WATER REUSE TECHNOLOGY DEMONSTRATION PROJECT

Demonstration Facility Pilot Study
Biological Aerated Filter (Nitrification)
Final Draft Report

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By

HDR Engineering, Inc.

BLACK & VEATCH

King County

Department of Natural Resources and Parks
Wastewater Treatment Division
Technology Assessment Program

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Executive Summary

The biological aerated filter (BAF) is a high-rate, fixed-film biological secondary treatment process that provides oxidation of BOD and ammonia in wastewater. This report summarizes the results from the use of the BIOFOR biological aerated filter (BAF #2) pilot unit for nitrification. (The results of using BAF #1 to oxidize BOD are discussed in another report.)

The BAF #2 pilot unit received effluent from the first stage biological aerated filter (BAF #1). Treated effluent from the BAF #2 was fed to the microfiltration (MF) unit for further treatment towards the end of the pilot study in late January 2002.

The BAF system tested in this study was manufactured by Ondeo Degrémont. In this system, the influent flows upward through a bed of media (BIOLITE, a proprietary expanded-clay media in BIOFOR) with aeration supplied to create an aerobic environment. The biomass attached to the filter media removes soluble pollutants biologically, and insoluble pollutants by filtration, eliminating the need for a separate solids separation stage for effluent clarification.

The focus of this pilot test was to evaluate a BAF nitrification process and produce Class A reuse water. The performance goals were:

- **NH4-N Removal:** > 90% or < 2 mg/L.
- **TSS Removal**: Effluent TSS < 10 mg/L, 90th percentile.
- **CBOD Removal**: Effluent BOD <10 mg/L, 90th percentile.
- **Effluent Turbidity**: <10 NTU, 90th percentile.
- **Backwash Flow**: < 8% of treated flow.

The pilot test was divided into four phases:

- **Phase I**: Initial Startup Period. BAF #2 was operated at a 72-hour backwash frequency and a hydraulic loading of 1.9 gpm/ft^2.
- **Phase II**: BAF #2 was operated at a 100-hour backwash frequency and hydraulic loading of 1.9 to 2.6 gpm/ft^2. Phase II was further divided into two sub-phases, Phase IIA and Phase IIB, according to hydraulic loading.
- **Phase III**: BAF #2 was operated at a 72-hour backwash frequency and hydraulic loading of 3.2 gpm/ft^2.
- **Phase IV**: BAF #2 was operated at a 48-hour backwash frequency and hydraulic loading of 3.8 to 4.5 gpm/ft^2. Phase IV was further divided into two sub-phases, Phase IVA and Phase IVB, according to hydraulic loading.

Table 1 summarizes the results of different test phases. No data is available from Phase I because this was the startup phase; at that point the testing had not yet started.

Table 1. BAF #2 Summary of Performance[1]

Parameter	Target	Phase IIA (11/7/01 to 12/5/01)	Phase IIB (12/6/01 to 12/17/01)	Phase III (12/18/01 to 1/9/02)	Phase IVA (1/10/02 to 1/25/02)	Phase IVB (1/26/02 to 2/27/01)
Effluent NH4-N[2], mg/L	< 2	0.29	0.31	0.49	0.16	1.68
NH4-N Removal[2]	> 90%	89%	90%	89%	97%	79%
Effluent TSS[2], mg/L	< 10	14.3	7.8	11.7	12.9	16.6
Effluent BOD[2], mg/L	<10	8.3	8.1	9.3	5.9	11.4
Effluent Turbidity[2], NTU	< 10	3.5	3.2	3.7	3.1	6.6
Backwash Flow	< 8% of treated flow	1.7%	1.2%	1.3%	1.8%	1.6%
Hydraulic Loading, gpm/ft^2	1.6 to 8.2 [3]	1.9	2.6	3.2	3.8	4.5
NH4-N Loading, lb/kcf/d	100[3]	5.4	12.8	14.9	30.2	32.6
TSS Loading, lb/kcf/d	188[3]	25.7	48.2	81.1	67.4	110.0
BOD Loading, lb/kcf/d	188[3]	36.9	54.3	108.3	130.7	91.8[4]
Backwash Frequency, hr	NA	100	100	72	48	48
Design/Test Temperature, ^{O}C	25	12.4	10.6	11.6	10.9	10.4

[1] No water quality data available for Phase I testing.

