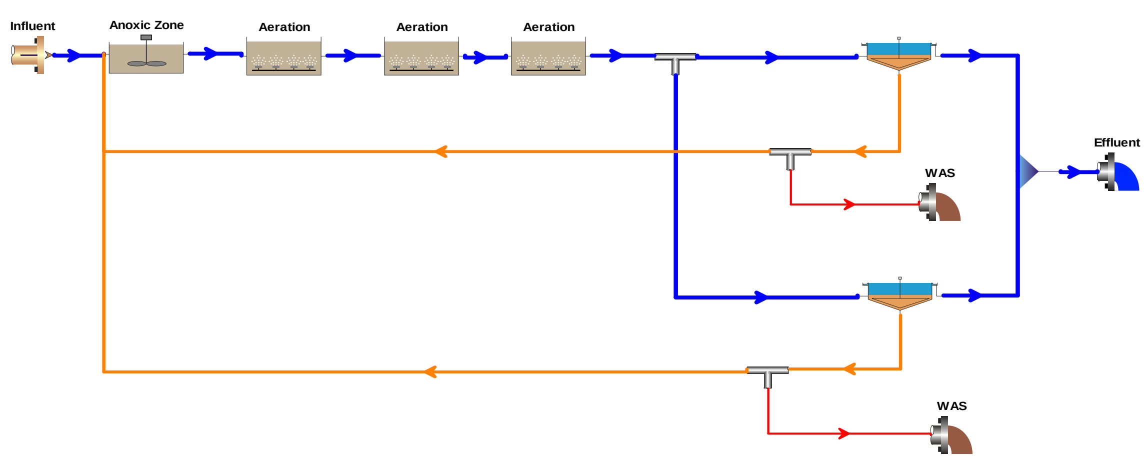

Figure A-3 Baseline Model, Athol, MA

The calibrated model was then used to develop the optimum nitrogen removal model. As with the baseline model, the first tank is anoxic and the next three are aerobic. Nitrate recycle was added (Figure A-4). By adding nitrate recycle, the model predicts a substantial improvement in nitrogen removal (Table A-2 Design Model Column).

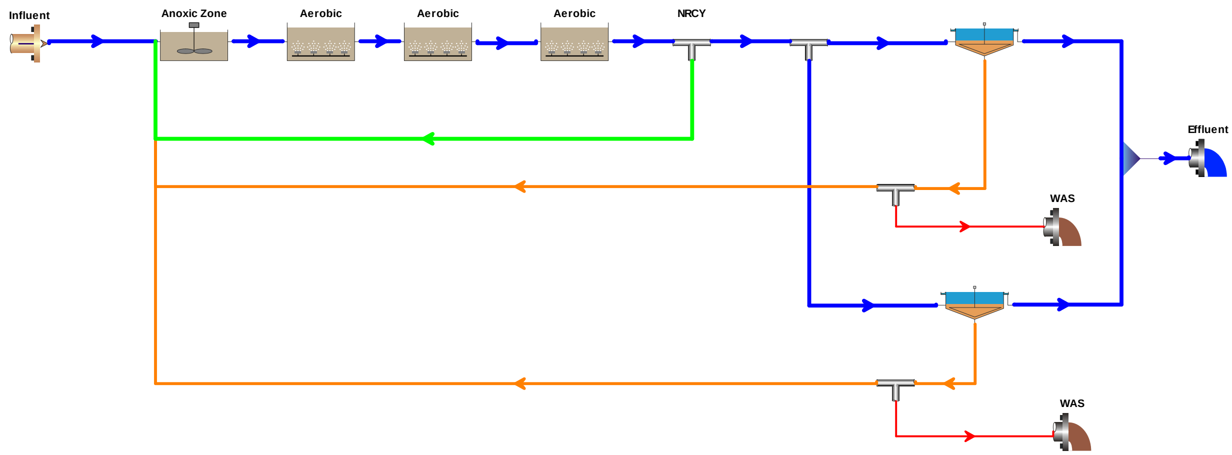

Figure A-4 Conceptual Nitrogen Design Model, Athol, MA

Currently, influent TN averages about 213 lbs/d and the plant discharges about 74 lbs/d resulting in a removal of about 139 lbs/d (213 lbs/d-74 lbs/d) or 65% removal. With the series configuration and nitrate recycle, the model predicts that the plant would discharge 33 lbs/d total nitrogen with a concentration of 5.28 mg/L, resulting in a removal of 180 lbs/d (213 lbs/d-33 lbs/d) or 85% removal. Therefore, the treatment plant would remove an additional 41 lbs/d of total nitrogen or about 15,045 lbs/year at average flow and temperature.

Table A-3 Summary of Results, Athol, MA

Current Influent TN, lbs/d	213
Current Effluent TN, lbs/d	74
Current Removal, lbs/d	139
Predicted Effluent TN, lbs/d	33
Predicted Removal, lbs/d	180
Net Change, lbs/d	41
Net Change, lbs/year	15,045
Winter Temperature, lbs/year	15,045

The model was then tested at 10^{o} C and at 10^{o} C with the flow at 80% of design. At 10^{o} C and current average daily flow, the plant still has the potential of removing 15,045 lbs/year total nitrogen at a concentration of 5.3 mg/L. However, when the flow was increased to 80% at 10^{o} C, effluent TN concentration increased to 5.7 mg/L. The plant still removes nitrogen but at a lower rate. A summary of these results are shown in Table A-3.

The equipment needed for this conceptual design includes nitrate recycle pumps, DO, ammonia, pH and nitrate analyzers. There is sufficient alkalinity in the influent so there is no need to provide a system to add alkalinity.

Cost Per Pound of Nitrogen Removed

A preliminary construction cost estimate was prepared based on the four reactors in series. This estimate was then used to calculate the cost per pound of nitrogen removed based on the model prediction.

The estimate includes the cost of all equipment (recycle pumps, piping, instrumentation and installation costs (Figure A-5). Plant personnel have already moved forward with a "low cost retrofit" by installing mixers to create an anoxic zone. The addition of instrumentation and nitrate recycle will enhance their efforts.

NEIWPCC **Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the upper Long Island Sound Watershed**		**COST ESTIMATE** **ATHOL, MA**	
Contractor Name:	JJ Environmental	Date:	30-Aug-14
Address:	17 Archer Lane	Project No.	0302-001
	Darien, Ct 06820	Proposal No.	2
Telephone No:	1-203-309-8768		
SECTION A: CONTRACTOR WORK			Revisions
1. Total Contractor Labor		$37,820.04	
2. Total Contractor Material		$66,000.00	
3. Total Contractor Equipment		$16,825.00	
4. Unit Price Costs			
5. Subtotal Contractor Cost		$120,645.04	
6. Contractor Mark-Up 15%		$18,096.76	
7. Contractor Total Section A		$138,741.80	
SECTION B: CONTRACTOR WORK			
8. Names Of Subcontractors			
A.	Electrical Subcontractor	$59,079.46	
B.	Instrumentation Integrator	$8,510.00	
C.			
D.			
E.			
F.			
9. Total Subcontractor's Proposals (A through F)		$67,589.46	
10. Contractor's Mark-Up On Subs Proposals (5%)		$3,379.47	
11. Subcontractor Total Section B		$70,968.93	
SECTION C: TOTAL CONTRACTED UNIT PRICE COSTS			
SECTION D: CONTRACTOR'S REQUEST			
12. Amount Requested (Total Lines 7 & 11)		**$209,710.73**	

Figure A-5 Cost Estimate, Athol, MA Conceptual Design

The total cost for retrofitting this system is estimated to be $209,711 plus an incremental O&M cost of $9,800 per year primarily for the operation of the nitrate recycle pumps. Since they are already using mixers, the cost of their operation and maintenance was not considered. The model is predicting that at average temperature and current flow, the plant will remove 15,045 lbs/year. Therefore the cost per pound for the ten year term is $2.27 (Table A- 4) and for the twenty year is $1.58 (Table A-5).

Table A-4 Athol, MA Cost of Nitrogen Removal (10-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
41	**Delta Pounds N Removed Per day**
15,045	Delta Pounds N Removed 1 Year
150,455	Delta Pounds N Removed 10 Year
300,909	Delta Pounds N Removed 20 Year
209,711	**Capital Cost of Conceptual Design**
$13.94	Cost Per Pound Over 1 Year
$1.39	Cost Per Pound Over 10 Years
$0.70	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
10	Loan Term in Years
$2,024.98	Monthly Payment (100% Financed)
$242,997.89	Total Cost P & I Over 10 Years
$98,000.00	Additional O&M over term
$340,997.89	Total Cost Over 10 Years
$2.27	**Total Cost Per Pound of Additional Nitrogen Removed Over 10 Years**

Table A-5 Athol, MA Cost of Nitrogen Removal (20-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
41	**Delta Pounds N Removed Per day**
15,045	Delta Pounds N Removed 1 Year
150,455	Delta Pounds N Removed 10 Year
300,909	Delta Pounds N Removed 20 Year
209,711	**Capital Cost of Conceptual Design**
$13.94	Cost Per Pound Over 1 Year
$1.39	Cost Per Pound Over 10 Years
$0.70	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
20	Loan Term in Years
$1,163.05	Monthly Payment (100% Financed)
$279,132.16	Total Cost P & I Over 20 Years
$196,000.00	Additional O&M over term
$475,132.16	Total Cost Over 20 Years
$1.58	**Total Cost Per Pound of Additional Nitrogen Removed Over 20 Years**

Belchertown, MA

Plant Description

Belchertown Water Reclamation Facility is a 1.0 MGD sequencing batch reactor (SBR) plant with a current average flow of 0.4 MGD or about 40% of design flow (Figure B-1). They have two SBRs and use one in the summer and two in the winter. The plant fully nitrifies and there is significant denitrification. Current permit limits are shown in Table B-1. Along with these permit limits; they are also required to monitor various nitrogen species once per month.

Figure B-1 Aerial View, Belchertown, MA Facility

It is a complex plant with wastewater entering equalization tanks prior to flowing to the SBRs. From there, wastewater flows to another set of equalization tanks then to two upflow clarifiers followed by disk filters and UV disinfection (Figure B-2) prior to discharging to Lampson Brook a tributary of the Connecticut River.

Table B-1 Current Permit Limits, Belchertown, MA

	Monthly	Weekly	Annual Goal
TSS, mg/L	15-30	X	X
BOD, mg/L	5-30	X	X
TN, lbs/d	X	X	43

BioWin Model and Conceptual Design

Average influent concentrations and an average influent temperature of 15^{o} C (Table B-2) were used for calibration of the model using a steady-state simulation. Model output was compared to average effluent data. The model was considered calibrated if the output matched effluent BOD5, TSS and total nitrogen within +/- 10% of the actual values. All parameters were within the 10%.

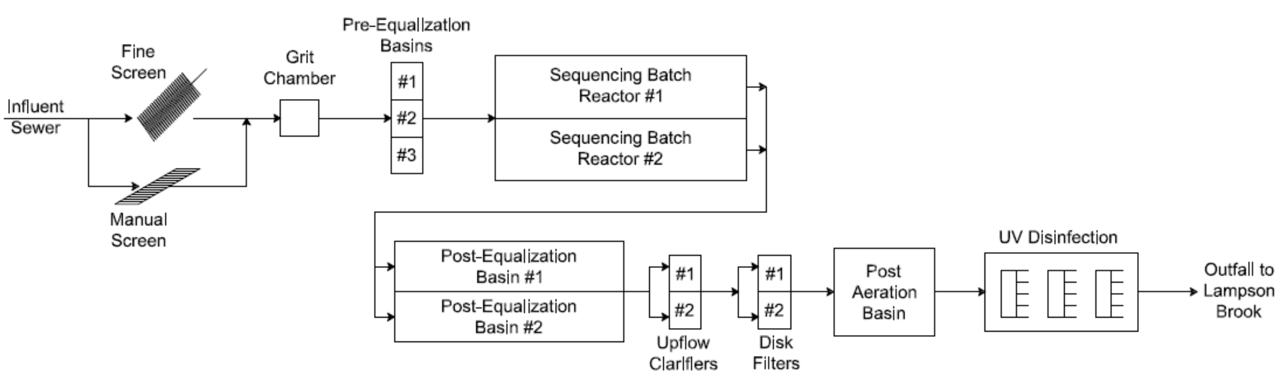

Figure B-2 Belchertown, MA Process Flow Diagram

Once the model was calibrated, various design alternatives and changes in process control parameters were evaluated to determine which alternative resulted in the lowest possible effluent total nitrogen. Sensitivity testing was also performed by reducing the temperature from 15° C to 10° C and increasing the flow to 80% of design at 10° C.

Table B-2 Baseline Model Comparison to Conceptual Design, Belchertown, MA

Plant Influent Data			Baseline Model Effluent		Design Model Effluent		Compare Baseline to Model Design	
Parameters	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d
Volatile suspended solids	195.2	651	2.4	8	2.4	8	**0.0**	**0.0**
Total suspended solids	244.0	814	3.0	10	3.0	10	**0.0**	**0.0**
Total Kjeldahl Nitrogen	43.3	144	1.2	4	1.2	4	**0.0**	**0.0**
Total Carbonaceous BOD	242.0	807	1.4	5	1.4	5	**0.0**	**0.0**
Total N	29.0	97	8.8	29	8.6	29	**0.2**	**0.7**
pH	7.0		6.8	23	6.8	23		
Ammonia N	27.0	90	0.3		0.3		**0.0**	**0.0**
Nitrate N	0.0	0	7.9	26	7.9	26	**0.0**	**0.0**
Parameters								
Temperature, °C	15		15		15			
Flow, MGD	0.400		0.400		0.400			

As stated earlier, plant personnel use one SBR in the summer and two in the winter. Two SBR trains were used for both the baseline and conceptual design models. The baseline model was configured (Figure B-3) and calibrated (Table B-2 Baseline Model Column). Average annual flow and temperature (0.4 MGD and 15° C) obtained from plant data were used for both the baseline and nitrogen design models.

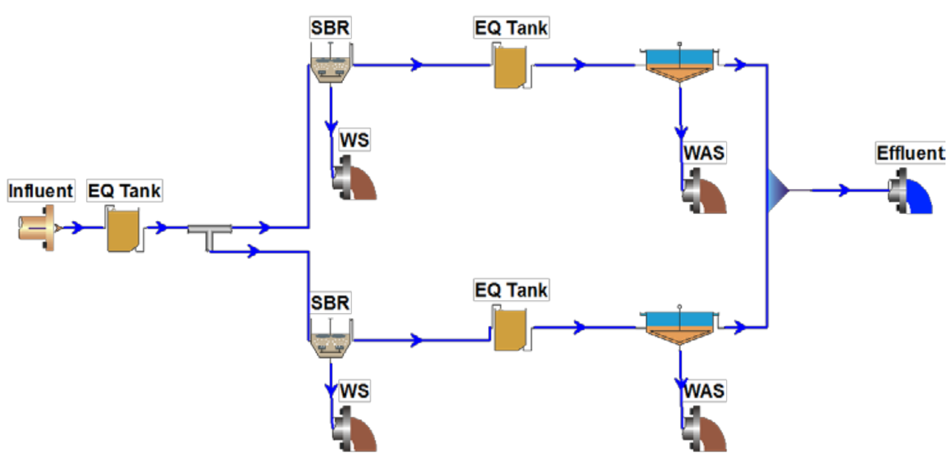

Figure B-3 Baseline Model, Belchertown, MA

The calibrated model was then used to develop the optimum nitrogen removal model. For Belchertown, the concept was to add nitrate recycle to the first equalization (EQ) tank. Figure B-4 is the conceptual process flow model showing nitrate recycle to the EQ Tank. This concept was then simulated to determine optimum effluent total nitrogen concentration.

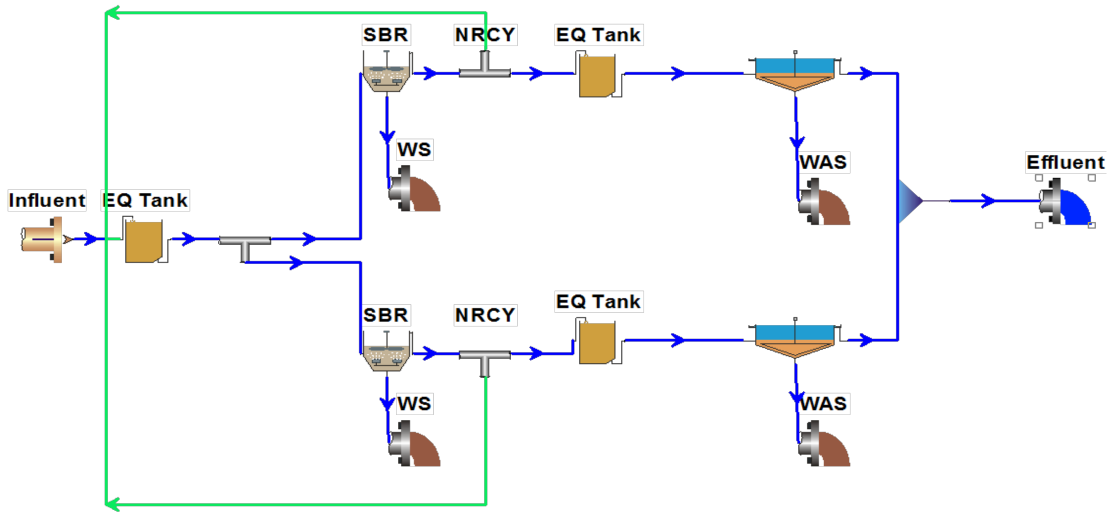

Figure B-4 Conceptual Nitrogen Design Model, Belchertown, MA

At average conditions, the output from the model compared to the baseline model is shown in Table B-2 (Design Model Column). The model predicts only a very small improvement in nitrogen removal.

Currently, influent TN averages about 96.7 lbs/d and the plant discharges about 29.4 lbs/d resulting in a removal of about 67.4 lbs/d (96.7 lbs/d-29.4 lbs/d) or 70% removal. With nitrate recycle, the model is predicting that the plant would discharge 28.7 lbs/d total nitrogen with a concentration of 8.6 mg/L resulting in a removal of 68 lbs/d (96.7 lbs/d-28.7 lbs/d) (70% removal). The increase removal over current performance is 0.667 lbs/d total nitrogen or about 244 lbs/year at average conditions.

Table B-3 Summary of Results, Belchertown, MA

Current Influent TN, lbs/d	96.7
Current Effluent TN, lbs/d	29.4
Current Removal, lbs/d	67.4
Predicted Effluent TN, lbs/d	28.7
Predicted Removal, lbs/d	68
Net Change, lbs/d	0.667
Net Change, lbs/year	244
Winter Temperature, lbs/year	244

The model was then tested at 10^{o} C and then at 10^{o} C with the flow at 80% of design. There was no increase in effluent total nitrogen concentration with either of these conditions. A summary of these results is shown in Table B-3. For this design, along with the nitrate recycle pumps and mixers for the EQ tank, the design included DO, ammonia, pH and nitrate analyzers.

Cost Per Pound of Nitrogen Removed

A preliminary construction cost estimate was prepared based on the conceptual design. This estimate was then used to calculate the cost per pound of nitrogen removed based on the model prediction. The estimate includes the cost of all equipment (mixers and pumps, piping, instrumentation and installation costs (Figure C- 4). The total cost for retrofitting this system is estimated to be $88,514.14. The increase O&M cost is $31,368 per year primarily additional electrical costs. The model is predicting that at average temperature and current flow, the plant would only remove an additional 0.667 lbs/d of nitrogen or 244 lbs/year over baseline conditions.

NEIWPCC Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the upper Long Island Sound Watershed		COST ESTIMATE BELCHERTOWN, MA	
Contractor Name:	JJ Environmental	Date:	28-Sep-14
Address:	17 Archer Lane	Project No.	0302-001
	Darien, Ct 06820	Proposal No.	3
Telephone No:	1-203-309-8768		

		Revisions
SECTION A: CONTRACTOR WORK		
1. Total Contractor Labor	$22,247.08	
2. Total Contractor Material	$31,600.00	
3. Total Contractor Equipment		
4. Unit Price Costs		
5. Subtotal Contractor Cost	$53,847.08	
6. Contractor Mark-Up 15%	$8,077.06	
7. Contractor Total Section A	$61,924.14	
SECTION B: CONTRACTOR WORK		
8. Names Of Subcontractors		
A. Electrical Subcontractor	$19,757.81	
B. Instrumentation Integrator	$5,566.00	
C.		
D.		
E.		
F.		
9. Total Subcontractor's Proposals (A through F)	$25,323.81	
10. Contractor's Mark-Up On Subs Proposals (5%)	$1,266.19	
11. Subcontractor Total Section B	$26,590.00	
SECTION C: TOTAL CONTRACTED UNIT PRICE COSTS		
SECTION D: CONTRACTOR'S REQUEST		
12. Amount Requested (Total Lines 7 & 11)	**$88,514.14**	

Figure B-5 Cost Estimate Belchertown, MA Conceptual Design

Therefore the cost per pound for the ten year term is $170.92 (Table B-4) and for the twenty year is $153 (Table B-5). Obviously, the driver for this cost is no significant improvement in nitrogen removal over current performance and a high expense relating to equipment and operation.

Table B-4 Belchertown, MA Cost of Nitrogen Removal (10-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
0.67	**Delta Pounds N Removed Per day**
244	Delta Pounds N Removed 1 Year
2,435	Delta Pounds N Removed 10 Year
4,871	Delta Pounds N Removed 20 Year
88,514	**Capital Cost of Conceptual Design**
$363.47	Cost Per Pound Over 1 Year
$36.35	Cost Per Pound Over 10 Years
$18.17	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
10	Loan Term in Years
$854.70	Monthly Payment (100% Financed)
$102,563.90	Total Cost P & I Over 10 Years
$313,680.00	Additional O&M over term
$416,243.90	Total Cost Over 10 Years
$170.92	**Total Cost Per Pound of Additional Nitrogen Removed Over 10 Years**

Table B-5 Belchertown, MA Cost of Nitrogen Removal (20-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
1	**Delta Pounds N Removed Per day**
244	Delta Pounds N Removed 1 Year
2,435	Delta Pounds N Removed 10 Year
4,871	Delta Pounds N Removed 20 Year
88,514	**Capital Cost of Conceptual Design**
$363.47	Cost Per Pound Over 1 Year
$36.35	Cost Per Pound Over 10 Years
$18.17	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
20	Loan Term in Years
$490.90	Monthly Payment (100% Financed)
$117,815.35	Total Cost P & I Over 10 Years
$627,360.00	Additional O&M over term
$745,175.35	Total Cost Over 20 Years
$153.00	**Total Cost Per Pound of Additional Nitrogen Removed Over 20 Years**

Gardner, MA

Plant Description

The Gardner Wastewater Treatment Plant (Figure G-1) is a 5 MGD trickling filter/activated sludge facility with a current average flow of 2.98 MGD or about 60% of design flow. The plant has two primary clarifiers, two trickling filters, two intermediate clarifiers, two bioreactor trains with three tanks in each train and three final clarifiers. Secondary effluent is disinfected using chlorine and then discharged to Millers River, a tributary to the Connecticut River (Figure G-2).

Figure G-1 Aerial View, Gardner, MA Facility

They currently run all unit processes except one final clarifier. Then can either run the biological reactors in parallel or series. They are currently operating in series. The model configuration was based on series operation. Permit limits for Gardner, MA, are shown in Table G-1. Along with these permit limits; they are also required to monitor various nitrogen species once per month.

Table G-1 Current Permit Limits, Gardner, MA

(Apr 1-Oct 31)	Monthly	Weekly	Annual Goal
TSS, mg/L	17.4	17.4	X
BOD, mg/L	8.7	8.7	
(Nov 1-Mar 31)			
TSS, mg/L	26.2	39.3	X
BOD, mg/L	26.2	39.3	
TN, lbs/day	X	X	

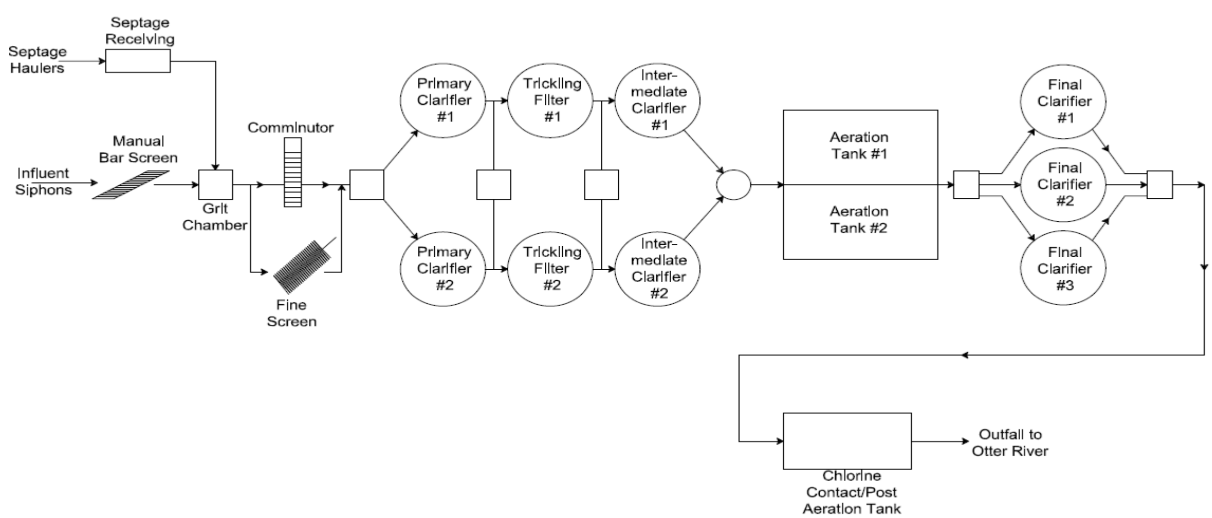

Figure G-2 Gardner, MA Process Flow Diagram

BioWin Model and Conceptual Design-Series Configuration

Average influent concentrations and an average influent temperature of 13.3^o C (Table G-2) were used for calibration of the model using a steady-state simulation. Model output was compared to average effluent data. The model was considered calibrated if the output typically matched effluent BOD5, TSS and total nitrogen within +/- 10% of the actual values in the data sets. For Gardner, all parameters were within the 10% except for effluent BOD which was >20%. The model predicated a lower effluent BOD concentration than the data set. Once the model was calibrated, various design alternatives and changes in process control parameters were evaluated to determine which alternative resulted in the lowest possible effluent total nitrogen. Sensitivity testing was also performed by reducing the temperature from 13.3^o C to 8^o C and increasing the flow to 80% of design at 8^o C.

Table G-2 Baseline Model Comparison to Conceptual Design, Gardner, MA

Plant Influent Data			Baseline Model Effluent		Design Model Effluent		Compare Baseline to Model Design	
Parameters	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d
Volatile suspended solids	161	4001	4.24	105	4.08	101	**0.16**	**3.98**
Total suspended solids	190.51	4735	5.44	135	5.26	131	**0.18**	**4.47**
Total Kjeldahl Nitrogen	31.12	773	2	39	2	53	**-1**	**-14**
Total Carbonaceous BOD	189	4697	2.07	51	2.36	59	**-0.29**	**-7.21**
Total N	31.54	784	14.7	366	4.4	108	**10.4**	**258**
Total inorganic N	20.96	521	14	338	3	76	**11**	**262**
pH	7.1		6.83		6.89	171		
Ammonia N	20.54	510	0.4	11	0.82	20	**0**	**-10**
Nitrate N	0.42	10	12.5	311	0.84	21	**11.68**	**290.29**
Parameters								
Temperature, ^{o}C	13.3		13.3		13.3			
Flow, MGD	2.98		2.98		2.98			

Plant personnel run all units except one of the secondary clarifiers so the series configuration with two secondary clarifiers was used for both the baseline and conceptual design models. The baseline model was configured (Figure G-2) and calibrated (Table G-2 Baseline Model Column). Average annual flow and temperature (2.98 MGD and 13.3^o C) obtained from plant data were used for both the baseline and nitrogen design models.

The calibrated model was then used to develop the optimum nitrogen removal model. Figure G-3 shows the conceptual nitrogen design model. The first two tanks are dedicated anoxic zones and the third tank is a swing zone. A swing zone is designed so that part of the time it is anoxic and if additional aerobic volume is needed for nitrification, it can quickly be converted to operate in an oxic (aerated) condition.

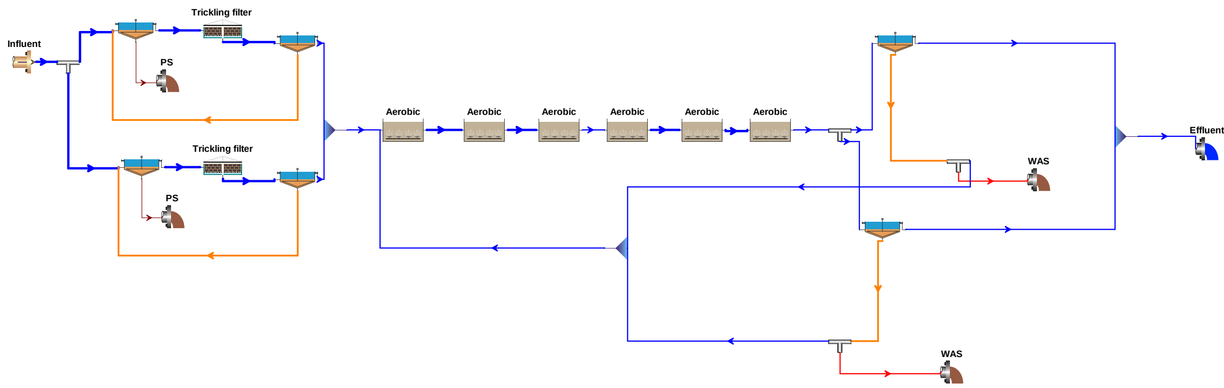

Figure G3 Baseline Model, Gardner, MA

Using this configuration, the model predicts substantial improvement in nitrogen removal (Table G-2 Design Model Column). Currently, influent TN averages about 784 lbs/d and the plant discharges about 366 lbs/d resulting in a removal of about 418 lbs/d (784 lbs/d-366 lbs/d) or 53% removal.

With the anoxic-aerobic reactor configuration, the model is predicting that the plant would discharge 108 lbs/d total nitrogen with a concentration of 4.4 mg/L resulting in a removal of 676 lbs/d (784 lbs/d-108 lbs/d) or 86% removal). The increased removal over current performance is 258 lbs/d total nitrogen or about 94,071 lbs/year at average conditions.

