# Section 2

# Quality Assurance Program

# SECTION 2 – QUALITY ASSURANCE PROGRAM

## 2.1 INTRODUCTION

This section of the report outlines the quality assurance (QA) program that was implemented to standardize the analysis of the twenty-one facilities that are a part of this study. The QA program consists of three main topics: Data Gathering, Evaluation and Modeling Procedures, and Cost Estimating.

The data gathering QA procedures consist of the manner in which data were requested for each facility and how the data were summarized and prepared for use. Summaries of all of the plant influent and effluent data are contained within this report. Summaries of the data collected at each facility are included in an appendix.

The evaluation and modeling QA procedures present a standard means of evaluating each of the facilities. It should be noted that these procedures were not developed to determine the most appropriate technology nor the most cost effective one for the individual facilities. They were developed to treat all facilities equally. Evaluation modeling procedures also cover the use of the data and how gaps in data were filled, specific modeling parameters, and considerations for achieving nitrogen removal at the facilities.

The cost estimating QA procedures outline the means by which capital costs and operation and maintenance costs were estimated for the purpose of this study. Included in these procedures are allowances for contingency and engineering.

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## 2.2 DATA COLLECTION PROCEDURES

The data collection procedures that were used for this study are detailed as follows.

A. **Data Gathering.** A site visit was conducted at each of the identified treatment facilities. During the visit, a meeting was conducted with the plant operations staff to review the current treatment process, obtain information on the current plant configuration and conditions, gather historical sampling data, and obtain existing operating costs.

Records of historical data were obtained for the period of January 2004 through December 2006. More detailed information about the historic data collected is contained in Section 2.2, D. Sampling Methods. A request form that details the type of information needed to complete this project was sent to each facility prior to the site visit. Refer to Appendix A for a sample data request form. In order to standardize the type of information gathered from each facility, an interview form was developed as a guide for each site visit. A sample interview form is also included in Appendix A. The completed interview forms are included in Appendix B.

Information (typically found on engineering drawings, specifications, and reports from previous construction and facility upgrades) about the treatment plant infrastructure was also gathered. This information was used to evaluate the potential upgrades to the plant to remove nitrogen. The following is an example of the type of information that was collected and how it was used.

**Table 2.2-1**

**PLANT DATA**

| OTHER PLANT DATA | USE OF DATA |
|---|---|
| Plant Site Plan | Verify sizes of existing process tanks and check available areas for new equipment or processes. |
| Plant Hydraulic Profile | Determine if additional pumping is required. |
| Engineering Specifications or Reports | Determine design criteria and design capacity of existing processes and equipment. Obtain process design schematic. |
| NPDES Permit | Determine current limits. |

B. **Data Evaluation.** Sampling data was collected in electronic or hard copy form depending on the available records from the treatment plants. The data was then imported into spreadsheets. The sampling data was from an instantaneous grab or composite sample. The sample frequency varied depending on the NPDES permit requirements.

The monthly average, seasonal average, maximum and minimum values were tabulated. The values for Biochemical Oxygen Demand (BOD) and nitrogen were compared to typical values for municipal wastewater. Municipal wastewater (without significant industrial discharges) is fairly uniform and changes only in relative strength. Some sewage collection systems experience infiltration of groundwater and inflow of storm water and therefore have a more dilute, low strength wastewater. Other systems have less dilution and a higher strength waste. The treatment plant sampling data were compared to *Wastewater Engineering: Treatment and Reuse*, Metcalf & Eddy, Fourth Edition 2003.

C. **Data Use.** Historic sampling data were used for the input for modeling work and as a basis for quantifying the amount of nitrogen that is currently discharged. Other information gathered at the plant was used to evaluate the needed process and equipment upgrades.

D. **Sampling Methods.** This project used existing sampling data collected by the individual treatment plants as part of their NPDES discharge monitoring requirements. The sampling procedures, sample analysis, and reporting is regulated by the NPDES permit.

E. **Data Review.** The existing data obtained were reviewed, and it was determined if sufficient data existed for evaluating each treatment plant. If it was determined that additional data was needed, the data was assumed in accordance with procedures developed in Section 2.3.

