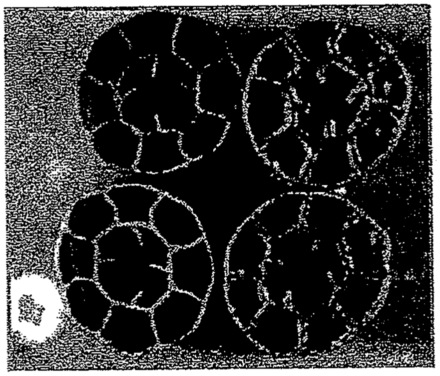

FIGURE III.2.4.2.2.2-1: CONORPAC™ MEDIA (COURTESY OF CONOR PACIFIC)

III.2.4.2.2.3 Hydroxyl

Hydroxyl Systems manufacturers a product called PAC media that is similar in size and shape to the ConorPAC media and has a specific surface area of 400 m^2/m^3. The Hydroxyl media was used in the pilot test unit at the FPWWTF with a 50 percent fill fraction. Hydroxyl has two full scale municipal pilot installations in the United States and North America and one in Raisio, Finland. Infilco Degremont has recently become the exclusive licensee of Hydroxyl media.

III.2.4.2.2.4 Kaldnes

Kaldnes, developed by AnoxKaldnes (a Norwegian Company) is a moving bed reactor (MBBR) technology and has also been used as an IFAS process with RAS. It contains small cylindrical shaped polyethylene carrier elements in bioreactors to support biofilm growth. Specific density of 0.96 g/cm3 with 10 mm in diameter and 7 mm in height is typically used (Rusten *et al.* 1995). The specific surface area of media is 500 m^2/m^3 at a 100 percent fill volume. An example of Kaldnes media material is shown in Figure III.2.4.2.2.4-1.

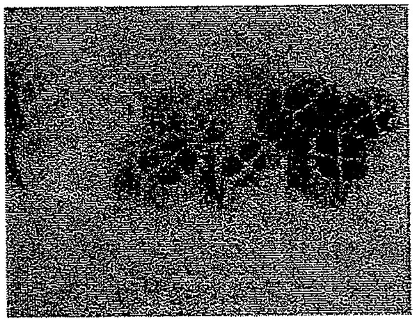

FIGURE III.2.4.2.2.4-1: CLEAN AND USED KALDNES MATERIAL (COURTESY OF ANOXKALDNES)

Kaldnes also manufactures a product called a Biochip™ that has a specific surface area of 1500 m^2/m^3. The media is approximately 1 mm in thickness and 3 cm in diameter. It has a grid pattern formed into the plastic media to retain the biofilm. There is not an equivalent product in the industry that has the specific surface area of the Biochip™.

Kaldnes media is typically applied in reactors that are operated without return activated sludge and with a great media occupation (60 to 70%) (Ødegaard *et al.* 1994). Most Kaldnes installations are not IFAS systems since they do not utilize an activated sludge system with RAS. However, some Kaldnes applications with RAS recycle can be found (e.g. Klippan, Sweden, Roti, Switzerland, Broomfield WRF, Colorado, and Cheyenne, Wyoming).

III.2.4.3 Process Maturity and Competition

IFAS technology has matured significantly over the last five years with larger (> 10 mgd) full-scale applications being completed or contemplated in several locations in the United States. Additionally the cost for media has dropped significantly due to industry competition and larger manufacturing facilities. The process is flexible and performs at a high rate due to the growth of heterotrophic and autotrophic bacteria on the media. Due to the vigorous agitation in the mixed liquor and between the free floating pieces, the media in free-floating media systems is self-cleaning, non-clogging and does not require backwashing.

Several facilities in Norway and Scandinavia operate on very cold and dilute wastewaters that are similar to the FPWWTF wastewater. Adapting the FPWWTF to the IFAS process would establish the plant as the one of the largest IFAS facilities in the United States.

The two largest manufacturers of free-floating plastic media provide competition in the municipal market and are strategically looking for larger full-scale applications for their products. One of the key issues in the design of plant upgrades with IFAS is the strategy for responding to the proprietary nature of each of the manufacturer's products in the procurement.