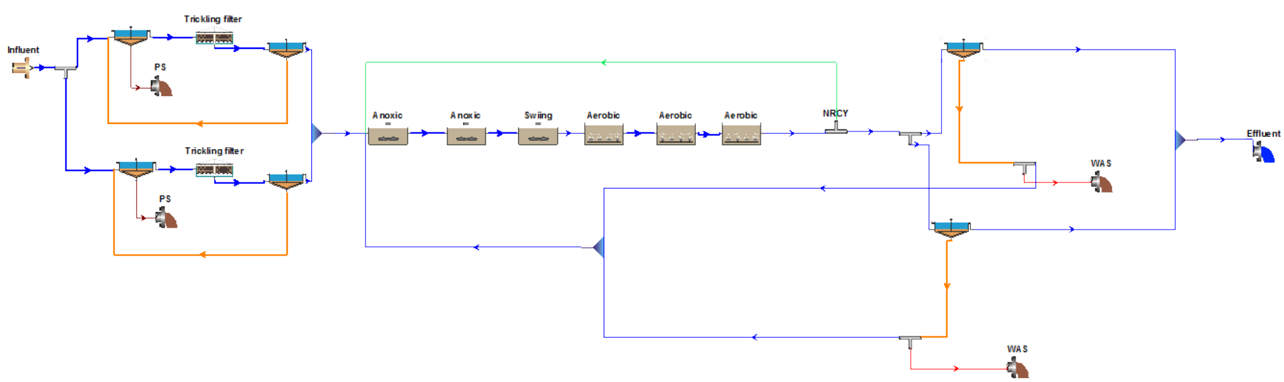

Figure G-4 Conceptual Nitrogen Design Model, Gardner, MA

The model was then tested at 8° C and at 8° C with the flow increased to 80% of design. At 8° C, the effluent total nitrogen concentration increased from 4.4 mg/L to 6.45 mg/L which decreased the mass of total nitrogen removed to 206 lbs/d or 75,021 lbs/year and effluent ammonia concentration increased to 1.4 mg/L. When the flow was increased to 80% at this temperature, the TN concentration increased to 9.17 mg/L. At the lower temperature and higher flow rate, the swing zone must be operated as an aerobic zone since a large aerobic volume is needed for nitrification.

Table G-3 Summary of Results, Gardner, MA

Current Influent TN, lbs/d	784
Current Effluent TN, lbs/d	366
Current Removal, lbs/d	418
Predicted Effluent TN, lbs/d	108
Predicted Removal, lbs/d	676
Net Change, lbs/d	258
Net Change, lbs/year	94,071
Winter Temperature, lbs/year	75,021

The equipment need for this conceptual design includes nitrate recycle pumps, mixers and DO, ammonia, pH and nitrate analyzers. There is a possibility that at higher flows, alkalinity will have to be added. The cost of that system was not included since it would only be needed at sustained flows of 4 MGD. A summary of these results is shown in Table G-3.

Cost Per Pound of Nitrogen Removed

A preliminary construction cost estimate was prepared based on the design shown in Figure G-3. This estimate was then used to calculate the cost per pound of nitrogen removed based on the model prediction. The estimate includes the cost of all equipment (baffles, mixers and pumps, piping, instrumentation and installation costs (Figure G- 5). The total cost for retrofitting this system is estimated to be $368,414.

The increase O&M cost is $99,300 per year primarily additional electrical costs; however, this cost is partially offset due to reduced aeration costs since two tanks will only be mixed and not aerated. The expected avoided cost is estimated at $43,100 per year so the net increase in O&M is estimated at $56,200 per year. The model is predicting at average temperature and current flow, the plant will remove an additional 94,071/year over baseline conditions. Therefore the cost per pound of nitrogen removed for the ten year term is $1.05 (Table G- 4) and for the twenty year is $0.86 (Table G-5).

NEIWPCC Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the upper Long Island Sound Watershed		COST ESTIMATE Gardner	
Contractor Name:	JJ Environmental	Date:	February 16, 215
Address:	17 Archer Lane	Project No.	0302-001
	Darien, Ct 06820	Proposal No.	5 (Rev 1)
Telephone No:	1-203-309-8768		

			Revisions
SECTION A: CONTRACTOR WORK			
1. Total Contractor Labor		$109,010.70	
2. Total Contractor Material		$100,100.00	
3. Total Contractor Equipment		$23,555.00	
4. Unit Price Costs			
5. Subtotal Contractor Cost		$232,665.70	
6. Contractor Mark-Up 15%		$34,899.86	
7. Contractor Total Section A		$267,565.56	
SECTION B: CONTRACTOR WORK			
8. Names Of Subcontractors			
A.	Electrical Subcontractor	$85,259.26	
B.	Instrumentation Integrator	$10,787.00	
C.			
D.			
E.			
F.			
9. Total Subcontractor's Proposals (A through F)		$96,046.26	
10. Contractor's Mark-Up On Subs Proposals (5%)		$4,802.31	
11. Subcontractor Total Section B		$100,848.57	
SECTION C: TOTAL CONTRACTED UNIT PRICE COSTS			
SECTION D: CONTRACTOR'S REQUEST			
12. Amount Requested (Total Lines 7 & 11)		**$368,414.13**	

Figure G-5 Cost Estimate Gardner, MA, Conceptual Design

Table G-4 Gardner, MA Cost of Nitrogen Removal (10-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
258	**Delta Pounds N Removed Per day**
94,071	Delta Pounds N Removed 1 Year
940,706	Delta Pounds N Removed 10 Year
1,881,412	Delta Pounds N Removed 20 Year
368,414	**Capital Cost of Conceptual Design**
$3.92	Cost Per Pound Over 1 Year
$0.39	Cost Per Pound Over 10 Years
$0.20	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
10	Loan Term in Years
$3,557.43	Monthly Payment (100% Financed)
$426,892.11	Total Cost P & I Over 10 Years
$562,000.00	Additional O&M over term
$988,892.11	Total Cost Over 10 Years
$1.05	**Total Cost Per Pound of Additional Nitrogen Removed Over 10 Years**

Table G-5 Gardner, MA Cost of Nitrogen Removal (20-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
258	**Delta Pounds N Removed Per day**
94,071	Delta Pounds N Removed 1 Year
940,706	Delta Pounds N Removed 10 Year
1,881,412	Delta Pounds N Removed 20 Year
368,414	**Capital Cost of Conceptual Design**
$3.92	Cost Per Pound Over 1 Year
$0.39	Cost Per Pound Over 10 Years
$0.20	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
20	Loan Term in Years
$2,043.22	Monthly Payment (100% Financed)
$490,371.82	Total Cost P & I Over 20 Years
$1,124,000.00	Additional O&M over term
$1,614,371.82	Total Cost Over 20 Years
$0.86	**Total Cost Per Pound of Additional Nitrogen Removed**

Great Barrington, MA

Plant Description

The Great Barrington Wastewater Treatment Plant (Figure GB-1) is an activated sludge plant with a design capacity 0f 3.2 MGD. It is currently treating an average flow of 1.08 MGD or about 34% of design flow. The plant has two primary clarifiers and two biological reactors. Aeration is provided by mechanical aerators. The flow from the biological system is then conveyed to two secondary clarifiers and/or one clariflocculator.

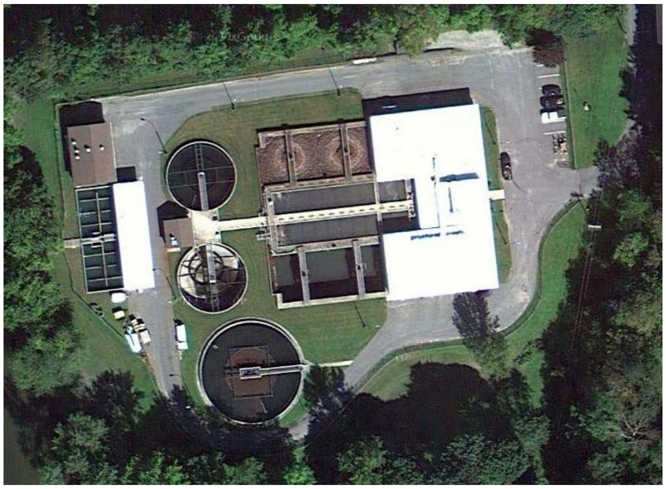

Figure GB-1 Aerial View Great Barrington, MA Facility

Secondary effluent is disinfected using chlorine and then discharged to the Housatonic River (Figure GB-2).   The current permit limits for Great Barrington, MA, are shown in Table GB-1. Along with these permit limits; they are also required to monitor various nitrogen species once per month. Currently the plant is operating two primary clarifiers, one biological reactor and typically the one clariflocculator. The model configuration was based on current operation.

Table GB-1 Current Permit Limits, Great Barrington, MA

	Monthly	Weekly	Annual Goal
TSS, mg/L	30	45	X
BOD, mg/L	30	45	X
TN, lbs/d	X	X	X

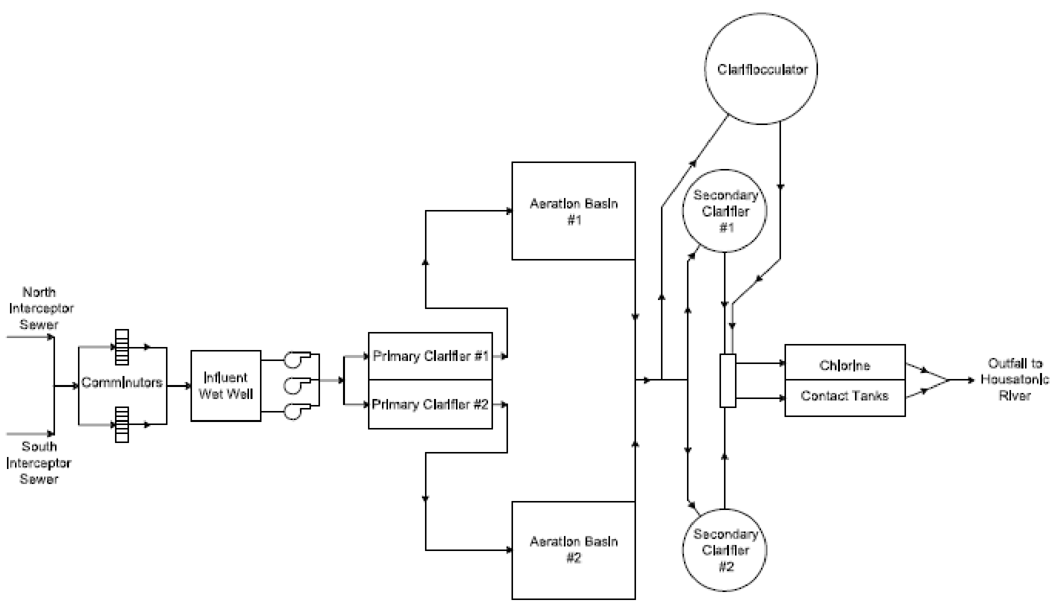

Figure GB-2 Great Barrington, MA Process Flow Diagram

BioWin Model and Conceptual Design

Average influent concentrations and an average influent temperature 14^{o} C (Table GB-2) were used for calibration of the model using a steady-state simulation. Model output was compared to average effluent data. The model was considered calibrated if the output typically matched effluent BOD5, TSS and total nitrogen within +/- 10% of the actual values in the data sets. All parameters were within the 10% except BOD5 which was 13% and TKN which was 15%. Once the model was calibrated, various design alternatives and changes in process control parameters were evaluated to determine which alternative resulted in the lowest possible effluent total nitrogen. Sensitivity testing was also performed by reducing the temperature from 14^{o} C to 10^{o} C and increasing the flow to 80% of design at 10^{o} C.

Table GB-2 Baseline Model Comparison to Conceptual Design, Great Barrington, MA

Plant Influent Data			Baseline Model Effluent		Design Model Effluent		Compare Baseline to Model Design	
Parameters	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d
Volatile suspended solids	129.0	1162	4.2	38	6.05	54	**-1.86**	**-16.75**
Total suspended solids	185.1	1667	6.4	58	9.21	83	**-2.81**	**-25.31**
Total Kjeldahl Nitrogen	20.0	180	2.0	18	2.48	22	**-0.45**	**-4.05**
Total Carbonaceous BOD	160.0	1441	3.6	32	3.53	32	**0.04**	**0.36**
Total N	20.0	180	11.9	107	4.85	44	**7.03**	**63.32**
pH	7.5		7.2		7.19			
Ammonia N	13.2	119	0.5	4	0.94	8	**-0.49**	**-4.41**
Nitrate N	0.0	0	9.8	88	2.07	19	**7.68**	**69.18**
Parameters								
Temperature, ^{o}C	14		14		14			
Flow, MGD	1.08		1.08		1.08			

The models for both the baseline and conceptual design used the current operation of two primary clarifiers, one biological reactor and clariflocculator. The baseline model was configured (Figure GB-3) and calibrated (Table GB-2 Baseline Model Column). Average annual flow and temperature (1.08 MGD and 14^{o} C) obtained from plant data were used for both baseline and nitrogen design models. The calibrated model was then used to develop the optimum nitrogen removal model.

Nitrogen can be removed at Great Barrington using the same operation as is currently used (one bioreactor and the clariflocculator) at average conditions. Because of the location of the surface aerators, one-half of the tank will be anoxic and one-half aerobic. Nitrate recycle is also required to achieve nitrogen removal (Figure GB-4). Using this configuration, the model predicts that Great Barrington can remove a substantial amount of nitrogen (Table GB-2 Design Model Column).

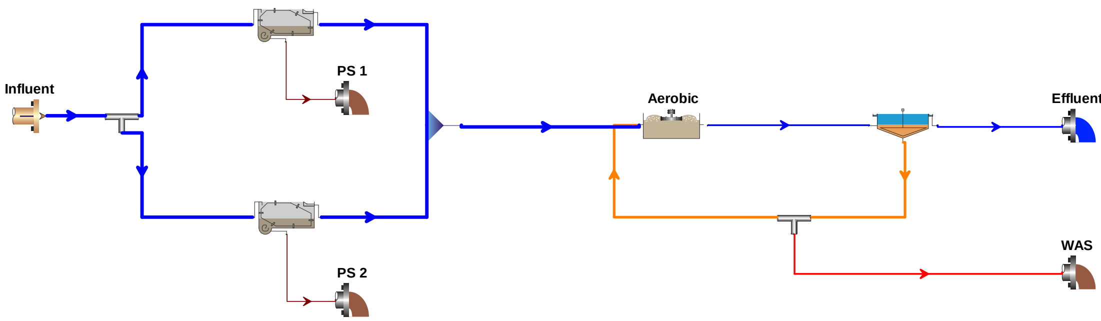

Figure GB-3 Baseline Model, Great Barrington, MA

Currently, influent TN averages about 180 lbs/d and the plant discharges about 107 lbs/d resulting in a removal of about 73 lbs/d (180 lbs/d-107 lbs/d) or 41% removal. With the anoxic-aerobic reactor configuration, the model is predicting that the plant would discharge 44 lbs/d total nitrogen with a concentration of 4.85 mg/L resulting in a removal of 136 lbs/d (180 lbs/d-44 lbs/d) or 76% removal. The increased removal over current performance is 63 lbs/d total nitrogen or about 23,112 lbs/year at average conditions.

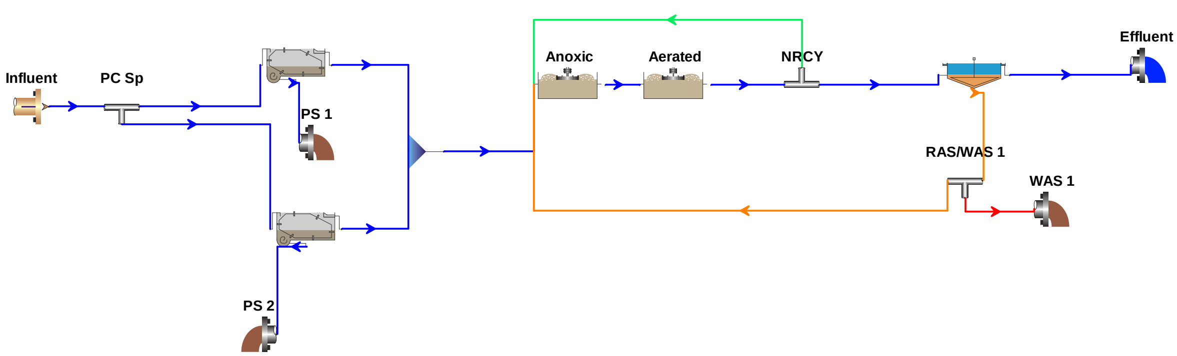

Figure GB-4 Conceptual Nitrogen Design Model, Great Barrington, MA

Table GB-3 Summary of Results, Great Barrington, MA

Current Influent TN, lbs/d	180
Current Effluent TN, lbs/d	107
Current Removal, lbs/d	73
Predicted Effluent TN, lbs/d	44
Predicted Removal, lbs/d	136
Net Change, lbs/d	63
Net Change, lbs/year	23,112
Winter Temperature, lbs/year	21,764

The model was then tested at 10^{o} C and then at 10^{o} C with the flow at 80% of design. At 10^{o} C, the effluent total nitrogen concentration increased from 4.85 mg/L to 5.26 mg/L of which less than 1.5 mg/L was ammonia-nitrogen resulting in a removal of 21,764/year of total nitrogen. When the flow was increased to 80% at this temperature, the total nitrogen concentration increased to 7.1 mg/L of which less than 2 mg/L was ammonia-nitrogen. A summary of these results is shown in Table GB-3. The equipment needed for this conceptual design includes nitrate recycle pumps, DO, ammonia, pH and nitrate analyzers.

Cost Per Pound of Nitrogen Removed

A preliminary construction cost estimate was prepared based on the design shown in Figure GB-4. This estimate was then used to calculate the cost per pound of nitrogen removed based on the model prediction.

NEIWPCC Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the upper Long Island Sound Watershed		COST ESTIMATE Great Barrington	
Contractor Name:	JJ Environmental	Date:	17-Feb-15
Address:	17 Archer Lane	Project No.	0302-001
	Darien, Ct 06820	Proposal No.	8 Rev 3
Telephone No:	1-203-309-8768		

		Revisions
SECTION A: CONTRACTOR WORK		
1. Total Contractor Labor	$85,095.09	
2. Total Contractor Material	$84,950.00	
3. Total Contractor Equipment	$15,564.00	
4. Unit Price Costs		
5. Subtotal Contractor Cost	$185,609.09	
6. Contractor Mark-Up 15%	$27,841.36	
7. Contractor Total Section A	$213,450.45	
SECTION B: CONTRACTOR WORK		
8. Names Of Subcontractors		
A. Electrical Subcontractor	$70,974.32	
B. Instrumentation Integrator	$9,085.00	
C.		
D.		
E.		
F.		
9. Total Subcontractor's Proposals (A through F)	$80,059.32	
10. Contractor's Mark-Up On Subs Proposals (5%)	$4,002.97	
11. Subcontractor Total Section B	$84,062.29	
SECTION C: TOTAL CONTRACTED UNIT PRICE COSTS		
SECTION D: CONTRACTOR'S REQUEST		
12. Amount Requested (Total Lines 7 & 11)	**$297,512.74**	

Figure GB-5 Cost Estimate Great Barrington, MA Conceptual Design

The estimate includes the cost of all equipment (mixers and pumps, piping, instrumentation and installation costs. The total cost for retrofitting this system is estimated to be $297,513. The increase O&M cost is $62,736 per year primarily additional electrical costs; however, this cost is partially offset due to the removal of two mechanical aerators. The expected avoided cost is estimated at $30,060 per year so the net increase in O&M is estimated at $32,676 per year. The model is predicting at average temperature and current flow, the plant will remove an additional 23,112 lbs/year over baseline conditions. Therefore the cost per pound for the ten year term is $2.91 (Table GB- 4) and for the twenty year is $2.27 (Table GB-5).

Table G-4 Great Barrington, MA Cost of Nitrogen Removal (10-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
63	**Delta Pounds N Removed Per day**
23,112	Delta Pounds N Removed 1 Year
231,120	Delta Pounds N Removed 10 Year
462,240	Delta Pounds N Removed 20 Year
$297,512.74	**Capital Cost of Conceptual Design**
$12.87	Cost Per Pound Over 1 Year
$1.29	Cost Per Pound Over 10 Years
$0.64	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
10	Loan Term in Years
$2,872.81	Monthly Payment (100% Financed)
$344,736.62	Total Cost P & I Over 10 Years
$326,760.00	Additional O&M over term
$671,496.62	Total Cost Over 10 Years
$2.91	**Total Cost Per Pound of Additional Nitrogen Removed Over 10 Years**

Table GB-5 Great Barrington, MA Cost of Nitrogen Removal (20-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
63	**Delta Pounds N Removed Per day**
23,112	Delta Pounds N Removed 1 Year
231,120	Delta Pounds N Removed 10 Year
462,240	Delta Pounds N Removed 20 Year
$297,512.74	**Capital Cost of Conceptual Design**
$12.87	Cost Per Pound Over 1 Year
$1.29	Cost Per Pound Over 10 Years
$0.64	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
20	Loan Term in Years
$1,650.00	Monthly Payment (100% Financed)
$395,999.64	Total Cost P & I Over 20 Years
$653,520.00	Additional O&M over term
$1,049,519.64	Total Cost Over 20 Years
$2.27	**Total Cost Per Pound of Additional Nitrogen Removed Over 20 Years**

Orange, MA

Plant Description

The Orange, MA, is a 1.10 MGD activated sludge facility. The average flow from January 2013 to October 2014 was 0.98 MGD or 89% of design. The plant has two biological reactors and two secondary clarifiers. Flow from the secondary clarifiers is disinfected using chlorine prior to discharge to Millers River, a tributary of the Connecticut River (Figure O-2).

Figure O-1 Aerial View Orange, MA Facility

The current permit limits for Orange, MA, are shown in Table O-1. Along with these permit limits; they are also required to monitor various nitrogen species.

Table O-1 Current Permit Limits, Orange MA

	Monthly	Weekly	Annual Goal
TSS, mg/L	30	45	X
BOD, mg/L	30	45	X
TN, lbs/d	X	X	

Orange, MA, was not selected for BioWin modeling and cost estimation, but for further analysis of plant data. Flow data as well as available nitrogen data were analyzed. During 2013 and 2014, influent flow averaged 85% of design flow and moreover, it is obvious that there is significant inflow and infiltration (I/I).

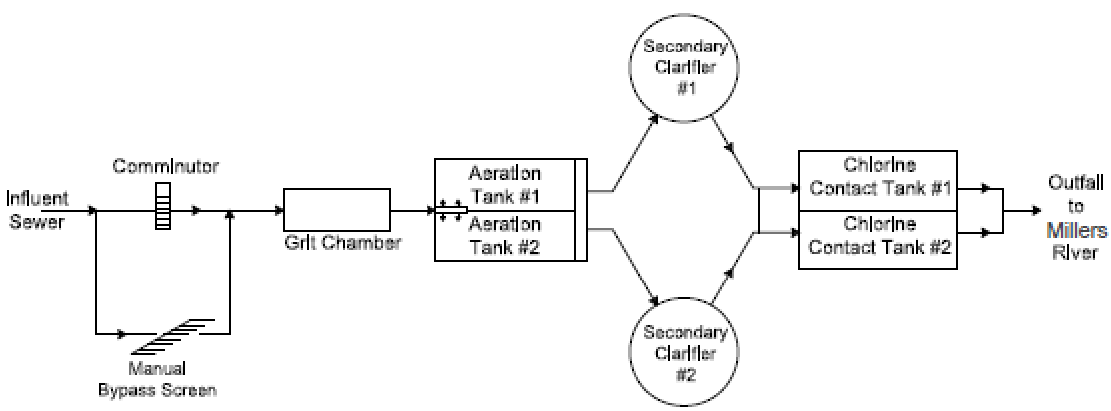

Figure O-2 Orange, MA Process Flow Diagram

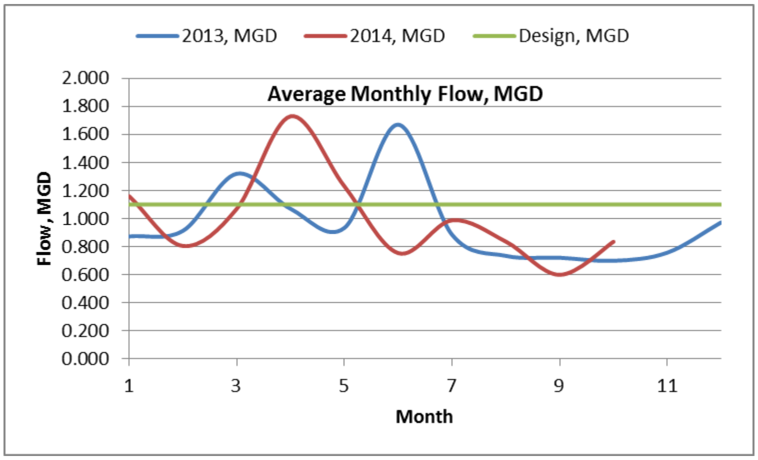

Figure O-3 Orange, MA Average Monthly Flow 2013-2014

Figure O-3 shows 2013 and 2014 average daily flow compared to plant design flow and depicts the variability of volume of influent wastewater.

Typically, the plant achieves fairly good nitrogen removal when flows are less than design and they can maintain efficient nitrification. Figure O-4 shows distribution of nitrogen species from 2006 to 2014. For most of that period, effluent ammonia was < 2mg/L which indicates consistent nitrification. Total nitrogen for 2013 based on quarterly testing averaged less than 10 mg/L with a range of 6.7 to 12.5 mg/L. Nitrate concentrations during this same period ranged from 1.6 mg/L to 11 mg/L showing inconsistency with denitrification.

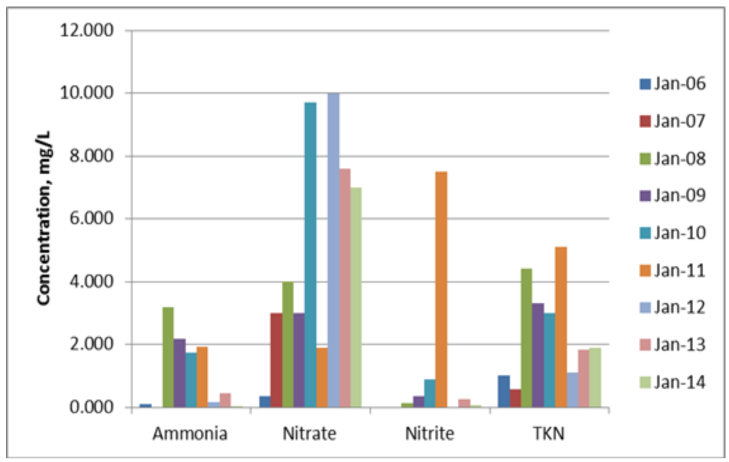

Figure O-4 Orange, MA Distribution of Nitrogen Species

Because the flows are so high relative to design flow, they are not a candidate for any modification to improve nitrogen removal since there is no significant amount of excess capacity available.

This plant would benefit by having instrumentation to help them monitor and optimize the process. The recommended instruments include ammonia, nitrate, DO and sensors.

Palmer, MA

Plant Description

The Palmer Wastewater Treatment Plant (Figure P-1) is a 5.6 MGD activated sludge facility. It is currently treating an average flow of 1.47 MGD or about 26% of design flow. The plant has two primary clarifiers and four independent bioreactors. Two of the reactors have fine bubble diffusers and two have coarse bubble diffusers Effluent from the bioreactors flows to two secondary clarifiers, then to a tertiary clarifier (also called a clariflocculator) and then to chlorine disinfection before being discharged to the Chicopee River, a tributary of the Connecticut River.

Figure P-1 Aerial View Palmer, MA Facility

Table P-1 Current Permit Limits, Palmer, MA

	Monthly	Weekly	Annual Goal
TSS, mg/L	30	45	X
BOD, mg/L	30	45	X
TN, lbs/d	X	X	376

Currently, they are using one primary clarifier, the two fine-bubble bioreactors, two secondary clarifiers and the clariflocculator. Palmer's permit limits are shown in Table P-1. Along with these permit limits; they are also required to monitor various nitrogen species.

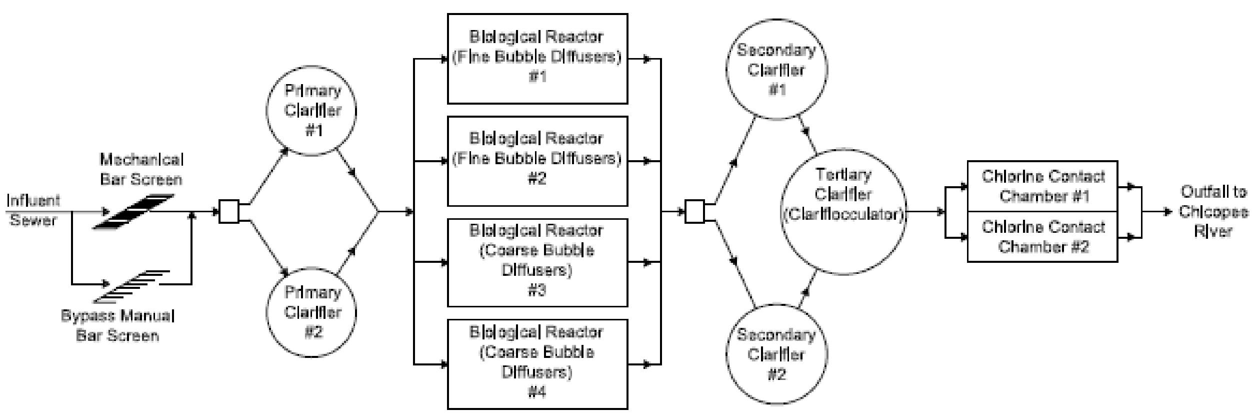

Figure P-2 Palmer, MA Process Flow Diagram

BioWin Model and Conceptual Design

Average influent concentrations and an average influent temperature of 13.7° C (Table P-2) were used for calibration of the model using a steady-state simulation. Model output was compared to average effluent data. The model was considered calibrated if the output typically matched effluent BOD5, TSS and total nitrogen within +/- 10% of the actual values in the data sets. All parameters were within the 10% except for BOD which was within 15%. Once the model was calibrated, various design alternatives and changes in process control parameters were evaluated to determine which alternative resulted in the lowest possible effluent total nitrogen concentration. Sensitivity testing was also performed by reducing the temperature from 13.7° C to 8° C and increasing the flow to 80% of design at 8° C.

Table P-2 Baseline Model Comparison to Conceptual Design Model, Palmer, MA

Plant Influent Data			**Baseline Model Effluent**		**Design Model Effluent**		**Compare Baseline to Model Design**	
Parameters	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d
Volatile suspended solids	158	1937	4.36	53	4.25	52	**0.11**	**1.35**
Total suspended solids	198.46	2433	6.41	79	6.29	77	**0.12**	**1.47**
Total Kjeldahl Nitrogen	28.6	351	3	36	2	30	**0**	**6**
Total Carbonaceous BOD	169	2072	2.18	27	2.06	25	**0.12**	**1.47**
Total N	28.6	351	13.8	169	6.4	78	**7.4**	**91.0**
pH	7		6.9		6.9			
Ammonia N	18.88	231	1.0	12	0.5	6	**0.5**	**6.1**
Nitrate N	0	0	9.8	121	3.8	47	**6.0**	**73.7**
Parameters								
Temperature, °C	13.7		13.7		13.7			
Flow, MGD	1.47		1.47		1.47			

The baseline model was configured (Figure P-3) using one primary clarifier, two fine-bubble reactors, two secondary clarifiers and the clariflocculator and calibrated (Table P-2 Baseline Model Column). Average annual flow and temperature (1.47 MGD and 13.7° C) obtained from plant data were used for both the baseline and nitrogen design models.

The calibrated model was then used to develop the optimum nitrogen removal model. To remove nitrogen at the Palmer, MA, facility, one-third of each of the fine-bubble reactors was converted to an anoxic zone with the other two-third remaining aerobic. Nitrate recycle was also added (Figure P-4). With this configuration, the model predicts that Palmer, MA, can achieve significant nitrogen removal (Table P-2 Design Model Column).