## 2.3 EVALUATION AND MODELING PROCEDURES

A. **Facility Upgrades for Nitrogen Removal.** The treatment plants were evaluated to determine the needed upgrades to meet the following nutrient removal goals:

1. Maximum achievable nitrogen reduction, seasonal or year round, resulting from operational and minor modifications/retrofits to the existing facility under existing flows. Such modifications would include changes to the operation of existing equipment and <u>not</u> installation of equipment or construction of tanks or walls. This work could be done either by plant

personnel or with a small purchase order (defined as one that would not require a public bid to complete). Examples of operational changes include operating aeration tanks in a series, operating at a higher solids retention time, and reducing the air input to portions of the tank to create anoxic conditions. An example of minor modifications/retrofits includes, the addition of timers to mechanical aerators to allow for cyclical aeration. No costs are associated with this goal since they are all assumed to be minimal.

2. At permitted capacity, meeting an effluent concentration of 8 mg/L total nitrogen seasonally (May – October) as a monthly average and as an annual average[1].

3. At permitted capacity, meeting an effluent concentration of 5 mg/L total nitrogen seasonally (May – October) as a monthly average and as an annual average[2].

Evaluations included developing capital and operational costs associated with the processes selected as discussed in further detail in Section 2.4.

B. **Data Analysis.** The historical influent sampling data were reviewed for quality and then used for the input for modeling or used with empirical methods. The influent concentration was used for modeling the plant at permitted capacity. Typically the plants were operating at less than their permitted flow. This means that even if the plant is currently nitrifying, it may not be able to at the higher permitted flow. A typical list of input data used for modeling is shown on the following page.

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[1] Due to the scope of the project, the annual average permit condition was modeled to meet a monthly limit of 8 mg/L. This yields a result that is conservative. See Section 2.3E for more information.
[2] Due to the scope of the project, the annual average permit condition was modeled to meet a monthly limit of 5 mg/L. This yields a result that is conservative. See Section 2.3E for more information.

**Table 2.3-1**

**TYPICAL MODEL INPUT PARAMETERS**

| PARAMETER | UNITS |
|---|---|
| Flow | mgd |
| $CBOD_5$ or $BOD_5$ | mg/L |
| Total Suspended Solids | mg/L |
| Total Kjeldahl Nitrogen | mg/L as N |
| Ammonia | mg/L as N |
| pH | -- |
| Temperature | Deg C |
| Alkalinity | mmol/L |

Data for modeling was taken from actual plant data unless recent flow and load data was available from a recent facility plan, plant upgrade, or other documents. In the event of a recent plant upgrade, the design loads for the upgrade were used. The reason for using design loads from a recent plant upgrade rather than actual plant data is because the time spent analyzing plant loads for an upgrade is presumed to be much greater than the time available for analyzing plant data for this study.

When actual plant data was utilized, maximum monthly loads were determined for the seasonal as well as the annual conditions. For modeling purposes, the design condition was defined by the maximum month BOD load and the minimum temperature. Maximum month Total Suspended Solids (TSS) loads were determined by using the three year ratio of this parameter to BOD. For this study, nitrogen data was typically scant. Thus a textbook Total Kjeldahl Nitrogen (TKN)/BOD ratio was applied to yield the design TKN when nitrogen data was not available. The textbook value of nitrogen was obtained from *Wastewater Engineering: Treatment and Reuse*, Metcalf & Eddy, Fourth Edition as follows: TN/BOD ratio of 0.18 for low strength wastewater (110 mg/L BOD) and medium strength wastewater (220 mg/L BOD) and 0.21 for high strength wastewater (400 mg/L) was applied to the influent BOD to determine a TN value for the facility. Nitrate and nitrite were assumed to be negligible.

The flow rate used for modeling purposes was determined by taking the flow rate during the month with the maximum month BOD load and then determining the future flow by multiplying that flow by the ratio of permitted (average) flow to current average flow. It should be noted that the flow rate at the maximum monthly loading condition is not necessarily the maximum monthly flow. The BOD concentration input for the model also was determined from the maximum month load.

