Maintenance Manager. Current levels and qualifications of operations and maintenance staff are adequate for monitoring processes, adjusting processes as necessary to maintain effluent quality, and maintaining, upgrading, and repairing machinery, instrumentation, piping, electrical items, and buildings and grounds.

The operations staff consists of operations supervisors, process monitors, operators, control systems personnel, and other support personnel. The maintenance staff includes mechanics, a carpenter, an electronics/instrumentation technician, and an electrician. Occasionally, operations or maintenance staff seeks assistance from outside specialists.

Supporting the FPWWTF staff is the NBC's Engineering Division, which includes engineering personnel that serve as an information resource to facility staff, monitor operation of the WWTF, handle major facility improvements and upgrades, and in other ways assist the facility staff in maintaining an efficiently operating treatment facility.

I.4.6 Adequacy of Sampling and Laboratory

Sampling of various process streams is necessary for RIPDES permit compliance, the pretreatment program, and for process control. Operations, laboratory, and pretreatment personnel collect the necessary samples and deliver them to the WWTF laboratory which analyzes for BOD, TSS, VSS, %TS, %VS, Chlorine Residual, pH, fecals, enterococcus, E. Coli, Oil & Grease, alkalinity, volatile acids, chlorides, water and salt water nutrients, cyanide, inorganic metals and volatile organics with specialized analyzers such as nitrogen, atomic absorption units and gas chromatographs. The laboratory is adequate for performing all necessary analyses, except for Bioassays and TCLP. The sampling program at the FPWWTF is adequate for fulfilling the requirements of the RIPDES permit and for maintaining proper operation of the treatment processes.

I.4.7 Cost Recovery and User Charge System

The financial requirements of operating and maintaining the FPWWTF are met through user rates. All ratepayers are required to pay user charges which consist of flat fees and consumption charges. NBC reviews rates on an on-going basis in order to assess the need for rate relief. All changes to the user rates are subject to review and approval by the Rhode Island Public Utilities Commission. The user rates cover the costs of operating and maintaining the FPWWTF and they support capital expenditures for facility improvements and upgrades. Additionally, the user rates support the NBC's interceptor collection system. At this time, the user rates provide adequate revenue for supporting the FPWWTF. However, there is a rate filing pending for FY 2007.

Revenues for the upcoming fiscal year are determined on an annual basis. Based upon these and other parameters, long and short-term budget guidelines are developed and communicated to the NBC directors and management. The Operations manager prepares a budget for operating and maintaining the FPWWTF. After preliminary review by NBC's Finance department, the budget is submitted to the Executive Director and the Board of Commissioners for approval as part of NBC's overall operating budget. This budget is implemented at the start of the fiscal year.

I.4.8 Water Quality of Narragansett Bay

RIDEM has established water quality standards for the various waterbody segments in the State of Rhode Island. These standards are contained in RIDEM's Water Quality Regulations, which were promulgated on August 6, 1997 and last amended on June 23, 2000. According to these regulations, the Providence River in the area of the FPWWTF outfall Nos. 001A and 002A is classified as an SB1(a) segment.

Being classified SB1(a), the river water in the area of the FPWWTF is designated for primary and secondary contact recreational activities and fish and wildlife habitat. The river's classification also designates the waters as being suitable for aquaculture uses, navigation, and industrial cooling uses, and to have good aesthetic value. Approved wastewater discharges into the river may adversely impact primary recreational activities. The (a) in the classification indicates that the river will likely be impacted by approved combined sewer overflows (CSO) that are in compliance with the Rhode Island CSO policy. Excerpts from the RIDEM Water Quality Regulations that explain the river classification in the area of the FPWWTF are contained in Appendix B.

Currently, RIDEM lists the Providence River in the area of the FPWWTF's two outfalls as an impaired segment because of low dissolved oxygen and high levels of nutrients. RIDEM is addressing this impaired condition by the modification of the FPWWTF RIPDES permit by limiting the effluent nitrogen concentration and load.

II CURRENT SITUATION

II.1 FPWWTF EFFLUENT CHARACTERISTICS

The FPWWTF maintains effluent within monthly permit limits for BOD_5, TSS, pH, Fecal Coliform, and Chlorine Residual. The monthly average effluent characteristics for January 2004 through April 2005 are presented in Table II.2-1 along with the corresponding RIPDES permit limits. As the data indicate, the effluent is well within the RIPDES permit limits.