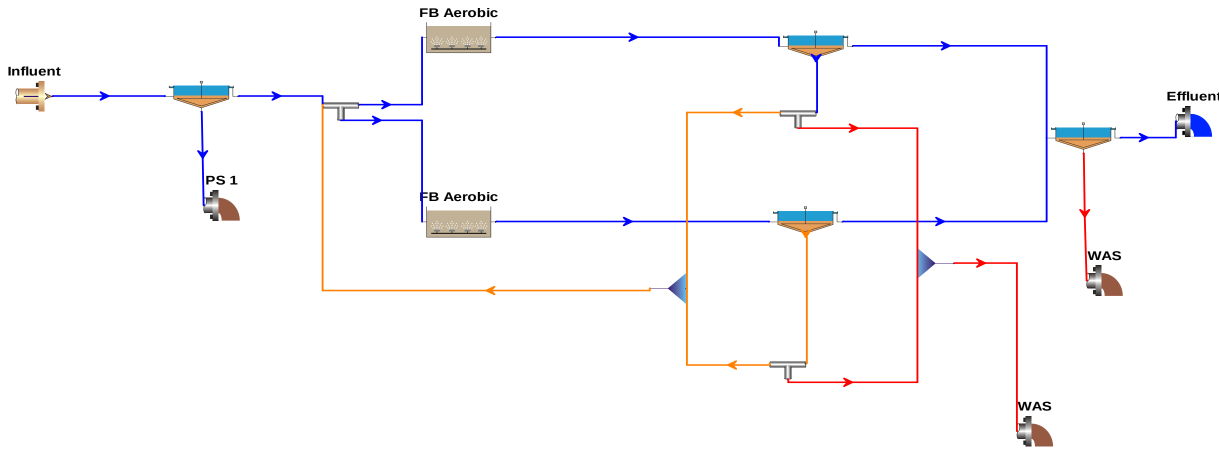

Figure P-3 Baseline Model, Palmer, MA

Currently, influent TN averages about 352 lbs/d and the plant discharges about 169 lbs/d resulting in a removal of about 182 lbs/d (351 lbs/d-169 lbs/d) or 52% removal. With the anoxic-aerobic reactor configuration and recycle pumps, the model is predicting that the plant would discharge 78 lbs/d total nitrogen with a concentration of 6.4 mg/L resulting in a removal of 273 lbs/d (351 lbs/d-78 lbs/d) or 78% removal. Increased removal over current performance is 91 lbs/d total nitrogen or about 33,215 lbs/year at average conditions.

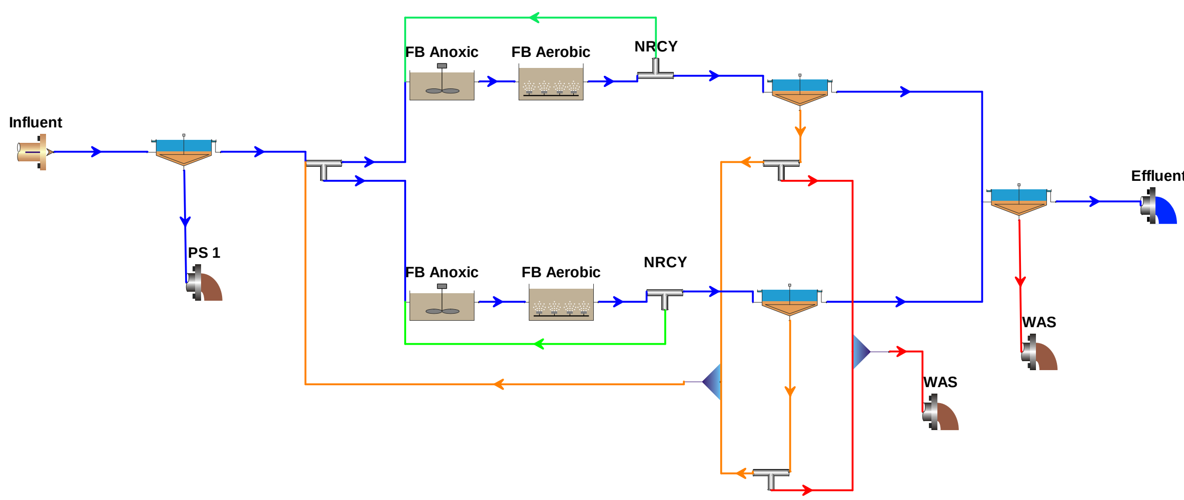

Figure P-4 Conceptual Nitrogen Design Model, Palmer, MA

Table P-3 Summary of Results, Palmer, MA

Current Influent TN, lbs/d	351
Current Effluent TN, lbs/d	169
Current Removal, lbs/d	182
Predicted Effluent TN, lbs/d	78
Predicted Removal, lbs/d	273
Net Change, lbs/d	91
Net Change, lbs/year	33,215
Winter Temperature, lbs/year	33,215

The model was then tested at 8^{o} C and then at 8^{o} C with the flow increased to 80% of design. At 8^{o} C, effluent total nitrogen concentration did not increase. When the flow was increased to 80% at this temperature, the effluent TN concentration increased slightly to 6.5 mg/L. A summary of these results is shown in Table P-3. The equipment needed for this conceptual design includes mixers, nitrate recycle pumps and DO, ammonia, pH and nitrate analyzers.

Cost Per Pound of Nitrogen Removed

A preliminary construction cost estimate was prepared based on the design shown in Figure P-4. This estimate was then used to calculate the cost per pound of nitrogen removed based on the model prediction. The estimate includes the cost of all equipment (mixers, pumps, piping and instruments) and installation costs. The total cost for retrofitting this system is estimated to be $320,722

NEIWPCC — Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the upper Long Island Sound Watershed

COST ESTIMATE — **Palmer MA**

Contractor Name:	JJ Environmental	Date:	1-Jun-14
Address:	17 Archer Lane	Project No.	0302-001
	Darien, Ct 06820	Proposal No.	18
Telephone No:	1-203-309-8768		

		Revisions
SECTION A: CONTRACTOR WORK		
1. Total Contractor Labor	$71,190.66	
2. Total Contractor Material	$104,600.00	
3. Total Contractor Equipment	$20,190.00	
4. Unit Price Costs		
5. Subtotal Contractor Cost	$195,980.66	
6. Contractor Mark-Up 15%	$29,397.10	
7. Contractor Total Section A	$225,377.76	
SECTION B: CONTRACTOR WORK		
8. Names Of Subcontractors		
A. Electrical Subcontractor	$81,719.19	
B. Instrumentation Integrator	$9,085.00	
C.		
D.		
E.		
F.		
9. Total Subcontractor's Proposals (A through F)	$90,804.19	
10. Contractor's Mark-Up On Subs Proposals (5%)	$4,540.21	
11. Subcontractor Total Section B	$95,344.40	
SECTION C: TOTAL CONTRACTED UNIT PRICE COSTS		
SECTION D: CONTRACTOR'S REQUEST		
12. Amount Requested (Total Lines 7 & 11)	**$320,722.16**	

Figure P-5 Cost Estimate Palmer, MA, Conceptual Design

The increase O&M cost is $26,140 per year primarily due to additional electrical costs. However, there is some cost reduction due to the smaller aerobic volume which is about $7,842 per year giving a net increase in O&M costs of $18,298 per year. The model is predicting at average temperature and current flow, the plant will remove an additional 33,215 lbs/year over baseline conditions. Therefore the cost per pound for the ten year term is $1.67 (Table P-4) and for the twenty year is $1.19 (Table P-5).

Table P-4 Palmer, MA Cost of Nitrogen Removal (10-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
91	**Delta Pounds N Removed Per day**
33,215	Delta Pounds N Removed 1 Year
332,150	Delta Pounds N Removed 10 Year
664,300	Delta Pounds N Removed 20 Year
$320,722.16	**Capital Cost of Conceptual Design**
$9.66	Cost Per Pound Over 1 Year
$0.97	Cost Per Pound Over 10 Years
$0.48	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
10	Loan Term in Years
$3,096.92	Monthly Payment (100% Financed)
$371,630.05	Total Cost P & I Over 10 Years
$182,980.00	Additional O&M over term
$554,610.05	Total Cost Over 10 Years
$1.67	**Total Cost Per Pound of Additional Nitrogen Removed Over 10 Years**

Table P-5 Palmer, MA Cost of Nitrogen Removal (20-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
91	**Delta Pounds N Removed Per day**
33,215	Delta Pounds N Removed 1 Year
332,150	Delta Pounds N Removed 10 Year
664,300	Delta Pounds N Removed 20 Year
$320,722.16	**Capital Cost of Conceptual Design**
$9.66	Cost Per Pound Over 1 Year
$0.97	Cost Per Pound Over 10 Years
$0.48	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
20	Loan Term in Years
$1,778.72	Monthly Payment (100% Financed)
$426,892.17	Total Cost P & I Over 20 Years
$365,960.00	Additional O&M over term
$792,852.17	Total Cost Over 20 Years
$1.19	**Total Cost Per Pound of Additional Nitrogen Removed Over 20 Years**

Pittsfield, MA

Plant Description

The Pittsfield Wastewater Treatment Plant (Figure PT-1) is a trickling filter process followed by the activated sludge facility. The plant is designed for 17.0 MGD and is currently treating an average of 11.94 MGD or about 70% of the design flow. Influent is first conveyed to primary clarifiers, then to trickling filters. The trickling filter effluent flows to the activated sludge process, then to secondary clarifiers followed by chlorine disinfection prior to discharging to the Housatonic River (Figure PT-2). Currently they are using four primary clarifiers, two trickling filters, two bioreactor trains and three secondary clarifiers.

Figure PT-1 Aerial View Pittsfield, MA, Facility

Table PT-1 Current Permit Limits Pittsfield, MA

	Monthly	Weekly	Annual Goal
TSS, mg/L	20	25	X
cBOD, mg/L	10	10	X
TN, lbs/d	X	X	1241

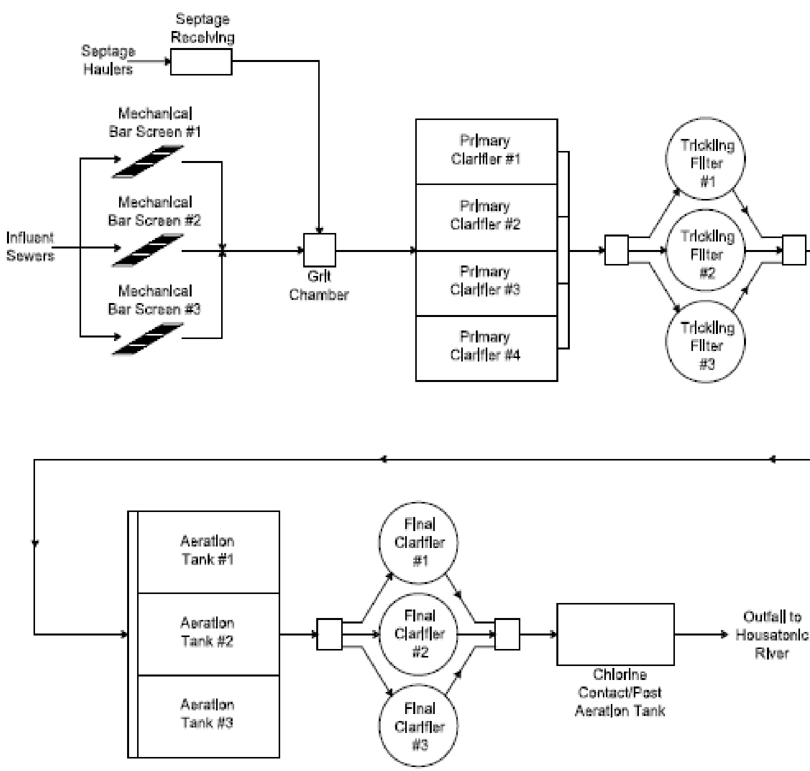

Figure PT-2 Pittsfield, MA, Process Flow Diagram

Pittsfield's permit limits are shown in Table PT-1. Along with these permit limits; they are also required to monitor various nitrogen species. Permit limits for Pittsfield, MA, are shown in Table PT-1. There are intermediate clarifiers located after the trickling filters and these units are not currently in operation.

BioWin Model and Conceptual Design

Average influent concentrations and an average influent temperature 13.9^o C were used for calibration of the model using a steady-state simulation. Model output was compared to average effluent data.

The model was considered calibrated if the output typically matched effluent BOD5, TSS and total nitrogen within +/- 10% of the actual values in the data sets. All parameters were within 10% except for effluent TKN which was about 49% higher and BOD which 29% higher than the actual plant data. Once the model was calibrated, various design alternatives and changes in process control parameters were evaluated to determine which alternative resulted in the lowest possible effluent total nitrogen. Sensitivity testing was also performed by reducing the temperature from 13.9^o C to 8^o C and increasing the flow to 80% of design at 8^o C.

The baseline model was configured (Figure PT-3) using four primary clarifiers, two trickling filters, two bioreactor trains and three secondary clarifiers and calibrated (Table PT-2 Baseline Model Column). Average annual flow and temperature (11.94 MGD and 13.9^o C) obtained from plant data were used for both the baseline and nitrogen design models.

Table PT-2 Baseline Model Comparison to Conceptual Design, Pittsfield, MA

Plant Influent Data			Baseline Model Effluent		Design Model Effluent		Compare Baseline to Model Design	
Parameters	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d
Volatile suspended solids	125	12447	3.43	342	3.13	312	**0.30**	**29.87**
Total suspended solids	156.34	15568	4.64	462	4.26	424	**0.38**	**37.84**
Total Kjeldahl Nitrogen	20	1992	1.9	187	3	249	**-1**	**-62**
Total Carbonaceous BOD	90	8962	1.55	154	1.58	157	**-0.03**	**-2.99**
Total N	20	1992	13.5	1339	4.87	485	**8.6**	**854.4**
pH	7.4		6.9		7.0	700		
Ammonia N	13.2	1314	0.4	41	1.3	126	**-0.9**	**-85.6**
Nitrate N	0	0	11.48	1143	1.53	152	**9.95**	**990.82**
Parameters								
Temperature, ^oC	13.9		13.9		13.90			
Flow, MGD	11.94		11.94		11.94			

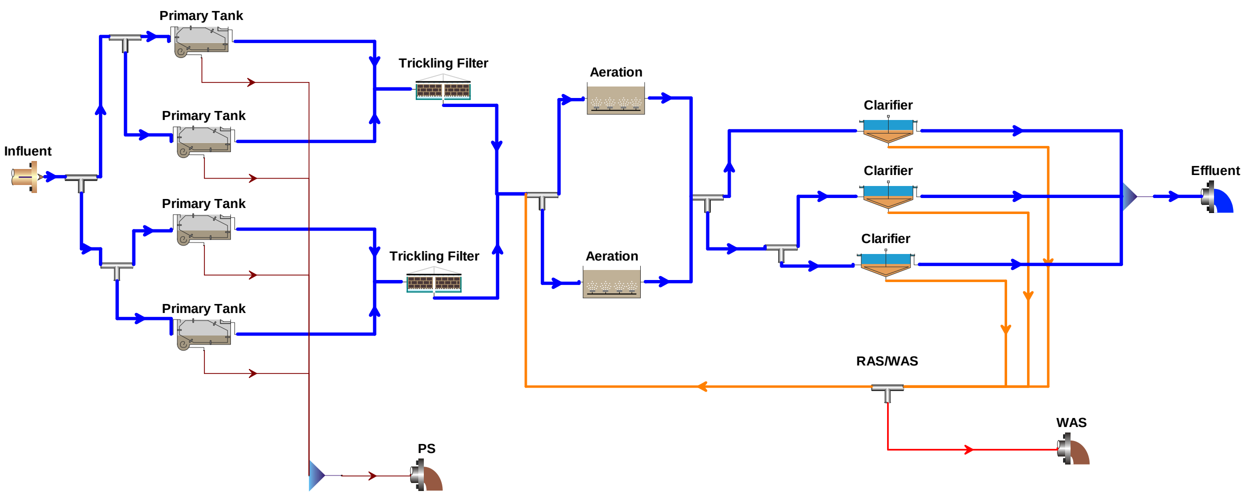

Figure PT-3 Baseline Model, Pittsfield, MA

To remove nitrogen at the Pittsfield, MA, facility, each bioreactor train was divided into four zones; one anoxic, one swing and two aerobic. The anoxic zone is 25% of the total volume of the reactor train as is the swing zone. The aerobic zone is 50% of the reactor volume. Nitrate recycle was also added (Figure PT-4). With this configuration, the model predicts that Pittsfield, MA, can achieve significant nitrogen removal (Table PT-2 Design Model Column).

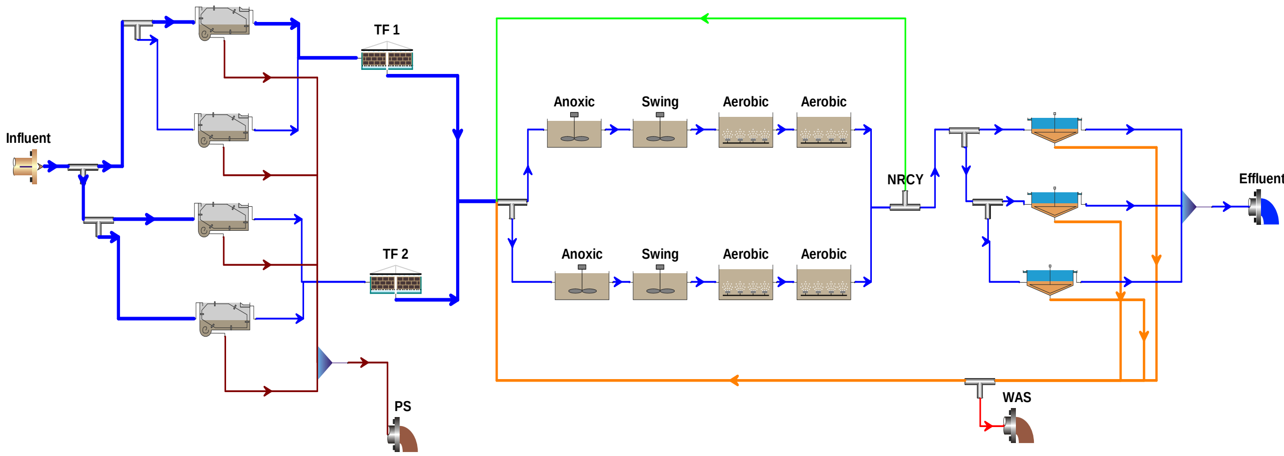

Figure PT-4 Conceptual Nitrogen Design Model, Pittsfield, MA

Table PT-3 Summary of Results, Pittsfield, MA

Current Influent TN, lbs/d	1,992
Current Effluent TN, lbs/d	1,339
Current Removal, lbs/d	653
Predicted Effluent TN, lbs/d	485
Predicted Removal, lbs/d	1,507
Net Change, lbs/d	854
Net Change, lbs/year	311,853
Winter Temperature, lbs/year	215,710

Currently, influent TN averages about 1,992 lbs/d and the plant discharges about 1,339 lbs/d resulting in a removal of about 653 lbs/d (1,992 lbs/d-1,339 lbs/d) or about 33%. With the anoxic, swing, aerobic reactor configuration and recycle pumps, the model is predicting that the plant would discharge 485 lbs/d total nitrogen with a concentration of 4.87 mg/L resulting in a removal of 1,507 lbs/d (1,992 lbs/d-485 lbs/d) or about 76%. The increased removal over current performance is 854.4 lbs/d total nitrogen or about 311,853 lbs/year at average conditions.

The model was then tested at 8^{o} C and then at 8^{o} C with the flow increased to 80% of design. At 8^{o} C and at 8^{o}C at 80% of design flow, effluent total nitrogen concentration increased to 7.53 mg/L with a removal of 215,710 lbs/year. It is necessary to operate the swing zone as an aerobic zone under both of these conditions. A summary of these results is shown in Table PT-3. The equipment needed for this design includes mixers, nitrate recycle pumps, DO, ammonia, pH and nitrate analyzers.

Because this plant has both primary settling tanks and trickling filters, more than half of the influent carbon is removed before the biological system. If either the primary tanks for trickling filters could be by-passed, the additional carbon entering the biological reactors would improve nitrogen removal under all conditions.

Cost Per Pound of Nitrogen Removed

A preliminary construction cost estimate was prepared based on the design shown in Figure PT-5. This estimate was then used to calculate the cost per pound of nitrogen removed based on the model prediction.

The estimate includes the cost of all equipment (mixers, pumps, piping and instruments) and installation costs. The total cost for retrofitting this system is estimated to be $745,033. The increase O&M cost is $112, 400 per year primarily additional electrical costs. However, there is a savings due to reducing the aerobic volume which is about $39, 210 per year giving a net increase in O&M costs of $73, 900 per year. The model is predicting at average temperature and current flow, the plant will remove an additional 311,853 lbs/year over baseline conditions. Therefore the cost per pound for the ten-year term is $0.51 (Table PT-4) and for the twenty-year term is $0.40 (Table PT-5).

NEIWPCC Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the upper Long Island Sound Watershed		COST ESTIMATE Pittsfield	
Contractor Name:	JJ Environmental	Date:	17-Feb-05
Address:	17 Archer Lane	Project No.	0302-001
	Darien, Ct 06820	Proposal No.	19 Rev 1
Telephone No:	1-203-309-8768		

		Revisions
SECTION A: CONTRACTOR WORK		
1. Total Contractor Labor	$155,729.58	
2. Total Contractor Material	$306,800.00	
3. Total Contractor Equipment	$30,285.00	
4. Unit Price Costs		
5. Subtotal Contractor Cost	$492,814.58	
6. Contractor Mark-Up 15%	$73,922.19	
7. Contractor Total Section A	$566,736.76	
SECTION B: CONTRACTOR WORK		
8. Names Of Subcontractors		
A. Electrical Subcontractor	$159,018.51	
B. Instrumentation Integrator	$10,787.00	
C.		
D.		
E.		
F.		
9. Total Subcontractor's Proposals (A through F)	$169,805.51	
10. Contractor's Mark-Up On Subs Proposals (5%)	$8,490.28	
11. Subcontractor Total Section B	$178,295.79	
SECTION C: TOTAL CONTRACTED UNIT PRICE COSTS		
SECTION D: CONTRACTOR'S REQUEST		
12. Amount Requested (Total Lines 7 & 11)	**$745,032.55**	

Figure PT-5 Cost Estimate Pittsfield, MA, Conceptual Design

Table P-4 Pittsfield, MA Cost of Nitrogen Removal (10-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
854	**Delta Pounds N Removed Per day**
311,853	Delta Pounds N Removed 1 Year
3,118,534	Delta Pounds N Removed 10 Year
6,237,069	Delta Pounds N Removed 20 Year
$745,032.55	**Capital Cost of Conceptual Design**
$2.39	Cost Per Pound Over 1 Year
$0.24	Cost Per Pound Over 10 Years
$0.12	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
10	Loan Term in Years
$7,194.09	Monthly Payment (100% Financed)
$863,290.77	Total Cost P & I Over 10 Years
$739,000.00	Additional O&M over term
$1,602,290.77	Total Cost Over 10 Years
$0.51	**Total Cost Per Pound of Additional Nitrogen Removed Over 10 Years**

Table P-5 Pittsfield, MA Cost of Nitrogen Removal (20-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
854	**Delta Pounds N Removed Per day**
311,853	Delta Pounds N Removed 1 Year
3,118,534	Delta Pounds N Removed 10 Year
6,237,069	Delta Pounds N Removed 20 Year
$745,032.55	**Capital Cost of Conceptual Design**
$2.39	Cost Per Pound Over 1 Year
$0.24	Cost Per Pound Over 10 Years
$0.12	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
20	Loan Term in Years
$4,131.93	Monthly Payment (100% Financed)
$991,663.83	Total Cost P & I Over 20 Years
$1,478,000.00	Additional O&M over term
$2,469,663.83	Total Cost Over 20 Years
$0.40	**Total Cost Per Pound of Additional Nitrogen Removed Over 20 Years**

South Hadley, MA

Plant Description

The South Hadley wastewater treatment plant (Figure SH-1) is an activated sludge treatment plant. It is designed for a flow of 4.2 MGD and is currently treating 2.66 MGD or about 63 % of the design flow. The plant has three primary settling tanks and two biological reactor trains with two tanks in each train. Aeration is provided by mechanical aerators on variable frequency drives (VFDs). The flow from the biological system is then conveyed to two secondary clarifiers. The effluent from the secondary clarifiers is disinfected with chlorine prior to discharge to the Connecticut River

Figure SH-1 Aerial View South Hadley, MA, Facility

Table SH-1 Current Permit Limits, South Hadley, MA

	Monthly	Weekly	Annual Goal
TSS, mg/L	30	45	X
BOD, mg/L	30	45	X
TN, lbs/d	X	X	682

The current permit limits for South Hadley, MA, are shown in Table SH-1. Along with these permit limits; they are also required to monitor various nitrogen species.

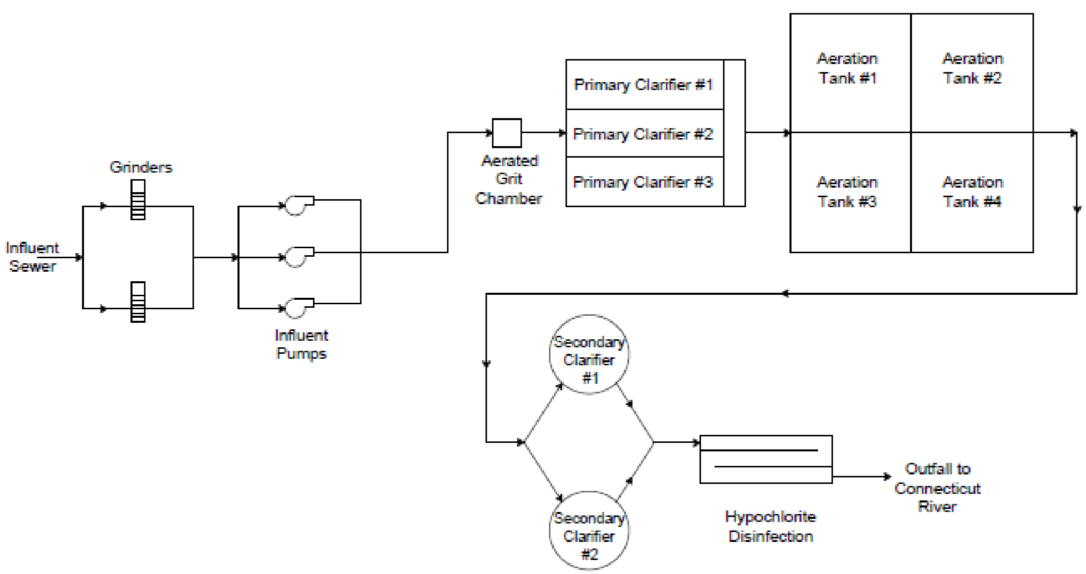

Figure SH-2 South Hadley, MA, Process Flow Diagram

Currently the plant operates two primary settling tanks (except during high flows when they place the third tank in service), two of the four biological reactors (operated in series) and both secondary clarifiers. Air is supplied by 50-hp mechanical aerators with variable frequency drives (VFDs). According to plant staff, they have difficulty maintaining sufficient DO concentrations in the reactors. This results in higher effluent ammonia nitrogen concentrations and higher effluent total nitrogen concentrations. In order to optimize nitrogen removal, it will be necessary to further investigate the output of the mechanical aerators to determine if they can supply sufficient DO. Investigation should include horsepower output and submergence.

BioWin Model and Conceptual Design

Average influent concentrations and an average influent temperature 15.2^{o} C were used for calibration of the model using a steady-state simulation. Model output was compared to average effluent data.

The model was considered calibrated if the output typically matched effluent BOD5, TSS and total nitrogen within +/- 10% of the actual values in the data sets. All parameters were within the 10% except for BOD (50% lower) and TKN (33% higher). Once the model was calibrated, various design alternatives and changes in process control parameters were evaluated to determine which alternative resulted in the lowest possible effluent total nitrogen. Sensitivity testing was also performed by reducing the temperature from 15.2^{o} C to 10^{o} C and increasing the flow to 80% of design at 10^{o} C.

Table SH-2 Baseline Model Comparison to Conceptual Design, South Hadley, MA

Plant Influent Data			Baseline Model Effluent		Design Model Effluent		Compare Baseline to Model Design	
Parameters	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d
Volatile suspended solids	152.49	3383	4.96	110	4.26	95	**0.7**	**16**
Total suspended solids	191.06	4239	6.79	151	6.13	136	**0.66**	**15**
Total Kjeldahl Nitrogen	35	776	2.99	66	2.74	61	**0.25**	**6**
Total Carbonaceous BOD	163.77	3633	3	67	2.29	51	**0.71**	**16**
Total N	35	776	18.9	419	6.35	141	**12.55**	**278**
pH	7.36		7.12	158	7.27	161		
Ammonia N	25.45	565	0.71		0.64	14	**0.07**	**-14**
Nitrate N	0	0	14.41	320	1.84	41	**12.57**	**279**
Parameters								
Temperature, ^{o}C	15.2		15.2		15.2			
Flow, MGD	2.66		2.66		2.66			

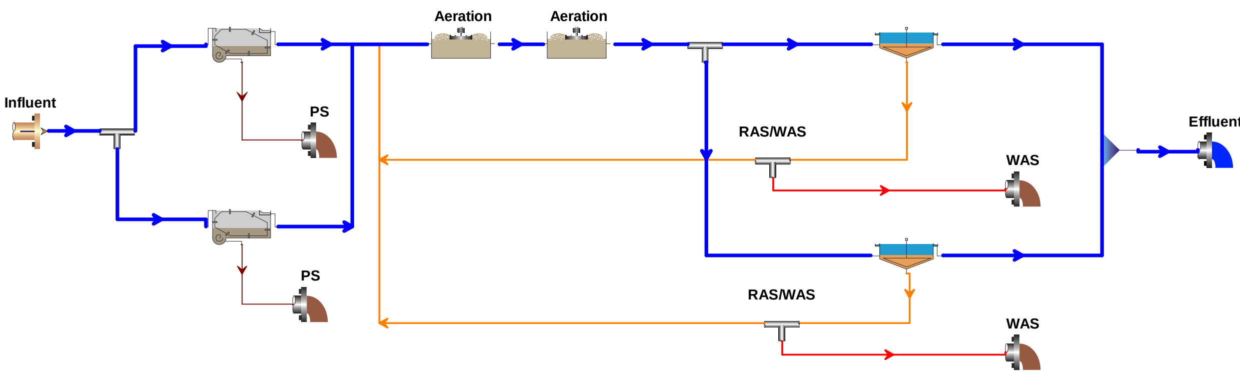

Figure SH-3 Baseline Model, South Hadley, MA

The baseline model was configured (Figure SH-3) using two primary clarifiers, one bioreactor train and two secondary clarifiers and calibrated (Table SH-2 Baseline Model Column). Average annual flow and temperature (2.64 MGD and 15.2^{o} C) obtained from plant data were used for both the baseline and nitrogen design models. To remove nitrogen at the South Hadley, MA, facility, the first is anoxic and the second tank aerobic. Nitrate recycle is also added (Figure SH-4). With this configuration, the model predicts that South Hadley, MA, can achieve significant nitrogen removal (Table SH-2 Design Model Column), provided there is sufficient DO for nitrification.