If temperature data was not available, temperatures that are consistent with plants in the same region were used. For the Blackstone River basin, $8^0$C was assumed for the annual average TN goal and $11^0$C was assumed for the seasonal TN goal. For the Connecticut River basin and sub-basins, $8^0$C was assumed for the annual average TN goal and $14^0$C was assumed for the seasonal TN goal. Temperature data was available for the plants in Ten Mile River basins. These are low temperatures for the region based on data from other plants.

All data was checked for outliers. An outlier was defined as a data point that was greater than two standard deviations above the mean.

When recycle loads were not included in the plant data, estimates for this data were made through the modeling process.

C. **Facility Evaluations.** Except for plants with SBRs and trickling filters the primary processes for achieving the nitrogen goals are as follows per the scope of this project:

- 8 mg/L: MLE (or Bardenpho - if BioWin predicts that an MLE process is not capable of achieving this goal)
- 5 mg/L: Bardenpho process with methanol addition to the second anoxic zone

When these processes were inadequate due to site constraints or other similar issues, the following were considered on a site by site basis in the order listed:

- Fixed film media: shall be used to enhance the nitrification process. The process is referred to as Integrated Fixed Film Activated Sludge (IFAS) in the study;
- Denitrification Filters: shall be used to accomplish all nitrate removal or to supplement the denitrification process.

When none of the above processes could be implemented on the existing site, other technologies were explored. Some technologies that were considered include biological aerated filters (BAFs) and membrane bioreactors. For the purposes of this study, BAFs were utilized.

Plants with specialized processes such as SBRs or trickling filters were evaluated on a case by case basis utilizing the same general progression of available technologies.

D. **Evaluation Parameters.** An initial model for each plant was constructed using the existing influent and effluent BOD and nitrogen data, if available. This approach served to determine if the model satisfactorily predicted the operation of the existing plant and could therefore be used to predict performance of the upgraded plant. If the model results did not correspond with sampled results, further investigation into the treatment process and sampling process is necessary, and this is noted in the report.

The evaluation for potential upgrades considered typical design standards and empirical sizing criteria. Examples of this type of information is indicated in the table below. Target values are shown in the table in parentheses. These typical design criteria were used as guidance but not as an absolute. Engineering judgment was used to determine if straying from these guidelines slightly was practical in order to produce reasonable simulation results.

**Table 2.3-2**

**TYPICAL DESIGN CRITERIA**

| UNIT PROCESS | TYPICAL DESIGN VALUE | REFERENCE |
|---|---|---|
| MLE process | Anoxic HRT up to 6 hours<br>Aerobic HRT up to10 hours<br>Total HRT of up to 16 hours<br>Aerobic SRT of 6 to 12 days<br>MLSS of 2,000 to 4,000 mg/L (maximum of 4000)<br>Nitrate recycle rate of 100% to 300% (300%) | 1, 2 |

(continued)

**Table 2.3-2 ( continued)**

**TYPICAL DESIGN CRITERIA**

| UNIT PROCESS | TYPICAL DESIGN VALUE | REFERENCE |
|---|---|---|
| Bardenpho process | Primary anoxic HRT up to 6 hours<br>Primary aerobic HRT up to 10 hours<br>Secondary anoxic HRT up to 4 hours<br>Secondary aerobic HRT up to 2 hours<br>Total HRT up to 22 hours<br>Aerobic SRT of 8 to 16 days<br>MLSS of 2,000 to 4,000 mg/L (maximum of 4000)<br>Nitrate recycle rate of 100% to 300% (300%) | 1, 2 |
| Trickling Filters | Hydraulic loading (gpd/sf)<br>- Standard rate 25 – 90<br>- Intermediate rate 90-230<br>- High rate 230 -900<br>Organic loading (lb BOD/day/1,000 cf)<br>- Standard rate 5-25<br>- Intermediate rate 15-30<br>- High rate 25-300 | 1 |
| IFAS | Plastic media at a maximum fill volume of 67% | 3 |
| Denitrification Filters | Upflow-type – by Degrémont Technologies - Infilco<br>(8-16 gpm/sq ft hydraulic loading rate) | 4 |