[2] 90th Percentile Values

[3] Maximum Ondeo design loading.

[4] Nitrification inhibitor was used in BOD analyses after February 3, 2002. Two data points out of twelve data points were analyzed without nitrification inhibitor in this test phase. If these two influent BOD data points are included, the average BOD loading to the system at this time period would be 106.4 lb/kcf/d.

Table 2 summarizes the comparison of the performance goals and performance of the unit during pilot testing.

Table 2. Comparison of Performance Goal and Performance of BAF2 During Pilot Testing

Performance Goal	BAF2 Performance
♦ Effluent NH4-N < 2 mg/L (90th percentile)	♦ Met performance goal in all test phases during pilot study.
♦ Effluent NH4-N >90% NH4-N Removal	♦ Met performance goal during Phase IIB and Phase IVA of the pilot study. ♦ Removal percentage (90th percentile) range from 79% to 97%.
♦ Effluent TSS < 10 mg/L (90th percentile)	♦ Met performance goal only during Phase IIB. ♦ Effluent TSS < 10 mg/L at 50th percentile level (i.e. average).
♦ Effluent BOD < 10 mg/L (90th percentile)	♦ Met performance goal in all test phases except in Phase IVB. ♦ The effluent BOD was 11.4 mg/L at 90th percentile during Phase IVB.
♦ Effluent Turbidity <10 NTU (90th percentile)	♦ Met performance goal in all test phases.
♦ Backwash <8% of treated flow	♦ Met performance goal in all test phases.

Based on the results of the study, a two-stage BAF system would be able to consistently produce an effluent BOD concentration of less than 10 mg/L for 90% of the time. It could not consistently produce an effluent TSS concentration of less than 10 mg/L, but it could produce an effluent TSS concentration of less than 15 mg/L for 90% of the time. A two-stage BAF system would be able to consistently produce an effluent turbidity of less than 10 NTU for 90%

of the time. If a higher degree of TSS and turbidity treatment is needed, a downstream sand filter could be used as required to produce Class A reuse water. The nitrification capacity of a BAF is severely hampered by low operating temperatures. The reduction in nitrification capacity is compounded by high BOD and TSS loading.

Based on the test results, the design criteria for a full-scale implementation are summarized as follows:

- Hydraulic Loading < 4.5 gpm/ft^2.
- Process Air = 1.9 scfm/ft^2.
- TSS Loading = 110 lb/kcf/d.
- BOD Loading = 90 lb/kcf/d.
- NH4-N Loading = 33 lb/kcf/d.
- Backwash Flow = 8.0 gpm/ft^2.
- Backwash Duration = 43 minutes or higher.
- Backwash Frequency = Minimum once every 48 hours.
- Design Temperature = 10 ^{O}C.

Introduction

The BIOFOR biological aerated filter (BAF #2), manufactured by Ondeo Degrémont, was tested as one of eight treatment processes in the King County Water Reuse Technology Demonstration Project. The demonstration testing facilities were configured to convey effluent from BAF #1 (BOD removal) to BAF #2. The focus of the testing was to evaluate its performance as a nitrifying process.

Description of the Technology

The biological aerated filter (BAF) is a biological fixed-film process. There are two different suppliers of BAF process equipment on the market: the BIOFOR BAF manufactured by Ondeo Degrémont, and the BIOSTYR BAF manufactured by US Filter. In both types of BAF, primary effluent flows upward through a bed of media (BIOLITE, a proprietary expanded-clay media in BIOFOR, or synthetic expanded floating polystyrene media in BIOSTYR) with aeration supplied to create an aerobic environment. The biomass attached to the filter media removes soluble pollutants biologically, and insoluble pollutants by filtration, eliminating the need for a separate solids separation stage for effluent clarification. For a first stage BAF, fine screening and primary clarification upstream are required to protect the media and nozzles from plugging and to make the system more cost effective. For the second stage BAF, fine screening is also required to protect the media and the nozzles from clogging. The BAF is a very high rate and compact wastewater treatment process. Only the BIOFOR BAF pilot plant from Ondeo Degrémont was used in this pilot study.

Figure 1 is a simplified schematic of the BAF treatment train tested during the pilot study, and Figure 2 is a simplified schematic of a typical BIOFOR BAF unit.