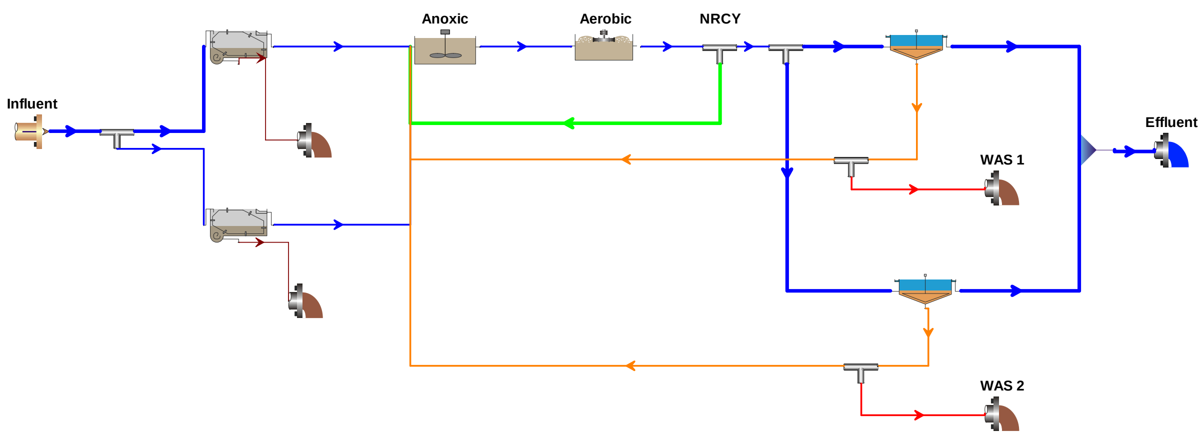

Figure SH-4 Conceptual Nitrogen Design Model, South Hadley, MA

Currently, influent TN averages about 776 lbs/d and the plant discharges about 419 lbs/d resulting in a removal of about 357 lbs/d (776 lbs/d-419 lbs/d) or 46% removal. With this configuration, the model is predicting that the plant would discharge 141 lbs/d total nitrogen with a concentration of 6.35 mg/L resulting in a removal of 635 lbs/d (776 lbs/d-141 lbs/d) or 82% removal. The increase removal over current performance is 278 lbs/d total nitrogen or about 101,470 lbs/year at average flow and temperature. At 10^{o} C and current average daily flow, there is insufficient capacity to completely nitrify. Effluent total nitrogen concentration is 8.2 mg/L with almost half being ammonia-nitrogen or a removal of 98,915 lbs/year. If the

Table SH-3 Summary of Results, South Hadley, MA

Current Influent TN, lbs/d	776
Current Effluent TN, lbs/d	419
Current Removal, lbs/d	357
Predicted Effluent TN, lbs/d	141
Predicted Removal, lbs/d	635
Net Change, lbs/d	278
Net Change, lbs/year	101,470
Winter Temperature, lbs/year	98,915

second train is put into service in cold weather, performance improves with effluent total nitrogen predicted a 6.7 mg/L with ammonia nitrogen less than 1 mg/L.

When the flow increased to 80% at this temperature and using both trains, the concentration of total nitrogen increased slightly to 6.8 mg/L with ammonia-nitrogen at 1.10 mg/L. Under these conditions, about 98,915 lbs/d of nitrogen would be removed. A summary of these results is shown in Table SH-3.

Cost Per Pound of Nitrogen Removed

A preliminary construction cost estimate (Figure SH-4) was prepared based on the design shown in Figure SH-3.

NEIWPCC — **COST ESTIMATE**

Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the upper Long Island Sound Watershed

South Hadley, MA

Contractor Name:	JJ Environmental	Date:	2-Aug-14
Address:	17 Archer Lane	Project No.	0302-001
	Darien, Ct 06820	Proposal No.	20
Telephone No:	1-203-309-8768		

		Revisions
SECTION A: CONTRACTOR WORK		
1. Total Contractor Labor	$62,291.83	
2. Total Contractor Material	$75,600.00	
3. Total Contractor Equipment	$26,920.00	
4. Unit Price Costs		
5. Subtotal Contractor Cost	$164,811.83	
6. Contractor Mark-Up 15%	$24,721.77	
7. Contractor Total Section A	$189,533.60	
SECTION B: CONTRACTOR WORK		
8. Names Of Subcontractors		
A. Electrical Subcontractor	$94,925.70	
B. Instrumentation Integrator	$12,765.00	
C.		
D.		
E.		
F.		
9. Total Subcontractor's Proposals (A through F)	$107,690.70	
10. Contractor's Mark-Up On Subs Proposals (5%)	$5,384.54	
11. Subcontractor Total Section B	$113,075.24	
SECTION C: TOTAL CONTRACTED UNIT PRICE COSTS		
SECTION D: CONTRACTOR'S REQUEST		
12. Amount Requested (Total Lines 7 & 11)	**$302,608.84**	

Figure SH-5 Cost Estimate South Hadley, MA, Conceptual Design

This estimate was then used to calculate the cost per pound of nitrogen removed based on the model prediction. The estimate includes the cost of all equipment (mixers, pumps, piping and instruments) and installation costs.

The cost estimate assumes that the existing aerators will be able to provide adequate DO. (A second cost estimate in the next section includes aeration system improvement costs. The total cost for retrofitting this system is estimated to be $302,609. The increased O&M cost is $31,368 per year primarily additional electrical costs. However, there is an electrical cost saving from not operating one surface aerator which is about $15,030 per year giving a net increase in O&M costs of $16,337 per year. The model is predicting at average temperature and current flow, the plant will remove an additional 101,470 lbs/year over baseline conditions. Therefore the cost per pound for the ten-year term is $0.51 (Table SH-4) and for the twenty-year is $0.36 (Table SH-5).

Table SH-4 South Hadley, MA Cost of Nitrogen Removal (10-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
278	**Delta Pounds N Removed Per day**
101,470	Delta Pounds N Removed 1 Year
1,014,700	Delta Pounds N Removed 10 Year
2,029,400	Delta Pounds N Removed 20 Year
$302,608.84	**Capital Cost of Conceptual Design**
$2.98	Cost Per Pound Over 1 Year
$0.30	Cost Per Pound Over 10 Years
$0.15	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
10	Loan Term in Years
$2,922.01	Monthly Payment (100% Financed)
$350,641.62	Total Cost P & I Over 10 Years
$163,370.00	Additional O&M over term
$514,011.62	Total Cost Over 10 Years
$0.51	**Total Cost Per Pound of Additional Nitrogen Removed Over 10 Years**

Table SH-5 South Hadley, MA Cost of Nitrogen Removal (20-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
278	**Delta Pounds N Removed Per day**
101,470	Delta Pounds N Removed 1 Year
1,014,700	Delta Pounds N Removed 10 Year
2,029,400	Delta Pounds N Removed 20 Year
$302,608.84	Capital Cost of Conceptual Design
$2.98	Cost Per Pound Over 1 Year
$0.30	Cost Per Pound Over 10 Years
$0.15	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
20	Loan Term in Years
$1,678.26	Monthly Payment (100% Financed)
$402,782.73	Total Cost P & I Over 10 Years
$326,740.00	Additional O&M over term
$729,522.73	Total Cost Over 20 Years
$0.36	**Total Cost Per Pound of Additional Nitrogen Removed Over 20 Years**

Additional Cost Analysis-South Hadley, MA

Since plant personnel expressed a concern about the mechanical aerators, a cost estimate was developed for replacing the mechanical aerators with fine bubble diffusers or with aerator/mixers. The cost of fine bubble diffusers including blowers and installation is estimated to be $1,760,276 and for aerator/mixers including blowers and installation, $1,814,253. This results in an estimated cost per pound of nitrogen removed about $2.20 for a 10-year term and about $1.34 for a 20-year term for the fine bubble alterative (Tables SH-6 and SH-7).

Table SH-6 South Hadley, MA Cost of Nitrogen Removal (10-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
278	**Delta Pounds N Removed Per day**
101,470	Delta Pounds N Removed 1 Year
1,014,700	Delta Pounds N Removed 10 Year
2,029,400	Delta Pounds N Removed 20 Year
$1,760,276.00	**Capital Cost of Conceptual Design**
$17.35	Cost Per Pound Over 1 Year
$1.73	Cost Per Pound Over 10 Years
$0.87	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
10	Loan Term in Years
$16,997.36	Monthly Payment (100% Financed)
$2,039,682.74	Total Cost P & I Over 10 Years
$184,316.00	Additional O&M over term
$2,223,998.74	Total Cost Over 10 Years
$2.19	**Total Cost Per Pound of Additional Nitrogen Removed**

Table SH-7 South Hadley, MA Cost of Nitrogen Removal (20-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
278	**Delta Pounds N Removed Per day**
101,470	Delta Pounds N Removed 1 Year
1,014,700	Delta Pounds N Removed 10 Year
2,029,400	Delta Pounds N Removed 20 Year
$1,760,276.00	Capital Cost of Conceptual Design
$17.35	Cost Per Pound Over 1 Year
$1.73	Cost Per Pound Over 10 Years
$0.87	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
20	Loan Term in Years
$9,762.45	Monthly Payment (100% Financed)
$2,342,987.62	Total Cost P & I Over 10 Years
$368,632.00	Additional O&M over term
$2,711,619.62	Total Cost Over 20 Years
$1.34	**Total Cost Per Pound of Additional Nitrogen Removed**

Spencer, MA

Plant Description

The Spencer Wastewater Treatment Plant (SP-1) is an activated sludge facility rated for 1.08 MGD. It currently has an average flow of 0.78 MGD or about 72% of the design flow. The plant has two biological reactor trains with diffused air and two secondary clarifiers. Each secondary clarifier is a different size and design. Secondary effluent is discharged to constructed wetlands, recollected and disinfected using ultraviolet light prior to discharge to Cranberry Brook a tributary of the Connecticut River (SP-2).

Figure SP-1 Aerial View Spencer, MA, Facility

Table SP-1 Current Permit Limits, Spencer, MA

(May 1-Oct 31)	Monthly	Weekly	Annual Goal
TSS, mg/L	5.6	7.5	X
BOD, mg/L	5.6	7.5	X
Ammonia, mg/L	0.56	0.84	X
(Nov 1-Nov 30)			
Ammonia, mg/L	8.5		X
(Nov 1-Apr 30)			
TSS, mg/L	30	45	X
BOD, mg/L	30	45	
(Dec 1-Apr 30)			X
Ammonia, mg/L	15.2		
TN, lbs/day	X	X	

Currently they use two biological reactors and one secondary clarifier. Spencer's permit limits are shown in Table SP-1. Along with these permit limits for ammonia-nitrogen; they are also required to monitor other nitrogen species.

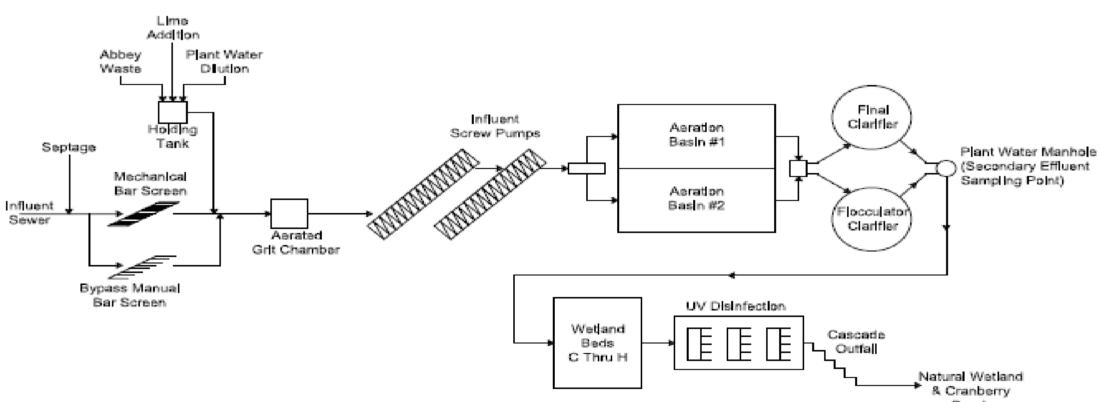

Figure SP-2 Spencer, MA, Process Flow Diagram

BioWin Model and Conceptual Design

Average influent concentrations and an average influent temperature 16^{o} C were used for calibration of the model using a steady-state simulation. Model output was compared to average effluent data.

Table SP-2 Baseline Model Comparison to Conceptual Design, Spencer, MA

Plant Influent Data			Baseline Model Effluent		Design Model Effluent		Compare Baseline to Model Design	
Parameters	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d
Volatile suspended solids	254	1652	5.01	33	4.32	28	**0.69**	**4.49**
Total suspended solids	343.72	2236	9.30	60	7.82	51	**1.48**	**9.63**
Total Kjeldahl Nitrogen	45	293	3	16	2	16	**0**	**1**
Total Carbonaceous BOD	262	1704	1.97	13	2.00	13	**-0.03**	**-0.20**
Total N	41	267	15.5	101	5.7	37	**9.8**	**63.8**
pH	7.48		6.8		6.9	45		
Ammonia N	29.7	193	0.5	3	0.6		**-0.1**	**3.4**
Nitrate N	0	0	12.77	83	3.14	20	**9.63**	**62.65**
Parameters								
Temperature, ^{o}C	16		16		16			
Flow, MGD	0.78		0.78		0.78			

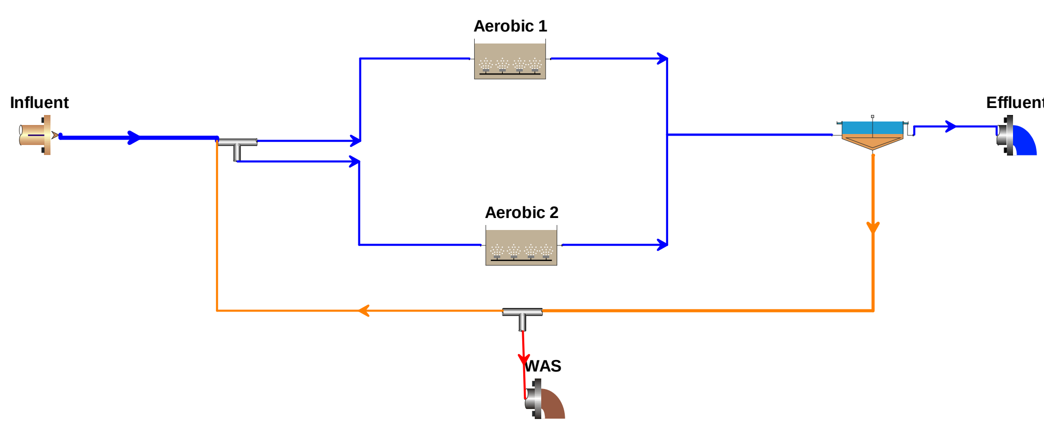

Figure SP-3 Baseline Model, Spencer, MA

The model was considered calibrated if the output typically matched effluent BOD5, TSS and total nitrogen within +/- 10% of the actual values in the data sets. Most of the parameters were within 10% as compared to their <u>secondary effluent</u> except for BOD which the model predicted a lower value. It is important to distinguish in this case, that the secondary effluent is considerably different from final effluent after passing through constructed wetlands. Once the model was calibrated, various design alternatives and changes in process control parameters were evaluated to determine which alternative resulted in the lowest possible effluent total nitrogen. Sensitivity testing was also performed by reducing the temperature from 16^{o} C to 10^{o} C and increasing the flow to 80% of design at 10^{o} C.

The baseline model was configured (Figure SP-3) using one biological reactor and two secondary clarifiers and calibrated (Table SP-2 Baseline Model Column). Average annual flow and temperature (0.78 MGD and 16^{o} C) obtained from plant data were used for both the baseline and nitrogen design models.

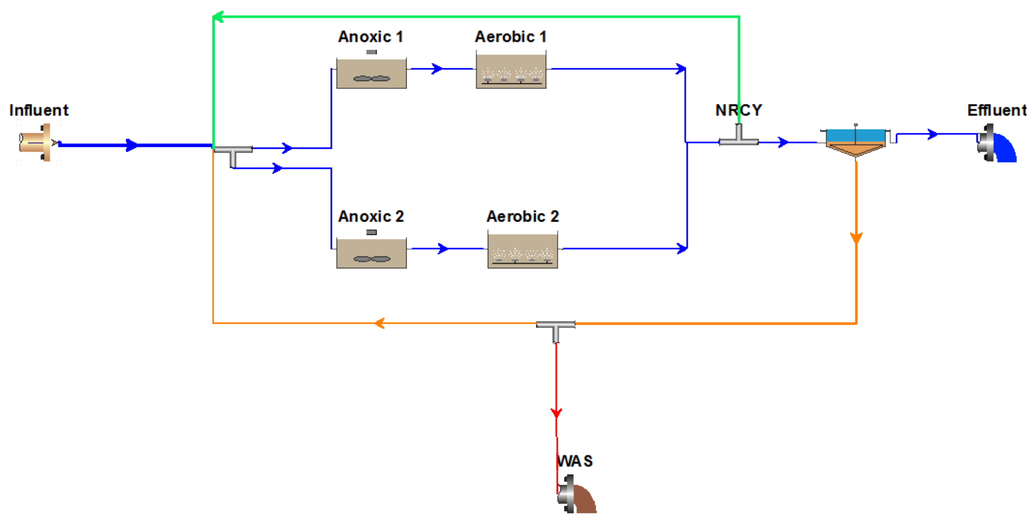

Figure SP-4 Conceptual Nitrogen Design Model, Spencer, MA

To remove nitrogen at the Spencer, MA, facility, an anoxic zone is created using approximately half of the volume of each reactor with the remaining portion aerobic. Nitrate recycle was also added (Figure SP-4). With this configuration, the model predicts that Spencer, MA, can achieve significant nitrogen removal (Table SP-2 Design Model Column). Currently, influent TN averages about 267 lbs/d and the plant discharges about 101 lbs/d resulting in a removal of about 166 lbs/d (267 lbs/d-101 lbs/d) or 62% removal.   With the anoxic, aerobic reactor configuration and recycle pumps, the model is predicting that the plant would discharge 37 lbs/d total nitrogen with a concentration of 5.7 mg/L resulting in a removal of 230 lbs/d (267 lbs/d-37 lbs/d) or 87% removal. Increased removal over current performance is approximately 64 lbs/d or 23,269 lbs/year.

Table SP-3 Summary of Results, Spencer, MA

Current Influent TN, lbs/d	267
Current Effluent TN, lbs/d	101
Current Removal, lbs/d	166
Predicted Effluent TN, lbs/d	37
Predicted Removal, lbs/d	230
Net Change, lbs/d	64
Net Change, lbs/year	23269
Winter Temperature, lbs/year	22201

The model was then tested at 10^{o} C and then at 10^{o} C with the flow increased to 80% of design. At 10^{o} C, the effluent total nitrogen concentration increased to 6.18 mg/L resulting in a removal of 22,201 lbs/d. At 80% design flow and 10^{o} C, effluent TN increased to 6.21 mg/L. A summary of these results is shown in Table SP-3. Along with a baffle to create the anoxic zone, equipment needed for this conceptual design includes mixers, nitrate recycle pumps, and DO, ammonia, pH and nitrate analyzers.

Cost Per Pound of Nitrogen Removed

A preliminary construction cost estimate was prepared based on the design shown in Figure SP-5. This estimate was then used to calculate the cost per pound of nitrogen removed based on the model prediction.

NEIWPCC **Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the upper Long Island Sound Watershed**		**COST ESTIMATE** **Spencer, MA**	
Contractor Name:	JJ Environmental	Date:	1-Jun-14
Address:	17 Archer Lane	Project No.	0302-001
	Darien, Ct 06820	Proposal No.	22
Telephone No:	1-203-309-8768		
SECTION A: CONTRACTOR WORK			Revisions
1. Total Contractor Labor		$86,763.62	
2. Total Contractor Material		$116,600.00	
3. Total Contractor Equipment		$20,190.00	
4. Unit Price Costs			
5. Subtotal Contractor Cost		$223,553.62	
6. Contractor Mark-Up 15%		$33,533.04	
7. Contractor Total Section A		$257,086.66	
SECTION B: CONTRACTOR WORK			
8. Names Of Subcontractors			
A.	Electrical Subcontractor	$81,719.19	
B.	Instrumentation Integrator	$9,085.00	
C.			
D.			
E.			
F.			
9. Total Subcontractor's Proposals (A through F)		$90,804.19	
10. Contractor's Mark-Up On Subs Proposals (5%)		$4,540.21	
11. Subcontractor Total Section B		$95,344.40	
SECTION C: TOTAL CONTRACTED UNIT PRICE COSTS			
SECTION D: CONTRACTOR'S REQUEST			
12. Amount Requested (Total Lines 7 & 11)		**$352,431.06**	

Figure SP-5 Cost Estimate for Spencer, MA, Conceptual Design

The estimate includes the cost of all equipment (mixers, pumps, piping and instruments) and installation costs. The total cost for retrofitting this system is estimated to be $352,431. The increased O&M cost is $75,806 per year primarily additional electrical costs. However, there is a cost savings due to reduced aeration which is about $11,763 per year giving a net increase in O&M costs of $64,403 per year. The model is predicting at average temperature and current flow, the plant will remove an additional 23,267lbs/year over baseline conditions. Therefore the cost per pound for the ten year term is $4.52 (Table SP-4) and for the twenty year is $3.78 (Table SP-5).

Table SP-4 Spencer, MA Cost of Nitrogen Removal (10-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
64	**Delta Pounds N Removed Per day**
23,269	Delta Pounds N Removed 1 Year
232,691	Delta Pounds N Removed 10 Year
465,382	Delta Pounds N Removed 20 Year
$352,431.06	**Capital Cost of Conceptual Design**
$15.15	Cost Per Pound Over 1 Year
$1.51	Cost Per Pound Over 10 Years
$0.76	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
10	Loan Term in Years
$3,403.10	Monthly Payment (100% Financed)
$408,372.07	Total Cost P & I Over 10 Years
$644,030.00	Additional O&M over term
$1,052,402.07	Total Cost Over 10 Years
$4.52	**Total Cost Per Pound of Additional Nitrogen Removed Over 10 Years**

Table SP-5 Spencer, MA Cost of Nitrogen Removal (20-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
64	**Delta Pounds N Removed Per day**
23,269	Delta Pounds N Removed 1 Year
232,691	Delta Pounds N Removed 10 Year
465,382	Delta Pounds N Removed 20 Year
$352,431.06	**Capital Cost of Conceptual Design**
$15.15	Cost Per Pound Over 1 Year
$1.51	Cost Per Pound Over 10 Years
$0.76	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
20	Loan Term in Years
$1,954.57	Monthly Payment (100% Financed)
$469,097.81	Total Cost P & I Over 20 Years
$1,288,060.00	Additional O&M over term
$1,757,157.81	Total Cost Over 20 Years
$3.78	**Total Cost Per Pound of Additional Nitrogen Removed Over 20 Years**

Warren, MA

Plant Description

The Warren Wastewater Treatment Plant (Figure WA-1) is a 1.5 MGD RBC facility with a current average flow of 0.312 MGD or about 21% of design flow. The treatment train includes two primary clarifiers, four trains of six RBCs and two secondary clarifiers.

Figure WA-1 Aerial View Warren, MA, Facility

The effluent is disinfected using chlorine prior to discharge to the Quaboag River, a tributary of the Connecticut River (Figure WA-2). The plant operates the two primary clarifiers, one train of RBCs and two secondary clarifiers.

The current permit limits for Warren MA, are shown in Table WA-1. Along with these permit limits; they are also required to monitor various nitrogen species.

Table WA-1 Current Permit Limits, Warren, MA

	Monthly	Weekly	Annual Goal
TSS, mg/L	30	45	X
BOD, mg/L	30	45	X
TN, lbs/d	X	X	X

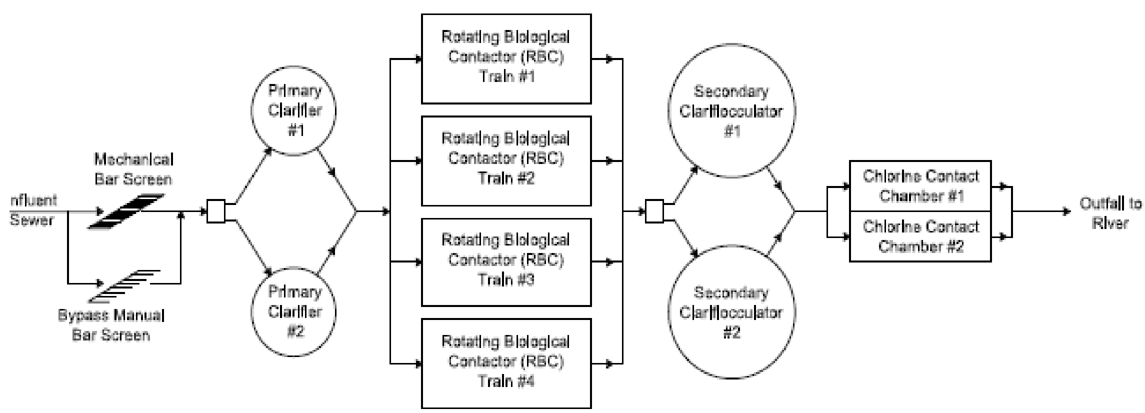

Figure WA-2 Warren, MA, Process Flow Diagram

Nitrogen Removal Concept and Cost Estimate

The BioWin model cannot simulate RBC treatment processes. So any potential nitrogen reductions were estimated based on amount of excess capacity, how well the plant was nitrifying and the potential to create a recycle of nitrified effluent to an anoxic zone.
In evaluating nitrate recycle; it was important to consider the potential impact of shear forces through the RBC caused by increased velocity from a large recycle flow since that might result in biomass shearing from the plastic media reducing treatment efficiency.
A certain amount of nitrogen removal always occurs in RBC processes through the assimilation of nitrogen into cell mass (typically 30% nitrogen removal). There is also nitrogen removal from denitrification occurring in secondary clarifiers and in anoxic zones within the biomass attached to the media in the RBC.

Under this study, we looked for ways to achieve denitrification at the Warren WWTP. If that were possible, not only would there be a decrease in effluent nitrogen, but also from the increase in alkalinity which would benefit the plant operations. However, achieving denitrification at Warren could not be accomplished with a simple retrofit.

Due to the hydraulic limitations, it will not be possible to run a recycle to the head of the plant or to the primary clarifiers for potential denitrification. Even without the hydraulic bottleneck, this option would be expensive to implement because a recycle pipe would need to be installed across the asphalt road that acts as the main entrance into the plant. Simultaneous nitrification – denitrification (SND) was also evaluated. There are case studies where limited SND has been achieved within the RBC biofilm. SND efficiencies of up to 65% were documented. However, this performance required very thick biofilms to be carried on the disks. High BOD loadings are required to support the thick biofilm growth. The successful examples of SND in RBCs were at plants treating high strength domestic and/or industrial wastes. Warren does not have high strength waste. Therefore, no additional nitrogen removal beyond what they are currently accomplishing could be estimated.

Webster, MA

Plant Description

The Webster Wastewater Treatment Plant (Figure W-1) is a 6.0 MGD activated sludge facility. It is currently treating an average flow of 2.99 MGD or 50% of design flow. There are four primary settling tanks, two bioreactor trains with three tanks in each train and three secondary clarifiers. Flow from the secondary clarifiers is conveyed to an Actiflo process for phosphorous removal and then disinfected using chlorine prior to discharge to the French River a tributary of the Thames River (Figure W-2).

Figure W-1 Aerial View Webster, MA, Facility

Table W-1 Current Permit Limits, Webster, MA

(Oct 1-Mar 31)	Monthly	Weekly	Annual Goal
TSS, mg/L	30	45	X
BOD, mg/L	30	45	X
(Apr 1-Sep 30)			
TSS,mg/L	15	15	X
CBOD, mg/L	10	10	X
(Apr 1-Apr 30)			
Ammonia, mg/L	10	10	X
(May 1-May 31)			
Ammonia, mg/L	5	5	X
(Jun 1-Sep 30)			
Ammonia, mg/L	2	2	X
TN, lbs/day	X	X	

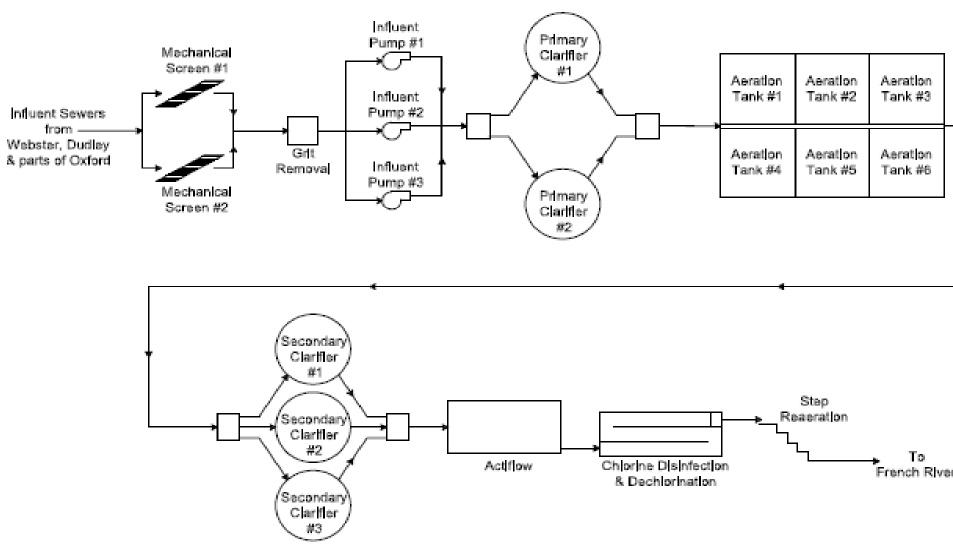

Figure W-2 Webster, MA Process Flow Diagram

Currently the plant does not use any primary clarifies. They use one bioreactor train and three secondary clarifiers. Permit limits for Webster, MA, are shown in Table W-1. Along with these permit limits; they are also required to monitor various nitrogen species.

BioWin Model and Conceptual Design

Average influent concentrations and an average influent temperature 13^{o} C were used for calibration of the model using a steady-state simulation. Model output was compared to average effluent data. The model was considered calibrated if the output typically matched effluent BOD5, TSS and total nitrogen within +/- 10% of the actual values in the data sets. Once the model was calibrated, various design alternatives and changes in process control parameters were evaluated to determine which alternative resulted in the lowest possible effluent total nitrogen.

