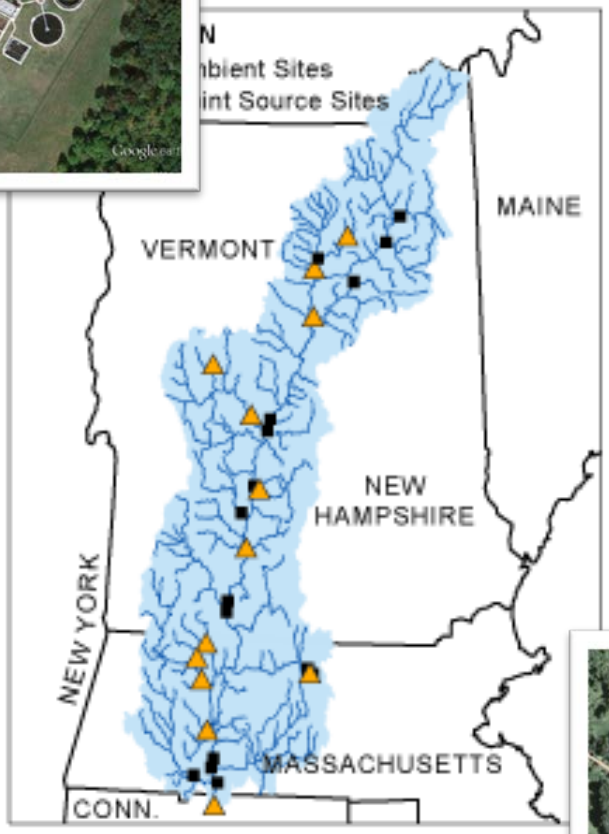
Technical Memorandum-Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the Upper Long Island Sound Watershed



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Prepared for NEIWPCC

First Draft: March 17, 2014
Final Draft: June 30, 2014
Final Memo: August 20, 2014

TECHNICAL MEMORANDUM- LOW COST RETROFITS FOR NITROGEN REMOVAL AT WASTEWATER TREATMENT PLANTS IN THE UPPER LONG ISLAND SOUND WATERSHED

1.0 INTRODUCTION

This technical memo is a summary of the work completed up to March 17, 2014 on the low cost nitrogen removal project. It includes a timeline of the project phases, the final list of plants for the initial study, a description of site visits and the special sampling program. Most important is the discussion on data analysis and the initial recommendation for the plants selected for further study. By definition for this project, the goal is to achieve effluent total nitrogen (TN) concentrations less than 10 mg/L year round at the lowest possible cost. At this point, no specific process modifications are recommended. Once BioWin modeling is finished on each of the selected plants, the type of modification can be then be identified. The types of modifications that would be considered in this project include addition of a recycle stream (either pumped or by gravity), creation of an anoxic zone coupled with a recycle stream, or cyclic aeration.

Timeline: The contract was approved and signed on January 29, 2013 and work was immediately started on the preparation and approval of the Quality Assurance and Project Plan (QAPP). In accordance with EPA grant requirements and the NEIWPCC Quality Management Plan, no data collection (primary or secondary) could occur until the QAPP was approved, including site visits. While waiting for approval, kick off meetings were held in June for plant personnel and the state agencies to ensure complete understanding of the project and what was expected from treatment plant personnel.

The QAPP was approved, signed and distributed on August 12, 2013. The first round of site visits began on August 20 and ended on October 25. During the site visit phase, various changes were made to the list of plants included in the study. The special sampling program began in September and ended in mid-November.

Data collected from the treatment plants and special sampling data were organized and then the analysis phase began. Using statistical analysis and an EXCEL based model, the initial determination was made on which plants would be included for further study (BioWin® Modeling and cost estimates). That phase ended with this technical memo.

Site Visits: All twenty-nine treatment plants were visited. The following occurred at each site visit:

- toured the treatment plant and discussed operating parameters and problems
- detailed explanation of the project to plant staff
- obtained various plant records and data, and
- ensured proper sampling technique and locations for the special sampling program.

Representatives from the state agencies were present at many of the site visits. Plant personnel were very cooperative helpful and very interested in the project, asking many questions and sharing their thoughts and ideas.

Treatment Facilities: At project start, there were 32 treatment plants included in the study (Table 1) of which four 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 four plants are highlighted in yellow in Table 1. 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 MassDEP staff, those four plants were included for the full study program.

Table 1 Original Facility List

Facility Name	State	Design Flow, MGD
Athol	MA	1.75
Belchertown	MA	1.00
Crane	MA	4.20
Easthampton*	MA	3.80
Erving #2	MA	2.70
Gardner	MA	5.00
Great Barrington	MA	3.20
Lee	MA	1.00
Lenox	MA	1.19
Montague	MA	1.83
Orange	MA	1.10
Palmer*	MA	5.60
Pittsfield	MA	17.00
South Hadley*	MA	4.20
Southbridge	MA	3.77
Spencer	MA	1.08
Templeton	MA	2.80
Ware*	MA	1.00
Warren	MA	1.50
Webster	MA	6.00
Winchendon	MA	1.10
Claremont WWTF	NH	3.89
Hanover WWTF	NH	2.30
Keene WWTF	NH	6.00
Lebanon WWTF	NH	3.18
Littleton WWTF	NH	1.50
Town of Randolph	VT	0.40
Town of Springfield	VT	2.20
Town of Windsor	VT	1.13
Town of St. Johnsbury	VT	1.60
Village of Ludlow	VT	1.05
Village of Lyndonville	VT	0.75

Additionally, some plants from the original list were deleted because they were in design or construction or they chose not to participate in the study. The final list for plants in Massachusetts is shown in Table 2 and plants in New Hampshire and Vermont in Table 3.

Special Sampling Program: Although some treatment plants had effluent nitrogen data, few had any influent nitrogen data. Furthermore, for modeling, parameters such as soluble chemical oxygen demand (SCOD), soluble Kjeldahl nitrogen (SKN) and influent alkalinity are necessary. NEIWPCC contracted with a laboratory (Chemserve) to process special samples.

The special sampling program included three consecutive days of sampling for each treatment plant, with plant personnel taking and preserving the samples according to instructions given to them during the site visits. The samples were transferred to a Chemserve courier, placed in a cooler and delivered to the laboratory. A chain of custody form was used for the sample transfer. Chemserve's program included testing for the following analytes: soluble COD, TKN, nitrate/nitrite (NO_3/NO_2), alkalinity, ammonia nitrogen, total suspended solids (TSS) and volatile suspended solids (VSS). The results of this special sampling program are being used, in part, for initial selection of plants for further study and will also be used in the BioWin® modeling step. At each treatment plant, three samples were taken of influent or primary effluent for six analytes (BOD_5, sCOD, NH_4-N, TKN, TSS/VSS and

Table 2 Final List of MA WWTPs to include in first round of site visits

Facility Name	State
Amherst	MA
Athol	MA
Belchertown	MA
Easthampton	MA
Gardner	MA
Great Barrington	MA
Lenox	MA
Montague	MA
Orange	MA
Palmer	MA
Pittsfield	MA
South Hadley	MA
Southbridge	MA
Spencer	MA
Ware	MA
Warren	MA
Webster	MA
Winchendon	MA

Alkalinity and three samples were taken of final effluent for five analytes (BOD_5, sCOD, NH_4-N, sKN and NO_x).

In determining whether a plant has the capability to remove nitrogen, it is important to understand what is entering the biological system, therefore, if the plant had primary clarifiers, primary effluent was sampled and if not the sample would be influent. Furthermore, the samples had to be taken after sidestreams entered the treatment plant. Sidestreams include digester supernatant, filtrate or centrate from thickening or dewatering operations, and any other discharge that would impact the biological process. During the site visits, the locations were identified to ensure samples would be representative and reflect the influent characteristics entering the biological system.

Table 3 Final List of NH and VT WWTPs to include in first round of

Facility Name	State
Claremont WWTF	NH
Hanover WWTF	NH
Hinsdale WWTF	NH
Keene WWTF	NH
Littleton WWTF	NH
Bellows Falls	VT
Town of Springfield	VT
Town of Windsor	VT
Town of St Johnsbury	VT
Village of Ludlow	VT
Village of Lyndonville	VT

2.0 DATA COLLECTION, ANALYSIS AND FACILITY SELECTION

Data Collection: During the 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 and locations of sidestreams. 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.

Data Analysis: 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 units such as bioreactors, clarifiers, and blower/aerators.

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 receiving flows a majority of the time 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 typical threshold for communities to limit future sewer connections. Other statistical analysis included determination of mean, standard deviation, linear regression and correlation for all important parameters such as flow, temperature, BOD, TSS and any nitrogen species.

Desk Top Model: In addition to the statistical 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, 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 which will be used for the next phase of the project for the selected plants. 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.

Basis for Facility Selection: In selecting plants for further study (BioWin modeling 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. The special sampling data were used to determine sCOD:TKN (C:N) ratio as well as the distribution of nitrogen in the effluent.