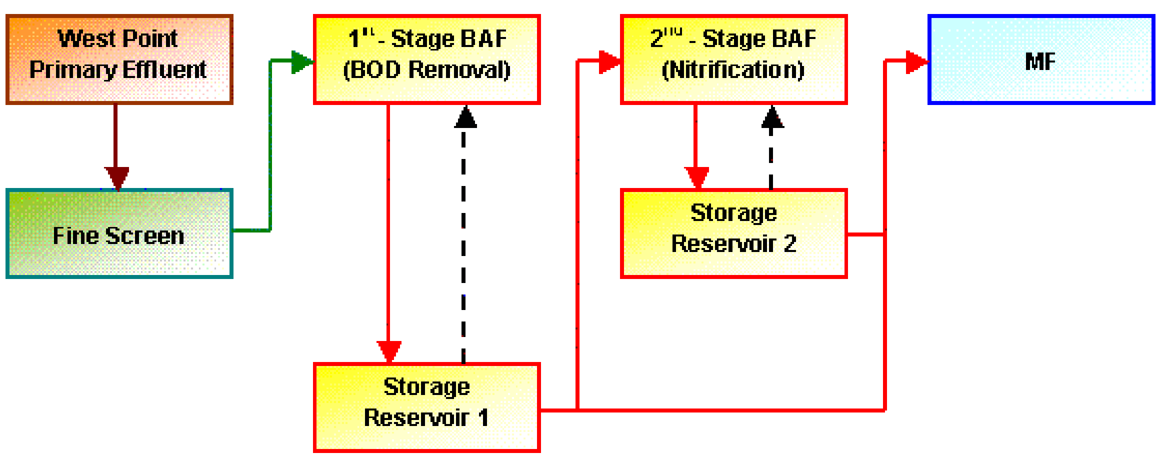

Figure 1. Simplified Schematic of the BAF-MF Treatment Train

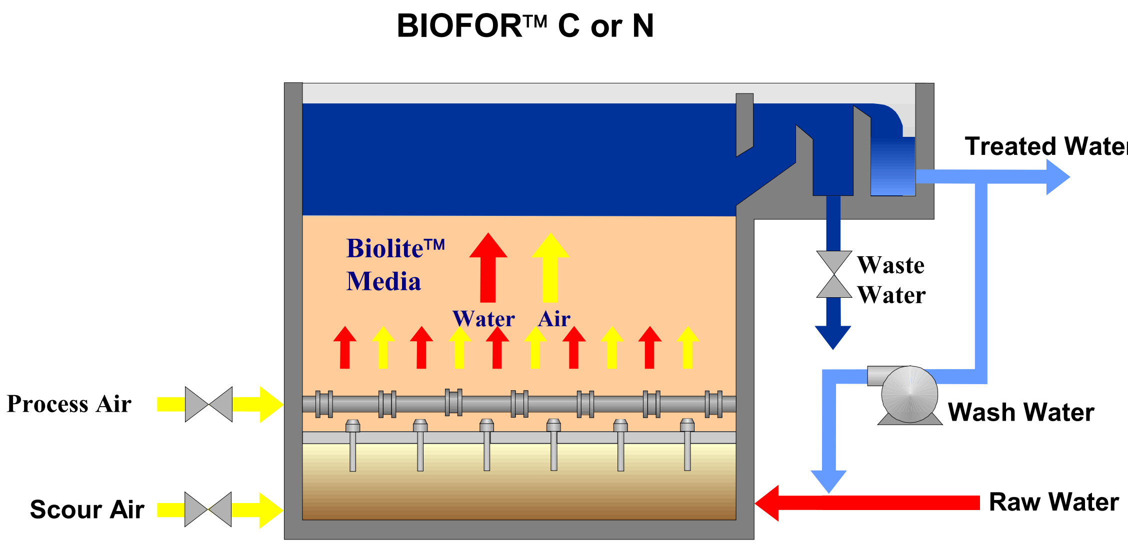

Figure 2. Simplified Schematic of a BAF Unit

Table 3 lists the full-scale BIOFOR BAF installations in the United States.