Table W-2 Baseline Model Comparison to Conceptual Design, Webster, MA

Plant Influent Data			Baseline Model Effluent		Design Model Effluent		Compare Baseline to Model Design	
Parameters	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d
Volatile suspended solids	181	4514	4.00	100	3.48	87	**0.52**	**12.97**
Total suspended solids	197.53	4926	5.01	125	4.41	110	**0.60**	**14.96**
Total Kjeldahl Nitrogen	41.6	1037	2	60	3	65	**0**	**-5**
Total Carbonaceous BOD	195	4863	1.18	29	1.58	39	**-0.40**	**-9.97**
Total N	41.6	1037	14.4	359	4.4	109	**10**	**250**
pH	6.9		6.77		6.85			
Ammonia N	27.46	685	0	12	1	27	**-1**	**-15**
Nitrate N	0	0	11.69	292	0.78	19	**10.91**	**272.06**
Parameters								
Temperature, ^{o}C	13		13		13.00			
Flow, MGD	2.99		2.99		2.99			

Sensitivity testing was also performed by reducing the temperature from 13^{o} C to 10^{o} C and increasing the flow to 80% of design at 10^{o} C. The baseline model was configured (Figure W-3) using no primary clarifiers, one biological reactor train and three secondary clarifiers and calibrated (Table W-2 Baseline Model Column). Average annual flow and temperature (2.99 MGD and 13^{o} C) obtained from plant data were used for both the baseline and nitrogen design models.

To remove nitrogen at the Webster, MA, facility, an anoxic zone was created using approximately one third of the volume of the bioreactor train with the remaining portion aerobic. Nitrate recycle was also added (Figure W-4). With this configuration, the model predicts that Webster, MA, can achieve significant nitrogen removal (Table W-2 Design Model Column).

Currently, influent TN averages about 1,037 lbs/d and the plant discharges about 359 lbs/d resulting in a removal of about 678 lbs/d (1,037 lbs/d-359 lbs/d) or 65% removal. With the anoxic, aerobic reactor configuration and recycle pumps, the model is predicting that the plant would discharge 109 lbs/d total nitrogen with a concentration of 4.4 mg/L resulting in a removal of 928 lbs/d (1,037 lbs/d-109 lbs/d) or 89% removal. The increase removal over current performance is 250 lbs/d total nitrogen or about 91,383 lbs/year at average conditions.

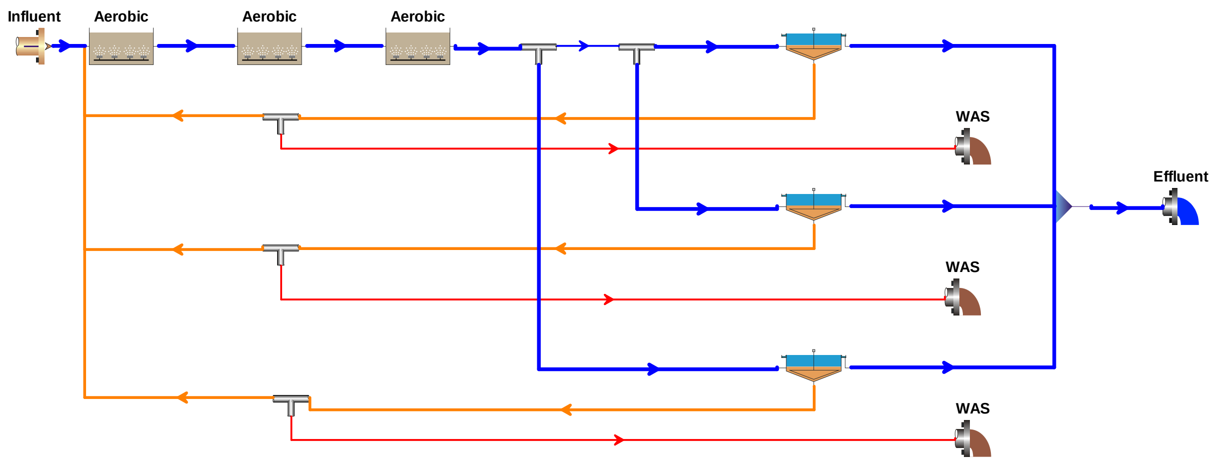

Figure W-3 Baseline Model, Webster, MA

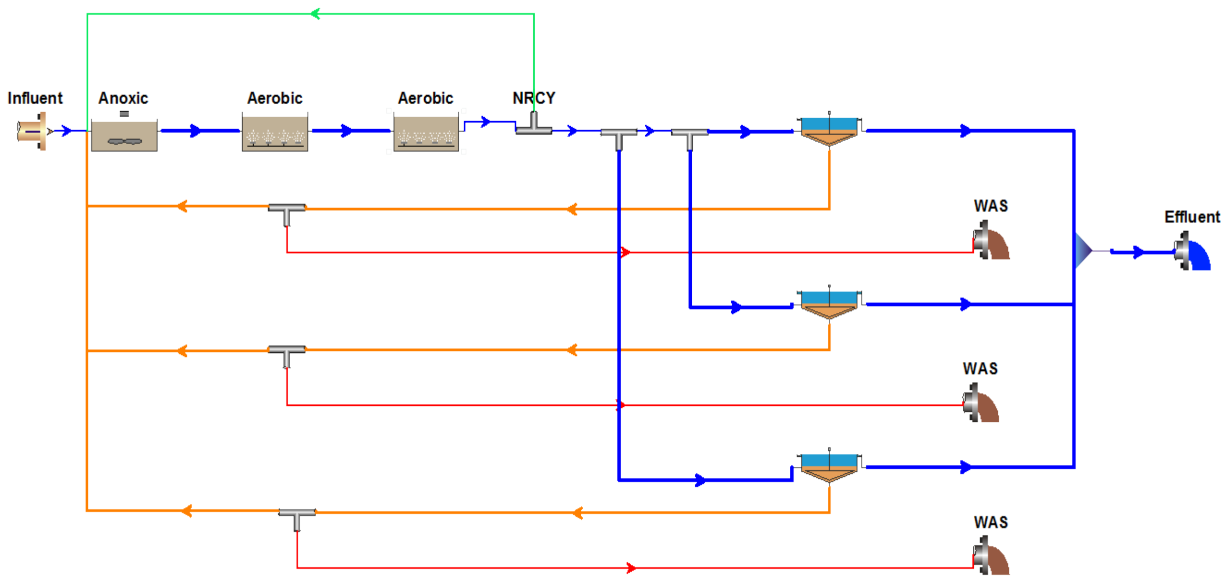

Figure W-4 Conceptual Nitrogen Design Model, Webster, MA

Table W-3 Summary of Results, Webster, MA

Current Influent TN, lbs/d	1037
Current Effluent TN, lbs/d	359
Current Removal, lbs/d	678
Predicted Effluent TN, lbs/d	109
Predicted Removal, lbs/d	928
Net Change, lbs/d	250
Net Change, lbs/year	91,383
Winter Temperature, lbs/year	82,928

The model was then tested at 10^{o} C and then at 10^{o} C with the flow increased to 80% of design. At 10^{o} C, the effluent total nitrogen concentration increased to 5.3 mg/L which results in removal of 82,928 lbs/year. When the flow increased to 80% at this temperature, effluent total nitrogen increased to 6.5 mg/L.

A summary of these results is shown in Table W-3. For this design, a valve would have to be added on one of the air pipes along with mixers, nitrate recycle pumps, DO, ammonia, pH and nitrate analyzers.

Cost Per Pound of Nitrogen Removed

A preliminary construction cost estimate (Figure W-5) was prepared based on the design shown in Figure W-4. This estimate was then used to calculate the cost per pound of nitrogen removed based on the model prediction. The cost estimate is for one train only.

NEIWPCC Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the upper Long Island Sound Watershed		COST ESTIMATE Webster	
Contractor Name: JJ Environmental		Date:	17-Feb-15
Address: 17 Archer Lane		Project No.	0302-001
Darien, Ct 06820		Proposal No.	27 Rev 1
Telephone No: 1-203-309-8768			
SECTION A: CONTRACTOR WORK			Revisions
1. Total Contractor Labor		$88,988.33	
2. Total Contractor Material		$112,600.00	
3. Total Contractor Equipment		$25,238.00	
4. Unit Price Costs			
5. Subtotal Contractor Cost		$226,826.33	
6. Contractor Mark-Up 15%		$34,023.95	
7. Contractor Total Section A		$260,850.28	
SECTION B: CONTRACTOR WORK			
8. Names Of Subcontractors			
A.	Electrical Subcontractor	$91,449.15	
B.	Instrumentation Integrator	$8,510.00	
C.			
D.			
E.			
F.			
9. Total Subcontractor's Proposals (A through F)		$99,959.15	
10. Contractor's Mark-Up On Subs Proposals (5%)		$4,997.96	
11. Subcontractor Total Section B		$104,957.11	
SECTION C: TOTAL CONTRACTED UNIT PRICE COSTS			
SECTION D: CONTRACTOR'S REQUEST			
12. Amount Requested (Total Lines 7 & 11)		**$365,807.39**	

Figure W-5 Cost Estimate Webster, MA, Conceptual Design

The estimate includes the cost of all equipment (valves, mixers, pumps, piping and instruments) and installation costs. The total cost for retrofitting this system is estimated to be $365,807. The increased O&M cost is $45,745 per year primarily additional electrical costs. However, there is a cost savings due to reduced aeration which is about $8,626 per year giving a net increase in O&M costs of $37,119 per year. The model is predicting at average temperature and current flow, the plant will remove an additional 91,383 lbs/year over baseline conditions. Therefore the cost per pound for the ten year term is $0.87 (Table W-4) and for the twenty year is $0.67 (Table W-5).

Table W-4 Webster, MA Cost of Nitrogen Removal (10-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
250	**Delta Pounds N Removed Per day**
91,383	Delta Pounds N Removed 1 Year
913,827	Delta Pounds N Removed 10 Year
1,827,653	Delta Pounds N Removed 20 Year
$365,807.39	**Capital Cost of Conceptual Design**
$4.00	Cost Per Pound Over 1 Year
$0.40	Cost Per Pound Over 10 Years
$0.20	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
10	Loan Term in Years
$3,532.26	Monthly Payment (100% Financed)
$423,871.61	Total Cost P & I Over 20 Years
$371,190.00	Additional O&M over term
$795,061.61	Total Cost Over 10 Years
$0.87	**Total Cost Per Pound of Additional Nitrogen Removed Over 10 Years**

Table W-5 Webster, MA Cost of Nitrogen Removal (20-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
250	**Delta Pounds N Removed Per day**
91,383	Delta Pounds N Removed 1 Year
913,827	Delta Pounds N Removed 10 Year
1,827,653	Delta Pounds N Removed 20 Year
$365,807.39	**Capital Cost of Conceptual Design**
$4.00	Cost Per Pound Over 1 Year
$0.40	Cost Per Pound Over 10 Years
$0.20	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
20	Loan Term in Years
$2,028.76	Monthly Payment (100% Financed)
$486,902.16	Total Cost P & I Over 20 Years
$742,380.00	Additional O&M over term
$1,229,282.16	Total Cost Over 20 Years
$0.67	**Total Cost Per Pound of Additional Nitrogen Removed Over 20 Years**

Winchendon, MA

Plant Description

The Winchendon, MA, Wastewater Pollution Control Plant (Figure WC-1) is a 1.1 MGD activated sludge facility with a current average flow of 0.51 MGD or about 46% of design flow. The plant has two primary settling tanks, two bioreactor trains and two secondary clarifiers. The flow from the secondary clarifiers is disinfected with ultraviolet light prior to being discharged to Millers River, a tributary of the Connecticut River (Figure WC-2)

Figure WC-1 Aerial View Winchendon, MA, Facility

They use one primary settling tank, one bioreactor train (two tanks) and one secondary clarifier. The current permit limits for Winchendon, MA, are shown in Table WC-1. Along with these permit limits; they are also required to monitor various nitrogen species.

Table WC-1 Current Permit Limits, Winchendon, MA

	Monthly	Weekly	Annual Goal
TSS, mg/L	15	25	X
BOD, mg/L	15	25	X
Ammonia, mg/L	4	6	
TN, lbs/d	X	X	

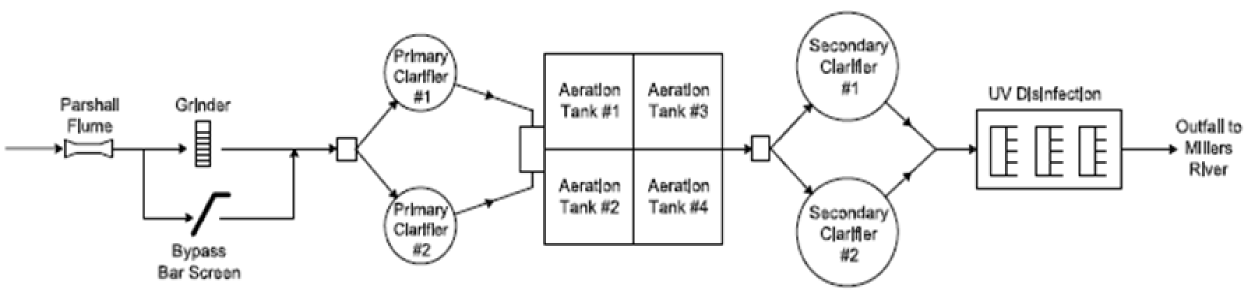

Figure WC-2 Winchendon, MA Process Flow Diagram

BioWin Model and Conceptual Design

Average influent concentrations and an average influent temperature 13.3^{o} C were used for calibration of the model using a steady-state simulation. Model output was compared to average effluent data. The model was considered calibrated if the output typically matched effluent BOD5, TSS and total nitrogen within +/- 10% of the actual values in the data sets. All parameters were within 10% except for effluent BOD. The model predicted a lower effluent concentration that the plant data indicates.

Table WC-2 Baseline Model Comparison to Conceptual Design, Winchendon, MA

Plant Influent Data			Baseline Model Effluent		Design Model Effluent		Compare Baseline to Model Design	
Parameters	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d
Volatile suspended solids	346	1472	2.41	10	2.36	10	**0.05**	**0.21**
Total suspended solids	384.94	1637	2.86	12	2.85	12	**0.01**	**0.04**
Total Kjeldahl Nitrogen	28	119	2	9	2	9	**0**	**0**
Total Carbonaceous BOD	292	1242	1.48	6	1.71	7	**-0.23**	**-0.98**
Total N	32	136	10.8	46	3.8	16	**7.0**	**29.77**
pH	7		6.9		7.0			
Ammonia N	18.48	79	0.4	2	0.5	2	**-0.1**	**-0.3**
Nitrate N	0	0	8.3	35	1.5	6	**6.9**	**29.2**
Parameters								
Temperature, ^{o}C	13.3		13.3		13.3			
Flow, MGD	0.51		0.51		0.51			

The baseline model was configured (Figure WC-3) using two primary clarifiers, one bioreactor train and two secondary clarifiers and calibrated (Table WC-2 Baseline Model Column). Average annual flow and temperature (0.51 MGD and 13.3^{o} C) obtained from plant data were used for both the baseline and nitrogen design models.

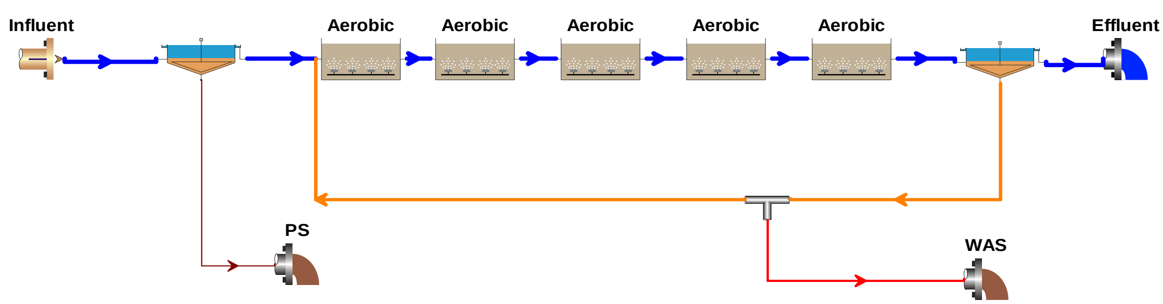

Figure WC-3 Baseline Model, Winchendon, MA

According to plant staff and as observed during site visits, the bioreactor train is divided into five sections or tanks with different dimensions and volumes. The conceptual design captures this geometry.

To remove nitrogen at the Winchendon, MA, facility, the first zone in each train will be anoxic, the second and third are swing zones and the fourth and fifth are aerobic zones. A swing zone is designed so that part of the time it is anoxic and if additional aerobic volume is needed for nitrification, it can be quickly converted to operate in an aerobic condition. A nitrate recycle was also added (Figure WC-4). With this configuration, the model predicts that Winchendon, MA, can see an improvement in nitrogen removal (Table WC-2 Design Model Column).

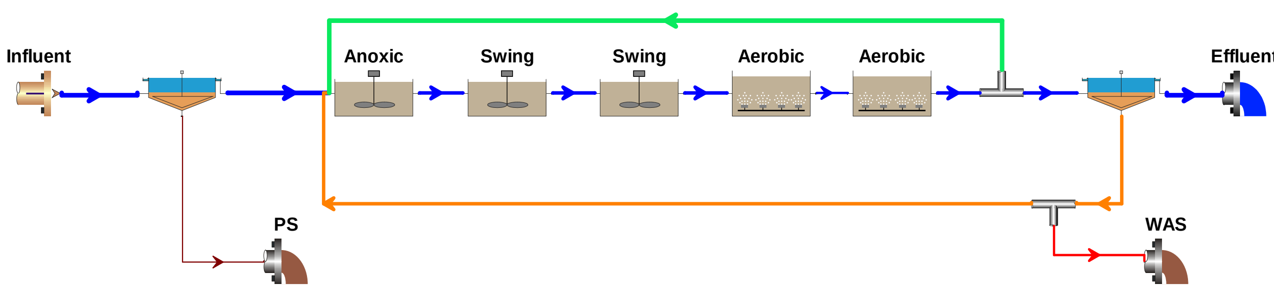

Figure WC-4 Conceptual Nitrogen Design Model, Winchendon, MA

Currently, influent TN averages about 136 lbs/d and the plant discharges about 46 lbs/d resulting in a removal of about 90 lbs/d (136 lbs/d-46 lbs/d) or 66% removal. With the anoxic, swing, aerobic reactor configuration and recycle pumps, the model is predicting that the plant would discharge 16 lbs/d total nitrogen with a concentration of 3.8 mg/L resulting in a removal of 120 lbs/d (136 lbs/d-16 lbs/d) or 88% removal. The increased removal over current performance is about 30 lbs/d total nitrogen or about 10,867 lbs/year at average conditions.

The model was then tested at 8^{o} C and then at 8^{o} C with the flow increased to 80% of design. At 8^{o} C and current flow, the effluent TN increased to 4.17 mg/L with the ammonia-nitrogen concentration at 1.3 mg/L. This would decrease nitrogen removal to about 10,262 lbs/year. At 8^{o} C and 80% design, the effluent TN increased to 6.04 mg/L with the ammonia-nitrogen concentration increasing to 3.12 mg/L. If the swing zone is operated as an aerobic zone under these conditions, the ammonia-nitrogen concentration decreases to 2 mg/L. A summary of these results is shown in Table WC-3. It is important to note that the operators have reported high effluent ammonia-nitrogen concentrations, even in the summer. The

Table WC-3 Summary of Results, Winchendon, MA

Current Influent TN, lbs/d	136
Current Effluent TN, lbs/d	46
Current Removal, lbs/d	90
Predicted Effluent TN, lbs/d	16
Predicted Removal, lbs/d	120
Net Change, lbs/d	30
Net Change, lbs/year	10,867
Winter Temperature, lbs/year	10,262

plant is designed for the first three to operate as anoxic or swing zones, but the operators state that they them all aerobic because the ammonia-nitrogen concentrations increase as soon as they convert these zones to anoxic conditions. This should be further evaluated.

The equipment needed for this design includes nitrate recycle pumps, DO, ammonia, pH and nitrate analyzers. They already have mixers installed in each of the three zones at the influent ends of the reactors.

Cost Per Pound of Nitrogen Removed

A preliminary construction cost estimate (Figure WC-5) was prepared based on the design shown in Figure WC-4. This estimate was then used to calculate the cost per pound of nitrogen removed based on the model prediction.

NEIWPCC **Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the upper Long Island Sound Watershed**		**COST ESTIMATE** **Winchendon**	
Contractor Name:	JJ Environmental	Date:	17-Feb-15
Address:	17 Archer Lane	Project No.	0302-001
	Darien, Ct 06820	Proposal No.	28 Rev (1)
Telephone No:	1-203-309-8768		
SECTION A: CONTRACTOR WORK			Revisions
1. Total Contractor Labor		$42,269.46	
2. Total Contractor Material		$63,400.00	
3. Total Contractor Equipment		$15,311.00	
4. Unit Price Costs			
5. Subtotal Contractor Cost		$120,980.46	
6. Contractor Mark-Up 15%		$18,147.07	
7. Contractor Total Section A		$139,127.52	
SECTION B: CONTRACTOR WORK			
8. Names Of Subcontractors			
A.	Electrical Subcontractor	$51,119.53	
B.	Instrumentation Integrator	$8,510.00	
C.			
D.			
E.			
F.			
9. Total Subcontractor's Proposals (A through F)		$59,629.53	
10. Contractor's Mark-Up On Subs Proposals (5%)		$2,981.48	
11. Subcontractor Total Section B		$62,611.01	
SECTION C: TOTAL CONTRACTED UNIT PRICE COSTS			
SECTION D: CONTRACTOR'S REQUEST			
12. Amount Requested (Total Lines 7 & 11)		**$201,738.53**	

Figure WC-5 Cost Estimate Winchendon, MA, Conceptual Design

The estimate includes the cost of all equipment (mixers, pumps, piping and instruments) and installation costs. The total cost for retrofitting this system is estimated to be $201,739. The increased O&M cost is $40,527 per year primarily additional electrical costs. However, there is a cost savings due to reduced aeration which is about $8,626 per year giving a net increase in O&M costs of $31,891 per year. The model is predicting at average temperature and current flow, the plant will remove an additional 10,867 lbs/year over baseline conditions. Therefore the cost per pound for the ten year term is $5.09 (Table WC-4) and for the twenty year is $4.17 (Table WC-5). The plant currently feeds hydroxide for pH adjustment. They may be able to reduce this chemical use once the denitrification process is established.

Table WC-4 Winchendon, MA Cost of Nitrogen Removal (10-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
30	**Delta Pounds N Removed Per day**
10,867	Delta Pounds N Removed 1 Year
108,674	Delta Pounds N Removed 10 Year
217,349	Delta Pounds N Removed 20 Year
$201,738.53	**Capital Cost of Conceptual Design**
$18.56	Cost Per Pound Over 1 Year
$1.86	Cost Per Pound Over 10 Years
$0.93	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
10	Loan Term in Years
$1,948.00	Monthly Payment (100% Financed)
$233,760.27	Total Cost P & I Over 10 Years
$318,910.00	Additional O&M over term
$552,670.27	Total Cost Over 10 Years
$5.09	**Total Cost Per Pound of Additional Nitrogen Removed Over 10 Years**

Table WC-5 Winchendon, MA Cost of Nitrogen Removal (20-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
30	**Delta Pounds N Removed Per day**
10,867	Delta Pounds N Removed 1 Year
108,674	Delta Pounds N Removed 10 Year
217,349	Delta Pounds N Removed 20 Year
$201,738.53	**Capital Cost of Conceptual Design**
$18.56	Cost Per Pound Over 1 Year
$1.86	Cost Per Pound Over 10 Years
$0.93	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
20	Loan Term in Years
$1,118.84	Monthly Payment (100% Financed)
$268,520.89	Total Cost P & I Over 20 Years
$637,820.00	Additional O&M over term
$906,340.89	Total Cost Over 20 Years
$4.17	**Total Cost Per Pound of Additional Nitrogen Removed Over 20 Years**

4.2 New Hampshire

Four treatment plants from New Hampshire were selected for BioWin modeling and cost estimation; Claremont, Hanover, Hinsdale and Littleton.

Claremont, NH

Plant Description

The Claremont, NH Wastewater Treatment Plant (Figure C-1) is an activated sludge plant with a design capacity of 3.89 MGD. It is currently treating an average flow of 1.23 MGD or about 33% of design flow. The plant has two primary clarifiers, two biological reactor trains with three reactors in each train. The flow from the biological system is then conveyed to three secondary clarifiers.

Figure C-1 Aerial View Claremont, NH, Facility

Secondary effluent is disinfected using chlorine and then discharged to the Sugar River, a tributary of the Connecticut River (Figure C-2).

Table C-1 Current Permit Limits, Claremont, NH

	Monthly	Weekly
TSS, mg/L	15	25
CBOD, mg/L	15	25
(June-October)		
Ammonia, mg/L	7.2	
(Nov-May)		
Ammonia, mg/L	10.9	

Currently the plant is operating one primary clarifier, four biological reactors and three secondary clarifiers. The model configuration was based on current operation. Permit limits for Claremont, NH, are shown in Table C-1. Along with these limits, they monitor various nitrogen species.

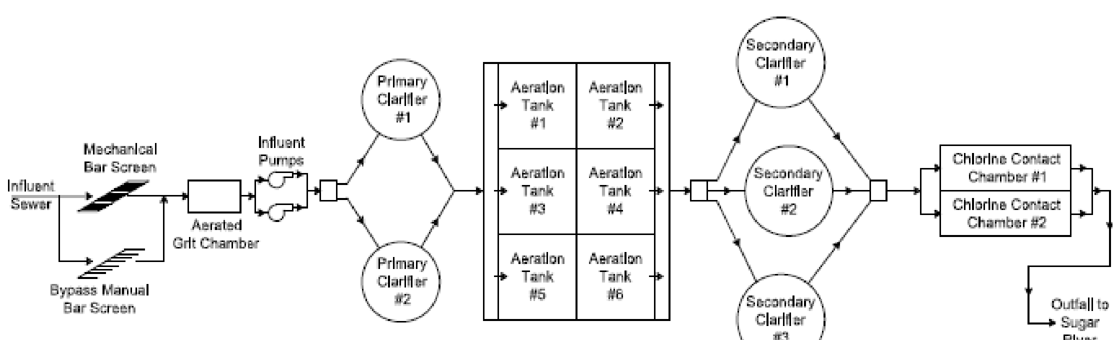

Figure C-2 Claremont, NH Process Flow Diagram

BioWin Model and Conceptual Design

Average influent concentrations and an average influent temperature 16^{o} C were used for calibration of the model using a steady-state simulation. Model output was compared to average effluent data. The model was considered calibrated if the output typically matched effluent BOD5, TSS and total nitrogen within +/- 10% of the actual values in the data sets. All parameters were within 10% except for effluent BOD. The model predicted a much lower effluent concentration (2 mg/L) than the data indicated (4.3 mg/L).

Table C-2 Baseline Model Comparison to Conceptual Design, Claremont, NH

Plant Influent Data			Baseline Model Effluent		Design Model Effluent		Compare Baseline to Model Design	
Parameters	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d
Volatile suspended solids	257	2636	3.85	39	4.32	44	**-0.47**	**-4.82**
Total suspended solids	286.78	2942	4.72	48	5.59	57	**-0.87**	**-8.92**
Total Kjeldahl Nitrogen	26	267	2	21	2	24	**0**	**-3**
Total Carbonaceous BOD	286	2934	1.73	18	2.64	27	**-0.91**	**-9.33**
Total N	26	267	15	156	4	41	**11**	**115.00**
pH	7.3		6.32		6.60			
Ammonia N	16.5	169	0	2	1	7	**-1**	**-6**
Nitrate N	0	0	13.07	134	1.43	15	**11.64**	**119.41**
Parameters								
Temperature, °C	16		16		16			
Flow, MGD	1.23		1.23		1.23			

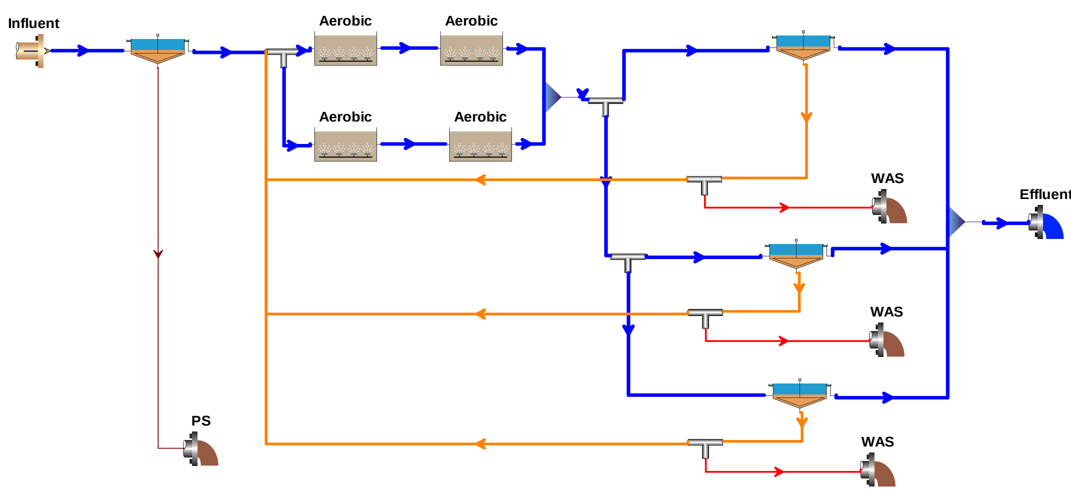

Figure C-3 Baseline Model, Claremont, NH

Once the model was calibrated, various design alternatives and changes in process control parameters were evaluated to determine which alternative resulted in the lowest possible effluent total nitrogen. Sensitivity testing was also performed by reducing the temperature from 16^{o} C to 10^{o} C and increasing the flow to 80% of design at 10^{o} C.

The baseline model was configured (Figure C-3) using one primary clarifier, four bioreactors (2 in each train) and three secondary clarifiers and calibrated (Table C-2 Baseline Model Column). Average annual flow and temperature (1.23 MGD and 16^{o} C) obtained from plant data were used for both the baseline and nitrogen design models. To remove nitrogen at the Claremont, NH facility, the first tank in each train will be anoxic and the second tank aerobic. A nitrate recycle was also added (Figure C-4). With this configuration, the model predicts that Claremont, NH, can achieve significant nitrogen removal (Table C-2 Design Model Column).