Table II.2-1: FPWWTF Average Monthly Effluent Characteristics and Permit Limits

Month, 2004	BOD_5, mg/L	BOD_5, lb/d	TSS, mg/L	TSS, lb/d	pH, SU	Fecal Coli, MPN,	Residual Cl, ug/l
Jan	18.61	6770	19.97	7264	6.93	14	7.36
Feb	16.67	5890	20.76	7335	6.92	7	8.08
March	12.03	4187	12.68	4411	6.94	7	11.78
April	12.52	6628	13.57	7180	6.82	14	7.80
May	11.06	4269	10.74	4144	6.79	11	7.84
June	11.87	3868	9.87	3216	6.86	14	8.04
July	12.5	4077	15.71	5125	6.99	85	9.30
Aug	10.04	3672	10.97	4012	6.88	21	7.81
Sep	14.26	5310	12.57	4681	7.00	50	7.86
Oct	17.6	6000	15.58	5311	6.98	64	7.80
Nov	20.63	7461	19.00	6872	7.07	42	7.80
Dec	23.99	10,259	19.81	8471	7.20	28	7.84
Average 2004	15.15	5699	15.10	5669	6.95	30	8.28
2005							
Jan	16.05	7571	18.81	8873	7.33	24	7.79
Feb	11.51	5213	15.86	7184	7.09	11	9.84
March	9.4	4396	14.55	6805	7.1	10	7.84
April	9.5	5049	16.27	8646	7.31	9	8.63
Average 2005	11.62	5557	16.37	7877	7.21	13.5	8.44
Permit (Avg Month)	30	16,263	30	16,263	6.0	200	65
Permit (Max Day)		32,109		32,109			
Permit (Avg Daily)	50	50		9.0	400	65	
Permit (Avg Weekly)	45	45			400		

III EVALUATION OF NITROGEN REMOVAL ALTERNATIVES

III.1 BACKGROUND

The Facility Planning process has been conducted in two stages. The first stage was initiated in March of 2001, prior to RIDEM establishing a total nitrogen (TN) permit limit for the FPWWTF. Twenty-four alternatives were evaluated to meet TN permit limits of 8, 5 and less than 5 mg/L on an annual basis and on a seasonal basis for four technologies. The four BNR technologies evaluated were:

- Step Feed
- Modified Ludzak-Ettinger (MLE)
- IFAS-Fixed media[1]
- IFAS-Floating media[2]

The resulting January 2002 technical memorandum determined that the step feed process was the most cost-effective based on an assumed effluent limit of 5 mg/L on a seasonal basis. Step feed is a proven process utilized with success at municipal wastewater treatment plants in the U.S.

The MLE, IFAS-Fixed and IFAS-Floating media technologies were eliminated in the evaluation. The MLE process would require construction of additional aeration capacity at the current site of the wet weather clarifiers. This additional tankage requirement resulted in significantly higher costs compared to the step feed process.

The IFAS fixed and floating media processes were eliminated because of high cost, uncertainty of process effectiveness due to the limited number of installations in the U.S. and reliability.

With the selection of the proven step feed process, there was still uncertainty whether the process could achieve the discharge limit on a monthly basis as required by the permit given the limited volume available within the existing aeration tanks and the fact that the FPWWTF has a combined sewer system with cooler water temperatures in the spring which is a problem when initiating the nitrification process. However, without a defined effluent permit limit, the NBC was unable to complete the Facility Plan and the contract with NBC's engineering consultant was put on-hold in January of 2002 for three years.

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[1] The January 2002 technical memorandum referred to the IFAS-Fixed media technology as a "Combined" and Hybrid" system.

[2] The January 2002 technical memorandum referred to the IFAS-Floating media technology as an "MBBR" (Moving Bed Biological Reactor).

Over the approximately three years during which RIDEM was developing the nitrogen limit for the FPWWTF, the United States wastewater treatment industry saw in increase in use of both IFAS fixed and the IFAS floating media processes with positive operating experiences for each. The IFAS -Floating technology was considered a "new" technology with small to mid-size municipal installations mostly in Europe. Its major advantage is that the biomass needed for nitrification can be significantly increased without increasing aeration tank volume. With tank volume being limited at FPWWTF and no room on the site for expansion, IFAS -Floating was an appealing alternative. Because of favorable recent experience, the NBC chose to re-evaluate these processes based on their ability to comply with the 5 mg/L TN limit and to compare them to the initially recommended step feed process.