Table 3. List of Full-Scale BIOFOR BAF Installations in the United States

Location	BIOFOR Type	No. of Filters	Filter Area (ft^2/unit)	Average Capacity (MGD)	Start Up
West Basin, CA MWD for Chevron	Nitrification	4	315	5	1995
West Basin, CA MWD for Mobil	Nitrification	4	315	5	1995
West Basin, CA MWD for Arco	Nitrification	1	315	0.9	1999
NYC DEP, NY	Nitrification	1	270	2	1997
	Denitrification	1	180		
Evesham, NJ	Nitrification	3	192	1.7	1997
Breckenridge, CO	Nitrification	4	278	1.0	1998
Roanoke, VA	BOD Removal	6	1036	14	1998
	Nitrification	6	649		
Irvine Ranch, CA	Denitrification	2	60	1.3	1998
Corpus Christi, TX	BOD Removal	6	314	1.8	2000
Binghamton-Johnson City, NY	BOD Removal	8	1400	70	2004
	Nitrification	8	1360		
	Denitrification	4	840		

Comparison to Conventional Processes

The footprint requirement of a 1 MGD conventional single-stage activated sludge system for both BOD removal and nitrification is compared to the footprint requirement of a two-stage

BAF system of the same capacity treating the same primary effluent. The influent wastewater characteristics are shown in Table 4. (The footprint requirement for the primary clarifier and the process building was not included in this comparison.) The conceptual design and footprint requirements for a conventional single-stage activated sludge system for both BOD removal and nitrification are shown in Table 5. The conceptual design and footprint requirements for a two-stage BAF system of equivalent capacity are shown in Table 6. The overall footprint of the two-stage BAF system is only 33% of that of a conventional two-stage activated sludge system.

Table 4. Summary of Influent Characteristics for Conceptual Design

Average Flow, MGD	**1**
First Stage Influent Characteristics (Effluent From Primary Clarifier)	
BOD, mg/L	130
TSS, mg/L	80
NH4-N, mg/L	15
Second Stage Influent Characteristics for Second Stage BAF Sizing Only (Effluent From First Stage BAF)	
BOD, mg/L	35
TSS, mg/L	25
NH4-N, mg/L	10

Table 5. Conceptual Design of a 1 MGD Conventional Single-Stage Activated Sludge System[1]

Activated Sludge for BOD Removal and Nitrification	
MLSS, mg/L	3,000
SRT, days	12
HRT, hours	10
Volume of Aeration Basin, ft^3	55,600
Depth, ft	18
Total Width of Aeration Basin[2], ft	34
Total Length of Aeration Basin[2], ft	106
Secondary Clarifier Diameter[2], ft	50
Overall Width of Activated Sludge System, ft	70
Overall Length of Activated Sludge System, ft	180
Overall Footprint of Activated Sludge System, ft^2	12,600

[1] Refer to Table 4 for influent characteristics.

[2] Include thickness of sidewalls and compartment walls.

Table 6. Conceptual Design of a 1 MGD Two-Stage BAF System[1]

First Stage BAF for BOD Removal	
Total Number of Cells	4
Number of Active Cells	3
Filter Area Per Cell, ft^2	110
Backwash Frequency, per day per cell	2
Backwash Volume, ft^3 per cell per wash	3,380
Number of Rows of Cells	2
Number of Cells per Row	2
Total Width[2], ft	24
Total Length[2], ft	24
Second Stage BAF for Nitrification	
Total Number of Cells	4
Number of Active Cells	3
Filter Area Per Cell, ft^2	90
Backwash Frequency, per day per cell	0.5
Backwash Volume, ft^3 per cell per wash	2,320
Number of Rows of Cells	2
Number of Cells per Row	2
Total Width[2], ft	22
Total Length[2], ft	22
Backwash Water Storage Reservoir	
Storage Volume (2 Consecutive Washes for one First Stage Cell and one Second Stage Cell), ft^3	11,400
Depth, ft	15
Total Width[2], ft	19
Total Length[2], ft	46
Overall Width of BAF System, ft	63
Overall Length of BAF System, ft	66
Overall Footprint of BAF System, ft^2	4,160

[1] Refer to Table 4 for influent characteristics.

[2] Include thickness of sidewalls and compartment walls.

Pilot Testing

Objectives and Goals

The objectives of the pilot study were to collect sufficient data to facilitate full-scale plant design, including the determination of maximum sustainable BOD, TSS, and NH4-N loading rates, and the maximum duration of the idle mode that would not severely affect the treatment efficiency when the unit was put back into operation.

Performance goals for BAF #2 during the pilot study are as follows:

- NH4-N Removal: > 90% or < 2 mg/L.
- TSS Removal: Effluent TSS < 10 mg/L, 90th percentile.
- CBOD Removal: Effluent BOD <10 mg/L, 90th percentile.
- Effluent Turbidity: <10 NTU, 90th percentile.
- Backwash Flow: < 8% of treated flow.