Additional information on the IFAS process is provided in Appendix D, IFAS System Case Studies.

III.2.5 Evaluation of the FPWWTF IFAS Pilot Testing

The Narragansett Bay Commission piloted an IFAS process to determine whether it was capable of achieving the proposed nitrogen permit limits, to examine operational flexibility and other operational factors, and to establish a design basis for full-scale implementation. A detailed description of the pilot process and the results of the study are presented in a report by Hydroxyl Systems, Inc. (April 2005). A summary of the Hydroxyl report and CH2M Hill's evaluation of the reported results of the pilot study are presented in this section.

III.2.5.1 Description of Hydroxyl IFAS Pilot Process

Hydroxyl Systems provided the pilot trailer and process guidance on the operation of the pilot facility. The pilot trailer was on site from late March 2004 to November 2004. The pilot trailer was operated by FPWWTF operations staff and laboratory personnel and monitored by Hydroxyl staff. Figure III.2.5.1-1 provides a depiction of the process that was housed in the pilot trailer.

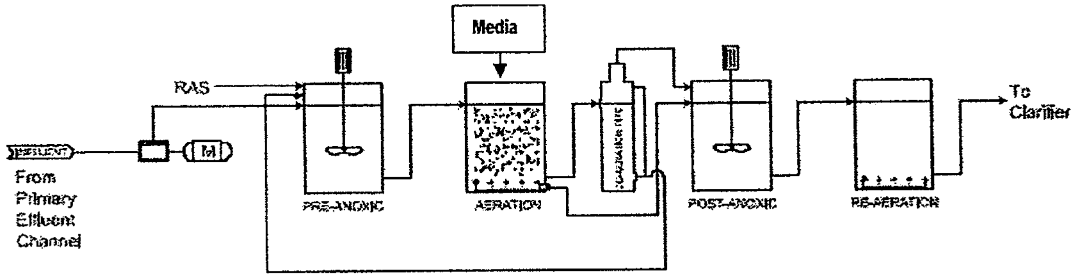

FIGURE III.2.5.1-1: FOUR-STAGE BARDENPHO IFAS PILOT PLANT

The pilot trailer and equipment included a 430-gallon pre-anoxic tank, 430-gallon aerobic tank with 50-percent media fill fraction, 430-gallon post-anoxic tank, a 150-gallon re-aeration tank, and a 430-gallon circular clarifier. The configuration also included a de-aeration pipe between the aerobic and secondary anoxic zone.

The IFAS pilot configuration was a four-stage Bardenpho process. The four stages included: pre-anoxic, aerobic, secondary anoxic and re-aeration zones. The configuration was selected because Hydroxyl Systems believed it could be retrofitted into the existing complete mix basins at the FPWWTF to meet a 5 mg/L TN seasonal monthly effluent limit without adding additional aeration basins.

In the four-stage Bardenpho process, the primary effluent is combined with return activated sludge and nitrified recycle in the pre-anoxic zone. The process of denitrification, where nitrates are reduced to nitrogen gas due to the growth of heterotrophic bacteria, occurs within this zone; the nitrogen gas is then stripped in the aerobic zone. Nitrification occurs in the aerobic zone through the growth of autotrophic bacteria that grow on the media and within the bulk liquid in the zone. Nitrification is the limiting step in the process due to the low specific growth rates of the autotrophic bacteria. The secondary anoxic zone is required for denitrification of any remaining nitrates as a secondary polishing step. Many systems require supplemental carbon (methanol, ethanol, or acetic acid) in order to complete denitrification. The supplemental carbon is required as the substrate for the heterotrophic bacteria. Finally, the reaeration zone is included to strip any remaining nitrogen gas within the mixed liquor.

III.2.5.2 Evaluation of Hydroxyl IFAS Pilot Study

In evaluating the Hydroxyl IFAS pilot study, the following ten factors were identified as key issues in analyzing the pilot testing results and in determining the requirements for full-scale implementation of IFAS at the FPWWTF:

- Type of Pretreatment
- Organic Load
- Sample Preparation
- Solids Retention Time (SRT)
- Dissolved Oxygen
- Wastewater Temperature
- Alkalinity
- Scum/Foam Abatement and Removal
- Denitrification
- Nitrification
- Ammonium (NH_4- N) Concentration

These issues are discussed below. Where appropriate, recommendations are provided for addressing these issues in a full-scale facility.