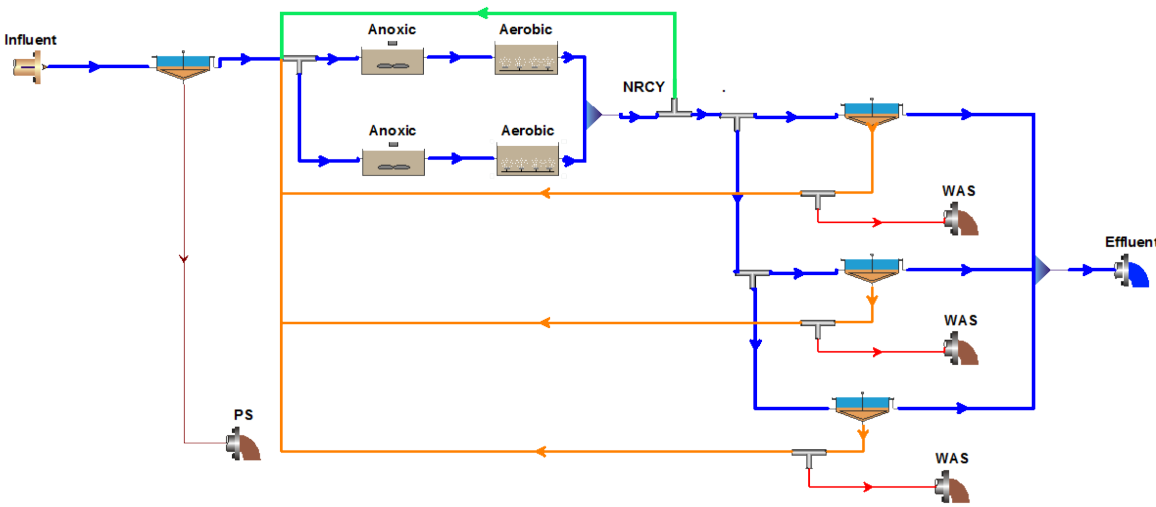

Figure C-4 Conceptual Nitrogen Design Model, Claremont, NH

Currently, influent TN averages about 267 lbs/d and the plant discharges about 156 lbs/d resulting in a removal of about 111 lbs/d (267 lbs/d-156 lbs/d) or 42% removal. With the anoxic-aerobic reactor configuration, the model is predicting that the plant would discharge 41 lbs/d total nitrogen with a concentration of 3.99 mg/L resulting in a removal of 226 lbs/d (267 lbs/d-41 lbs/d) or 85% removal. The increase removal over current performance is 115 lbs/d total nitrogen or about 41,975 lbs/year at average conditions. The model was then tested at 10^{o} C and then at 10^{o} C with the flow at 80% of design. At 10^{o} C, the effluent total nitrogen concentration increased from 3.99 mg/L to 4.63 mg/L (decreasing nitrogen removal by 2,494 lbs/year) or 39,481 lbs/year removed. When the flow increased to 80% at this

Table C-3 Summary of Results, Claremont, NH

Current Influent TN, lbs/d	267
Current Effluent TN, lbs/d	156
Current Removal, lbs/d	111
Predicted Effluent TN, lbs/d	41
Predicted Removal, lbs/d	226
Net Change, lbs/d	115
Net Change, lbs/year	41,975
Winter Temperature, lbs/year	39,481

temperature, the concentration increased to 5.25 mg/L. A summary of these results is shown in Table C-3. In order to create the anoxic zone, some modifications of the air piping are necessary including installation of valves. Equipment needed for this design includes nitrate recycle pumps, mixers, and DO, ammonia, pH and nitrate analyzers.

Cost Per Pound of Nitrogen Removed

A preliminary construction cost estimate was prepared based on the conceptual design. This estimate was then used to calculate the cost per pound of nitrogen removed based on the model prediction.

NEIWPCC Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the upper Long Island Sound Watershed		COST ESTIMATE CLAREMONT, NH	
Contractor Name: JJ Environmental		Date:	1-Jun-14
Address: 17 Archer Lane, Darien, Ct 06820		Project No.	0302-001
Telephone No: 1-203-309-8768		Proposal No.	4
SECTION A: CONTRACTOR WORK			Revisions
1. Total Contractor Labor		$71,190.66	
2. Total Contractor Material		$118,000.00	
3. Total Contractor Equipment		$26,920.00	
4. Unit Price Costs			
5. Subtotal Contractor Cost		$216,110.66	
6. Contractor Mark-Up 15%		$32,416.60	
7. Contractor Total Section A		$248,527.26	
SECTION B: CONTRACTOR WORK			
8. Names Of Subcontractors			
A.	Electrical Subcontractor	$111,258.92	
B.	Instrumentation Integrator	$11,914.00	
C.			
D.			
E.			
F.			
9. Total Subcontractor's Proposals (A through F)		$123,172.92	
10. Contractor's Mark-Up On Subs Proposals (5%)		$6,158.65	
11. Subcontractor Total Section B		$129,331.57	
SECTION C: TOTAL CONTRACTED UNIT PRICE COSTS			
SECTION D: CONTRACTOR'S REQUEST			
12. Amount Requested (Total Lines 7 & 11)		**$377,858.83**	

Figure C-5 Cost Estimate Claremont, NH, Conceptual Design Model

The estimate includes the cost of all equipment (mixers and pumps, piping, instrumentation and installation costs (Figure C- 5). The total cost for retrofitting this system is estimated to be $377,859.

The increased O&M cost is $99,000 per year which is primarily due to additional electrical costs; however, this cost is partially offset due to reduced aeration costs since two tanks will only be mixed and not aerated. The expected avoided cost is estimated at $40,000 per year so the net increase in O&M is estimated at $59,000 per year. The model is predicting that at average temperature and current flow, the plant will remove an additional 115 lbs/d of nitrogen or 41,975 lbs/year over baseline conditions. Therefore the cost per pound for the ten year term is $2.45 (Table C- 4) and for the twenty year is $2.01 (Table C-5).

Table C-4 Claremont, NH Cost of Nitrogen Removal (10-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
115	**Delta Pounds N Removed Per day**
41,975	Delta Pounds N Removed 1 Year
419,748	Delta Pounds N Removed 10 Year
839,497	Delta Pounds N Removed 20 Year
377,859	**Capital Cost of Conceptual Design**
$9.00	Cost Per Pound Over 1 Year
$0.90	Cost Per Pound Over 10 Years
$0.45	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
10	Loan Term in Years
$3,648.63	Monthly Payment (100% Financed)
$437,835.96	Total Cost P & I Over 10 Years
$590,000.00	Additional O&M over term
$1,027,835.96	Total Cost Over 10 Years
$2.45	**Total Cost Per Pound of Additional Nitrogen Removed**

Table C-5 Claremont, NH Cost of Nitrogen Removal (20-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
115	**Delta Pounds N Removed Per day**
41,975	Delta Pounds N Removed 1 Year
419,748	Delta Pounds N Removed 10 Year
839,497	Delta Pounds N Removed 20 Year
377,859	**Capital Cost of Conceptual Design**
$9.00	Cost Per Pound Over 1 Year
$0.90	Cost Per Pound Over 10 Years
$0.45	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
20	Loan Term in Years
$2,095.60	Monthly Payment (100% Financed)
$502,943.04	Total Cost P & I Over 20 Years
$1,180,000.00	Additional O&M over term
$1,682,943.04	Total Cost Over 20 Years
$2.00	**Total Cost Per Pound of Additional Nitrogen Removed**

Hanover, NH

Plant Description

The Hanover Wastewater Reclamation Plant (Figure H-1) is a 2.3 MGD activated sludge facility. It is currently treating an average flow of 1.25 MGD or about 54% of the design flow. They have two primary clarifiers, two bioreactors and three secondary clarifiers. The flow from the biological system is then conveyed to two secondary clarifiers. Secondary effluent is disinfected using chlorine and discharged to the Connecticut River (Figure H-2).

Figure H-1 Aerial View Hanover, NH, Facility

Currently the plant is operating two primary clarifiers, two biological reactors and two secondary clarifiers. Each bioreactor has a small anoxic selector. The model configuration was based on current operation. Hanover's permit limits are shown in Table H-1. They monitor specific nitrogen species in influent and effluent on a voluntary basis.

Table H-1 Current Permit Limits, Hanover, NH

	Monthly	Weekly
TSS, mg/L	30	45
CBOD, mg/L	25	40

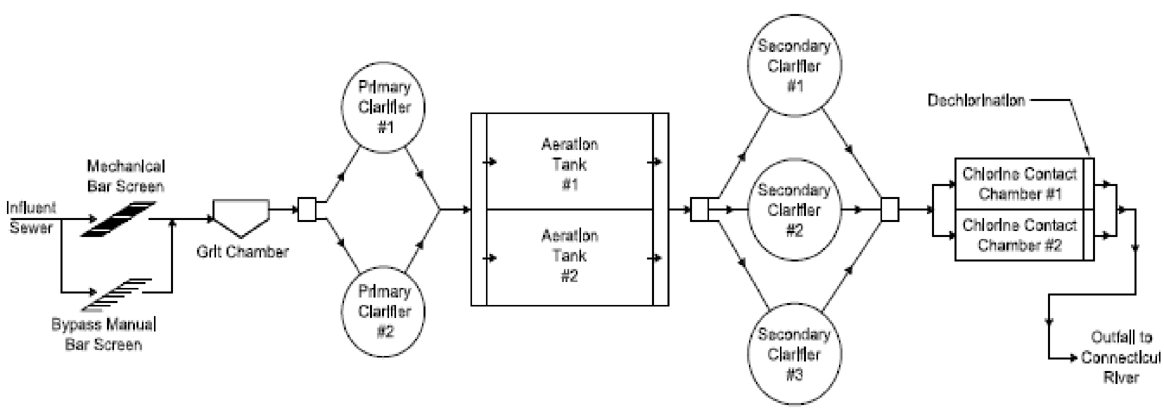

Figure H-2 Hanover, NH, Process Flow Diagram

BioWin Model and Conceptual Design

Average influent concentrations and an average influent temperature 16^{o} C were used for calibration of the model using a steady-state simulation. Model output was compared to average effluent data.

Table H-2 Baseline Model Comparison to Conceptual Design, Hanover, NH

Plant Influent Data			Baseline Model Effluent		Design Model Effluent		Compare Baseline to Model Design	
Parameters	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d
Volatile suspended solids	203	2116	4.19	44	3.78	39	**0.41**	**4.27**
Total suspended solids	258.76	2698	5.64	59	4.97	52	**0.67**	**6.98**
Total Kjeldahl Nitrogen	50.83	530	12.4	129	4	38	**9**	**91**
Total Carbonaceous BOD	294	3065	3.71	39	2.62	27	**1.09**	**11.36**
Total N	50.83	530	24.0	250	8.35	87	**16**	**163**
pH	7.3		6.85		6.82			
Ammonia N	33.55	350	10.1	105	1.2	12	**9**	**93**
Nitrate N	0	0	11.6	121	3.91	41	**7.69**	**80.17**
Parameters								
Temperature, ^{o}C	16		16		16			
Flow, MGD	1.25		1.25		1.25			

The model was considered calibrated if the output typically matched effluent BOD5, TSS and total nitrogen within +/- 10% of the actual values in the data sets. All parameters were within 10% except for BOD. The model prediction was a lower effluent BOD concentration (3.71 mg/L) compared to actual data (5.17 mg/L). Once the model was calibrated, various design alternatives and changes in process control parameters were evaluated to determine which alternative resulted in the lowest possible effluent total nitrogen.

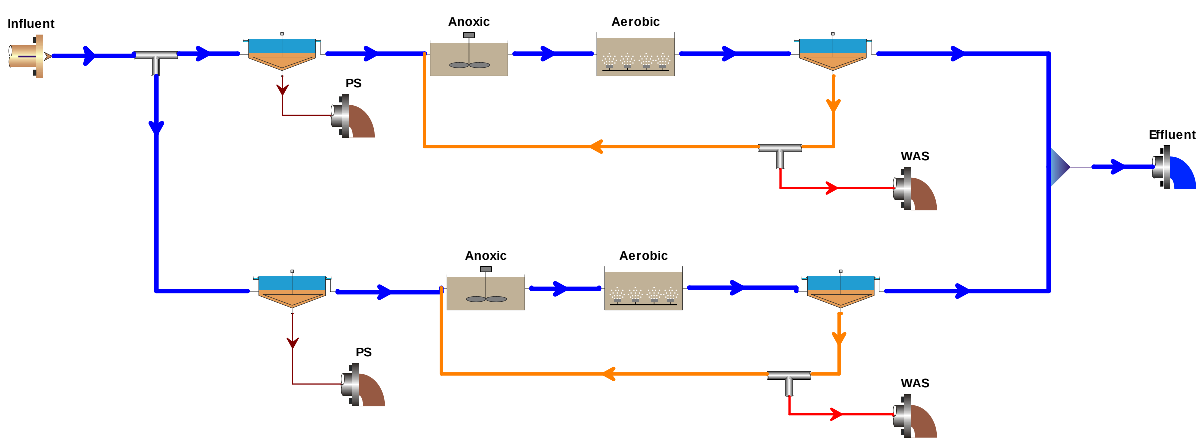

Figure H-3 Baseline Model, Hanover, NH

Sensitivity testing was also performed by reducing the temperature from 16^{o} C to 8^{o} C and increasing the flow to 80% of design at 8^{o} C.

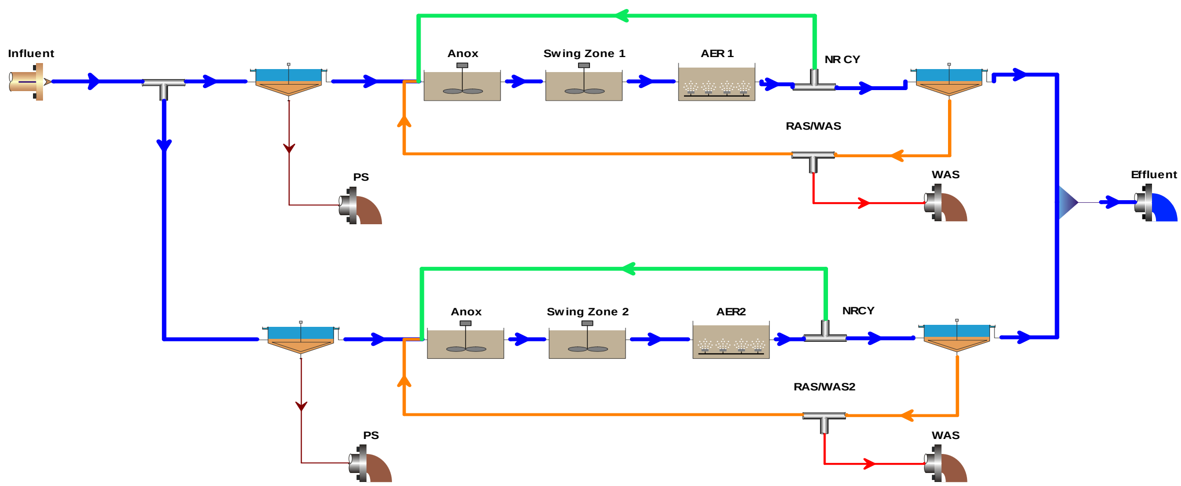

Figure H-4 Conceptual Nitrogen Design Model, Hanover, NH

The baseline model was configured (Figure H-3) using two primary clarifiers, two bioreactors and two secondary clarifiers and calibrated (Table H-2 Baseline Model Column). Average annual flow and temperature (1.25 MGD and 16^{o} C) obtained from plant data were used for both the baseline and nitrogen design models.

In order to remove nitrogen at Hanover, it is necessary to increase the size of the existing anoxic zone. However, in colder temperatures, that same volume might be needed as an aerated zone, therefore, the conceptual design creates a swing zone. A swing zone is designed so that part of the time it is anoxic and if additional aerobic volume is needed for nitrification, then it can be operated with that environmental condition. A nitrate recycle was also added (Figure H-4). With this configuration, the model predicts that Hanover, NH, can achieve significant improvement in nitrogen removal (Table H-2 Design Model Column) except during periods of very low wastewater temperatures.

Currently, influent TN averages about 530lbs/d and the plant discharges about 250 lbs/d resulting in a removal of about 280 lbs/d (530 lbs/d-250 lbs/d) or 53% removal. With the anoxic-aerobic reactor configuration, the model is predicting that the plant would discharge 87 lbs/d total nitrogen with a concentration of 8.35 mg/L resulting in a removal of 443 lbs/d (528 lbs/d-96 lbs/d) or 84% removal. The increased removal over current performance is 163 lbs/d total nitrogen or about 59,550 lbs/year at average conditions. The model was then tested at 8^{o} C and then at 8^{o} C with the flow increased to

Table H-3 Summary of Results, Hanover, NH

Current Influent TN, lbs/d	530
Current Effluent TN, lbs/d	250
Current Removal, lbs/d	280
Predicted Effluent TN, lbs/d	87
Predicted Removal, lbs/d	443
Net Change, lbs/d	163
Net Change, lbs/year	59,550
Winter Temperature, lbs/year	36,643

80% of design. At 8^{o} C, the effluent total nitrogen concentration increased from 8.35 mg/L to 14.37 mg/L of which 3.4 mg/L was ammonia-nitrogen or 36,643 lbs/d of nitrogen removed. When the flow was increased to 80% at this temperature, the total nitrogen concentration increased to 14.99 mg/L of which 3.78 mg/L was ammonia nitrogen. For both the cold temperature and high flows at cold temperatures, the swing zone was converted to an aerobic environment thus the reduction in denitrification. A summary of these results is shown in Table H-3.

The alkalinity of the Hanover influent wastewater is low such that the potential exists for the wastewater pH to drop below the effluent permit limit of 6.0 when nitrification occurs. Although alkalinity will be gained back through the denitrification process once an internal nitrate recycle is established, inefficiencies can occur and the pH may still drop to levels that are inhibitory to the maximum potential nitrification rate. As a result, it has been assumed that an alkalinity chemical storage and feed system will be added to ensure that nitrification is not inhibited by low pH. For this conceptual design, a baffle would be installed in a section of the existing tank to create the additional anoxic volume. Equipment includes a new alkalinity chemical storage and feed system, mixers for each of the anoxic zone, nitrate recycle pumps and DO, ammonia, pH and nitrate analyzers.

Cost Per Pound of Nitrogen Removed

A preliminary construction cost estimate was prepared based on the design shown in Figure H-4. This estimate was then used to calculate the cost per pound of nitrogen removed based on the model prediction. The cost estimate includes the cost of all equipment (baffles, mixers and pumps, piping and instruments) and installation costs as well as the cost of the chemical feed system for adding alkalinity.

The total cost for retrofitting this system is estimated to be $410,027. The increase O&M cost is $65,652 per year primarily additional electrical costs; however, this cost is partially offset due to a slight decrease in aeration requirements. The expected avoided cost is estimated at $9,800 per year so the net increase in O&M is estimated at $55,852 per year. The model is predicting at average temperature and current flow, the plant will remove an additional 59,550 pounds of nitrogen per year over baseline conditions. Therefore the cost per pound for the ten year term is $1.74 (Table H- 4) and for the twenty year is $1.40 (Table H-5).

NEIWPCC Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the upper Long Island Sound Watershed		COST ESTIMATE Hanover	
Contractor Name:	JJ Environmental	Date:	17-Feb-15
Address:	17 Archer Lane	Project No.	0302-001
	Darien, Ct 06820	Proposal No.	9 Rev 1
Telephone No:	1-203-309-8768		

		Revisions
SECTION A: CONTRACTOR WORK		
1. Total Contractor Labor	$109,010.70	
2. Total Contractor Material	$124,100.00	
3. Total Contractor Equipment	$21,873.00	
4. Unit Price Costs		
5. Subtotal Contractor Cost	$254,983.70	
6. Contractor Mark-Up 15%	$38,247.56	
7. Contractor Total Section A	$293,231.26	
SECTION B: CONTRACTOR WORK		
8. Names Of Subcontractors		
A. Electrical Subcontractor	$102,148.99	
B. Instrumentation Integrator	$9,085.00	
C.		
D.		
E.		
F.		
9. Total Subcontractor's Proposals (A through F)	$111,233.99	
10. Contractor's Mark-Up On Subs Proposals (5%)	$5,561.70	
11. Subcontractor Total Section B	$116,795.69	
SECTION C: TOTAL CONTRACTED UNIT PRICE COSTS		
SECTION D: CONTRACTOR'S REQUEST		
12. Amount Requested (Total Lines 7 & 11)	**$410,026.95**	

Figure H-5 Cost Estimate for Hanover, NH, Conceptual Design Model

Table H-4 Hanover, NH Cost of Nitrogen Removal (10-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
163	**Delta Pounds N Removed Per day**
59,550	Delta Pounds N Removed 1 Year
595,502	Delta Pounds N Removed 10 Year
1,191,004	Delta Pounds N Removed 20 Year
$410,026.95	**Capital Cost of Conceptual Design**
$6.89	Cost Per Pound Over 1 Year
$0.69	Cost Per Pound Over 10 Years
$0.34	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
10	Loan Term in Years
$3,959.25	Monthly Payment (100% Financed)
$475,110.09	Total Cost P & I Over 10 Years
$558,520.00	Additional O&M over term
$1,033,630.09	Total Cost Over 10 Years
$1.74	**Total Cost Per Pound of Additional Nitrogen Removed Over 10 Years**

Table H-5 Hanover, NH Cost of Nitrogen Removal (20-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
163	**Delta Pounds N Removed Per day**
59,550	Delta Pounds N Removed 1 Year
595,502	Delta Pounds N Removed 10 Year
1,191,004	Delta Pounds N Removed 20 Year
$410,026.95	**Capital Cost of Conceptual Design**
$6.89	Cost Per Pound Over 1 Year
$0.69	Cost Per Pound Over 10 Years
$0.34	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
20	Loan Term in Years
$2,274.00	Monthly Payment (100% Financed)
$545,759.91	Total Cost P & I Over 20 Years
$1,117,040.00	Additional O&M over term
$1,662,799.91	Total Cost Over 20 Years
$1.40	**Total Cost Per Pound of Additional Nitrogen Removed Over 20 Years**

Hinsdale, NH

Plant Description

The Hinsdale Wastewater Treatment Plant (Figure HD-1) is a 0.3 MGD oxidation ditch facility. It is currently treating an average flow of 0.25 MGD or about 83% of design flow. The plant has two oxidation ditches and two secondary clarifiers. Each ditch is equipped with one brush aerator. After the flow leaves the secondary clarifiers, it passes through disinfection and then to the Ashuelot River, a tributary of the Connecticut River (Figure HD-2).

Figure HD-1 Aerial View Hinsdale, NH, Facility

Table HD-1 Current Permit Limits, Hinsdale, NH

	Monthly	Weekly
TSS, mg/L	30	45
BOD, mg/L	30	45

Currently the plant is operating one oxidation ditch and two secondary clarifiers. The model configuration was based on current operation.

Permit limits for Hinsdale, NH, are shown in Table HD-1. Along with these limits, they also monitor specific nitrogen species.

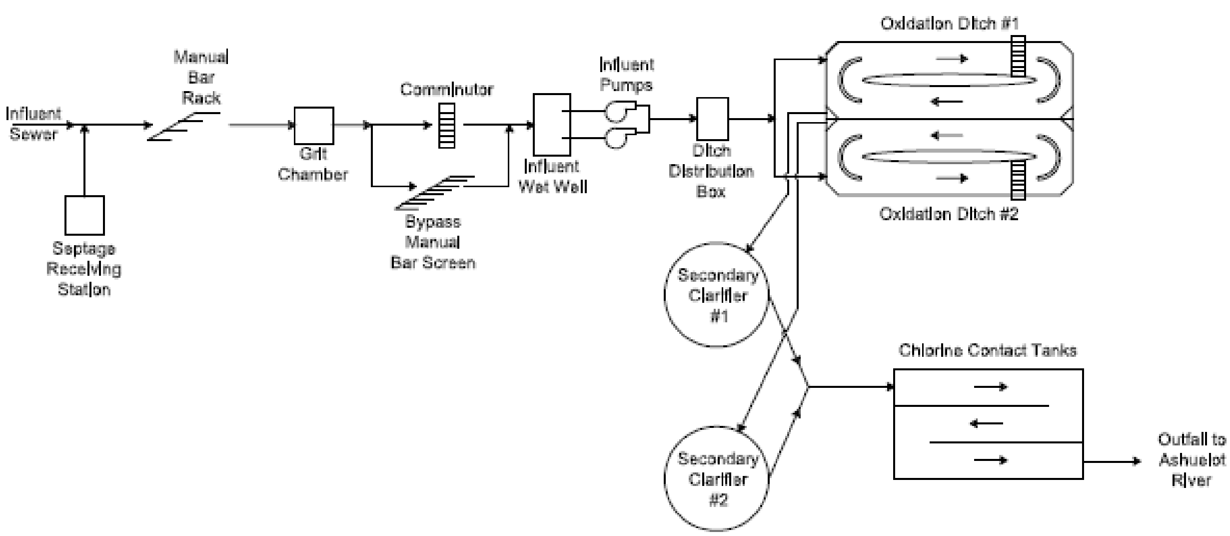

Figure HD-2 Hinsdale, NH, Process Flow Diagram

BioWin Model and Conceptual Design

Average influent concentrations and an average influent temperature 13° C were used for calibration of the model using a steady-state simulation. Model output was compared to average effluent data. The model was considered calibrated if the output typically matched effluent BOD5, TSS and total nitrogen within +/- 10% of the actual values in the data sets. All parameters are within the 10% except for effluent BOD. The model predicts a lower value (2.17 mg/L) than the data indicates (5.17 mg/L). Once the model was calibrated, various design alternatives and changes in process control parameters were evaluated to determine which alternative resulted in the lowest possible effluent total nitrogen.

Sensitivity testing was also performed by reducing the temperature from 13° C to 8° C. Since Hinsdale is already close to 80% design flow, the models already represent high flow conditions. The baseline model was configured (Figure HD-3) using one oxidation ditch and two secondary clarifiers and calibrated (Table HD-2 Baseline Model Column). Average annual flow and temperature (0.23 MGD and 13° C) obtained from plant data were used for both the baseline and nitrogen design models.

Table HD-2 Baseline Model Comparison to Conceptual Design, Hinsdale, NH

Plant Influent Data			**Baseline Model Effluent**		**Design Model Effluent**		**Compare Baseline to Model Design**	
Parameters	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d
Volatile suspended solids	131	273	4.64	10	4.24	9	**0.40**	**0.83**
Total suspended solids	142.43	297	5.56	12	5.07	11	**0.49**	**1.02**
Total Kjeldahl Nitrogen	27.4	57	2	5	3	6	**-1**	**-1**
Total Carbonaceous BOD	160	334	2.17	5	1.94	4	**0.23**	**0.48**
Total N	27.4	57	11.24	23	4.73	10	**6.51**	**13.57**
pH	7		6.82		6.98			
Ammonia N	18.08	38	0.34	1	1.41	3	**-1.07**	**-2.23**
Nitrate N	0	0	8.84	18	0.08	0	**8.76**	**18.26**
Parameters								
Temperature, ^{o}C	13		13		13			
Flow, MGD	0.25		0.25		0.25			

The oxidation ditch model shows various zones in which DO concentrations can be adjusted and/or monitored. This model was calibrated and then used to develop the optimum nitrogen removal model. Figure HD-4 shows the conceptual design process flow model for nitrogen removal.

The only difference between these two models is the DO concentration in each of the oxidation ditch zones which cannot be seen in the process flow diagram but the result of these DO changes can be seen in the model output data (Table HD-2 Design Model Column).

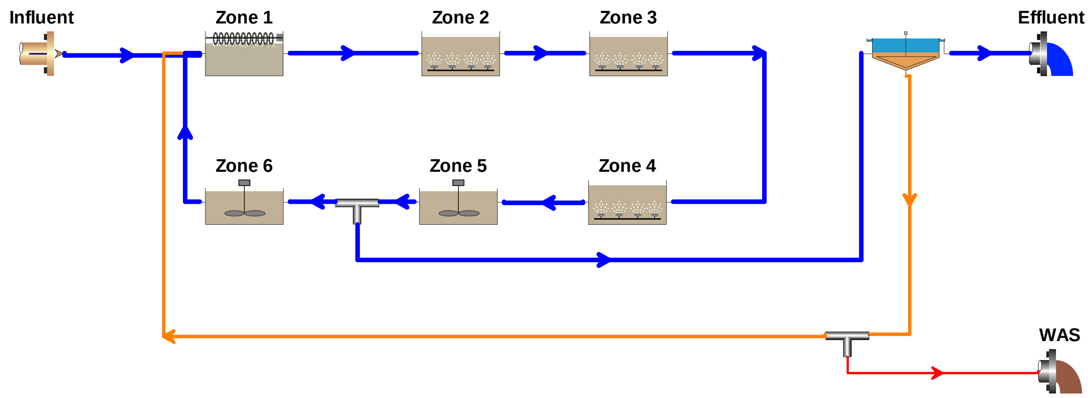

Figure HD-3 Baseline Model, Hinsdale, NH

Currently, influent TN averages about 57 lbs/d and the plant discharges about 23 lbs/d resulting in a removal of about 34 lbs/d (57lbs/d-23 lbs/d) or 59% removal. With the reduction in DO concentration proposed in this design, the model is predicting that the plant would discharge 15 lbs/d total nitrogen with a concentration of 4.73 mg/L resulting in a removal of 47 lbs/d (57 lbs/d-10 lbs/d) or 83% removal.

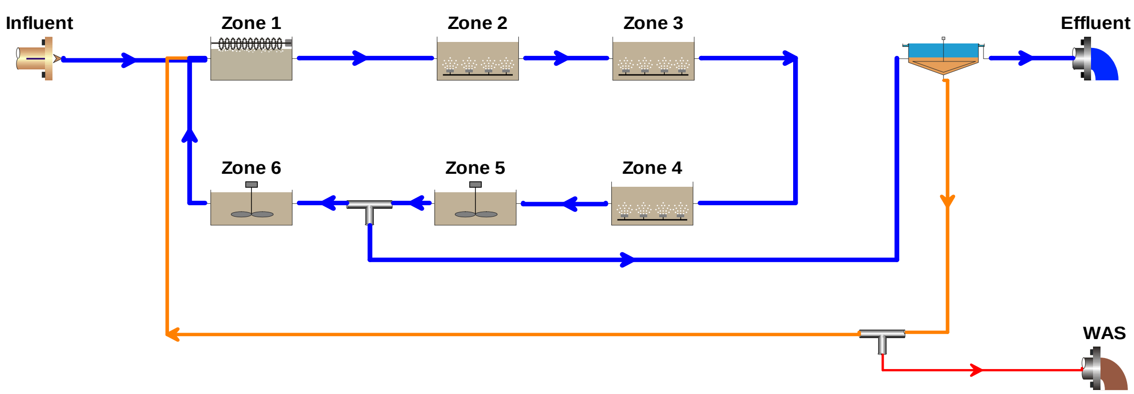

Figure HD-4 Conceptual Nitrogen Design Model, Hinsdale, NH

The increased removal over current performance is 13 lbs/d total nitrogen or about 4,954 lbs/year at average conditions. The model was then tested at 8° C. The results show a slight increase in an effluent total nitrogen concentration to 6.54 mg/L or about 3,577 lbs/year. A summary of these results is shown in Table HD-3. To achieve these total nitrogen concentrations, variable frequency drives would be added to the brush aerators to control DO concentrations as well as DO, ammonia, pH and nitrate analyzers.

Table HD-3 Summary of Results, Hinsdale, NH

Current Influent TN, lbs/d	57
Current Effluent TN, lbs/d	23
Current Removal, lbs/d	34
Predicted Effluent TN, lbs/d	10
Predicted Removal, lbs/d	47
Net Change, lbs/d	13
Net Change, lbs/year	4,954
Winter Temperature, lbs/year	3,577

Cost Per Pound of Nitrogen Removed

A preliminary construction cost estimate (Figure HD-4) was prepared based on this design. This estimate was then used to calculate the cost per pound of nitrogen removed based on the model prediction. The estimate includes the cost of all equipment (variable frequency drives), instrumentation and installation costs.