Table 4 Facility Selection for Further Study

Facility Name	TYPE	Q,DES	Q, AVG	SCOD:TKN*	EFF NH4-N, mg/L*	EFF NOx-N, mg/L*	EFF TN, mg/L*	FUTHER STUDY
Amherst Wastewater Pollution Control Facility	AS	7.1	4.3	5.0	15.3 (7.3)	4.7 (4.2)	20.2 (15.5)	No
Athol Wastewater Treatment Plant	AS	1.75	0.94	5.0	0.2	15.9	16	Yes
Belchertown Water Reclamation Facility	SBR	1.0	0.375	3.0	0.6 (0.3)	11.6 (7.9)	12.1 (9.1)	Yes
Easthampton Wastewater Treatment Plant	AS	3.8	1.4	5.0	4.5 (8.0)	13.4 (8.6)	25 (17.9)	No
Gardner Wastewater Treatment Plant	AS	5.0	3.1	2.0	0.16 (0.08)	24.5	25	Yes
Great Barrington Wastewater Treatment Facility	AS	3.2	1.1	4.3	0.18 (2.1)	19	19.5	Yes
Lenox Wastewater Pollution Control Plant	AS	1.18	0.6	5	1.1	5.7	7	No
Montague Wastewater Treatment Plant	AS	1.83	0.9	0.2	1.9	1.8	3.5	No
Orange Wastewater Treatment Pant	AS	1.10	1.06	3.3	0.9	5.1	6.7	Yes
Palmer Wastewater Treatment Facility	AS	5.6	1.5	4.2	1.5 (9.2)	5.1 (7.7)	7 (16.9)	Yes
Pittsfield Wastewater Treatment Plant	TF,AS	17.0	12	2.9	0.13 (0.11)	15.8 (12.5)	16.3 (12.6)	Yes
South Hadley Wastewater Treatment Plant	AS	4.2	2.66	2.7	8.8	11 (8.8)	22 (21)	Yes
Southbridge Wastewater Treatment Plant	AS	3.77	1.75	2.9	0.15	6.1	6.6	No
Spencer Wastewater Treatment Plant	AS	1.08	0.79	1.9	0.2	19.4	19.9	Yes
Ware Wastewater Treatment Plant	AS	1.0	0.63	4.5	0.17 (0.3)	16.9	17.4	No
Warren Wastewater Treatment Plant	RBC	1.5	0.312	3.5	0.6	18.4	19.4	Yes
Webster Wastewater Treatment Facility	AS	6.0	3.1	3.2	1.3	11.9	14.8 (15)	Yes
Winchendon Wastewater Pollution Control Facility	AS	1.1	0.548	6.5	0.2 (2)	17.5 (8)	18 (10)	Yes
Claremont WWTF	AS	3.89	1.7	18.4**	1.0 (0.4)	16.1	18.4	Yes
Hanover Wastewater Treatment Redamation Facility	AS	2.3	1.32	4.3	5.8	13	19.6	Yes
Hinsdale Wastewater Treatment Plant	OD	0.3	0.25	2.9	0.3(5.7)	7.4	7.9	Yes
Keene Wastewater Treatment Plant	AS	6.0	3.4	3.6	1.5	4.6	6.3	No
Littleton Wastewater Treatment Reclamation Facility	OD	1.5	0.75	3.2	0.2 (0.71)	10.8	11	Yes
Bellows Falls	RBC	1.4	0.53	2.8	19.3 (15)	8.9 (3)	29.6 (28.2)	No
Ludlow Wastewater Treatment Facility	OD	1.05	0.432	2.9	0.3	10.9	11.4	Yes
Lyndonville Wastewater Treatment Pant	AS	0.75	0.175	5.2	0.52	1.8	3.0	Yes
Springfield Wastewater Treatment Plant	AS	2.2	1.0	2.5	0.38	11.9 (10.9)	12.6 (12.2)	Yes
St. Johnsbury Wastewater Treatment Facility	RBC	1.6	1.0	4.7	1.0	6.4 (10.7)	8.9 (14.2)	Yes
Windsor	RBC	1.13	0.268	3.9	0.6	20.1	21.7	Yes
* Based Special Samples, however if plants had additional data, those date were also used and are shown in parenthesis								
** Unusually high value								

The C:N ratio is important since denitrification is performed by facultative heterotrophic organisms which use organic carbon as the electron donor. If there is insufficient readily biodegradable carbon available, these organisms will not function efficiently and denitrification will be minimal. If plants had additional nitrogen data this was used to verify and enhance the special sampling data. In addition, inflow and infiltration (I/I) and industrial discharges were also taken into consideration when making the selection. In general, if a plant had a sCOD:TKN ratio less than 4, had little or no nitrification, had significant industrial discharge to the plant which had an impact on plant operations, had a high level of inflow and infiltration (I/I), or had limited hydraulic or organic loading capacity, they were not selected for further study. However, in some cases plants that had lower sCOD:TKN ratios were selected because plant data and preliminary modeling indicated potential for nitrogen removal.

Also, if the plant was already achieving total annual effluent nitrogen concentrations of less than 10 mg/L, in many cases they were not selected since the assumption was made they were already doing low-cost nitrogen removal.

Table 4 is the list of plants selected for further study, some key data and selection status for future study. In the next section, there is a discussion on each facility describing why they were either selected or not selected. Each of the facilities selected appears to have sufficient accessibility of process units to make retrofits possible.

3.0 DETAILED FACILITY SELECTION INFORMATION

Amherst, MA: Amherst is a 7.1 MGD activated sludge plant with a current average of 4.2 MGD. The plant staff has been working to remove nitrogen over the past two to three years and has a significant amount of nitrogen monitoring data. Their goal is to reduce the mass loading of nitrogen leaving the plant to 547 lbs/day. The nitrogen data set spanned a period beginning April 18, 2012 to September 11, 2013. Since mid-April 2013 to September 2013, the plant has been consistently meeting this goal. Figure 1 is a comparison of effluent TN versus plant goal over a two year period and showing the increase in nitrogen removal from 2012 to 2013. This indicates that there has been considerable improvement removing nitrogen from the effluent from 2012 to 2013. This facility receives flow from the University of Massachusetts. Therefore, seasonal variation in flow is expected with high flows from September to mid-December and from Mid-January to mid-May.

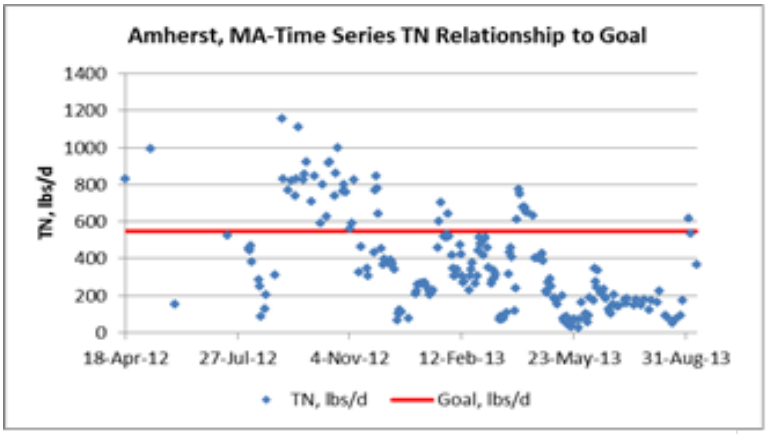

Figure 1 Time series graph showing relationship of effluent TN with goal

However, there is a potential to remove additional nitrogen. The plant is not fully nitrifying with a significant concentration of effluent ammonia ranging from an average of 7.3 mg/L from the Amherst data set to 15.3 mg/L from special sampling. Additionally, the plant has enough hydraulic capacity (about 80% of the time, the flow is less than 80% of design flow, Figure 2). Furthermore, the sCOD:TKN ratio of 5 indicates that there is sufficient carbon for denitrification. Output from the Excel model shows potential for increased nitrogen removal.

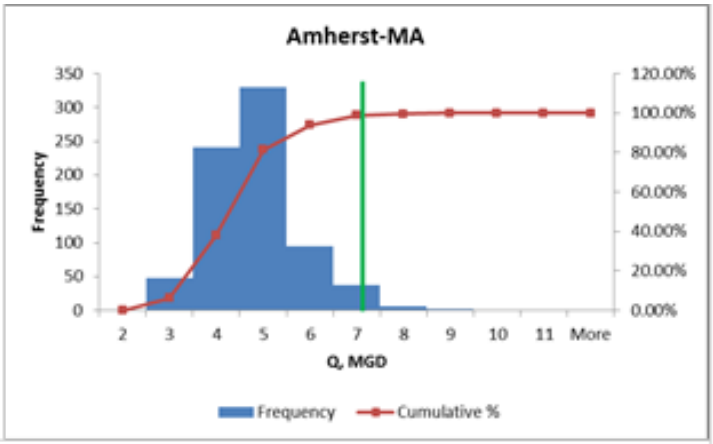

Figure 2 Amherst, MA-Flow Histogram

However, they are currently working independently on a project to optimize nitrogen removal and therefore, will not be included in this study.

Athol, MA: Athol is a 1.75 MGD activated sludge facility with a current average flow of 0.94 MGD. They do not monitor effluent nitrogen species in their influent or effluent. The average flow at the plant is about 54% of design flow. Furthermore, 89% of the time they are less than 80% of design flow so there is sufficient hydraulic capacity (Figure 3).