III.2.5.2.1 Type of Pretreatment

There have been differences of opinion between manufacturers and consultants about the need for fine screens to protect the IFAS process. The pilot report does not provide a discussion of the need for fine screening. It does not appear there was any indication of fouling and string buildup in the pilot plant. This may be due to the short duration of the pilot testing. The need for fine screens in a full-scale facility would be dependent on the amount of material that passes through the screens at the Ernest Street pumping station and the primary clarifiers at the plant. This may become an issue with regard to the protection of the treatment process. In order to protect the media and the media retention screens from plugging the installation of fine screens is recommended upstream of the BNR reactors with a screen aperture of 6 mm or less.

The pilot data indicated that the VSS/TSS fraction was relatively low during the pilot study. This agrees with historical data at the FPWWTF and may indicate a relatively low level of effectiveness in the grit chambers and primary treatment. The primary clarifiers can not be expected to consistently protect the aeration system with the IFAS process. The provision of fine screens will limit the amount of material that is transported to the aeration basins and reduce the need for cleaning of the retention screens, resulting in lower maintenance costs for the process.

III.2.5.2.2 Organic Load

Data reported in the pilot study indicated that the organic load of the primary effluent ranged from 98 mg/L BOD to 146 mg/L BOD and soluble COD between 113 mg/L and 138 mg/L. This is a relatively weak primary effluent and is consistent with previous primary effluent data for FPWWTF. The BOD to COD ratio is also consistent with previous data. Overall the organic load to the pilot trailer was reasonably consistent and variations were not outside of historical ranges. Since the FPWWTF service area is a combined sewer overflow (CSO) area, there will be wide ranges in organic load to the full- scale plant during pump-out events of the new tunnel infrastructure. These changes in load will need to be countered by a well-run and flexible full-scale facility. The four- stage Bardenpho process is a flexible process that should allow these organic loads to be stabilized and treated. However there may be other IFAS configurations that provide similar reliability. The pilot facility was able to achieve nitrification with these loads based on a 40% aerobic volume in the pilot unit following the seeding of the pilot with well nitrified sludge.

The soluble COD concentration in the pre-anoxic zone was generally below 30 mg/L with NO_3-N effluent levels of less than 0.5 mg/L. This corresponds to effective de-nitrification and indicates that the COD level is adequate for the pre-anoxic zone. However, in the secondary anoxic zone the soluble COD concentration was less than 20 mg/L and there were some excursions of nitrate removal that may indicate a carbon deficiency. Supplemental carbon addition may need to be included in the full-scale facility as a secondary measure to optimize denitrification and provide additional system flexibility.

III.2.5.2.3 Sample Preparation

The samples collected during the pilot testing for nitrogen species were filtered through a 0.45 micron filter to remove particulates to determine the total dissolved or soluble (and non-biodegradable) portion of total nitrogen in the wastewater. The requirements for reporting effluent concentrations for the RIPDES permit are not filtered to this degree and would contain higher nitrogen concentration due to particulates.

III.2.5.2.4 Solids Retention Time (SRT)

The aerobic solids retention time was one of the most critical operational parameters in achieving full nitrification in the pilot system. The aerobic SRT was adjusted through changing the wasting rate from the clarifier. The total SRT ranged from > 25 days to 3.8 days. The aerobic SRT ranged from 17.1 days to 1.9 days. The aerobic SRT was calculated from the aerobic zone only, whereas the total SRT was calculated from the combined anoxic and aerobic zones. Normally the aerobic SRT needs to be in the 4 to 5 day range in order for the process to adequately nitrify. Figure III.2.5.2.4-1 depicts the SRT ranges for the pilot testing.