Description and Graphic Presentation of the Demonstration Setup

Table 7 summarizes the features of the BAF pilot unit for nitrification facilities.

Table 7. Summary of BAF Pilot Unit Facilities

Shipping Weight	10,000 lbs
Operating Weight	14,000 lbs
BAF Unit Footprint	7' 0½" x 10' 0"
Clearwell Footprint	8' 0" diameter x 5' 8" tall
Overall BAF Column Height	22' 0"
Media Depth	12' 0"
Reactor Diameter	2' 0"
Filter Area	3.1 ft^2
Reactor Volume	NA
Bed Volume	38 ft^3
Electrical Requirements	460V, 3 Phase, 25 amp
	Raw Water Pump – 3.0 hp, 460/3/60
	Backwash Pump – 1.5 hp, 460/3/60
	Scour Air Compressor – 2.0 hp, 460/3/60
	Process Air Compressor – 1.0 hp, 460/3/60
Influent Connection	2" half coupling
Effluent Connection	4" male NPT
Service Water	¾" female connection

Figure 3 shows the BAF #2 pilot plant at the Westpoint Wastewater Treatment Plant.

Figure 3. BAF #2 Pilot Plant at Westpoint Wastewater Treatment Plant

Testing Plan

The original testing plan for BAF #2 is included in Appendix A. Changes were made to the original test plan during the course of the pilot study, and those changes are noted on the insert to Appendix A.

The pilot study of BAF #2 was divided into four phases as follows:

- Phase I – Initial Startup Period (November 1, 2001 to November 6, 2001): Backwash frequency was once every 72 hours. Hydraulic loading rate was 1.9 gpm/ft^2. No water quality sampling was conducted during this phase.
- Phase II (November 7, 2001 to December 17, 2001): Backwash frequency was once every 100 hours. Hydraulic loading rate ranged from 1.9 to 2.6 gpm/ft^2. Phase II was further divided into two sub-phases, Phase IIA and Phase IIB, based on hydraulic loadings.
- Phase III (December 18, 2001 to January 9, 2002): Backwash frequency was once every 72 hours. Hydraulic loading rate was 3.2 gpm/ft^2.
- Phase IV (January 10, 2002 to February 27, 2002): Backwash frequency was once every 48 hours. Hydraulic loading rate ranged from 3.8 to 4.5 gpm/ft^2. Phase IV was further divided into two sub-phases, Phase IVA and Phase IVB, based on hydraulic loadings.

At the end of Phase IV testing, BAF #2 was put into idle mode on two occasions, once for a duration of 45.5 hours and once for 67 hours. Intensive sampling of the BAF effluent was conducted immediately after the unit was put back online to investigate the rate of treatment capability recovery after switching out of idle mode.

Results

Overview of Presentation of Results

The **first subsection** following this subsection presents the overall results of the pilot study from October 22, 2001 to February 27, 2002 in a series of figures. The figures show the time trend of different test conditions and water quality parameters, the relationships between loading and effluent concentrations, and the statistical distributions of different effluent parameters. The maximum Ondeo loading values for a **nitrifying BAF** are shown as a comparison to the test conditions. During BOD analyses, the date on which a nitrification inhibitor was added is shown on figures showing BOD loadings, concentrations, and removal efficiencies.

The results from the pilot study are then presented in four test phases. Two test phases are further subdivided into two sub-phases, giving 7 total periods of discussion.

- Phase I represents the startup (November 1, 2001 to November 6, 2001). No water quality data was available during Phase I testing.
- Phase II represents the period when the pilot plant was backwashed at a frequency of once every 100 hours (November 7, 2001 through December 17, 2001). Phase II testing were further divided into two time periods based on hydraulic loadings.
  - Phase IIA (November 7, 2001 through December 5, 2001) represents a hydraulic loading of 1.9 gpm/ft^2.
  - Phase IIB (December 6, 2001 through December 17, 2001) represents a hydraulic loading of 2.5 gpm/ft^2.
- Phase III represents the period when the pilot plant was backwashed at a frequency of once every 72 hours and a hydraulic loading of 3.2 gpm/ft^2 (December 18, 2001 through January 9, 2002).
- Phase IV represents the period when the pilot plant was backwashed at a frequency of once every 48 hours (January 10, 2002 through February 27, 2002). Phase IV testing were further divided into two time periods based on hydraulic loadings.
  - Phase IVA (January 10, 2002 through January 25, 2002) represents a hydraulic loading of 3.8 gpm/ft^2.
  - Phase IVB (January 26, 2002 through February 27, 2002) represents a hydraulic loading of 4.5 gpm/ft^2. Effluent BOD samples collected during Phase IVB testing (all except 2 samples) were analyzed with the nitrification inhibitor.