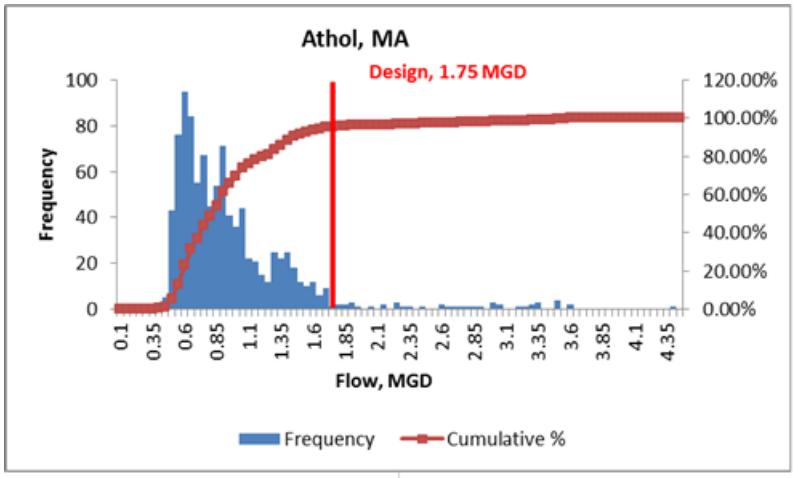

Figure 3 Athol, MA- Flow Histogram

Currently, the plant is completely nitrifying and has a sCOD:TKN ratio of 5:1 indicating sufficient carbon for denitrification. This means this plant has potential for a significant reduction in effluent nitrogen. The Excel model shows that there is sufficient aerobic and clarifier capacity. Based on these reasons, Athol has been selected for BioWin modeling and cost estimation of any low-cost improvements necessary for nitrogen removal.

Belchertown, MA: Belchertown Water Reclamation Facility is a 1.0 MGD sequencing batch reactor (SBR) plant with a current average daily flow of 0.375 MGD. An analysis of flow data for the past two years indicates that they never exceed 80% of design flow (Figure 4). There is no unusual seasonal variation in flow or organic load.

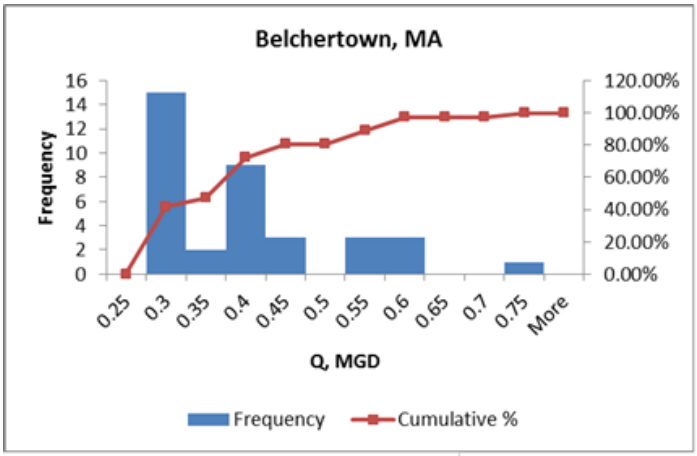

Figure 4 Belchertown, MA- Flow Histogram

The sCOD:TKN ratio is very low, 3.0 which is a concern. This indicates that there might not be enough carbon for denitrification. Plant data indicate that the plant is completely nitrifying with an average ammonia nitrogen concentration of 0.3 mg/L, a nitrate/nitrite (NOx) concentration of 7.9 mg/L and an effluent TN of 9.1 mg/L. The special samples confirmed that the plant is completely nitrifying. The average effluent ammonia concentration was 0.2 mg/L, NOx was 11.6 mg/L and TN was 12.1 mg/L. Additionally, the Excel model indicates that denitrification is possible given the current tank volumes and clarifier capacity. Therefore, even though the sCOD:TKN ratio is low, Belchertown is selected for BioWin modeling and cost estimates if modifications are recommended.

Bellows Falls, VT: The Bellows Falls Wastewater Treatment Plant is a 1.4 MGD rotating biological contactor (RBC) plant with a current average flow of 0.53 MGD. The VT DEC did some monitoring of effluent nitrogen species beginning in June 2012 to February 2013 to monitor influent and effluent nitrogen species at several treatment plants. The analytes tested included ammonia,

nitrate/nitrite and TKN. Bellows Falls was along those plants monitored so those data along with the special sampling data were used to determine the plant was a good candidate for further study. The plant is hydraulically under loaded with flows 99% of the time less than 80% design flow (Figure 5). There are no unusual seasonal variations in flow or organic load.

The sCOD:TKN ratio is very low, 2.8, which indicates insufficient carbon for denitrification. The plant only partially nitrifies with effluent ammonia concentrations averaging 15 mg/L based on plant testing and 19.3 mg/L based on special sampling program. Because of this, it is doubtful that any nitrogen removal beyond assimilation will occur.

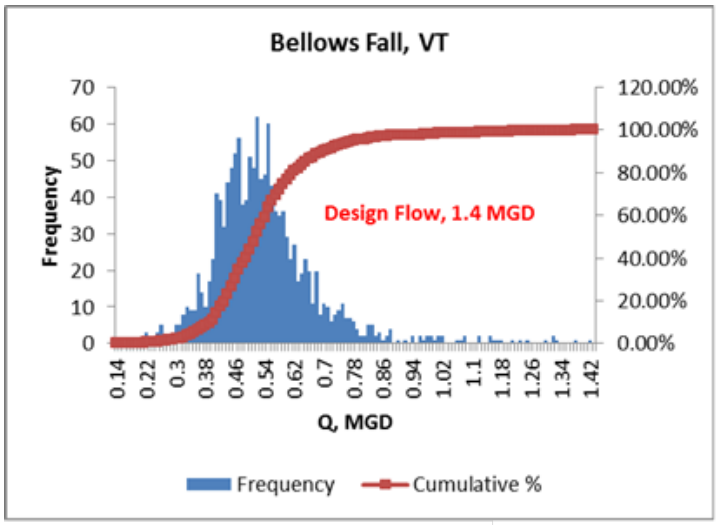

Figure 5 Bellows Falls, VT- Flow Histogram

Since neither the Excel model nor the BioWin model can be used for RBC plants, selection was made based on theoretical calculations, plant data and environmental conditions including temperature, hydraulic capacity and sCOD:TKN. Even though the plant has excess hydraulic capacity will not be considered for further study because the sCOD:TKN ratio is very low and the plant is not nitrifying,

Claremont, NH: The Claremont Wastewater Treatment Plant is an activated sludge plant with a design capacity of 3.89 MGD. It is currently treating an average flow of 1.4 MGD. Analysis of the flow data shows that 99% of the time the flow is less than 80% of the design flow (Figure 6). There is no unusual seasonal variation in flow or organic load. The plant has a significant amount of extra tankage including one primary clarifier, one secondary clarifier and two aeration tanks.

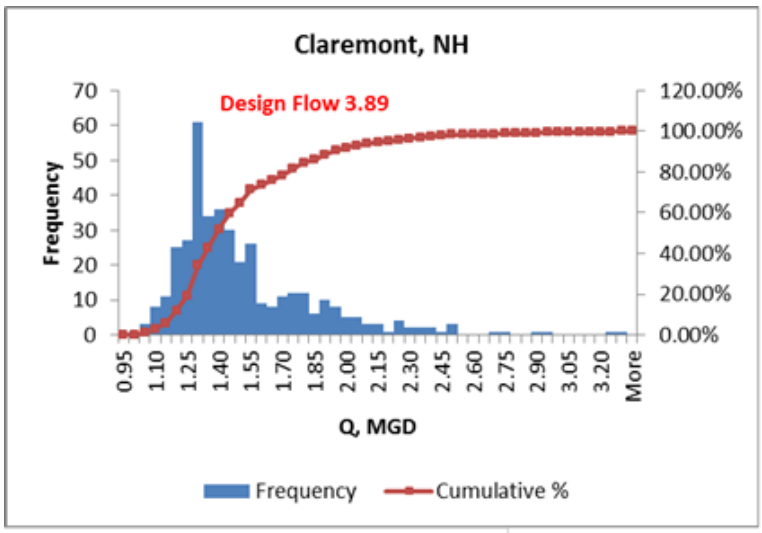

Figure 6 Claremont, NH- Flow Histogram

Based on the special sampling, the sCOD:TKN ratio averaged 18.4 which is unusually high. This can be explained by the extremely high influent sCOD concentrations which average 391 mg/L over the three-day sampling period . The plant achieves good nitrification; influent ammonia concentrations average 17 mg/L and effluent concentrations 0.4 mg/L. The Excel model indicates that denitrification can be achieved. Therefore, Claremont has been selected for BioWin modeling and cost estimates if modifications are recommended.

East Hampton, MA: Easthampton Wastewater Treatment Plant is a 3.8 MGD activated sludge facility with a current average daily flow of 1.7 MGD. Analysis of the flow shows that 94% of the time,

the flow is less than 80% of design (Figure 7). There does not appear to be any unusual seasonal variations in flows or loads.