The second stage of the Facility Planning process began when NBC arranged a BNR pilot plant study with a manufacturer of a proprietary IFAS floating media system in the spring of 2004. An evaluation of the study is included in Section III.2.5 of this report.

In December 2004, RIDEM issued draft effluent permit limits for Total Nitrogen and on July 27, 2005 RIDEM issued the final modifications. These modifications require that NBC reduce the nitrogen concentration of the FPWWTF's final effluent to 5 mg/L on a monthly average basis from May 1 through October 31.

The Facility Planning contract was re-initiated in the spring of 2005 and included a re-evaluation of the IFAS -Fixed and Floating technologies. The MLE process, eliminated during the initial alternatives evaluation due to cost, was not re-evaluated. Because there had been no new MLE process developments between the initial alternatives evaluation in 2001 and the issuance of the effluent permit limit in 2005, it was assumed that the cost of this alternative would not be any less.

In August 2005 NBC engineering staff visited two step-feed treatment facilities. One of the facilities was in Maryland and the other was in Virginia. They also visited three IFAS floating media wastewater treatment facilities - one in Rhode Island in early 2005, and one each in Toronto, Canada and Denver, Colorado in October 2005. All facilities were operating successfully and were meeting their design effluent nitrogen limits. However, the two step feed facilities had nearly twice the aeration tank capacity of the FPWWTF based on influent flow. As stated earlier, the requirement to provide more aeration tanks would greatly increase the cost of any alternative due to site constraints at the FPWWTF. Therefore, this visit raised some concerns about the adequacy of the existing aeration tank capacity for the step feed process at the FPWWTF.

For a detailed review of the work done prior to July 2005, please refer to Appendix C.

III.2 ALTERNATIVES EVALUATION

III.2.1 Introduction

The three processes that were re-evaluated were:

1. Step Feed Process – This process is a suspended growth (activated sludge) process which uses several cells in series to form a plug flow pattern for mixed liquor with a step feed pattern for introduction of primary effluent.
2. IFAS Floating Media – The IFAS processes are hybrid systems consisting of both suspended and attached biomass growth. In this alternative the attached growth occurs on free floating media consisting of small pieces of sponge or rigid plastic pieces with high specific surface areas. The analysis was based on rigid plastic media as manufactured by Hydroxyl Systems, Inc. or Anox Kaldnes.
3. IFAS Fixed Media – In this hybrid system, the attached growth occurs on media that is fixed in the tank. The most common types of fixed media are fabric (cord/rope-type and web-type) media and sheet/strip-type media. Rope type media as manufactured by Ringlace Japan was selected for this alternative's analysis.

The alternatives were evaluated based on a number of factors including:

- Their ability to meet the anticipated permit limit of 5.0 mg/L within the existing tank volume
- The additional modifications required to meet the 5.0 mg/L limit if the existing tank volume is inadequate
- Capital and operating and maintenance costs
- Operational flexibility, process reliability
- Constructability
- Hydraulic limitations

III.2.2 Nitrogen Removal Goals

Nitrogen removal goals at the FPWWTF are based on the requirements of the final modifications to the RIPDES permit issued by RIDEM in July 2005. The permit calls for reduced levels of total nitrogen (TN) in the WWTF effluent as a means of improving water quality in the Providence River. A copy of the permit modification is provided in Appendix A. The permit requires that the average monthly TN concentration and loading in the WWTF effluent not exceed 5.0 mg/L and 2711 pounds/day respectively during the months of May through October.

III.2.3 Biological Nitrogen Removal

All three of the alternatives use the process of biological nitrogen removal (BNR) to reduce the total nitrogen concentration of the wastewater to acceptable discharge levels. BNR is a two-step process. The first step, nitrification, satisfies the nitrogenous oxygen demand of the wastewater by converting ammonia to nitrate. This is accomplished by autotrophic bacteria under fully aerobic conditions. The second step, denitrification, occurs when heterotrophic bacteria use nitrate as a terminal electron acceptor in the absence of oxygen. Denitrification converts nitrate to nitrogen gas.