Results of estimated backwash volumes, TSS wasting, and idle tests are presented in subsections after the performance results.

Performance of Nitrifying BAF

Figure 4 and Figure 5 show the flow and hydraulic loading rates to BAF #2 during the entire test period. Different phases and their corresponding backwash frequencies are identified on the figures. In each phase, the unit was operated at a different flow rate and/or backwash frequency. Figure 6 shows the influent and effluent ammonia concentrations during the same period. The first effluent ammonia data was collected mid November (30 days after startup) at which time the unit was nitrifying already. Additional trend plots and summaries of the pilot data are shown in Appendix C.

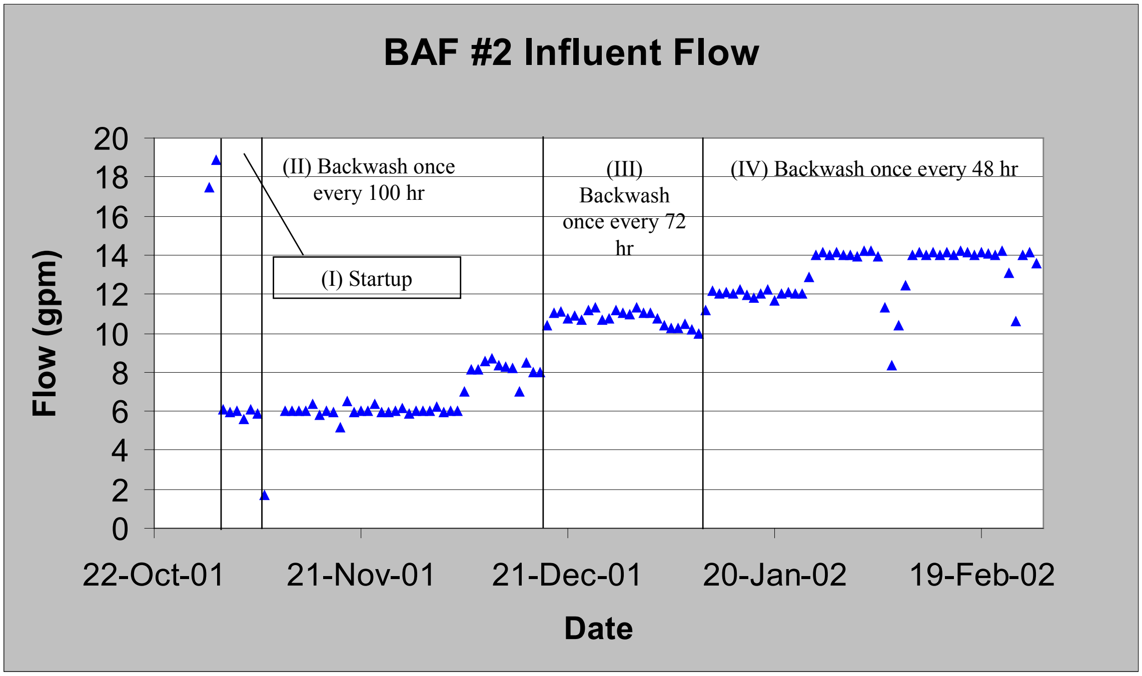

Figure 4. Influent Flow During Pilot Study

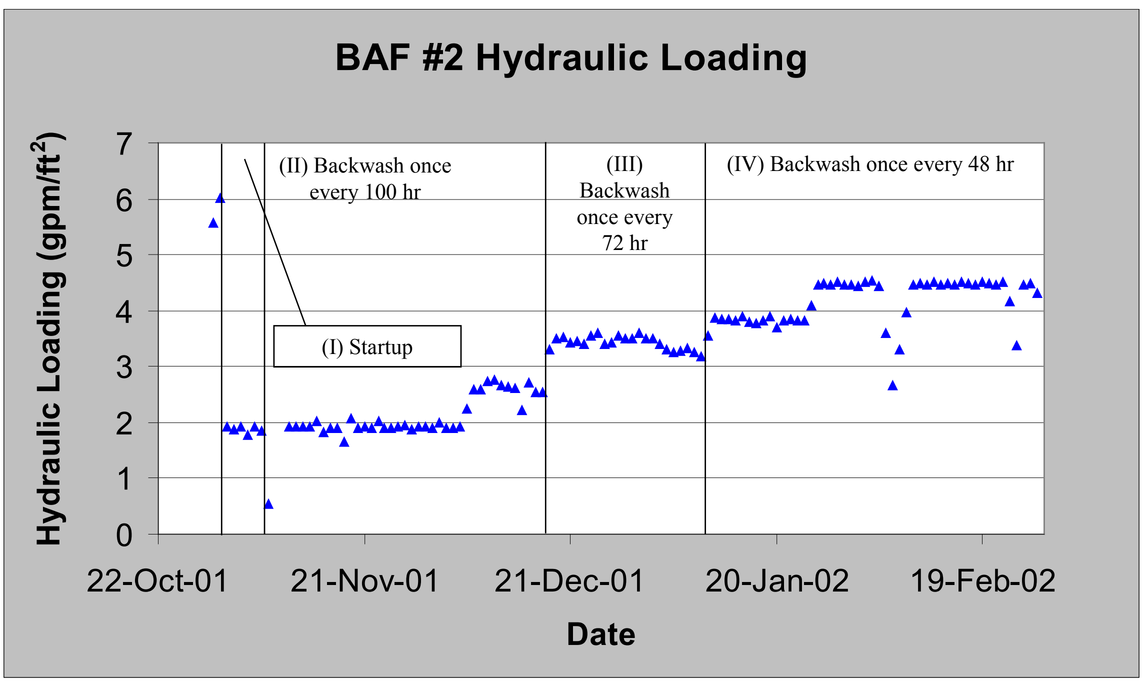

Figure 5. Hydraulic Loading Rate During the Pilot Study

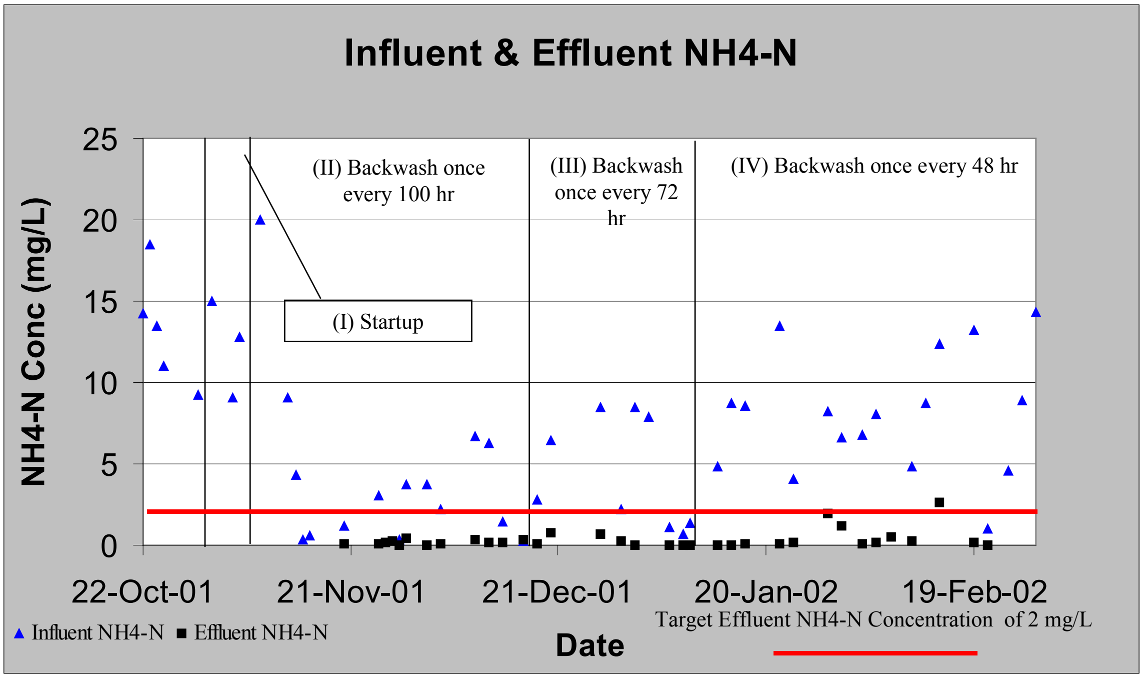

Figure 6. Influent and Effluent NH4-N During Pilot Study

General Notes – Sampling and Data Collection Issues

- Before February 4, 2002, no nitrification inhibitor was added to effluent BOD samples from BAF #1 and BAF #2 during the BOD analyses. As a result, the effluent BOD values in these time periods reflect both the carbonaceous biological demand, and the partial nitrogenous oxygen demand in the effluent of BAF #1 and BAF #2. The effluent from BAF #1 was fed to BAF #2. It is impossible to estimate the inhibited BOD loading as the degree of nitrogenous demand exerted may have varied from sample to sample. The effluent BOD however is a good measure, since most of the NH4-N is very low in BAF #2 effluent adding minimal nitrogenous demand to the test. The effluent samples and the results of BOD analysis without a nitrification inhibitor would be fairly similar to tests with the inhibitor.