**References**

1. *Guides for the Design of Wastewater Treatment Works* (TR-16), New England Interstate Water Pollution Control Commission,
2. *Wastewater Engineering Treatment and Reuse*, Metcalf & Eddy, Fourth Edition 2003
3. Based on *Hydroxyl Media,* as sold by Degrémont Technologies – Infilco
4. Based on equipment manufactured by Degrémont Technologies – Infilco

1. **Other Evaluation Parameters.** Other design/evaluation criteria included those for secondary clarification, effluent filtration, and the application of other technologies for space limited sites.

a. **Secondary Clarifiers.** In order to achieve the proposed nitrogen limits within the existing site limitations, the mixed liquor suspended solids (MLSS) in the aeration tanks often will be higher than the MLSS currently being maintained at each facility. The higher concentration will help provide a higher solids retention time in a smaller volume. The effects of the higher suspended solids concentration must be considered in relation to secondary clarifier performance.

Existing clarifiers at each suspended solids activated sludge facility were evaluated using a solids flux analysis. Daigger's (1995) relationship for unstirred SVI and an SVI of 150 were used to determine the Vesilind settling constants. The overflow rate was based on maximum day flow times a safety factor of 1.3. Maximum-day peaking factors were determined if sufficient data for flow was available. Otherwise, a peaking factor of 1.7-1.8 was used for separate collection systems and 2.2-2.5 for combined systems. New clarifiers were added in full-tank increments based on the existing tank sizes.

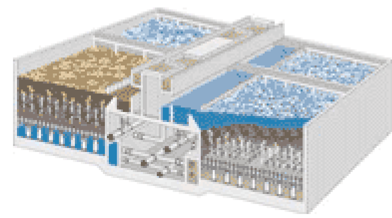
The clarifiers were also compared with the TR-16 recommendation for depth at nitrogen removal facilities. The recommended minimum depth is 13 feet. For the purpose of this study, any clarifiers that were less than 10 feet deep were recommended for replacement. Clarifiers with depths of 10 to 13 feet will require further evaluation regarding their ability to perform effectively over the long term without being derated. Clarifier performance is a very important aspect of nitrogen removal especially when trying to meet an effluent TN of 5 mg/L. Careful consideration should be given to the performance of the shallow clarifiers when facilities are further evaluated.

Trickling filter plants were evaluated based on maintaining an overflow rate of less than 1,200 gpd/ft$^2$ at peak hour flow per the TR-16 Guidelines.

b. **Denitrification Filters.** There are many types of denitrification filters available including both downflow and upflow-type reactors. For the purpose of this study, the upflow denitrification filter by Degrémont Technologies – Infilco was considered. The upflow filter can be loaded hydraulically at higher rates than the downflow filters and would thus also have the benefit of a smaller footprint which is why the upflow filters were selected.

These tanks require backwashing and thus require a clearwell and a backwash water tank. Sizing for each filter package was provided by Degrémont Technologies – Infilco based on the BIOFOR™ system. The supplier sizing is such that BIOFOR cells will handle all the hydraulic, ammonia, nitrate, BOD and TSS loads with one cell under a backwash cycle. For the purpose of this study, the assumed bed depth of the denitrification cells is 20 ft.

c. **Biological Aerated Filters.** For facilities that are very space limited or have specialized processes, other technologies needed to be considered. As stated previously, biological aerated filters (BAFs) were considered for this study rather than membranes. BAFs by Degrémont Technologies – Infilco were sized by the manufacturer on a plant by plant basis. The BIOFOR™ BAF is a high-rate, up-flow biological fixed-film system. It employs a dense media that acts as a biological contactor as well as a filter, thus secondary clarifiers are not required.



These tanks require backwashing and thus require a clearwell and a backwash water tank. The supplier sizing is such that BIOFOR cells will handle all the hydraulic, ammonia, nitrate, BOD and TSS loads with one cell under a backwash cycle. For the purpose of this study, the assumed bed depth of the denitrification cells is 23.5 feet.