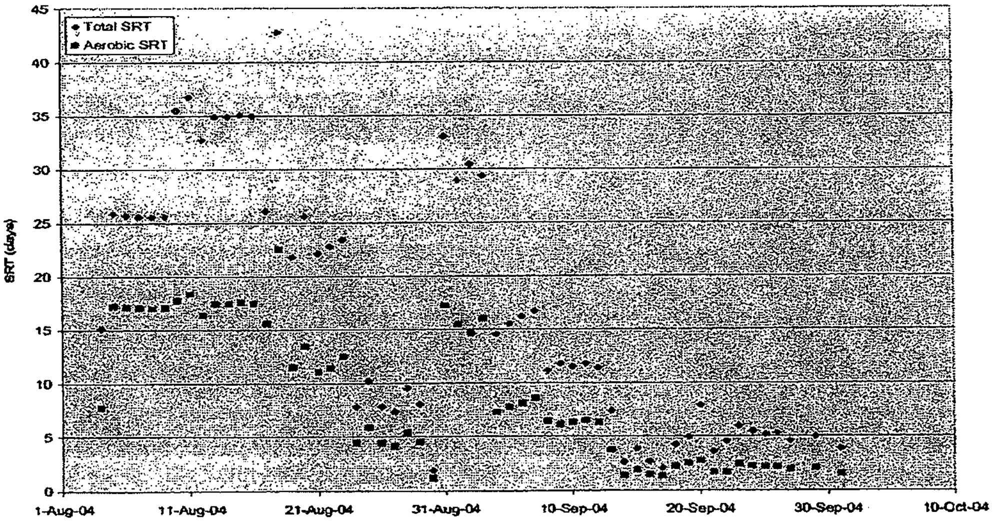

FIGURE III.2.5.2.4-1: PILOT STUDY SRT RANGES

III.2.5.2.5 Dissolved Oxygen in Aerobic Zones and Anoxic Zones

The dissolved oxygen (DO) in the aerobic zone of the pilot ranged from about 2 mg/L to over 9 mg/L. This was a large range and DO was not controlled to any great extent in the pilot. The target range for the operation of IFAS is somewhere between 4 and 5 mg/L DO in the aerobic zone. Variations in influent organic load will be attenuated through the IFAS process and, therefore, the bulk transfer efficiency of oxygen on and through the media is more important than in a suspended growth process to maintain proper sloughing and acclimation. Consequently, it is very important to control the DO levels in the full-scale BNR reactors/basins with more precision than was used in the pilot study. The standard oxygen transfer efficiency for the IFAS process is a function of the coarse/medium bubble diffusers that are used by each manufacturer. Therefore the efficiency of the system is important in the design of the aeration blowers. Turn-down of aeration capacity is more difficult due to the wider range in DO than in a standard suspended growth process.

The DO was not controlled enough to achieve nitrification in the pilot unit until after August 5, 2004, when the unit was seeded with nitrifying mixed liquor. The varying levels of dissolved oxygen and foam were issues that were difficult to address in the pilot unit due to the physical configuration of the tanks and piping. In the full-scale facility, the DO control and trim system will need accurate feedback control loops for the aerobic and re-aeration zones.

In general, dissolved oxygen in the anoxic zones will reduce the efficiency of the de-nitrification process. The aerated grit chamber and screw lift pump station at the FPWWTF introduce dissolved oxygen into the wastewater. The largest contributor of the dissolved oxygen has been determined to be at the aerated grit chamber effluent weirs. Dissolved oxygen concentration upstream of the anoxic zone will need to be reduced in the design of the full-scale facilities. The impact to the optimization of the initial denitrification step in the nitrogen removal process is significant. Between September 20th and October 5th the nitrate removal efficiency in the pre-anoxic tank dropped significantly. The DO levels in the pre-anoxic zone went from 0.45 mg/L to 0.8 mg/L, indicating a strong relationship between DO levels and nitrogen removals in the pre-anoxic zone.

The pilot unit included a de-aeration pipe following the first aerobic zone. The function of the de-aeration pipe was to eliminate oxygen prior to the second anoxic zone. This de-aeration pipe cannot be emulated precisely in a full-scale design. In effect, it optimizes the performance of the second anoxic zone since oxygen bleed-through is eliminated. The media retention screens are not designed or intended to be a quiescent zone. It is possible that the de-nitrification of the pilot was over-stated slightly due to this feature. In a full scale system, it may be possible to construct a dual-stage baffle that would function as a quiescent zone between the highly aerated aerobic zone and the secondary anoxic zone to reduce dissolved oxygen bleed through. The need to control dissolved oxygen bleed through to the second anoxic zone from an upstream aerobic zone becomes increasingly important with an IFAS system because of the higher bulk oxygen concentrations in the aerobic zone. This quiescent zone should be investigated further in the design and configuration of a full-scale BNR system.