- Influent flow was kept constant during a test phase or sub-phase, in an attempt to keep the organic and solids loading constant. However, BODt, TSS, and NH4-N concentrations in the influent varied because of the varying performance of the upstream BAF unit (BAF #1). Therefore the organic and solids loading to BAF #2 during each test phase and sub-phases fluctuated even though the influent flow was kept constant.
- The influent TSS concentration to BAF #2 was 21 mg/L while the effluent TSS concentration from BAF #2 was 22 mg/L on February 6, 2002. The influent BOD concentration to BAF #2 was 7 mg/L while the effluent BOD concentration from BAF #2 was 10 mg/L on February 7, 2002. The operator's log indicated that the control

valve between the backwash storage tank and the feed pump was stuck opened on these two days and this allowed the mixing of feed and treated effluent. Therefore these data points were not used in the statistical analyses.

- The influent NH4-N concentration to BAF #2 was 0.26 mg/L while the effluent NH4-N concentration from BAF #2 was 0.33 mg/L on December 16, 2001. This translated to a negative removal efficiency and indicated the lack of nitrification. The effluent NO3-N concentration was approximately two times the influent NO3-N concentration on the same day, indicating good nitrification. Apparently, there is some error associated with the results of the NH4-N concentration analysis. To avoid introducing such uncertainty into the statistical analysis, these NH4-N data points were not included in the statistical analysis.