E. **Modeling.** The potential plant modifications and upgrades were evaluated based on modeling and the use of standard design values. The BioWin Version 3 simulation package by EnviroSim was used for modeling. Within the BioWin software are a series of chemical and biological models used to simulate the processes that occur at a wastewater treatment plant.

Modeling and analyses of the biological processes are most effective when secondary influent data is used. This is especially true when plant internal recycle loads (filtrate, supernatant, etc) that are typically not measured separately are introduced after influent sampling points. Recycle loads were included in the analysis according to the following:

- When influent sampling included plant recycle loads, plant model was based on sampled influent loads (include primary clarifiers in the model if they exist at the facility). TSS removal percentages that closely match calculated removal percentages for primary clarifiers were used in the model
- When primary effluent sampling included recycle loads, plant model was based on primary effluent loads so primary clarifiers were not modeled.

- When recycle loads were not included in any sampling, sidestreams were modeled.

It was assumed that the percent removal of particulate TKN is the same as the percent removal of TSS in the primary treatment process in order to calculate primary effluent TKN loads when primary clarifiers were not modeled.

Default BioWin model parameters were used in all instances except where specific data is otherwise available to allow these to be adjusted. One parameter that was adjusted if data was available was the Fna parameter (fraction of influent TKN which is ammonia). The default for Fna is 0.75, but this ratio varies from plant to plant. A COD/$BOD_5$ ratio of 2.0, the default in BioWin, was assumed unless otherwise known. If the COD/BOD ratio is out of the ordinary, it is noted in the report. Although the accuracy of the models could have been improved by collecting nitrification and denitrification rate data, this analysis can be very time consuming and costly and was not justified for this study.

For modeling purposes, it was assumed that alkalinity was not a limiting factor at the facilities, but the alkalinity consumption was factored into the cost analysis (see Section 2.4).

The ideal clarifier model was used in the simulation. Please refer back to Section 2.3.D for more information regarding clarifier evaluation criteria.

All modeling was done based on steady state. Steady state models were run as follows for the following conditions:

**Seasonal**: Minimum monthly temperature and maximum month loading conditions for the May-October period over the three year period. This was modeled to achieve a monthly limit.

**Annual Average**: Minimum monthly temperature and maximum month loading conditions over the three year period. Due to the scope of the project, this permit condition was also modeled to achieve a monthly limit which yields a conservative result for the annual average condition.

For seasonal limits, the modeling assumed that the plant may lose nitrification when the permit is not in effect (i.e. it is assumed that there will be no year-round ammonia limit).

In the modeling process, one zone (single tank) was used for each of the following: first anoxic zone, aerobic zone, second anoxic zone, and reaeration zone - unless the arrangement of the existing tanks dictated a different approach.

As nitrification is the limiting biological process, an aerobic SRT was determined that will achieve adequate nitrification at minimum temperatures. This was done by using conventional hand calculations based on the WERF "Methods of Wastewater Characterization in Activated Sludge" 2003 method:

$$SRT = \frac{SF}{\mu_{\max}\left(\frac{DO}{1+DO}\right)\left(\Theta_{\mu_{\max}}\right)^{(T-15)} - k_d\left(\Theta_{k_d}\right)^{(T-15)}}$$

where

| | |
|---|---|
| $\mu_{\max}$ | = 0.9 (at 15 C) |
| DO | = 2.0 |
| $\Theta_{\mu_{\max}}$ | = 1.072 |
| $k_d$ | = 0.17 (at 15 C) |
| $\Theta_{k_d}$ | = 1.029 |
| SF | = 2.5 |
| T | = minimum monthly temperature |

Once the aerobic SRT was selected, the aerobic basin size was adjusted in full tank increments to achieve an MLSS concentration that fell within the design criteria and enabled the increased tank volume to fit within the site constraints of each facility. Anoxic volumes and nitrate recycle were adjusted within the design criteria to provide the desired effluent limits. If the required volume was too large to meet site constraints, an IFAS system was added to the aerobic zone in order to decrease its size. The IFAS system enables a higher solids concentration to be carried in a smaller volume without negatively impacting clarifier performance.