Both the step feed and IFAS BNR processes use a reactor basin with anoxic and aerobic zones to provide the right environment for the two processes, nitrification and denitrification, to occur. Several configurations have been developed and successfully employed.

A description of each of these processes is provided in the following sections.

III.2.4 The Integrated Fixed Film Activated Sludge (IFAS) Process

III.2.4.1 General

The IFAS process is a hybrid system consisting of both suspended and attached biomass growth achieved by incorporating some type of biofilm support media into the existing aerobic zone of an activated sludge plant (Yerrel *et al.* 2001). Therefore, an IFAS system is the combination of suspended growth (activated sludge systems) and attached growth (biofilm) systems. The suspended media provide longer Sludge Retention Times (SRTs) for nitrifying biomass attached to the media, while maintaining shorter SRTs for suspended growth. The advantages of this technology are:

- Allows expansion or upgrade of existing facilities without the construction of additional tankage (Brink *et al.* 1996).
- Increases the effective biomass inventory in existing aeration basin without increasing suspended solids inventory in mixed liquor (Brink *et al.* 1996). Therefore, increases mean cell residence time (MCRT) of the plant without increasing the final clarifier solids loading.
- Reduces basin requirement (Metcalf and Eddy, 2003) for a given nitrification capacity.
- Minimizes shock load and toxic load problems due to maintaining large amount of biomass on support media.
- May achieve simultaneous denitrification within the submerged media in the aerobic zone (Sen, 1994, Ph.D. dissertation).

- Provides an additional safety factor for improved nitrogen removal at colder wastewater temperatures (Brink *et al.*, 1996).

The first application of an IFAS system to wastewater treatment was started in Germany in the early 1980s. Since then, substantial research has been performed through pilot and full scale studies to evaluate the nitrification performance of activated sludge systems and to determine design parameters and optimum operation conditions. Now, IFAS is an alternative for existing plants which need to upgrade their treatment process but lack available land, or for existing plants not achieving year round nitrification requirements. IFAS is typically applied to existing activated sludge plants to improve their performance without adding any biological treatment units. The major component of an IFAS process is the biofilm media. Features of the IFAS process are:

- Biofilm media is incorporated into only a part of the activated sludge basins or a part of the process trains. Media typically occupy 20-65 percent of the total activated sludge basin volume.
- Return activated sludge (RAS) is typically employed (moving bed biofilm reactors without RAS are not IFAS).
- The retention of media in the desired location of basin is essential. Therefore floating media are retained within basins with steel or aluminum screens or cages.
- Airlift pumps are used to redistribute sponge-type free floating media.
- For free floating media applications, air knives are installed to continuously clean the screen and a pump is used to return a portion of the nitrified wastewater to the influent end of the reactor.

This innovative technology has mainly been applied to existing plants where a modification/upgrade or retrofit is required. No application of IFAS to the design of a new plant is found in the literature.

Numerous factors can impact the performance of an IFAS system (e.g. desired ammonia concentration in effluent, dissolved oxygen concentration in aeration basin, water temperature, influent COD and TKN values). Three main criteria must be considered during design. These are the type of media, the volume percentage of the biofilm media with respect to total reactor volume and the specific amount of biomass per unit of biofilm carrier (Muller, 1998). However, the support media is the most essential parameter so it usually defines the IFAS process.

III.2.4.2 Biomass Support Media

Biomass support media can be classified as fixed and free-floating media. A description and examples of each type are provided below.

III.2.4.2.1 Fixed Media (IFAS-Fixed)

Fixed media are fixed in the tank and constantly remain in the same place. The most common types of fixed media are fabric (cord/rope type media and web-type media) and sheet/strip type. In a fabric media, ropes are woven in a way that results in many loops per unit length of strand to provide a greater surface area for biomass attachment (Yerrell, *et al.* 2001). The media extend vertically as single strands on a metal frame that is installed into the aeration basin. Sheet media consists of flexible polyethylene sheets or strips, and rigid polyethylene material fixed within cage structures. Rope-type media were originally developed in Japan for the enhancement of CBOD removal within the confines of an existing activated sludge basin. The rope-type products were then applied in Germany and United States to upgrade treatment facilities for nitrification (WERF, 2000). Different forms of polyvinyl chloride (PVC) based rigid plastic media have also been applied to IFAS systems. These media (Tropac, Flocor E) have mainly been applied in Germany although a limited number of applications have been implemented in the U.S. (Bionet). Commonly used fixed media and their manufacturers are: Ringlace (Japan); Biomatrix(USA);Bioweb(USA);Accuweb(BrentwoodIndustries, USA);Tropac(Germany); Floccor E (ICI, Germany); and Bioweb (NCW, USA).