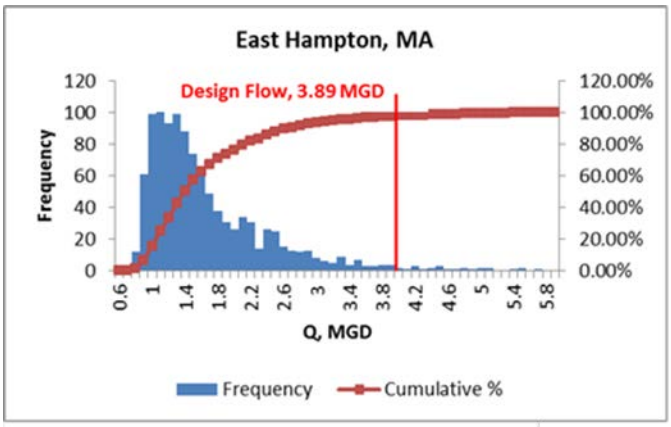

Figure 7 East Hampton, MA- Flow Histogram

Over the past year, the plant has been monitoring influent and effluent nitrogen species, ammonia, TKN and NOx. In evaluating those data it is obvious that there is significant variability in sustaining nitrification. Figure 10 is a graph of effluent ammonia and NOx for 2013. Effluent ammonia concentration varied from 1.1 to 18.0 mg/L, nitrate varied from 1.3 to 19 mg/L and TKN from 1.7 to 21 mg/L. It appears as if nitrification is very sensitive to temperature except for the August data point. For nitrogen removal, the nitrification process must be consistent and sustainable. Although the sCOD:TKN ratio is in the acceptable range, given the variability of nitrification, this plant was not selected for further study.

Gardner, MA: The Gardner Wastewater Treatment Plant is a 5 MGD trickling filter/activated sludge facility with a current average daily flow of 3.1 MGD. Analysis of the flow shows that 87% of the time, the flow is less than 80% of design (Figure 8). There does not appear to be any unusual variation in flows or loads.

The sCOD:TKN is very low so there is a concern that there might be insufficient carbon for denitrification. Gardner monitors effluent ammonia and TKN. The concentrations of both of those parameters are low; 0.08 and 0.15 mg/L respectively. It appears that the plant is completely nitrifying which is also supported by the special samples which showed low effluent concentrations of ammonia (0.16 mg/L), TKN (0.5 mg/L) and NOx (24.5 mg/L).

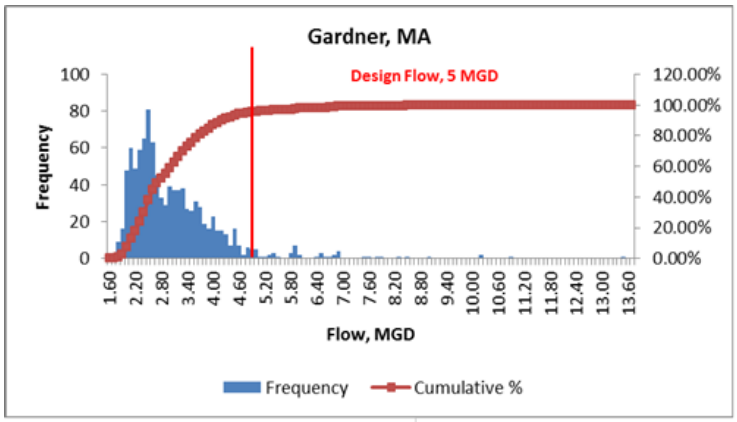

Figure 8 Gardner, MA- Flow Histogram

The output from the Excel model shows that there is enough plant capacity for nitrogen removal but carbon was limiting when using the sCOD:TKN ratio of 2. However, using plant BOD data, carbon was no longer limiting. Therefore, Gardner has been selected for BioWin modeling and cost estimates if modifications are recommended.

Great Barrington, MA: The Great Barrington Wastewater Treatment Plant is a 3.2 MGD activated sludge facility with a current average flow of 1.1 MGD. Analysis of the flow shows that 97% of the time, the flow is less than 80% of design (Figure 9).

The sCOD:TKN ratio is slightly low but should supply sufficient carbon for denitrification. The plant completely nitrifies. Effluent ammonia averages 2.1 mg/L based on the two-year data set and 0.18 mg/L with a NOx concentration of 19 mg/L based on the special samples.

Output from the Excel model indicates the potential for nitrogen removal. Therefore, Great Barrington has been selected for BioWin modeling and cost estimates if modifications are recommended.

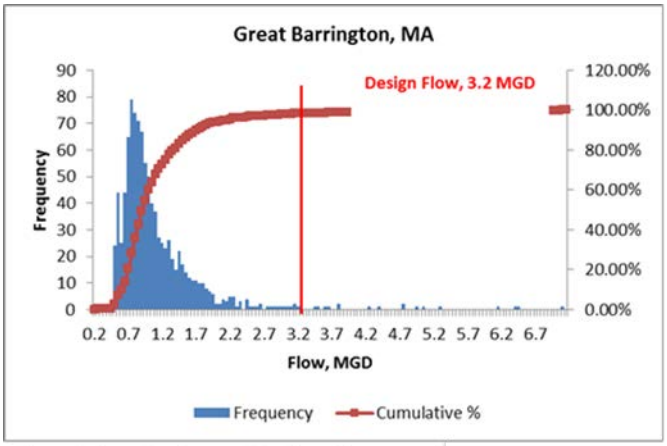

Figure 9 Great Barrington, MA- Flow Histogram

Hanover, NH: The Hanover Wastewater Reclamation Plant is a 2.3 MGD activated sludge facility with a current average flow of 1.32 MGD. Analysis of the flow shows that 93% of the time, the flow is less than 80% of design (Figure 10). Dartmouth College is located in Hanover. They are on a trimester basis so there is some seasonality in flows and loads but it did not appear to be significant.

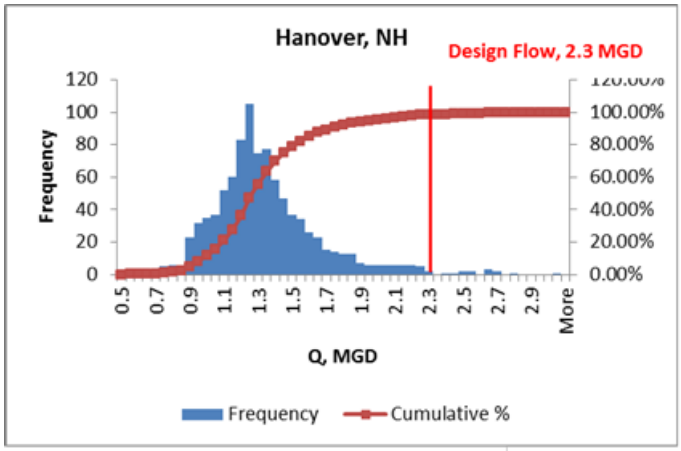

Figure 10 Hanover, NH- Flow Histogram

The sCOD:TKN ratio is slightly low but should supply sufficient carbon for denitrification. Based on the special samples, the plant appears to be partially nitrifying with an effluent ammonia concentration of 5.8 mg/L and NOx concentration of 6.6 mg/L. Output from the Excel model indicates the potential for nitrogen removal especially since they already have an anoxic selector. Therefore, Hanover has been selected for BioWin modeling and cost estimates if modifications are recommended.

Hinsdale, NH: The Hinsdale Wastewater Treatment Plant is a 0.3 MGD oxidation ditch facility with a current average flow of 0.25 MGD. Analysis of the flow shows that 58 % of the time, the flow is less than 80% of design (Figure 11).

The plant monitors effluent ammonia. Over a two-year period from June 2011 to July 2013, the average effluent ammonia concentration was 5.7 mg/L, however since November 2012; the average effluent ammonia concentration was 1.32 mg/L. Furthermore, the data obtained in the special sampling program showed not only complete nitrification but significant denitrification with an average effluent total nitrogen concentration of 7.9 mg/L.

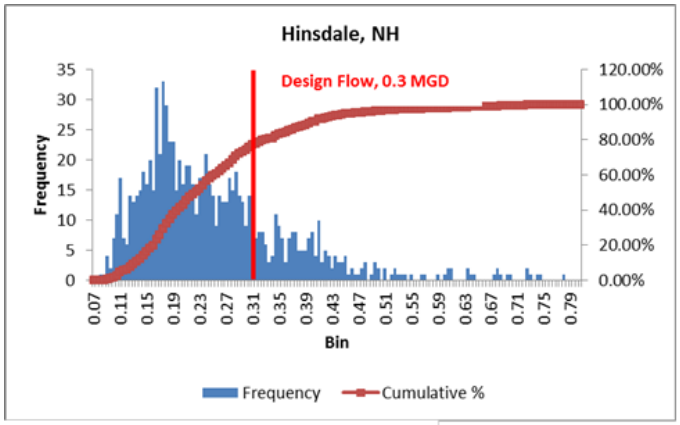

Figure 11 Hinsdale, NH- Flow Histogram

The sCOD to TKN ratio was low at 2.9 but there appears to be significant carbon available for denitrification based on the Excel model. Hinsdale is selected for BioWin modeling and cost estimates if modifications are recommended.

Keene, NH: The Keene Wastewater Treatment Plant is a 6.0 MGD activated sludge facility with a current average flow of 3.4 MGD. Analysis of the flow shows that 97 % of the time, the flow is less than 80% of design (Figure 12). There is no unusual seasonal variation in flow or organic load although there is a significant inflow and infiltration (I/I) problem.

The plant monitors effluent ammonia and they have in-line instrumentation including effluent nitrate analyzers. The effluent ammonia concentration based on the two year data set was 1.4 mg/L. The special sampling determined an effluent ammonia concentration of 1.5 mg/L, NOx concentration of 4.6 mg/L and total nitrogen of 6.3 mg/L. According to plant personnel, the effluent NOx concentration is about 5 to 6 mg/L based on the in-line effluent nitrate analyzer. Keene was not selected for further study because they are already achieving a high level of nitrogen removal.