Plants requiring BAF technology were not modeled in BioWin except to determine the requirements for conventional technologies.

F. **Special Training and Certification.** The data used in this project did not require any formal certification to use or evaluate. However, the people performing the modeling all completed training by EnviroSim on the proper application and use of the BioWin model.

G. **Verification and Validation Methods.** The modeling results were compared to typical design and operating values for each proposed unit process such as in the examples given below.

**Table 2.3-3**
**ANTICIPATED PERFORMANCE**

| UNIT PROCESS | TYPICAL PERFORMANCE | REFERENCE |
|---|---|---|
| SBRs, MLE process | Effluent TN of 8 to 10 mg/L | 1 |
| Bardenpho process | Effluent TN of 4 to 6 mg/L | 1 |
| SBRs, nitrification only tanks, or MLE configuration tanks all with denitrification filters | Effluent TN of 4 to 6 mg/L | 1, 2 |
| Trickling filters with denitrification Filters | Effluent TN of 4 to 6 mg/L | 2 |

**References:**

1. *Guides for the Design of Wastewater Treatment Works* (TR-16), New England Interstate Water Pollution Control Commission
2. *Wastewater Engineering: Treatment and Reuse*, Metcalf & Eddy, Fourth Edition 2003

H. **Reconciliation with Use Requirements.** The proposed alternatives for each facility were reviewed at internal quality review meetings to determine if the selected alternatives are consistent with current operating practices in the industry.

The following is the evaluation criteria utilized:

1. Can this process be readily constructed at this site?
2. Does this process achieve the nitrogen removal goals?

## 2.4 COST ESTIMATING PROCEDURES

A. **General Cost Estimating Information.** Conceptual-level cost estimates were developed for each of the 21 facilities included in this study. There are at least four estimates for each facility in order to compare costs for meeting the four different permit requirements for nitrogen removal. One additional cost was developed for facilities at which the MLE process was not effective at meeting a total nitrogen limit of 8 mg/L. This cost was estimated to demonstrate the difference in cost between an MLE process and a Bardenpho process since it is not possible to rule out MLE as a treatment alternative based on uncalibrated models with limited influent nitrogen data. It was assumed that the MLE would reduce the required volume by the size of the second anoxic zone and reaeration zone.

Costs represent an order-of-magnitude cost for the process alternative which met the process selection criteria identified in Section 2.3 and the proposed effluent limits at the facility's permitted capacity. As such, costs presented do not purport to represent the results of detailed analyses which compare various alternatives and select the most appropriate and/or most cost-effective solution.

In addition, the costs represent the incremental costs associated with the nitrogen removal facilities. It is likely that the costs developed herein are lower than actual project costs since the scope of this cost estimating effort is limited to improvements directly related to achieving lower nitrogen effluent limits. The actual project costs likely would be higher since the typical design life of a wastewater treatment facility is 20 years, and a good number of the facilities evaluated have exceeded their original design life without major improvements having been made. The upgrades made for nitrogen removal would likely be coupled with improvements to various other unit processes. Identifying such required improvements was not a part of this scope; they would be identified during the planning stages of a plant upgrade project.

Lastly, costs are based on treating the facility's permitted capacity. In some cases, the permitted capacity exceeds the expected 20-year design flow and as such nitrogen removal could be achieved with less tankage.

An Engineering News Record (ENR) construction cost index of 8092[3] was used as the datum for developing construction costs. The accuracy associated with the cost estimates is considered to be +50/-30 percent.

B. **Capital Cost Methodology.** The costs are being developed on a site-specific basis and include both component costs and non-component costs. Both are explained in detail as follows.

[3] Use of the Boston area ENR index would yield slightly higher results since local inflation factors are dampened in the national index. For the purposes of this report, it was decided that the national ENR index was adequate.