NEIWPCC Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the upper Long Island Sound Watershed		COST ESTIMATE Hinsdale, NH	
Contractor Name:	JJ Environmental	Date:	1-Jun-14
Address:	17 Archer Lane	Project No.	0302-001
	Darien, Ct 06820	Proposal No.	10
Telephone No:	1-203-309-8768		

SECTION A: CONTRACTOR WORK		Revisions
1. Total Contractor Labor	$20,022.37	
2. Total Contractor Material	$37,900.00	
3. Total Contractor Equipment	$2,503.00	
4. Unit Price Costs		
5. Subtotal Contractor Cost	$60,425.37	
6. Contractor Mark-Up 15%	$9,063.81	
7. Contractor Total Section A	$69,489.18	
SECTION B: CONTRACTOR WORK		
8. Names Of Subcontractors		
A. Electrical Subcontractor	$19,067.81	
B. Instrumentation Integrator	$8,510.00	
C.		
D.		
E.		
F.		
9. Total Subcontractor's Proposals (A through F)	$27,577.81	
10. Contractor's Mark-Up On Subs Proposals (5%)	$1,378.89	
11. Subcontractor Total Section B	$28,956.70	
SECTION C: TOTAL CONTRACTED UNIT PRICE COSTS		
SECTION D: CONTRACTOR'S REQUEST		
12. Amount Requested (Total Lines 7 & 11)	**$98,445.88**	

Figure HD-5 Cost Estimate for the Hinsdale, NH, Conceptual Design

The total cost for retrofitting this system is estimated to be $98,446. The increased O&M cost is $1,000 per year which is primarily for instrument maintenance. The model is predicting at average temperature and current flow, the plant will remove an additional 4,954 lbs TN/year over baseline conditions. Therefore the cost per pound for the ten year term is $2.50 (Table HD- 4) and for the twenty year is $1.52 (Table HD-5). This plant is already performing well so the incremental change in nitrogen removal is small.

Table HD-4 Hinsdale, NH Cost of Nitrogen Removal (10-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
13.57	**Delta Pounds N Removed Per day**
4,954	Delta Pounds N Removed 1 Year
49,543	Delta Pounds N Removed 10 Year
99,085	Delta Pounds N Removed 20 Year
$98,445.88	**Capital Cost of Conceptual Design**
$19.87	Cost Per Pound Over 1 Year
$1.99	Cost Per Pound Over 10 Years
$0.99	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
10	Loan Term in Years
$950.60	Monthly Payment (100% Financed)
$114,072.09	Total Cost P & I Over 10 Years
$10,000.00	Additional O&M over term
$124,072.09	Total Cost Over 10 Years
$2.50	**Total Cost Per Pound of Additional Nitrogen Removed Over 10 Years**

Table HD-5 Hinsdale, NH Cost of Nitrogen Removal (20-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
13.57	**Delta Pounds N Removed Per day**
4,954	Delta Pounds N Removed 1 Year
49,543	Delta Pounds N Removed 10 Year
99,085	Delta Pounds N Removed 20 Year
$98,445.88	**Capital Cost of Conceptual Design**
$19.87	Cost Per Pound Over 1 Year
$1.99	Cost Per Pound Over 10 Years
$0.99	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
20	Loan Term in Years
$545.98	Monthly Payment (100% Financed)
$131,034.84	Total Cost P & I Over 20 Years
$20,000.00	Additional O&M over term
$151,034.84	Total Cost Over 20 Years
$1.52	**Total Cost Per Pound of Additional Nitrogen Removed Over 20 Years**

Littleton, NH

Plant Description

The Littleton Wastewater Reclamation Plant (L-1) is a 1.5 MGD oxidation ditch facility. It is currently treating an average flow of 0.82 MGD or about 55% of the design flow. There is one oxidation ditch with three concentric channels. Each channel can be run independently. There are four rotating disk aerators in the outer-most channel and two each in the two inner channels.

The flow from the biological system is then conveyed to two secondary clarifiers. After the flow leaves the secondary clarifiers, it passes through UV disinfection and then to the Ammonoosuc River, a tributary of the Connecticut River (Figure L-2).

Figure L-1 Aerial View Littleton, NH, Facility

Currently the plant is operating all three concentric channels in the oxidation ditch and two secondary clarifiers. The model configuration was based on current operation. Permit limits for Littleton, NH, are shown in Table L-1. In addition to these limits, they also monitor specific nitrogen species.

Table L-1 Current Permit Limits, Littleton, NH

	Monthly	Weekly
TSS, mg/L	30	45
BOD, mg/L	30	45

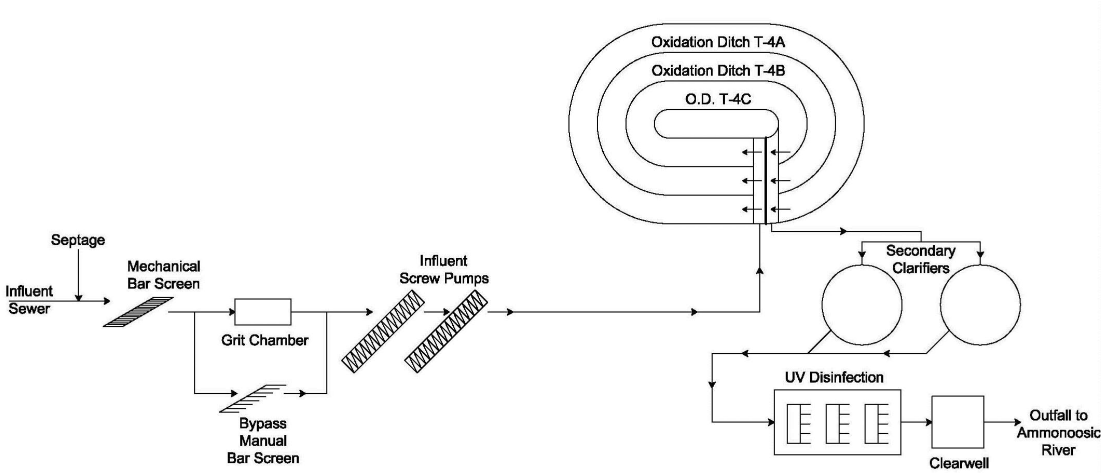

Figure L-2 Littleton, NH, Process Flow Diagram

BioWin Model and Conceptual Design

A BioWin model and conceptual design was developed based on the original set of data provided for the period of mid-2011 to mid-2013. The model indicated that with control of the DO concentrations within the oxidation ditch that nitrogen could be removed. The expected total nitrogen concentration predicted by the model was 5.3 mg/L.

Prior to any knowledge of that model, plant staff on their own began developing methods to control the rotors in the oxidation ditch to better control DO and therefore remove nitrogen. They have done an excellent job in reducing effluent total nitrogen. The staff provided data from that work which began in June 2013 and is continuing. An analysis of those data, indicate the plant is very efficiently removing nitrogen. Figure L-1 shows a time series graph with the various species of nitrogen. They monitor ammonia, nitrate and nitrite. Total nitrogen (TN) was calculated from these. TKN is not determined and can typically range from 0.5 to 2 mg/L depending on influent characteristics. As is seen by the graph, they have shown excellent results in optimization during that period.

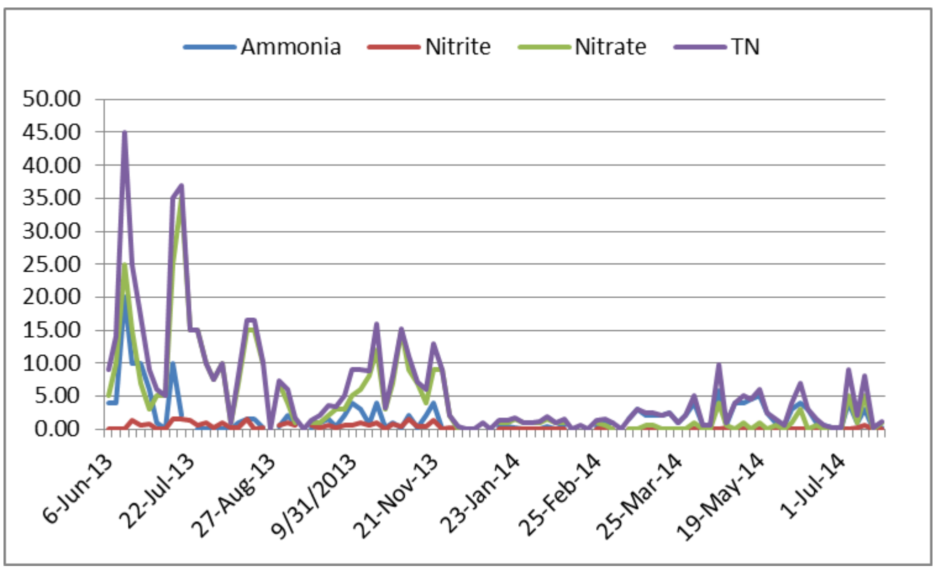

Figure L-1 Results of plant optimization showing decrease in nitrogen species

Table L-1 shows the average of ammonia, nitrate, nitrite and total nitrogen over this period and the percent removal. Littleton is averaging about 6.6 mg/L TN with an almost 81% removal over this year period. Coincidently, the model predicted effluent total nitrogen concentration of 5.3 mg/L TN by controlling the DO, so these data are an independent verification that low concentrations of TN could be achieved (L-2).

Table L-1 Average Data-June 2013 to July 2014

	Influent	Effluent	% Removal
NH4-N, mg/L	32.6	2.01	93.8
NO2-N, mg/L	0.05	0.03	
NO3-N, mg/L	1.16	4.51	
TN	33.8	6.55	80.6

The cost estimate originally developed for the project included the following: a rotor panel installed with a PLC which could take the input signal from either DO or nitrate probes to start and stop rotors based on various set points and also various instruments to help the operators monitor the process. That cost estimate for this equipment was $183,653.32. Since they are already achieving low-cost nitrogen removal, that cost will not be included in the summary nor will the nitrogen benefit they are achieving.

Table L-2 Baseline Model Comparison to Conceptual Design, Littleton, NH

Plant Influent Data			Baseline Model Effluent		Design Model Effluent		Compare Baseline to Model Design	
Parameters	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d
Volatile suspended solids	121	827	3.83	26	3.89	27	**-0.06**	**-0.41**
Total suspended solids	145.58	996	4.96	34	5.02	34	**-0.06**	**-0.41**
Total Kjeldahl Nitrogen	22	150	2	14	2	15	**0**	**0**
Total Carbonaceous BOD	235	1607	1.58	11	1.66	11	**-0.08**	**-0.55**
Total N	23	157	11.9	81	5.3	36	**6.6**	**45.4**
pH	7.13		6.7		6.7	46		
Ammonia N	14.52	99	0	2	0	3	**0**	**0**
Nitrate N	0	0	9.71	66	2.98	20	**6.73**	**46.03**
Parameters								
Temperature, ^{o}C	13		13		13			
Flow, MGD	0.82		0.82		0.82			

4.3 Vermont

Five treatment plants from Vermont were selected for BioWin modeling and cost estimation; Ludlow, Lyndonville, Springfield, St. Johnsbury and Windsor.

Ludlow, VT

Plant Description

The Ludlow Wastewater Treatment Plant (Figure LU-1) is a 1.05 MGD oxidation ditch facility. It is currently treating an average flow of 0.36 MGD or 34% of the design flow. The plant has two oxidation ditches and two secondary clarifiers. Each oxidation ditch has two brush aerators. There is also an anoxic selector at the head of each ditch. After the flow leaves the secondary clarifiers, it passes through chlorine disinfection and then to the Black River, a tributary of the Connecticut River (Figure LU-2).

Figure LU-1 Aerial View Ludlow, VT, Facility

Currently the plant is operating one oxidation ditch and one secondary clarifier. The model configuration was based on current operation. Permit limits for Ludlow, VT, are shown in Table LU-1. Along with these permit limits; they also monitor various nitrogen species.

Table LU-1 Current Permit Limits, Ludlow, VT

	Monthly	Weekly
TSS, mg/L	30	45
BOD, mg/L	30	45

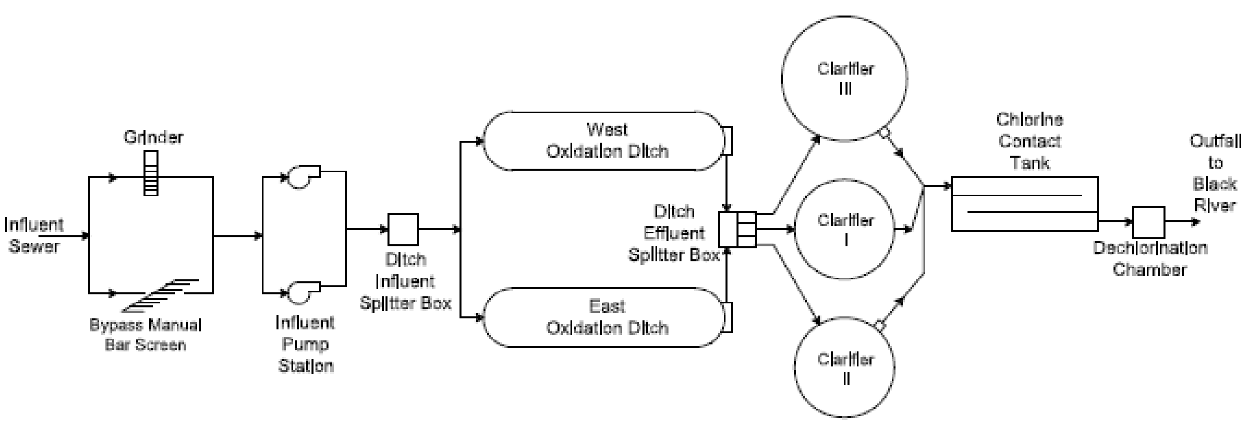

Figure LU-2 Ludlow, VT, Process Flow Diagram

BioWin Model and Conceptual Design

Average influent concentrations and an average influent temperature 13^{o} C were used for calibration of the model using a steady-state simulation. Model output was compared to average effluent data.

The model was considered calibrated if the output typically matched effluent BOD5, TSS and total nitrogen within +/- 10% of the actual values in the data sets. All parameters were within the 10% except for BOD.

Table LU-2 Baseline Model Comparison to Conceptual Design, Ludlow, VT

Plant Influent Data			Baseline Model Effluent		Design Model Effluent		Compare Baseline to Model Design	
Parameters	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d
Volatile suspended solids	101	303	3.53	11	5.47	16	**-1.94**	**-5.82**
Total suspended solids	121.36	364	4.91	15	7.61	23	**-2.70**	**-8.11**
Total Kjeldahl Nitrogen	29.2	88	2	7	2	7	**0**	**-1**
Total Carbonaceous BOD	140	420	1.56	5	1.65	5	**-0.09**	**-0.27**
Total N	29.2	88	11.9	36	6.1	18	**5.9**	**17.6**
pH	7		6.4		6.8			
Ammonia N	19.27	58	0	1	1	2	**-1**	**-2**
Nitrate N	0	0	9.59	29	3.53	11	**6.06**	**18.19**
Parameters								
Temperature, ^{o}C	13		13		13.00			
Flow, MGD	0.36		0.36		0.36			

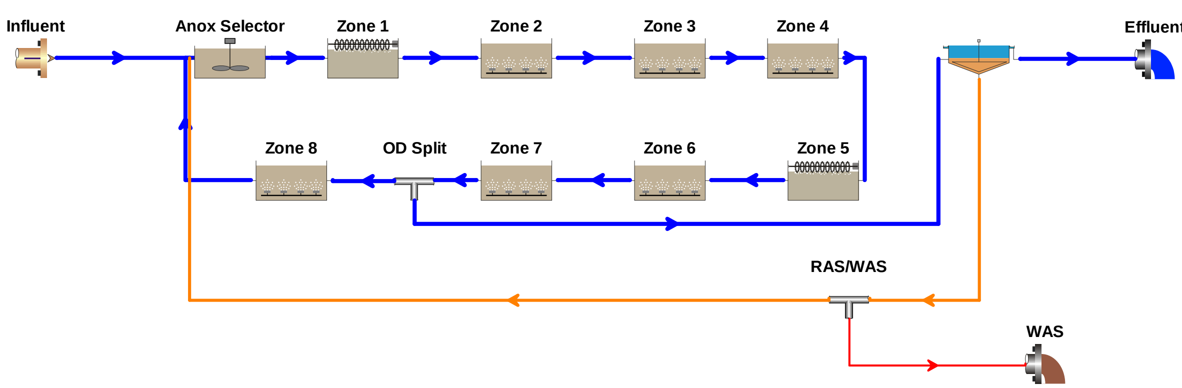

Figure LU-3 Baseline Model, Ludlow, VT

The model predicted a lower BOD than the plant data. Once the model was calibrated, various design alternatives and changes in process control parameters were evaluated to determine which alternative resulted in the lowest possible effluent total nitrogen. Sensitivity testing was also performed by reducing the temperature from 13^{o} C to 8^{o} C and increasing the flow to 80% of design at 8^{o} C.

Figure LU-3 shows the baseline process flow model. The baseline model was configured (Figure LU-3) and calibrated (Table LU-2 Baseline Model Column). The oxidation ditch model shows various zones in which DO concentrations can be adjusted and/or monitored. This model was calibrate and then used to develop the optimum nitrogen removal model (Figure LU-4). To remove nitrogen at Ludlow, it is necessary to reduce DO in the various zones of the oxidation ditch. The only difference between the two models (Figure LU-3 and LU-4) is the DO concentration in each of the oxidation ditch zones which cannot be seen in the process flow diagram but the result of these DO changes can be seen in the model output data (Table LU-2 Design Model Column). One concern about reducing aerator speed is a reduction in mixing and possible settling of solids in the ditch. This would have to be monitored and may require the addition of a mixer.

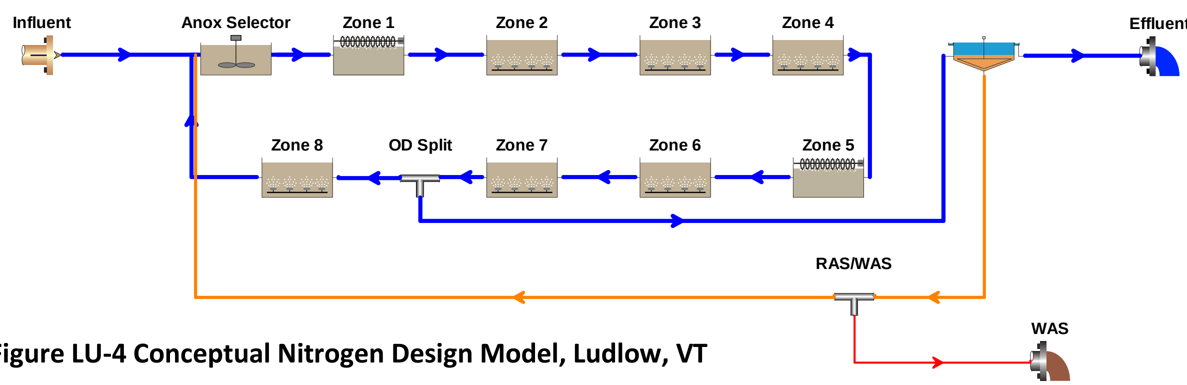

Figure LU-4 Conceptual Nitrogen Design Model, Ludlow, VT

Currently, influent TN averages about 88 lbs/d and the plant discharges about 36 lbs/d resulting in a removal of about 52 lbs/d (88 lbs/d-36 lbs/d) or 59% removal. With the reduction in DO concentration proposed in this design, the model is predicting that the plant would discharge 18.3 lbs/d total nitrogen with a concentration of 6.1 mg/L resulting in a removal of 69 lbs/d (88 lbs/d-18.3 lbs/d). The increased removal over current performance is 17.6 lbs/d total nitrogen or about 6,411 lbs/year at average conditions.

The model was then tested at 8^{o} C and then at 8^{o} C with the flow increased to 80% of design. At 8^{o} C, the effluent total nitrogen concentration increased from 6.1 mg/L to 6.3 mg/L (6,128 lbs/year removed), virtually no difference in nitrogen removal. However, when the flow was increased to 80% at this temperature, the total nitrogen concentration increased to 10.5 mg/L. A summary of these results is shown in Table LU-3. The increase in total nitrogen is due to an increase in ammonia concentration. With the combination of high flow and low winter temperature, there is insufficient aerobic volume to fully nitrify and denitrify. The model indicates that ammonia concentrations could be reduced, even at high flow and winter temperatures, with very precise control of the rotors resulting in precise control of DO. However, this cannot this cannot be done with the plant's existing rotors and controls.

As discussed earlier, there is an existing anoxic selector. During the site visit, DO was measured in the anoxic zone and the concentration was above 0.3 mg/L so the zone was not truly anoxic. This is probably due to the fact that there is a gap between the end of the discharge pipe and the water surface of the anoxic selector. To ensure a truly anoxic zone, an extension of the pipe to ensure below water surface discharge is included in the cost estimate. Furthermore, Ludlow has low alkalinity concentration in the influent; therefore, a small chemical feed system is included in the cost estimate to ensure sufficient alkalinity.

Table LU-3 Summary of Results, Ludlow, VT

Current Influent TN, lbs/d	88
Current Effluent TN, lbs/d	36
Current Removal, lbs/d	52
Predicted Effluent TN, lbs/d	18
Predicted Removal, lbs/d	69
Net Change, lbs/d	18
Net Change, lbs/year	6,411
Winter Temperature, lbs/year	6,128

To remove nitrogen at Ludlow, a rotor panel would be installed with a PLC that can take the input signal from either DO or nitrate probes to start and stop rotors based on various set points. It is important the lowest speed of the rotors doesn't result in settling of mixed liquor in the ditch. Ammonia and pH probes would also be installed.

Cost Per Pound of Nitrogen Removed

A preliminary construction cost estimate was prepared based on this design (Figure LU-4). This estimate was then used to calculate the cost per pound of nitrogen removed based on the model prediction. Ludlow has a very low influent alkalinity which may limit nitrification at times and therefore alkalinity may have to be added periodically, so a chemical feed system is included in this conceptual design.

The estimate includes the cost of all equipment (rotor control system, chemical feed system), instrumentation and installation costs. The cost for retrofitting this system is estimated to be $214,779.71. The increase O&M cost is $5,850 per year for chemical costs and instrument maintenance. The model is predicting at average temperature and current flow, the plant will remove an additional 6,411 lbs/year over baseline conditions. Therefore the cost per pound for the ten year term is $4.79 (Table LU- 4) and for the twenty year is $3.14 (Table LU-5).

NEIWPCC Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the upper Long Island Sound Watershed		COST ESTIMATE Ludlow VT	
Contractor Name:	JJ Environmental	Date:	7-Dec-14
Address:	17 Archer Lane	Project No.	0302-001
	Darien, Ct 06820	Proposal No.	14A
Telephone No:	1-203-309-8768		

		Revisions
SECTION A: CONTRACTOR WORK		
1. Total Contractor Labor	$24,471.79	
2. Total Contractor Material	$57,700.00	
3. Total Contractor Equipment	$3,982.00	
4. Unit Price Costs		
5. Subtotal Contractor Cost	$86,153.79	
6. Contractor Mark-Up 15%	$12,923.07	
7. Contractor Total Section A	$99,076.86	
SECTION B: CONTRACTOR WORK		
8. Names Of Subcontractors		
A. Electrical Subcontractor	$72,749.19	
B. Instrumentation Integrator	$37,444.00	
C.		
D.		
E.		
F.		
9. Total Subcontractor's Proposals (A through F)	$110,193.19	
10. Contractor's Mark-Up On Subs Proposals (5%)	$5,509.66	
11. Subcontractor Total Section B	$115,702.85	
SECTION C: TOTAL CONTRACTED UNIT PRICE COSTS		
SECTION D: CONTRACTOR'S REQUEST		
12. Amount Requested (Total Lines 7 & 11)	**$214,779.71**	

Figure LU-5 Cost Estimate for Ludlow, VT, Conceptual Design

Table LU-4 Ludlow, VT Cost of Nitrogen Removal (10-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
17.56	**Delta Pounds N Removed Per day**
6,411	Delta Pounds N Removed 1 Year
64,109	Delta Pounds N Removed 10 Year
128,217	Delta Pounds N Removed 20 Year
$214,779.71	**Capital Cost of Conceptual Design**
$33.50	Cost Per Pound Over 1 Year
$3.35	Cost Per Pound Over 10 Years
$1.68	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
10	Loan Term in Years
$2,073.93	Monthly Payment (100% Financed)
$248,871.46	Total Cost P & I Over 10 Years
$58,500.00	Additional O&M over term
$307,371.46	Total Cost Over 10 Years
$4.79	**Total Cost Per Pound of Additional Nitrogen Removed Over 10 Years**

Table LU-5 Ludlow, VT Cost of Nitrogen Removal (20-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
18	**Delta Pounds N Removed Per day**
6,411	Delta Pounds N Removed 1 Year
64,109	Delta Pounds N Removed 10 Year
128,217	Delta Pounds N Removed 20 Year
$214,779.71	**Capital Cost of Conceptual Design**
$33.50	Cost Per Pound Over 1 Year
$3.35	Cost Per Pound Over 10 Years
$1.68	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
20	Loan Term in Years
$1,191.16	Monthly Payment (100% Financed)
$285,879.15	Total Cost P & I Over 20 Years
$117,000.00	Additional O&M over term
$402,879.15	Total Cost Over 20 Years
$3.14	**Total Cost Per Pound of Additional Nitrogen Removed Over 20 Years**

Lyndonville, VT

Plant Description

Figure LY-1 Aerial View Lyndonville, VT, Facility

The Lyndonville Wastewater Treatment Plant is a 0.75 MGD activated sludge (extended aeration) facility with a current average flow of 0.16 MGD or 21% of design flow. The plant was just recently upgraded. They have three bioreactors trains each with an anoxic zone. The flow from the biological system is conveyed to two secondary clarifiers. Secondary effluent is disinfected using chlorine prior to discharge to the Passumpsic River, a tributary of the Connecticut River.

Currently the plant is operating two biological reactors and two secondary clarifiers. Each bioreactor has a small anoxic selector. The model configuration was based on current operation. Lyndonville's permit limits are shown in Table LY-1. Along with these permit limits; they also monitor various nitrogen species.

Table LY-1 Current Permit Limits, Lyndonville, VT

	Monthly	Weekly
TSS, mg/L	30	45
BOD, mg/L	30	45

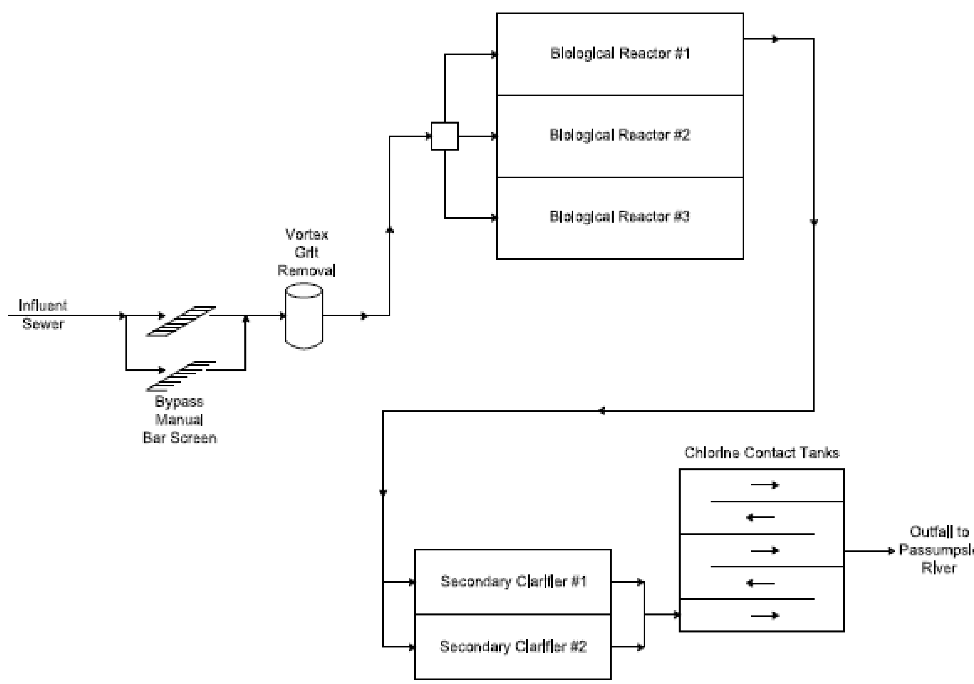

Figure LY-2 Lyndonville, VT Process Flow Diagram

A BioWin model and conceptual design was developed based on the original set of data provided. This is a new plant and currently is only receiving about 21% of the design flow.

The plant staff at Lyndonville has been experimenting with cyclic aeration to reduce nitrogen without having to use a recycle pump. By turning aerators on and off, anoxic and aerobic environments are created. This concept has been used successfully since the early 1990's provided that aeration equipment can be stopped and started at frequent intervals without damage. They have recently provided data for this cyclic operation which they have been doing for over a year. Figure LY-1 is a time series graph showing how the various nitrogen species change with time. They provided ammonia, nitrite and nitrate data. Total nitrogen (TN) was calculated from those data. Unfortunately there is no TKN data so the TN will be understated to some extent. Furthermore, the most recent three months show an increase in total nitrogen so they will need to evaluate the effect of colder temperatures on the cyclic operation.

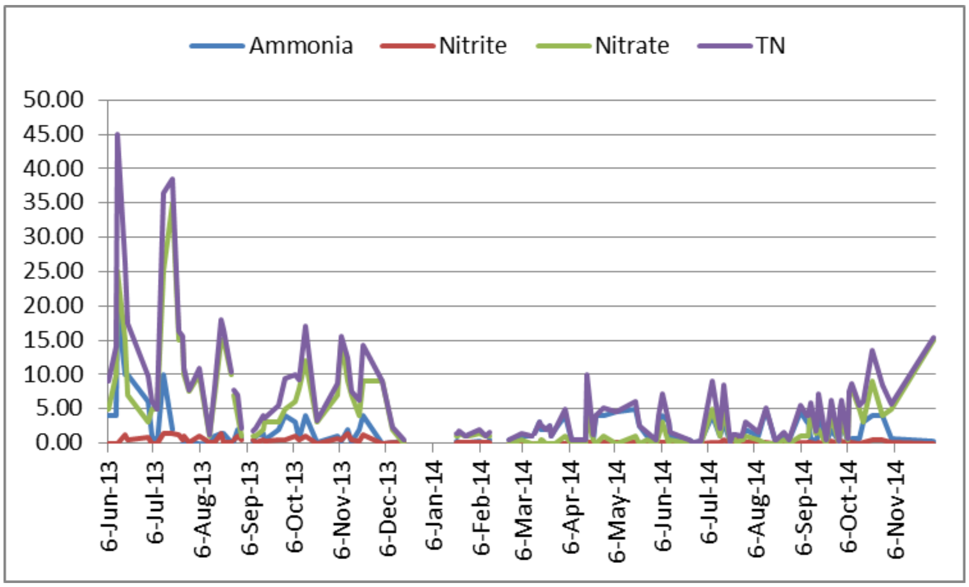

Figure LY-1 Results of Cyclic Aeration, Lyndonville, VT

The graph clearly shows good nitrogen removal over extended periods, except for colder temperatures. By doing cyclic aeration, there is an energy cost savings over using a recycle pump. As they continue to monitor this process, they may be able to adjust cycle times based on flow or diurnal variations in nitrogen loadings, as well as temperature effects.