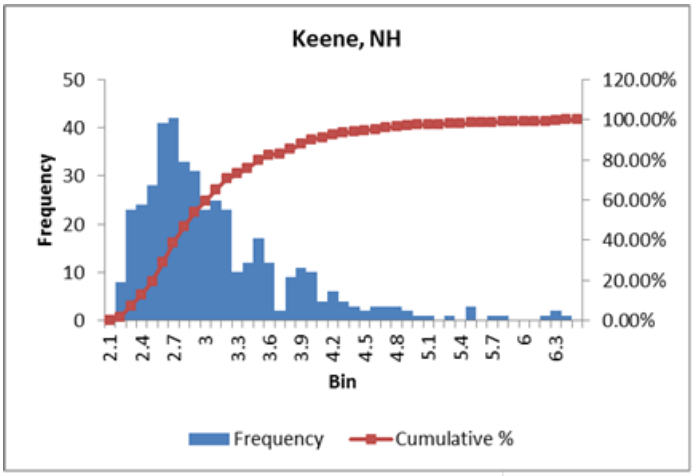

Figure 12 Keene, NH- Flow Histogram

Lenox, MA: The Lenox Wastewater Pollution Control Plant is a 1.18 MGD activated sludge facility with a current average flow of 0.6 MGD. There is no unusual seasonal variation in flow or organic load. The plant had some nitrogen data. That coupled with the results from the special sampling indicate that the plant is already removing nitrogen. The results from the special sampling showed an effluent ammonia concentration of 1.1 mg/L, a NOx concentration of 5.7 mg/L and an effluent total nitrogen concentration of 7 mg/L. Lenox was not selected for further study because it appears based on limited data that they are already achieving nitrogen removal.

Littleton, NH: The Littleton Wastewater Reclamation Plant is a 1.5 MGD oxidation ditch facility with a current average flow of 0.86 MGD. Analysis of the flow shows that 93 % of the time, the flow is less than 80% of design (Figure 13). There is no unusual seasonal variation in flow or organic load.

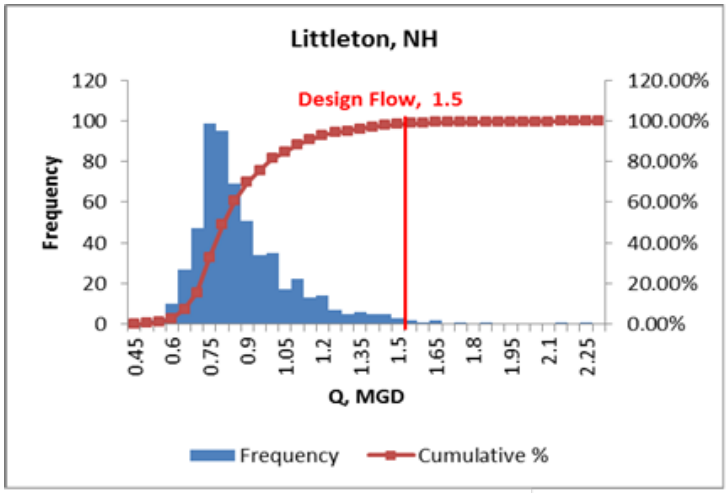

Figure 13 Littleton, NH- Flow Histogram

The sCOD:TKN ratio is low but should supply sufficient carbon for denitrification. Based on the special samples, the plant appears to be completely nitrifying with an effluent ammonia concentration of 0.2 mg/L, NOx concentration 10.8 mg/L and final effluent total nitrogen of 11 mg/L. They monitor effluent ammonia and the two-year average is 0.71 mg/L. Output from the Excel model indicates a high potential for nitrogen removal. Therefore, Littleton has been selected for BioWin modeling and cost estimates if modifications are recommended.

Ludlow, VT: The Ludlow Wastewater Treatment Plant is a 1.05 MGD oxidation ditch facility with a current average flow of 0.432 MGD. Analysis of the flow shows that 98.9 % of the time, the flow is less than 80% of design (Figure 14). There is no unusual seasonal variation in flow or organic load.

The sCOD:TKN ratio is low, 3.2, but may supply sufficient carbon for denitrification. Based on the special samples, the plant appears to be completely nitrifying with an effluent ammonia concentration of 0.3 mg/L, NOx concentration 10.9 mg/L and final effluent total nitrogen of 11.4 mg/L. The State of Vermont did special nitrogen testing from June, 2012 to February, 2013. The average results over that period showed an effluent TKN concentration of 1.6 mg/L, a NOx concentration of 7.8 mg/L and a final effluent TN concentration of 9.3 mg/L. The plant is already achieving a fairly high level of nitrogen removal. Output from the Excel model indicates the potential for significant nitrogen removal especially because there is an anoxic selector for each of the ditches. Therefore, Ludlow has been selected for BioWin modeling and cost estimates if modifications are recommended.

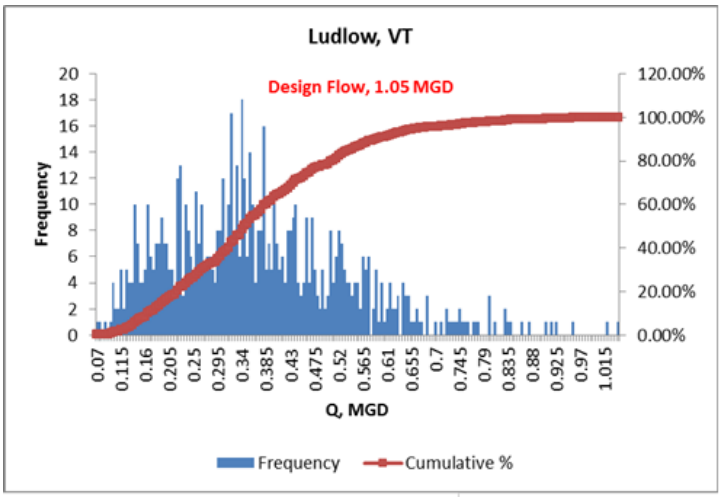

Figure 14 Ludlow, VT- Flow Histogram

Lyndonville, VT: The Lyndonville Wastewater Treatment Plant is a 0.75 MGD activated sludge (extended aeration) facility with a current average flow of 0.175 MGD. The plant was just recently upgraded. Analysis of the flow shows that 100 % of the time, the flow is less than 80% of design (Figure 15). There is no unusual seasonal variation in flow or organic load.

The sCOD:TKN ratio is 5.2 and should supply sufficient carbon for denitrification. Based on the special samples, the plant appears to be completely nitrifying with an effluent ammonia concentration of 0.52 mg/L, NOx concentration of 1.8 mg/L and a final effluent TN of 3 mg/L which indicates effective denitrification. The State of Vermont special nitrogen testing from June, 2012 to February, 2013 average results over that period of time showed an effluent TKN concentration of 3.8 mg/L, a NOx concentration of 14.8 mg/L and a final effluent TN concentration of 18.3 mg/L. Output from the Excel model shows promising nitrogen removal on a year round basis. Therefore, Lyndonville has been selected for further BioWin modeling and cost estimates if modifications are recommended.

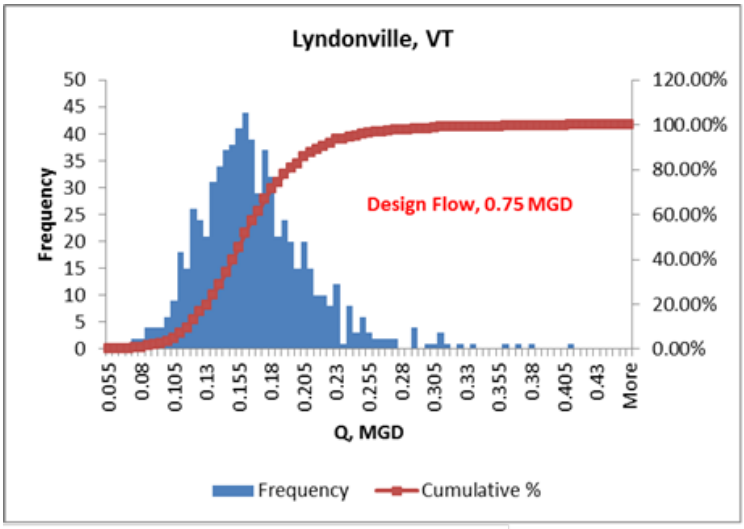

Figure 15 Lyndonville, VT- Flow Histogram

Montague, MA: The Montague Wastewater Treatment Plant is a 1.83 MGD activated sludge facility with a current average flow of 0.9 MGD. This is an unusual treatment plant with an average

influent BOD of 632 mg/L and a primary effluent BOD of 1185 mg/L. The data provided for 2012 (11 months) showed a 2012 average daily flow of 0.883 MGD with an influent BOD of 615 mg/L and a primary effluent BOD of 798 mg/L. The data for 2013 (four months) showed the flow increasing to an 2013 average of 1.026 MGD, an influent BOD of 798 mg/L and a primary effluent BOD of 2248 mg/L. The high primary effluent BOD may be due to recycle.

The sCOD:TKN ratio was 0.2 based on a sCOD of 70 mg/L and an influent TKN of 328 mg/L. They have been putting a great deal of effort into nitrogen removal. The three year average of nitrogen species shows an effluent NOx concentration of 0.6 mg/L, effluent TKN of 10 mg/L and an effluent TN of 10.3 mg/L. Montague was not selected for further study because it appears that they are already achieving 10 mg/L or less.