1. **Component Costs.** Each component was handled in a different fashion to come up with the most accurate cost estimates within the limits of the study's scope. Costs for each individual item are totaled to determine the total component cost. The components that were addressed are listed below:

- Aeration Tanks
- Blowers
- Clarifiers
- Intermediate Pump Stations
- Methanol Storage and Feed Facility
- Sequencing Batch Reactors
- Nitrification Filters
- Denitrification Filters
- Integrated Fixed Film/Activated Sludge (IFAS) systems
- Compensatory Storage

Costs for aeration tanks, blowers, clarifiers, intermediate pump stations and methanol storage and feed facilities are based on cost estimates from previous projects. At least two costs for each component were brought up to current ENR; these costs include a 20% allowance for contractor overhead and profit. The costs are based on system capacity so intermediate values can be extrapolated. Aeration tank, clarifier, and methanol costs are based on total volume; blower and pump station facilities are based on permitted flow of the facility for which they were designed. The costs for each component used in the analyses are included in Appendix C. When the volume required for new process units or the permitted flow rate for a facility does not match a component capacity exactly, the 0.6 rule[4] (shown below) was applied to determine the costs.

$$Cost_A = \left(\frac{Capacity_A}{Capacity_B}\right)^{0.6} Cost_B$$

Conceptual design layouts, which would include sizing equipment and details of structural modifications, were not developed for this level of a study; therefore, component costs were based on combining individual pieces of the design into larger components when possible. For example, two different types of aeration tanks were considered: retrofit and new. Both costs include mixers, diffusers and nitrate recycle pumps in addition to the structural work required.

[4] The "0.6 rule" is an approximation of a cost curve.

New tanks include excavation and other site work costs as well. For the purpose of this study, no cost difference is assumed between an MLE and a Bardenpho tank of equal volume. Clarifier costs include concrete and mechanical equipment. Blowers and intermediate pump station costs include equipment as well as structures; while methanol feed facilities include storage and feed equipment.

Costs for the sequencing batch reactors, nitrification filters, denitrification filters, and IFAS systems were provided on a site-specific basis by suppliers. Installation costs were then estimated, and 20% for contractor overhead and profit was applied to determine the total cost for each process unit. It is assumed that nitrification and denitrification filters are enclosed in a masonry structure. Specific unit costs were assumed in order to complete the cost estimates:

(1) Installed concrete for base slab - $450/cubic yard
(2) Installed concrete for tank walls - $750/cubic yard
(3) Sheeting (as required) - $45/square foot
(4) Excavation (including backfill and hauling) - $25/cubic yard
(5) Building enclosure cost - $160/square foot

The sequencing batch reactor (SBR) costs were provided by Siemens based on their Omniflo® system or Aqua-Aerobic System, Inc. depending upon the existing SBRs at the plant. The costs include diffusers, pumps, mixers, valves, supports, control panel and other ancillary items including manufacturer field services. The nitrification and denitrification filter costs were provided by Degrémont Technologies – Infilco. The costs include media, support gravel, underdrain system, air piping, diffusers and blowers (for nitrification filters only), pumps, valves, control system and other ancillary items including manufacturer field services. The IFAS costs also were provided by Degrémont and are based on the METEOR® technology by Hydroxyl Systems, Inc. The manufacturer costs include the media, media retention screens, and manufacturer field services. The amount of media required was determined using the BioWin models and was provided to the manufacturer for pricing.

For plants located in floodplains, or flood ways, the compensatory storage cost for new wetlands is based on a $17 per square foot estimate. The storage area was determined from the amount of open space required to construct the necessary nitrogen removal facilities. Twenty percent for contractor overhead and profit was applied to determine total cost. All facilities will be located within the existing treatment site property lines so no cost for land purchase is included.

2. **Non-Component Costs.** An allowance was made for miscellaneous non-component items which typically cannot be determined until the final design stage of the project. These allowances were used to escalate the project cost, as appropriate, after the component costs for each alternative were estimated.

Non-component items include yard piping, electrical, instrumentation and controls, and site work (including demolition) as shown in Table 2.4-1. The non-component costs also include an allowance for more difficult soil conditions for which piles would be required or removal of rock ledge would be required. An allowance for retrofit work was also included to adjust for work being done on existing sites and the difficulties this can present including maintenance of plant operations during construction and construction near existing structures. The final non-component allowances include a 40% contingency and a 20% allowance for engineering, which includes design and construction services. Any modifications required that are not in the component list are assumed to be covered in the contingency.