III.2.5.2.6 Scum/Foam Abatement and Removal

As surface tension in the mixed liquor concentration changes and as surfactants change concentration based on influent wastewater characteristics, there may be a tendency for foaming to occur. Foaming is a potential problem for the three alternatives evaluated. Foaming was an issue in the pilot facility. To address this issue in the full-scale facility, it may be necessary to install de-foaming agents when the reactors are seeded and as mixed liquor builds to operating concentrations. Increased foam production will likely affect the scum build-up on the basins. Scum can be controlled effectively through mechanical collection and separation and by hydraulically designing the basin to allow it to cascade across and through the anoxic, aerobic, and re-aeration zones. During summer months when the temperatures are warmer and nocardia is prevalent, the facility may require additional wasting and control of filamentous bacteria. Control of filamentous bacteria with an IFAS process is important because it can be more difficult to remove filamentous bacteria from a fixed film suspended growth process than from an activated sludge system that does not contain growth media.

III.2.5.2.7 Wastewater Temperature

The design temperature that was developed during the previous work was 14 degrees C. The 14 degree C design temperature was selected in order to achieve full nitrification in the month of April prior to the seasonal permit limit of 5 mg/L TN, which is in effect from May 1 to October 31. Although the permit requires nitrification to be maintained to the maximum extent possible during the months of November through April, during very cold winters it is possible that nitrification will be lost. In this case, April is the month to encourage growth of the nitrifying population to a level that will meet permit conditions in May. The pilot unit was operated from April until November 2004. However acclimation and nitrification was not evident until the pilot was seeded with well-nitrified mixed liquor in August 2004. The initial temperature at which nitrification was found to occur was approximately 16 degrees C. During the piloting, temperatures ranged from a minimum of 15.3 degrees C to approximately 27 degrees C, as shown in Figure III.2.5.2.7-1. The pilot was not proven to nitrify at 14 degrees C. This inability to nitrify at low temperatures means that, during the critical start-up period in April, additional aeration capacity will be required. Process modeling indicated this second anoxic zone needs to be designed as a swing (anoxic/aerobic) zone for April start-ups or additional aerobic process capacity would be required. The swing zone provides flexibility that will provide additional nitrification capacity in early spring when the wastewater temperatures are 14 degrees C as with a particularly cold spring thaw.