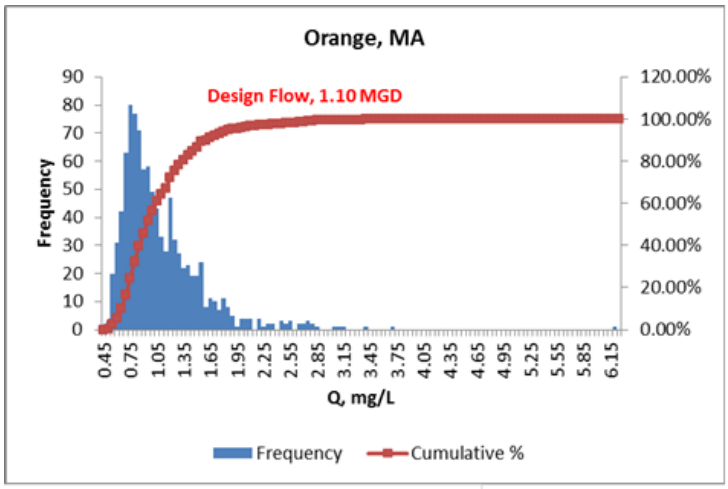

Figure 16 Orange, MA - Flow Histogram

Orange, MA: The Orange Wastewater Treatment Plant is a 1.1 MGD activated sludge facility with a current average flow of 1.06 MGD. Analysis of the flow shows that 43% of the time, the flow is less than 80% of design (Figure 16). The data obtained in the special sampling program not only showed complete nitrification but significant denitrification with an average effluent total nitrogen concentration of 6.7 mg/L. The sCOD to TKN ratio was low at 3.3 but there appears to be sufficient carbon available for denitrification based on the Excel model.

A review of additional nitrogen data indicates that Orange is already removing a significant amount of nitrogen most of the time. Since there are periods when effluent total nitrogen increases, Orange is selected for further study to identify the causes.

Palmer, MA: The Palmer Wastewater Treatment Plant is a 5.6 MGD activated sludge facility with a current average flow of 1.5 MGD. Analysis of the flow shows that 100 % of the time, the flow is less than 80% of design (Figure 17). There is no unusual seasonal variation in flow or organic load.

The sCOD:TKN ratio is slightly low at 4.2, but should supply sufficient carbon for denitrification. Based on the special samples, the plant appeared to be removing nitrogen with an effluent ammonia concentration of 1.5 mg/L, NOx concentration 5.1 mg/L and final effluent total nitrogen of 7 mg/L. However, other data indicate very little nitrification or nitrogen removal was occurring. There is very little data available; however, they have excess capacity and unused tankage.

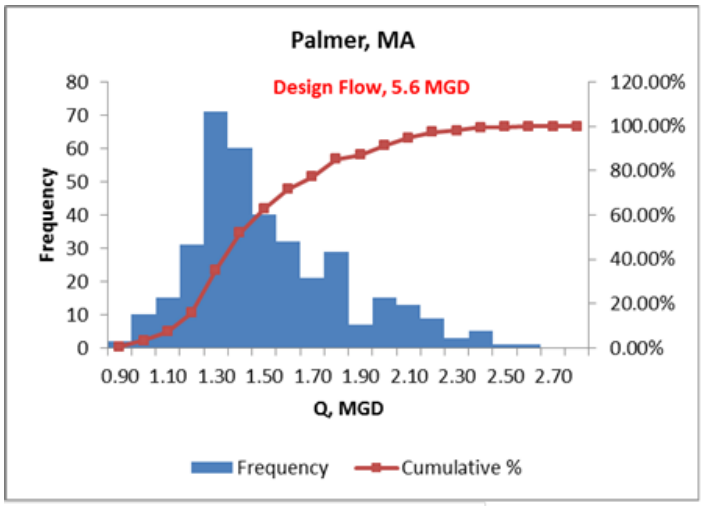

Figure 17 Palmer, MA - Flow Histogram

Output from the Excel model indicates the potential for significant nitrogen removal. Therefore, Palmer has been selected for BioWin modeling and cost estimates if modifications are recommended.

Pittsfield, MA: The Pittsfield Wastewater Treatment Plant is rated for 17 MGD. It currently has an average flow of 12 MGD. This is a very complex treatment plant; biofilm (trickling filters), intermediate settling tanks followed by activated sludge. The sCOD:TKN ratio is very low, 2.9, which probably means that a good portion of the readily biodegradable COD is removed in the trickling filters and may not be available for denitrification. Results from the special samples show an effluent ammonia concentration of 0.13 mg/L, NOx concentration 15.8 mg/L and final effluent total nitrogen of 16.3 mg/L. This indicates complete nitrification. Plant data are very similar with an effluent ammonia concentration of 0.11 mg/L, NOx concentration 12.5 mg/L and final effluent total nitrogen of 12.6 mg/L.

Output from the Excel model indicates little potential for significant nitrogen removal based on current operation. However, because Pittsfield is a large treatment plant and even a relatively small increase in TN removal may be significant, they have been selected for BioWin modeling and cost estimates if modifications are recommended.

South Hadley, MA: The South Hadley Wastewater Treatment Plant is a 4.2 MGD activated sludge facility with a current average flow of 2.7 MGD. Analysis of the flow shows that 83 % of the time, the flow is less than 80% of design (Figure 18). There is no unusual seasonal variation in flow or organic load. The sCOD:TKN ratio is very low; 2.7. Based on the special samples, there is limited nitrification. The effluent ammonia concentration was 11 mg/L, NOx concentration 10.6 mg/L and final effluent total nitrogen of 22 mg/L. The plant has made the commitment to do extensive monitoring of nitrogen species and other parameters critical to nitrogen removal. For the period from January 2013 to the end of September 2013, the average effluent ammonia concentration was 8.8 mg/L, NOx concentration 11 mg/L and final effluent total nitrogen of 21 mg/L. More recent data indicates that there has been some improvement in nitrification. Because of those results and the fact that they discharge directly to the Connecticut River, they are selected for BioWin modeling and cost estimates if modifications are recommended.

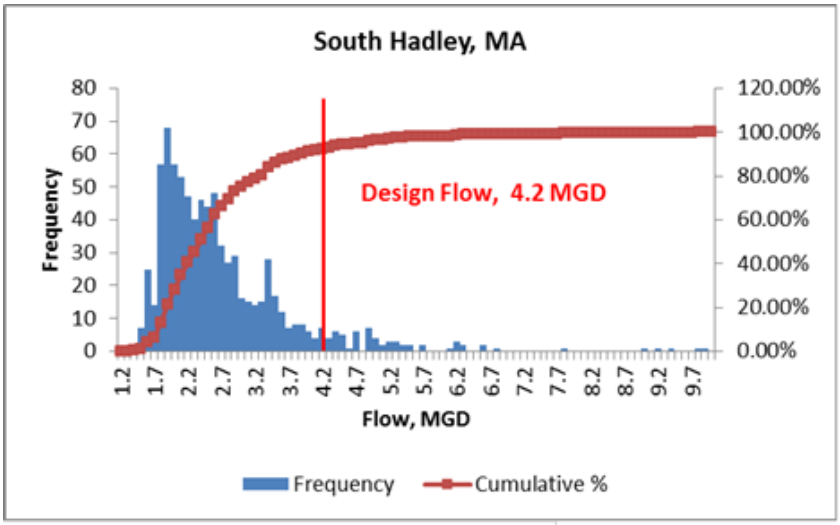

Figure 18 South Hadley, MA - Flow Histogram

Southbridge, MA: The Southbridge Wastewater Treatment Plant is rated for 3.77 MGD. It currently has an average flow of 2.29 MGD. This is a complex treatment plant; activated biofilter followed by activated sludge. The sCOD:TKN ratio is very low, 2.9, which probably means that a portion of the readily biodegradable COD is removed in the biotowers and may not be available for denitrification. Results from the special samples show an effluent ammonia concentration of 0.15

mg/L, NOx concentration 6.1 mg/L and final effluent total nitrogen of 6.6 mg/L. This indicates complete nitrification and very good denitrification. Some limited plant data are similar to these results with final effluent TN of less than 10 mg/L. Output from the Excel model indicates little potential for improvement on current operation primarily because of carbon limitation. Therefore, because of the low sCOD:TKN ratio, but also on the fact that they appear to be achieving TN less than 10 mg/L, Southbridge was not selected for further study.

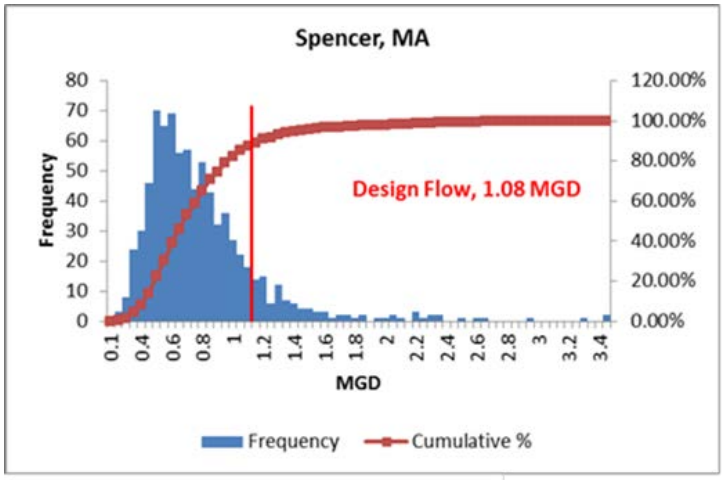

Figure 19 Spencer, MA - Flow Histogram

Spencer, MA: The Spencer Wastewater Treatment Plant is an activated sludge facility rated for 1.08 MGD. It currently has an average flow of 0.79 MGD. About 72% of the time, the flows are below 80% of the design flow (Figure 19).