**Table 2.4-1**
**NON-COMPONENT ALLOWANCES**

| ITEM | PERCENTAGE INCREASE |
| --- | --- |
| Foundation Type | 10% |
| Retrofit Work | 15% |
| Yard Piping | 10% |
| Electrical | 15% |
| Controls and Instrumentation | 5% |
| Site Work | 10% |
| Contingency | 40% |
| Engineering | 20% |

A factored component cost was calculated based on the product of the first six allowances (1.85). This factored value was then used to determine the total capital cost with a 40% contingency. Total project cost was then calculated using the 20% engineering allowance.

C. **Present Worth Methodology.** Annual operation costs were estimated for incremental increases associated with the nitrogen removal facilities. The costs considered in this study include labor, power, and chemicals. Annual costs are based on permitted average daily flow. It was assumed for seasonal permit limits that chemical costs for all treatment systems and power costs related to denitrification filters only occur over 184 days during the year. Blower power costs associated with nitrification also were assumed to occur only over the 184-day seasonal limit.

It was assumed that changing to a different suspended growth activated sludge process (i.e. MLE or Bardenpho) would not require any additional operators. Except as noted, it also was assumed that no additional maintenance staff would be needed for any plant larger than 2 mgd or for SBR plants. It was assumed that one additional maintenance person would be required for plants smaller than 2 mgd. It was assumed that the addition of IFAS alone would not require additional staff. If a plant requires add-on attached growth biological filters to achieve denitrification, it is assumed that one additional operator is required. If this occurs at a plant smaller than 2 mgd, it is assumed that only a new operator would be hired and no maintenance person would be hired. It was assumed no additional new staff was required for the facilities in which the biological treatment process is completely changed. It is assumed that a new operator would work five days a week at a salary of $58,000. A new maintenance person is assumed to work five days a week at a salary of $46,000. These salaries are based on $28/hr for an operator and $22/hr for a maintenance person. The overhead requirement for municipal staff is assumed to be 45% of the salary; therefore, the annual cost for a new operator is $84,100 and for a new maintenance person the annual cost is $66,700.

The increase in power usage was based on historical power estimates for the first five components. Incremental power increases were then calculated based on the number of aeration tanks constructed and/or modified; the number of new clarifiers required; and flow-paced estimates for blowers, pump stations and methanol feed facilities. Power estimates for the SBRs and filters were provided by the manufacturers. Annual power costs were estimated based on the average electricity cost for the 21 facilities. The electricity costs were provided by each facility during the data gathering phase of the study. An average unit cost of $0.12/kwh was used to determine the power costs.

Chemical costs include methanol for use as an exogenous carbon source for suspended growth systems and for the attached growth denitrification filters. The cost of methanol fluctuates greatly on a monthly basis. A price of $1.80/gallon is used for this study as this was the highest it had been when the cost analyses were performed for this study.

Chemical costs also include caustic soda for supplemental alkalinity. A case-by-case evaluation was done for each plant to determine whether or not supplemental alkalinity would have to be added in order to maintain an effluent alkalinity of 60 mg/L. Average influent alkalinity concentrations were compared with alkalinity consumed, as predicted by BioWin, to determine if caustic soda would be required. A price of $0.18/dry lb of 50% caustic soda solution was used for this study.

The operation costs for the 20-year planning period were analyzed at an interest rate of 4.875% to develop present-worth costs. This discount rate was published in October 2007 by Federal Water Resources Planning. The present worth operation and maintenance costs were summed with the capital costs to determine the present worth cost of providing nitrogen removal to the proposed limits at each facility.

## 2.5 REFERENCES

1. New England Interstate Water Pollution Control Commission (1998). *Guides for the Design of Wastewater Treatment Works*, Technical Report #16 (TR-16).

2. *Wastewater Engineering: Treatment and Reuse*, Metcalf & Eddy, Fourth Edition 2003.

3. Daigger, G. T. (1995). "Development of Refined Clarifier Operating Diagrams Using an Updated Settling Characteristics Database." *Water Environment Research*, 67, 95.