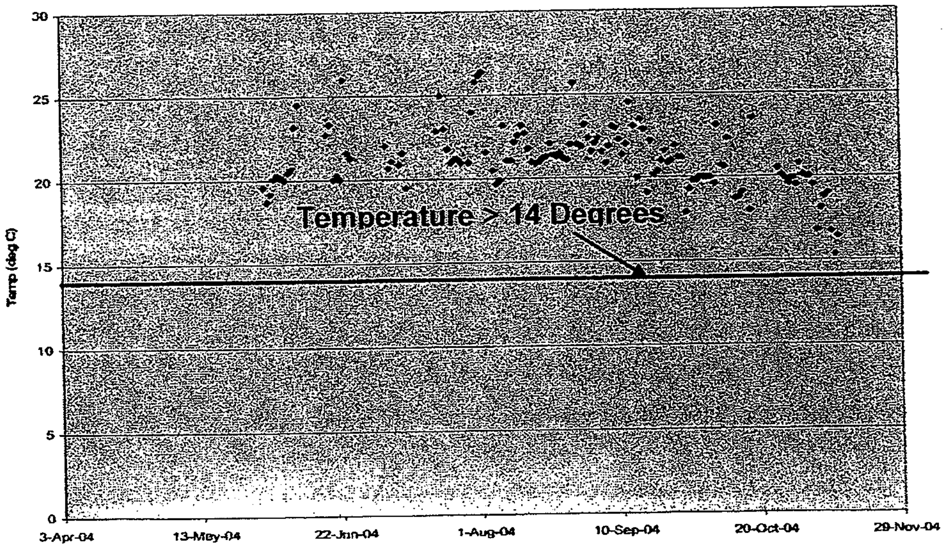

FIGURE III.2.5.2.7-1: PILOT STUDY WASTEWATER TEMPERATURE

III.2.5.2.8 Alkalinity

The alkalinity during the pilot test ranged from 100 mg/L to 113 mg/L. Influent ammonia was between 11 and 14 mg/L on average. During the nitrification startup period, approximately 7.2 mg/L alkalinity is required for each 1 mg/L of influent ammonia in order to initiate nitrification; an additional 50 mg/L should be available to provide buffering capacity for periods of lower strength wastewater. From the data collected in the pilot test, the primary effluent does not appear to have adequate buffering capacity to fully nitrify the ammonia during seasonal variations in wastewater strength. This alkalinity deficiency would be particularly critical during diurnal peaks in ammonia loadings, when the ammonia concentration would be higher than the averages reported. This alkalinity deficiency may have contributed to the fact that the pilot was unable to nitrify at the lower wastewater temperatures. Therefore, in the full-scale facility, the ability to provide supplemental alkalinity would be required for all of the biological nitrogen removal alternatives. Providing supplemental alkalinity will be especially important during CSO storm events when the low wastewater alkalinity will be further diluted by stormwater.

III.2.5.2.9 Ammonia Concentration

The pilot unit had ammonia influent concentrations of 11 to 14 mg/L, which represents a fairly consistent ammonia concentration entering the pilot unit. Historically, the ammonia in the Field's Point primary effluent has stayed relatively consistent and this has resulted in the TKN: NH4-N ratio to be relatively stable. However, influent ammonia concentrations may be affected by recycle stream characteristics to the extent that they could affect the performance of the nitrification process. The addition of supplemental alkalinity, as recommended above, will provide the ability to address variable ammonia concentrations in the full-scale facility.

Other constituents in recycle streams can also affect nitrification rates. The cyanide levels in the primary effluent have been as high as 0.29 mg/L based on data received from the NBC. Cyanide is produced from incomplete combustion in the multiple hearth incinerator and is recycled in the tray scrubber recycle water. Previous work on inhibition has indicated that cyanide levels of 0.1 mg/L or greater could impact nitrification or acclimation. Large variations in the cyanide concentrations can exacerbate the acclimation of the nitrification process. This could have been a contributing factor to the acclimation of the pilot plant from April to August prior to seeding it with well-nitrified mixed liquor. The seeding could have allowed the cyanide inhibition to be overcome once the microbial population was well established. Although cyanide could have been an issue during the pilot study, it is not expected that cyanide will affect the BNR process in the future because the incinerator was permanently shut down in December 2005.

III.2.5.2.10 Organic Nitrogen Concentrations

Data collected during the pilot study reported a level of 1.5 to 2.0 mg/L of organic nitrogen in the effluent. These values are typical of nitrifying systems. Historical data collected at FPWWTF has shown wide fluctuations in organic nitrogen data, which is typical of a non-nitrifying wastewater treatment facility. The historical fluctuations in organic nitrogen concentrations are primarily due to the method of calculating the organic nitrogen values (finding the difference between the analytical concentrations of ammonia and TKN, which are two large numbers in non-nitrified wastewater, to determine the organic nitrogen concentration, a smaller number), and probably do not result from a high variability in the amount of organic nitrogen. The data collected during the pilot reflect the actual FPWWTF effluent organic nitrogen concentrations more accurately, since they are based on nitrified wastewater in which the ammonia and TKN concentrations are small and the difference between the two values is more reliable.

III.2.5.2.11 Denitrification

The pilot was shown to be able to de-nitrify the wastewater to levels less than 0.5 mg/L of combined nitrate and nitrite after it was seeded in August with nitrifiers. The recirculation from the first aerobic zone to the pre-anoxic zone was shown to be an effective de-nitrification polishing step. In a full-scale plant, the need to de-nitrify and de-gas to relieve the potential for denitrifying / floating sludge in the secondary clarifiers is an important design consideration.