The sCOD:TKN ratio is extremely low, 1.9. Results from the special samples show an effluent ammonia concentration of 0.2 mg/L, NOx concentration 19.4 mg/L and final effluent total nitrogen of 19.9 mg/L. This indicates complete nitrification but no denitrification. The plant monitors ammonia concentration and the plant consistently achieves effluent ammonia concentrations less than 0.5 mg/L.

Output from the Excel model indicates some potential for nitrogen removal. The BioWin model is more sophisticated and may give greater insight to nitrogen removal; therefore, Spencer is selected for BioWin modeling and cost estimates if modifications are recommended.

Springfield, VT: The Springfield Wastewater Treatment Plant is a 2.4 MGD activated sludge facility with a current average flow of 1.0 MGD. Analysis of the flow shows that 98 % of the time, the flow is less than 80% of design (Figure 20). There is no unusual seasonal variation in flow or organic load.

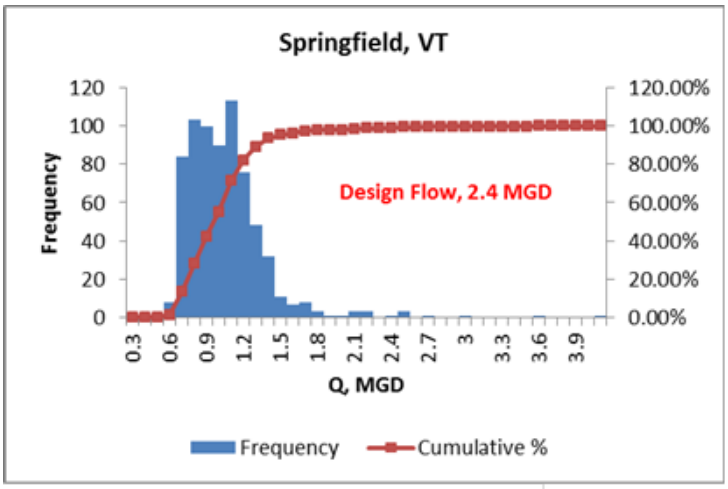

Figure 20 Springfield, VT - Flow Histogram

The sCOD:TKN ratio is 2.5 which is very low and may not supply sufficient carbon for denitrification. The results of the special samples show an effluent ammonia concentration of 0.38 mg/L, NOx concentration of 11.9 mg/L and a final effluent TN of 12.6 mg/L, indicating complete nitrification. The State of Vermont did special nitrogen testing from June, 2012 to February, 2013. The average results over that period showed an effluent TKN concentration of 1.7 mg/L, a NOx concentration of 10.9 mg/L and a final effluent TN concentration of 12.7 mg/L, also verifying substantial nitrification. This plant has substantial excess capacity and there is no concern with flows.

Output from the Excel model indicates the potential for some nitrogen removal. Therefore, Springfield has been selected for BioWin modeling and cost estimates if modifications are recommended.

St. Johnsbury, VT: The Saint Johnsbury Wastewater Treatment Plant is a 1.6 MGD RBC facility with a current average flow of 1.0 MGD. Analysis of the flow shows that 82 % of the time, the flow is less than 80% of design (Figure 21). There is no unusual seasonal variation in flow or organic load.

The sCOD:TKN ratio is 4.7 which should supply sufficient carbon for denitrification. The results of the special samples show an effluent ammonia concentration of 1.2 mg/L, NOx concentration of 6.4 mg/L and a final effluent TN of 8.9 mg/L, indicating complete nitrification. The State of Vermont did special nitrogen testing from June, 2012 to February, 2013. The average results over that period showed an effluent TKN concentration of 4.0 mg/L, a NOx concentration of 10.7 mg/L and a final effluent TN concentration of 14.2 mg/L, also verifying substantial nitrification. Neither the EXCEL nor BioWin model can be used for RBC processes. However, using theoretical calculations for biofilm systems, there appears to be a high potential for substantial nitrogen removal. Furthermore, JJE has experience with modifications to RBC processes which have resulted in nitrogen removal. Therefore, St. Johnsbury has been selected for additional analysis and cost estimates if modifications are recommended.

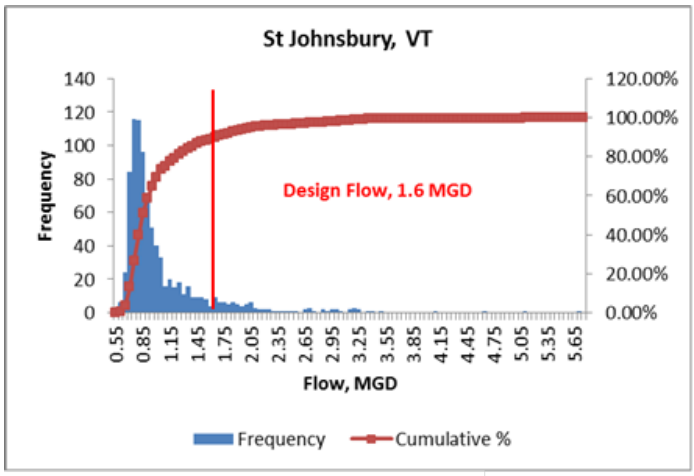

Figure 21 St Johnsbury, VT - Flow Histogram

Ware, MA: The Ware Wastewater Treatment Plant is a 1.0 MGD activated sludge facility with a current average flow of 0.63 MGD. Analysis of the flow shows that 86 % of the time, the flow is less than 80% of design (Figure 22). There is no unusual seasonal variation in flow but there is a significant industrial discharge.

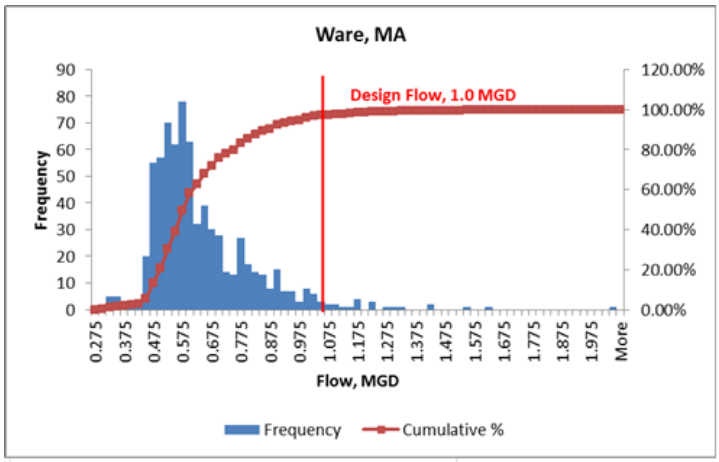

Figure 22 Ware, MA - Flow Histogram

The sCOD:TKN ratio is slightly low; 2.7. Based on the special samples, there appears to be complete nitrification. The effluent ammonia concentration was 0.17 mg/L, NOx concentration 16.9 mg/L and final effluent total nitrogen of 17.4 mg/L. The plant monitors ammonia and TKN. The average effluent ammonia concentration was 0.3 and the average effluent TKN was 1.2 mg/L which also confirmed complete nitrification. The major concern with this plant is the industrial discharge. Large amounts of solids (four feet thick) build up in the aerators and they have to be cleaned periodically. This reduces the effective volume of the tanks. The Excel model showed potential for nitrogen removal, but the buildup of solids cannot be modeled. Therefore, because of the industrial discharge, Ware has not been selected for further study.

Warren, MA: The Warren Wastewater Treatment Plant is a 1.5 MGD RBC facility with a current average flow of 0.312 MGD. Analysis of the flow shows that 100 % of the time, the flow is less than 80% of design (Figure 23). There is no unusual seasonal variation in flow or organic load.

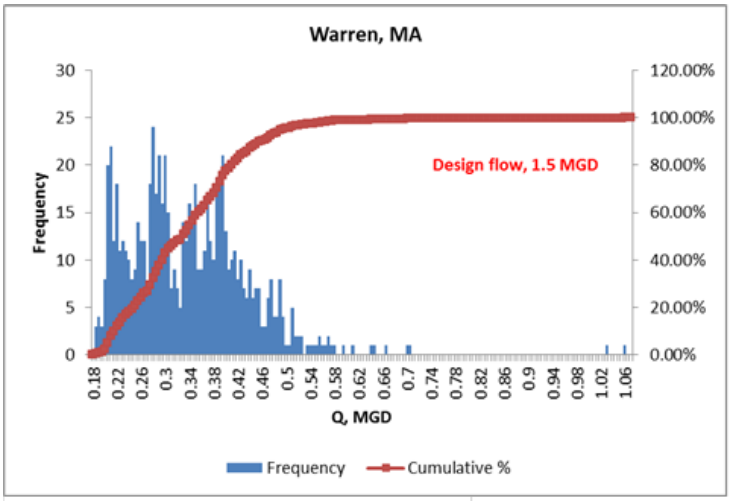

Figure 23 Warren, MA - Flow Histogram

The sCOD:TKN ratio is 3.5 which is low and may not supply sufficient carbon for denitrification. The results of the special samples show an effluent ammonia concentration of 0.6 mg/L, NOx concentration of 18.4 mg/L and a final effluent TN of 19.4 mg/L, indicating complete nitrification.