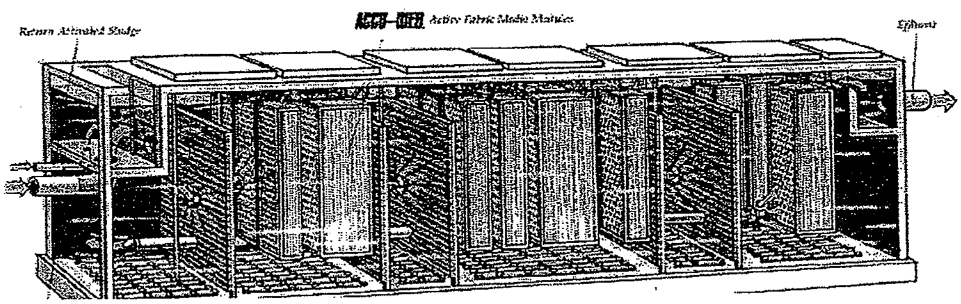

FIGURE III.2.4.2.1-1: CROSS-SECTION OF ACCUWEB MEDIA INSTALLED IN MAMARONECK WWTP, NY (COURTESY OF BRENTWOOD INC.)

A typical cross-section of an Accuweb media installation is shown in Figure III.2.4.2.1-1.

III.2.4.2.2 Free-Floating Media (IFAS-Floating)

Free-floating or dispersed media consist of small pieces of sponge or rigid plastic pieces with high specific surface areas. Dimensions of the media vary by manufacturer. The specific density of material is less than water. Some material, like foam pads which are used in Captor and Linpor with a specific density of about 0.95 g/cm^3, are placed into the reactor in a free-floating fashion. The foam-type media typically occupy 20 to 30 percent of the bioreactor volume (Metcalf and Eddy, 2003). Plastic media can occupy up to 65 percent of the bioreactor volume. A diffused aeration system provides mixing and circulates the sponges, foam pads or plastic pieces within the basin. A screen or cage is required for media retention in the activated sludge basin. Air knives are installed to clean accumulated debris on the screens. Floating media need to be replenished periodically due to wearing out from the abrasion in the tank (Metcalf and Eddy, 2003). The plastic media are very similar to sponge media with respect to their installation. However, media recycle pumps and cleaning pumps are not required due to the noncompressible nature of the media (WERF, 2000). The most widely used sponge media is Linpor and other polyurethane foams. The most common free-floating plastic media are manufactured by Hydroxyl and Kaldnes.

III.2.4.2.2.1 Captor and Linpor

In the Captor and Linpor processes, polyurethane foam pads are placed in activated sludge basins in a dispersed fashion and retained there by effluent screens (Reimann 1990). Despite the accumulation of biomass inside of the porous material, the foam pads may float on the water surface due to their low density (Grady *et al.* 1999). The typical dimension of the foam pads is 30 x 25 x 25 mm (Metcalf and Eddy, 2003). The Captor foam media system is manufactured by Simon Waste Solution, Inc. and was installed in one of the aeration basins of Moundsville (WV) WWTP. Linpor media is installed in the Westerly, RI WWTF. The Linpor sponge media is effective and maintains its shape through the recirculation process. Attrition and wear have been reported to be minimal.

III.2.4.2.2.2 ConorPac™

The ConorPac™ (Conor Pacific) media is manufactured by Marine Technology International, USA, from high density polyethylene or polypropylene with a specific gravity slightly less than water. ConorPac™ media has very high internal specific area to maximize biomass growth with significant void space. The media, shown in Figure III.2.4.2.2.2-1, consist of two concentric cylinders connected by internal walls along the length of the media. Since biomass growth occurs mainly on the protected internal surface, only the internal specific surface area is used for design. ConorPac™ media with 25 percent of working volume was incorporated to activated sludge basins for pilot and full scale applications (Zimmerman *et al.* 2001). The media specific surface area was 390 m^2/m^3.