Table LY-1 Average Data-June 2013 to July 2014 Lyndonville, VT

	Influent	Effluent	% Removal
NH4-N, mg/L	33.15	1.91	94
NO2-N, mg/L	0.04	0.25	
NO3-N, mg/L	0.94	4	
TN, mg/L	34.12	6.14	82

They are showing good removal efficiencies using this process especially during periods of warmer wastewater temperatures. Table LY-2 shows the average of all species for the entire period as well as the TN (without TKN included) and ammonia removal efficiencies. They are achieving very good removals; 94% removal of ammonia and 82% removal of TN (without TKN included). Effluent TN (without TKN included) averaged over the entire period 6.14 mg/L. Depending on influent characteristics, the TKN can range from 0.5 to about 2 mg/L. The output from the BioWin model for effluent TN without TKN included was 2.2 mg/L on an annual average and less than 4.9 mg/L when wastewater temperatures were 8^{o} C.

The cost capital cost for Lyndonville for recycle pumps and instruments was $194,139. Neither this cost nor the nitrogen benefit was included in the summary tables since they are currently achieving nitrogen removal.

Springfield, VT

Plant Description

The Springfield Wastewater Treatment Plant is a 2.4 MGD activated sludge facility. They are currently treating an average flow of 0.97 MGD or 40% of design. The plant has two primary clarifiers, four biological reactors and two secondary clarifiers. The flow from the secondary clarifiers is disinfected and discharged to Beavers Brook, a tributary of the Connecticut River (Figure FY-2). In addition, it has a small anoxic selector.

Figure SF-1 Aerial View Springfield, VT, Facility

Table SF-1 Current Permit Limits, Springfield, VT

	Monthly	Weekly
TSS, mg/L	30	45
BOD, mg/L	30	45

Springfield, VT, currently uses two primary clarifiers, three biological reactors and two secondary clarifiers. Their permit limits are shown in Table LY-1. Along with these permit limits; they also monitor various nitrogen species

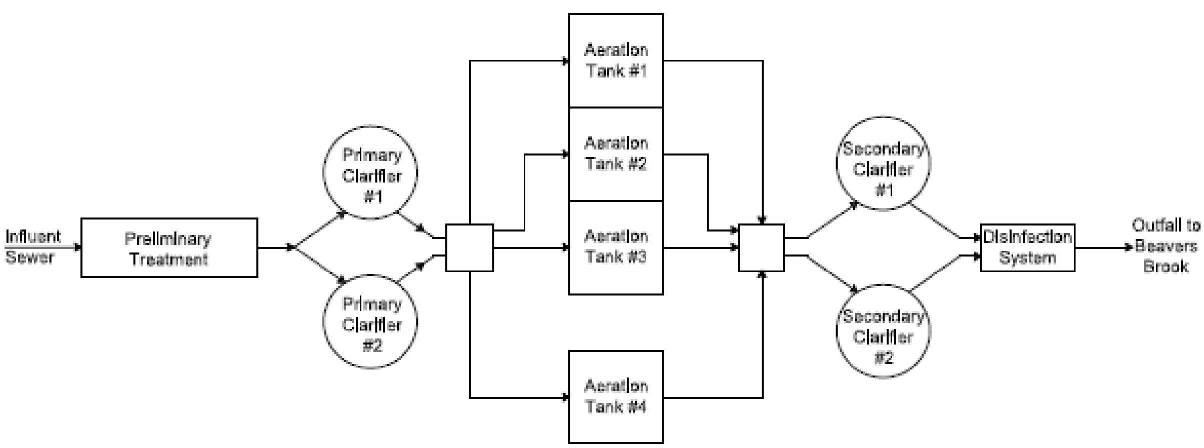

Figure SF-2 Springfield, VT, Process Flow Diagram

BioWin Model and Conceptual Design

Average influent concentrations and an average influent temperature 13.9^{o} C were used for calibration of the model using a steady-state simulation. Model output was compared to average effluent data.

The model was considered calibrated if the output typically matched effluent BOD5, TSS and total nitrogen within +/- 10% of the actual values in the data sets. All parameters were within the 10% except for effluent BOD. The model predicted a lower effluent concentration than the actual data. Once the model was calibrated, various design alternatives and changes in process control parameters were evaluated to determine which alternative resulted in the lowest possible effluent total nitrogen. Sensitivity testing was also performed by reducing the temperature from 13.9^{o} C to 10^{o} C and increasing the flow to 80% of design at 10^{o} C.

Table SF-2 Baseline Model Comparison to Conceptual Design, Springfield, VT

Plant Influent Data			Baseline Model Effluent		Design Model Effluent		Compare Baseline to Model Design	
Parameters	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d	mg/L	lbs/d
Volatile suspended solids	152	1230	3.67	30	4.87	39	**-1.20**	**-9.71**
Total suspended solids	190.97	1545	5.33	43	7.11	58	**-1.78**	**-14.40**
Total Kjeldahl Nitrogen	37	299	2	19	3	24	**-1**	**-5**
Total Carbonaceous BOD	165.55	1339	1.87	15	1.97	16	**-0.10**	**-0.81**
Total N	35	283	15.00	121	5.82	47	**9.18**	**74.26**
pH	7.45		6.87		6.94			
Ammonia N	23.1	187	0.14	1	0.88	7	**-0.74**	**-5.99**
Nitrate N	0	0	12.64	102	2.39	19	**10.25**	**82.92**
Parameters								
Temperature, ^{o}C	13.9		13.9		13.9			
Flow, MGD	0.97		0.97		0.97			

The baseline model was configured (Figure SF-3) using two primary clarifiers, existing anoxic selector, three bioreactor trains and two secondary clarifiers and calibrated (Table SF-2 Baseline Model Column). Average annual flow and temperature (0.97 MGD and 13.9^{o} C) obtained from plant data were used for both the baseline and nitrogen design models. To remove nitrogen at Springfield, along with the existing anoxic selector, another anoxic zone is created in each reactor using approximately one-third of the volume with the remaining portion aerobic. Nitrate recycle pumps were included in the design process flow model as well.

Currently, influent TN averages about 283 lbs/d and the plant discharges about 121 lbs/d resulting in a removal of about 162 lbs/d (283 lbs/d-121 lbs/d) or 57% removal.   With the larger

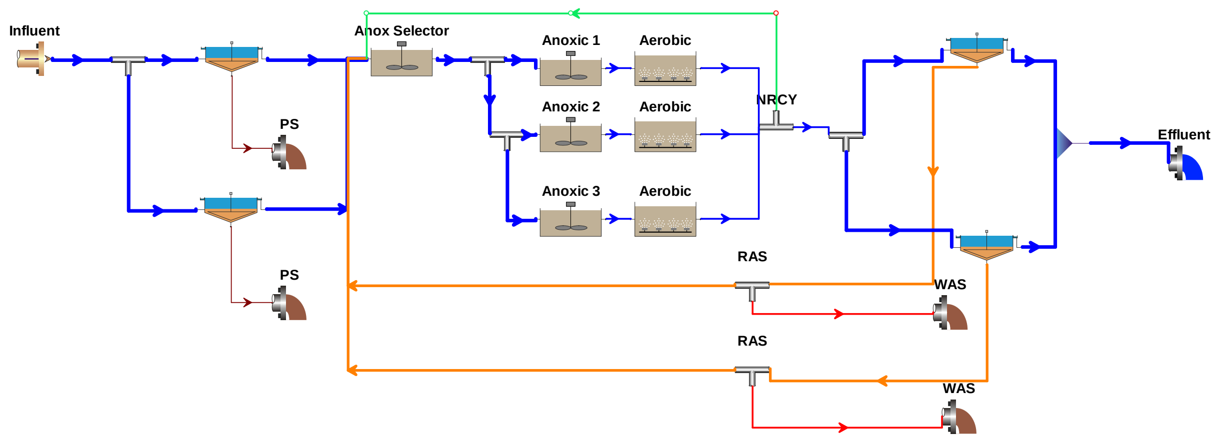

Figure SF-3 Baseline Model, Springfield, VT

anoxic zones and aerobic reactor configuration and recycle pumps, the model is predicting that the plant would discharge 47 lbs/d total nitrogen with a concentration of 5.8 mg/L resulting in a removal of 236 lbs/d (283 lbs/d-47 lbs/d) or 83% removal. The increased removal over current performance is 74 lbs/d total nitrogen or about 27,106 lbs/year at average conditions.

The model was then tested at 10^{o} C and then at 10^{o} C with the flow increased to 80% of design. At 10^{o} C, the effluent total nitrogen concentration did not increase and it only increased to 7.2

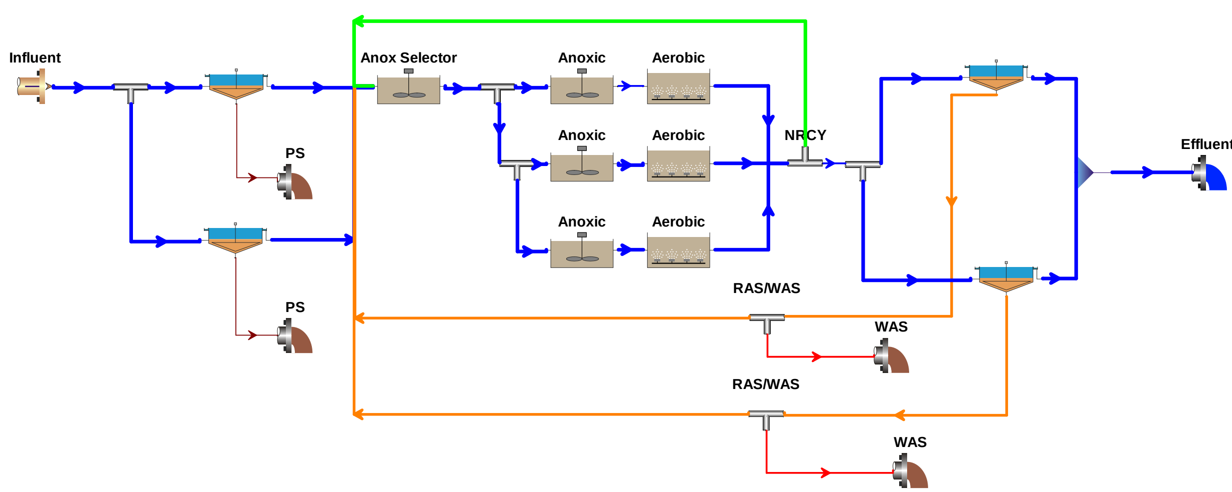

Figure SF-4 Conceptual Nitrogen Design Model, Springfield, VT

mg/L (23,032 lbs/year removed) when the flow increased to 80% at this temperature. A summary of these results is shown in Table SF-3. For this design, mixers and nitrate recycle pumps would be installed along with DO, ammonia, pH and nitrate analyzers.

Cost Per Pound of Nitrogen Removed

A preliminary construction cost estimate (Figure SF-4) was prepared based on the design shown in Figure SP-3. This estimate was then used to calculate the cost per pound of nitrogen removed based on the model prediction.

Table SF-3 Summary of Results, Springfield, VT

Current Influent TN, lbs/d	283
Current Effluent TN, lbs/d	121
Current Removal, lbs/d	162
Predicted Effluent TN, lbs/d	47
Predicted Removal, lbs/d	236
Net Change, lbs/d	74
Net Change, lbs/year	27,106
Winter Temperature, lbs/year	23,032

The cost estimate includes the cost of all equipment (mixers, pumps, piping and instruments) and installation costs. The estimate also includes installing isolation valves on the drop legs to create the anoxic zone.

NEIWPCC Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the upper Long Island Sound Watershed		COST ESTIMATE Springfield VT	
Contractor Name:	JJ Environmental	Date:	27-Sep-14
Address:	17 Archer Lane	Project No.	0302-001
	Darien, Ct 06820	Proposal No.	23
Telephone No:	1-203-309-8768		
SECTION A: CONTRACTOR WORK			Revisions
1. Total Contractor Labor		$91,213.04	
2. Total Contractor Material		$144,000.00	
3. Total Contractor Equipment		$19,490.00	
4. Unit Price Costs			
5. Subtotal Contractor Cost		$254,703.04	
6. Contractor Mark-Up 15%		$38,205.46	
7. Contractor Total Section A		$292,908.49	
SECTION B: CONTRACTOR WORK			
8. Names Of Subcontractors			
A.	Electrical Subcontractor	$84,939.19	
B.	Instrumentation Integrator	$9,085.00	
C.			
D.			
E.			
F.			
9. Total Subcontractor's Proposals (A through F)		$94,024.19	
10. Contractor's Mark-Up On Subs Proposals (5%)		$4,701.21	
11. Subcontractor Total Section B		$98,725.40	
SECTION C: TOTAL CONTRACTED UNIT PRICE COSTS			
SECTION D: CONTRACTOR'S REQUEST			
12. Amount Requested (Total Lines 7 & 11)		**$391,633.89**	

Figure SF-5 Cost Estimate for Springfield, VT, Conceptual Design

The total cost for retrofitting this system is estimated to be $391,634. The increase O&M cost is $121,550 per year primarily due to additional electrical costs. However, there is a cost savings due to reduced aeration which is about $43,131 per year giving a net increase in O&M costs of $78,420 per year. The model is predicting at average temperature and current flow, the plant will remove an additional 27,106 pounds of nitrogen per year over baseline conditions. Therefore the cost per pound for the ten year term is $4.57 (Table SF-4) and for the twenty year is $3.85 (Table SF-5).

Table SF-4 Springfield, VT Cost of Nitrogen Removal (10-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
74	**Delta Pounds N Removed Per day**
27,106	Delta Pounds N Removed 1 Year
271,065	Delta Pounds N Removed 10 Year
542,130	Delta Pounds N Removed 20 Year
$391,633.89	**Capital Cost of Conceptual Design**
$14.45	Cost Per Pound Over 1 Year
$1.44	Cost Per Pound Over 10 Years
$0.72	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
10	Loan Term in Years
$3,781.65	Monthly Payment (100% Financed)
$453,797.52	Total Cost P & I Over 10 Years
$784,200.00	Additional O&M over term
$1,237,997.52	Total Cost Over 10 Years
$4.57	**Total Cost Per Pound of Additional Nitrogen Removed Over 10 Years**

Table SF-5 Springfield, VT Cost of Nitrogen Removal (20-yr)

Cost Per Pound of Additional Nitrogen Removed as Compared to Capital Improvement Costs	
74	**Delta Pounds N Removed Per day**
27,106	Delta Pounds N Removed 1 Year
271,065	Delta Pounds N Removed 10 Year
542,130	Delta Pounds N Removed 20 Year
$391,633.89	**Capital Cost of Conceptual Design**
$14.45	Cost Per Pound Over 1 Year
$1.44	Cost Per Pound Over 10 Years
$0.72	Cost Per Pound Over 20 Years
Cost Per Pound of Additional Nitrogen Removed Including Interest & Operational Costs	
3.00%	Interest Rate
20	Loan Term in Years
$2,171.99	Monthly Payment (100% Financed)
$521,278.12	Total Cost P & I Over 20 Years
$1,568,400.00	Additional O&M over term
$2,089,678.12	Total Cost Over 20 Years
$3.85	**Total Cost Per Pound of Additional Nitrogen Removed Over 20 Years**

St. Johnsbury, VT

Plant Description

The St. Johnsbury Wastewater Treatment Plant (Figure SJ-1) is a 1.6 MGD RBC facility. It is currently treating an average flow of 1.0 MGD or 63% of the design flow. The treatment train includes two primary clarifiers, four trains of four RBCs, and two secondary clarifiers. Flow from the secondary clarifiers is disinfected with chlorine prior to discharge to the Passumpsic River, a tributary of the Connecticut River.

Figure SJ-1 Aerial View St. Johnsbury, VT, Facility

The plant operates two primary clarifiers, three trains of RBCs and two secondary clarifiers. St. Johnsbury's current permit limits are shown in Table SJ-1. Along with these permit limits; they also monitor some nitrogen species.

Table SJ-1 Current Permit Limits, St. Johnsbury, VT

	Monthly	Weekly
TSS, mg/L	30	45
BOD, mg/L	30	45

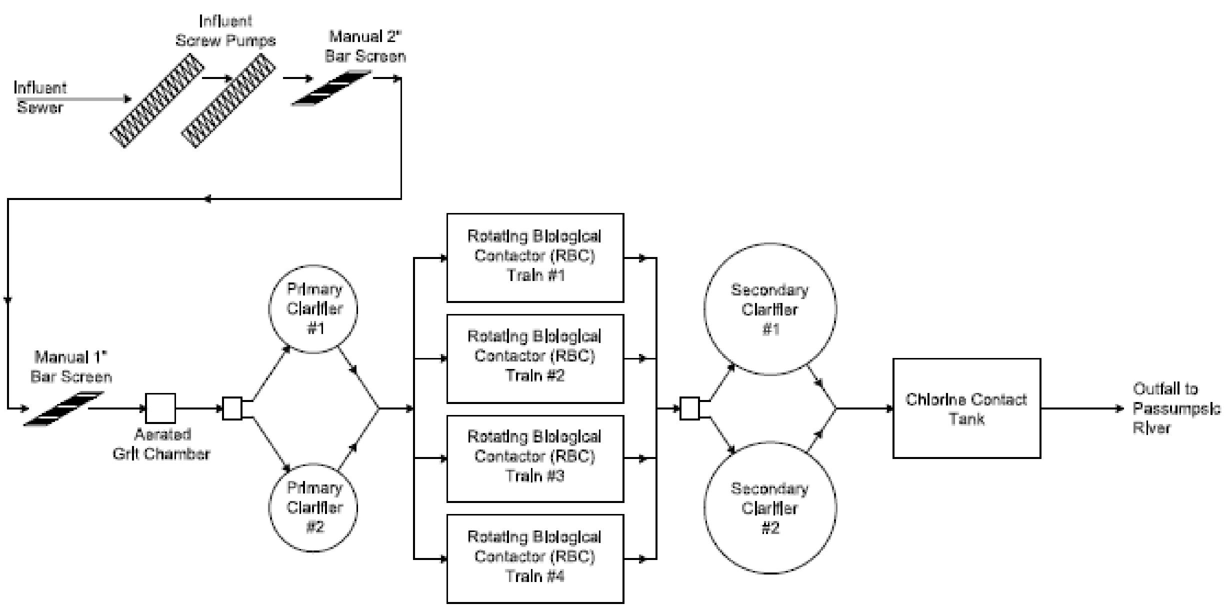

Figure SJ-2 St. Johnsbury, VT Process Flow Diagram

Nitrogen Removal Concept

The BioWin model cannot simulate RBC treatment processes. So any potential nitrogen reductions were estimated based on amount of excess capacity, how well the plant was nitrifying and the potential to create a recycle of nitrified effluent to an anoxic zone.
In evaluating nitrate recycle; it was important to consider the potential impact of shear forces through the RBC caused by increased velocity from a large recycle flow since that might result in biomass shearing from the plastic media reducing treatment efficiency.

A certain amount of nitrogen removal always occurs in RBC processes through the assimilation of nitrogen into cell mass (typically 30% nitrogen removal). There is also nitrogen removal from denitrification occurring in secondary clarifiers and in anoxic zones within the biomass attached to the media in the RBC.

Under this study, we looked for ways to achieve denitrification at St. Johnsbury. There is substantial nitrification at the St. Johnsbury plant. Therefore, it is just a question of how to denitrify the RBC effluent. Various possibilities were evaluated but because of the cold climate it would be impossible to install a pump and piping for recycle at a reasonable cost. One possible way of creating a recycle is through the drain valves at the end of the RBC train or through RAS flow to a primary clarifier. The RBC drains go back to the head of the plant which can act as an anoxic zone as does the primary clarifier. However, this concept needs to be tested to determine any adverse impacts on the process.

Simultaneous nitrification – denitrification (SND) was also evaluated. There are case studies where limited SND has been achieved within the RBC biofilm. SND efficiencies of up to 65% were documented. However, this performance required very thick biofilms to be carried on the disks. High BOD loadings are required to support the thick biofilm growth. The successful examples of SND in RBCs were at plants treating high strength domestic and/or industrial wastes.

It is not possible to accurately quantify any nitrogen removal without testing. St. Johnsbury would be the ideal location to test various recycle possibilities since they have efficient and stable nitrification and excess capacity. At the very least, instrumentation may help plant staff to better monitor the process. The cost to supply and install instruments for each RBC train and influent and effluent locations is $53,844.70 including all equipment and installation.

Windsor, VT

Plant Description

The Windsor Wastewater Treatment Plant (Figure WD-1) is a 1.13 MGD RBC facility with a current average flow of 0.268 MGD or 24% of the design flow. The treatment train includes two primary clarifiers, three trains of RBCs and two secondary clarifiers. The flow from the clarifiers is disinfected by chlorine and then discharged to the Connecticut River (Figure WD-2).

Figure WD-1 View of RBCs at Windsor, VT, Facility

Windsor's permit limits are shown in Table WD-1. Along with these limits; they also monitor specific nitrogen species.

Table WD-1 Current Permit Limits, Windsor, VT

	Monthly	Weekly
TSS, mg/L	30	45
BOD, mg/L	30	45

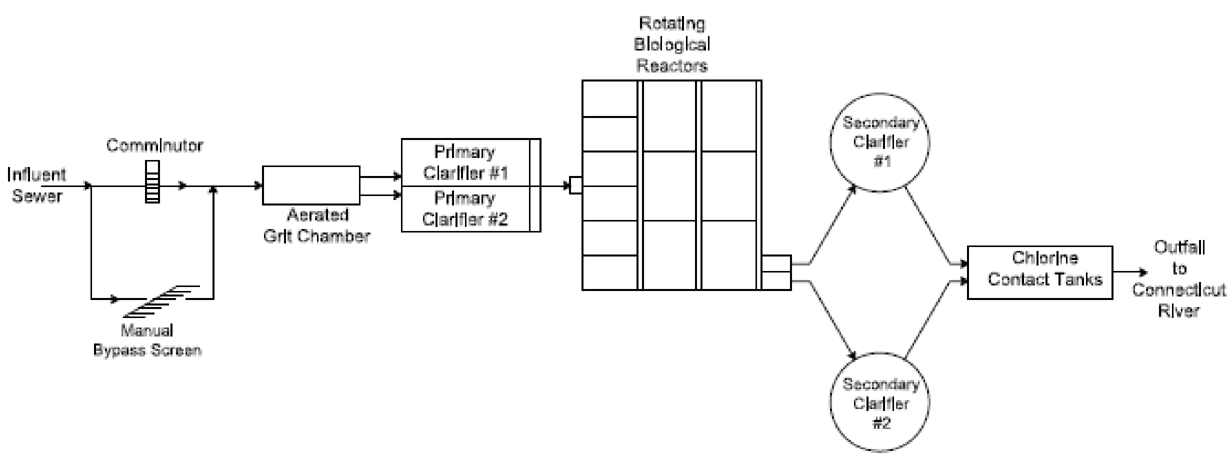

Figure WD-2 Windsor, VT Process Flow Diagram

Nitrogen Removal Concept and Cost Estimate

The BioWin model cannot simulate RBC treatment processes. So any potential nitrogen reductions were estimated based on amount of excess capacity, how well the plant was nitrifying and the potential to create a recycle of nitrified effluent to an anoxic zone.
In evaluating nitrate recycle; it was important to consider the potential impact of shear forces through the RBC caused by increased velocity from a large recycle flow since that might result in biomass shearing from the plastic media reducing treatment efficiency.

A certain amount of nitrogen removal always occurs in RBC processes through the assimilation of nitrogen into cell mass (typically 30% nitrogen removal). There is also nitrogen removal from denitrification occurring in secondary clarifiers and in anoxic zones within the biomass attached to the media in the RBC.

Under this study, we looked for ways to achieve denitrification at Windsor. Windsor achieves good nitrification. Therefore, it is just a question of how to denitrify the RBC effluent. Various possibilities were evaluated but because of the cold climate it would be impossible to install a pump and piping for recycle at a reasonable cost. One possible way of creating a recycle is through the drain valves at the end of the RBC train or through RAS flow to a primary clarifier. The RBC drains go back to the head of the plant which can act as an anoxic zone as does the primary clarifier. However, this concept needs to be tested to determine any adverse impacts on the process.

Simultaneous nitrification – denitrification (SND) was also evaluated. There are case studies where limited SND has been achieved within the RBC biofilm. SND efficiencies of up to 65% were documented. However, this performance required very thick biofilms to be carried on the disks. High BOD loadings are required to support the thick biofilm growth. The successful examples of SND in RBCs were at plants treating high strength domestic and/or industrial wastes.

It is not possible to accurately quantify any nitrogen removal without testing. At the very least, instrumentation may help plant staff to better monitor the process. The cost to supply and install instruments for each RBC train and influent and effluent locations is $53,844.70 including all equipment and installation.

5.0 Summary

This study began with a potential for low cost retrofits at 29 treatment plants. Of those 29, twenty were selected for BioWin modeling and cost estimating. Based on model predictions all twenty treatment plants can remove additional nitrogen to varying degrees, including RBC facilities. If these retrofits are made, the model predicts as much as 2,313 lbs/d or 844,525 lbs/year of nitrogen could be removed from the watershed for a capital investment of $4,736,238.

Tables 5.0-1, 5.0-2 and 5.0-3 are summary tables for the MA, NH and VT Facilities respectively showing design flow, current average daily flow, predicted lbs/d TN removed, predicted lbs/year TN removed (at current average daily flow and average temperature), capital cost, cost per pound of nitrogen removed over at 10 year term including projected O&M and cost per pound of nitrogen removed over a 20 year term. There were two separate cost estimates for the South Hadley Facility. The lower cost estimate is included in Table 5.0-1 since the amount of nitrogen removed shown in the table correlates with existing conditions.

Table 5-1 Summary Table for MA Facilities

MA FACILITIES	Design, MGD	ADF, MGD	lbs TN/day	lbs TN/year	Capital Cost, $	Cost/lb (10 yrs)	Cost/lb (20 yrs)
Athol	1.75	0.75	41	15,045	$209,710	$2.27	$1.58
Belchertown	1.00	0.40	0.70	244	$88,514	$170.92	$153.00
Gardner	5.00	2.98	258	94,071	$368,414	$1.05	$0.86
Great Barrington	3.20	1.08	63	23,112	$297,513	$2.91	$2.27
Palmer	5.60	1.47	91	33,215	$320,722	$1.67	$1.19
Pittsfield	17.00	11.94	854	311,853	$745,033	$0.51	$0.40
South Hadley	4.20	2.66	278	101,470	$302,609	$0.51	$0.36
Spencer	1.08	0.78	64	23,269	$352,431	$4.52	$3.78
Warren	1.50	0.31	N/A	N/A	N/A	N/A	N/A
Webster	6.00	2.99	250	91,383	$365,807	$0.87	$0.67
Winchendon	1.10	0.51	30	10,867	$201,739	$5.09	$4.17
TOTAL	**47.43**	**25.87**	**1,930**	**704,529**	**$3,252,492**		

From the information in these tables, it is obvious that the majority of nitrogen removal is coming from the eleven plants in MA. There are more of them and they are larger plants so any decrease in final effluent TN concentration translates into a greater reduction in TN mass loading.

Table 5-2 Summary Table for NH Facilities

NH FACILITIES	Design, MGD	ADF, MGD	lbs TN/day	lbs TN/year	Capital Cost, $	Cost/lb (10 yrs)	Cost/lb (20 yrs)
Claremont	3.89	1.23	115	41,975	$377,859	$2.45	$2.00
Hanover	2.30	1.25	163	59,550	$401,027	$1.74	$1.40
Hinsdale	0.30	0.25	13	4,954	$98,446	$2.50	$1.52
Littleton	1.50	0.82	N/A	N/A	N/A	N/A	N/A
TOTAL	**7.99**	**3.55**	**291**	**106,479**	**$877,332**		

Table 5-3 Summary Table for VT Facilities

VT FACILITIES	Design, MGD	ADF, MGD	lbs TN/day	lbs TN/year	Capital Cost, $	Cost/lb (10 yrs)	Cost/lb (20 yrs)
Ludlow	1.05	0.36	18	6,411	$214,780	$4.79	$3.14
Lyndonville	0.75	0.16	N/A	N/A	N/A	N/A	N/A
Springfield	2.40	0.97	74	27,106	$391,634	$4.57	$3.85
St. Johnsbury	1.60	1.00	N/A	N/A	N/A	N/A	N/A
Windsor	1.13	0.27	N/A	N/A	N/A	N/A	N/A
TOTAL	**6.93**	**2.76**	**92**	**33,517**	**$606,414**		

Table 5.0-4 shows the total estimated lbs/d, lbs/year and capital cost for the entire watershed. Table 5.0-5 shows the watershed these plants discharge to and Table 5.0-6 shows the cost and potential nitrogen removal by watershed. The majority of treatment plants discharge to the Connecticut River or its tributaries, so the load to that river shows the greatest reduction.

Table 5-4 Predicted TN Removal and Capital Cost

STATE	lbs TN/day	lbs TN/year	Capital Cost, $
MA	1,930	704,529	$3,252,492
NH	291	106,479	$877,332
VT	92	33,517	$606,414
TOTAL	**2,313**	**844,525**	**$4,736,238**

There were only two plants in the study discharging to the Housatonic River, but one of the treatment plants contributes almost 12 MGD to that river and any retrofits significantly impact the nitrogen load. There was only one plant in the study discharging into the Thames River watershed.

The results of this study show that with a relatively small capital investment, the nitrogen load to Long Island Sound can be reduced though process control adjustments and low cost retrofits.

Table 5-5 Facility by Watershed

FACILITY	RECEIVING WATER	RIVER
Athol, MA	Millers	Connecticut
Belchertown, MA	Lampson Brook	Connecticut
Claremont, NH	Sugar	Connecticut
Gardner, MA	Millers	Connecticut
Hanover, NH	Connecticut	Connecticut
Hinsdale, NH	Ashuelot	Connecticut
Littleton, NH	Ammonoosuc	Connecticut
Ludlow, VT	Black River	Connecticut
Palmer, MA	Chicopee	Connecticut
Lyndonville, VT	Passumpsic	Connecticut
South Hadley, MA	Connecticut	Connecticut
Spencer, MA	Cranberry Brook	Connecticut
Springfield, VT	Black River	Connecticut
St Johnsbury	Passumpsic	Connecticut
Warren, MA	Quaboag	Connecticut
Winchendon, MA	Millers	Connecticut
Windsor, VT	Connecticut	Connecticut
Great Barrington, MA	Housatonic	Housatonic
Pittsfield, MA	Housatonic	Housatonic
Webster, MA	French River	Thames

Table 5-6 TN Removal and Capital Cost by Watershed

WATERSHED	Design, MGD	ADF, MGD	lbs TN/day	lbs TN/year	Capital Cost, $
Connecticut River	36.15	16.17	1,146	418,177	$3,327,885
Housatonic River	20.2	13.0	917	334,965	$1,042,546
Thames River	6.00	2.99	250	91,383	$365,807
TOTAL	**62.35**	**32.18**	**2,313**	**844,525**	**$4,736,238**

6.0 Acknowledgements

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The Team is indebted to the treatment plant staff at each facility for their cooperation on this project. They supplied information on a timely basis, gave freely of their time to answer questions and to give plant tours.

7.0 References

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2. Mullaney, J.R., and Schwarz, G.E., 2013, Estimated nitrogen loads from selected tributaries in Connecticut draining to Long Island Sound, 1999–2009: U.S. Geological Survey Scientific Investigations Report 2013–5171, 65 p., http://dx.doi.org/10.3133/sir20135171. ISSN 2328–0328 (online)