The model does not work for biofilm systems but using theoretical calculations, there is a potential for nitrogen removal since they are hydraulically under loaded and they appear to completely nitrify. Therefore, Warren has been selected for additional analysis and cost estimates if modifications are recommended.

Webster, MA: The Webster Wastewater Treatment Plant is a 6.0 MGD activated sludge facility with a current average flow of 3.1 MGD. Analysis of the flow shows that 95 % of the time, the flow is less than 80% of design (Figure 24). There is no unusual seasonal variation in flow or organic load.

The sCOD:TKN ratio is 3.2 which is low and may not supply sufficient carbon for denitrification. The results of the special samples show an effluent ammonia concentration of 1.3 mg/L, NOx concentration of 11.9 mg/L and a final effluent TN of 14.8 mg/L, indicating complete nitrification. The plant monitors TKN and nitrate. The average results show an effluent TKN concentration of 1.0 mg/L, and a final effluent nitrate concentration of 5.0 mg/L, verifying substantial nitrification. This plant has excess capacity and there is no concern with flows.

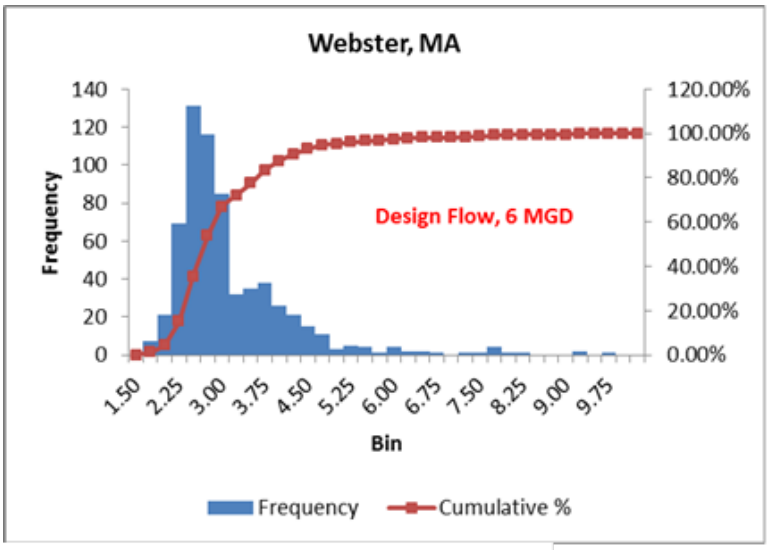

Figure 24 Webster, MA - Flow Histogram

Output from the Excel model indicates the potential for some nitrogen removal. Therefore, Webster has been selected for BioWin modeling and cost estimates if modifications are recommended.

Winchendon, MA: The Winchendon Wastewater Pollution Control Plant is a 1.1 MGD activated sludge facility with a current average flow of 0.548 MGD. Analysis of the flow shows that 92 % of the time, the flow is less than 80% of design (Figure 25).

The sCOD:TKN ratio is 6.5 which indicates sufficient carbon for denitrification. Based on the special samples, the plant appears to be completely nitrifying with an effluent ammonia concentration of 0.2 mg/L and NOx concentration of 17.5mg/L. The plant monitors effluent ammonia, TKN, nitrate and nitrite. Over the two year data set, the average effluent TN was 10 mg/L.

Output from the Excel model indicates the potential for additional nitrogen removal. Therefore, Winchendon has been selected for BioWin modeling and cost estimates if modifications are recommended.

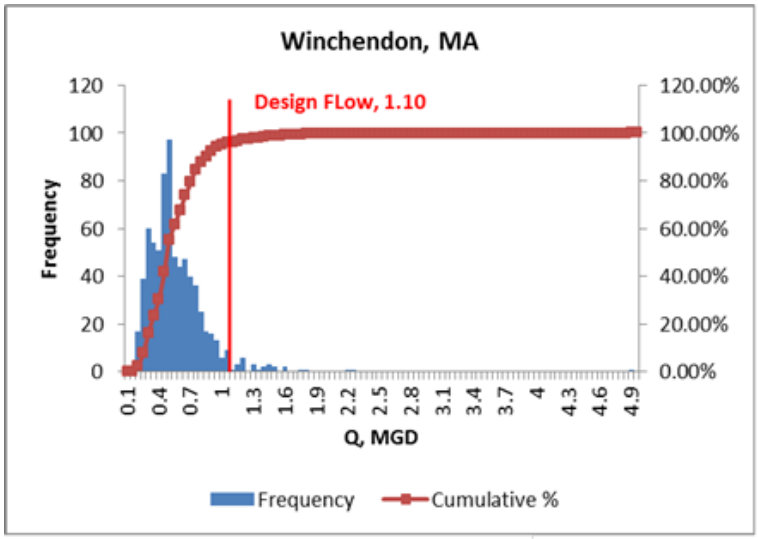

Figure 25 Winchendon, MA - Flow Histogram

Windsor, VT: The Windsor Wastewater Treatment Plant is a 1.13 MGD RBC facility with a current average flow of 0.268 MGD. Analysis of the flow shows that 86 % of the time, the flow is less than 80% of design (Figure 26). There is no unusual seasonal variation in flow or organic load.

The sCOD:TKN ratio is 3.9 which is low but may supply sufficient carbon for denitrification. The results of the special samples show an effluent ammonia concentration of 0.6 mg/L, NOx concentration of 20.1 mg/L and a final effluent TN of 21.7 mg/L, indicating complete nitrification. The State of Vermont did special nitrogen testing from June, 2012 to February, 2013. The average results over that period of time showed an effluent TKN concentration of 4.2 mg/L, a NOx concentration of 20.2 mg/L and a final effluent TN concentration of 24.4 mg/L, also verifying substantial nitrification. The model does not work for biofilm systems but using theoretical calculations, there is a potential for nitrogen removal at the plant. Therefore, Windsor has been selected for additional analysis and cost estimates if modifications are recommended.

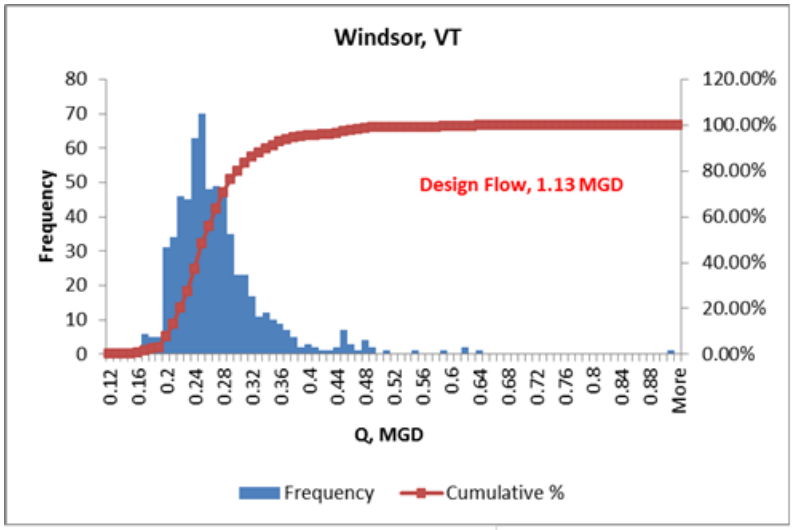

Figure 26 Windsor, VT - Flow Histogram

SECTION 4: CONCLUSIONS

The next phase of the project will be BioWin modeling of most of the selected plants, and further evaluation using empirical method for RBC plants selected for further study. Based on data analysis and preliminary modeling, twenty one of the original twenty nine plants have been selected; four in New Hampshire, five in Vermont and twelve in Massachusetts (Table 5).

It is important to note that some plants supplied a large amount of daily data and others supplied very little. Most had no influent nitrogen data and many had limited effluent nitrogen data which made decision making difficult.

Based on the results of the BioWin modeling and the type of modifications identified, the second round of site visits will be conducted to discuss those modifications with plant personnel to ensure they are in agreement and see no problems that might impact plant performance and compliance with existing permit requirements. Finally, cost estimates based on those modifications will be developed for each plant. Once those steps are completed, the final report will be drafted and submitted for review.

Table 5 Facilities for Further Study (BioWin Modeling or other) and Second Round of Site Visits

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
Orange Wastewater Treatment Facility	**MA**
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**

SECTION 5: ACKNOWLEDGEMENT

This project was funded by an agreement awarded by the Environmental Protection Agency to the New England Interstate Water Pollution Control Commission in partnership with the Long Island Sound Study.

Although the information in this document has been funded wholly or in part by the United States Environmental Protection agency under agreement GRANT # LI96144501 to NEIWPCC, it has not undergone the Agency's publications review process and therefore, may not necessarily reflect the views of the Agency and no official endorsement should be inferred. The viewpoints expressed here do not necessarily represent those of Long Island Sound Study, NEIWPCC, or EPA, nor does mention of trade names, commercial products, or causes constitute endorsement or recommendation for use.

Long Island Sound Study
A Partnership to Restore and Protect the Sound

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