- The influent alkalinity was 24 mg/L $CaCO_3$ and the effluent alkalinity was 63 mg/L $CaCO_3$ on February 7, 2002. On the same day, the effluent NH4-N was 0.5 mg/L. The influent NO3-N was 2.2 mg/L and the effluent NO3-N was 10.7 mg/L. The NH4-N and NO3-N data showed that nitrification was complete. It is therefore assumed that the influent and effluent alkalinity data was switched accidentally, but this could not be confirmed. However, the alkalinity data points were not used in the statistical analyses to keep uncertainty out of the analysis.

BODt Removal Performance

- As shown in Table 8, except for the second time period in Phase IV, the effluent BOD concentration from BAF #2 was consistently less than 10 mg/L (90^{th} Percentile). In Phase IV, the effluent BOD was 11.4 mg/L (90^{th} Percentile). The effluent BOD would be less than 10 mg/L for only 83% of the time under the Phase IV (second time period) operating conditions.

Table 8. Summary of Average Influent and Effluent BOD Concentrations at Different Test Phases

Parameters	Phase IIA 11/7/01 to 12/5/01		Phase IIB 12/6/01 to 12/17/01		Phase III 12/18/01 to 1/9/02		Phase IVA 1/10/02 to 1/25/02		Phase IVB 1/26/02 to 2/27/02	
	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.
BOD in (mg/L)	20.5	8.6	21.2	9.0	32.0	10.6	34.8	10.8	24.5	6.8
BOD out (mg/L)	5.5	2.1	6.6	1.1	8.6	0.6	4.3	1.3	7.2	3.3
90^{th} Percentile BOD out (mg/L)	8.3		8.1		9.3		5.9		11.4	
Percentage of Time BOD out Less Than 10 mg/L	>90%		>90%		>90%		>90%		83%	
BOD Loading (lb/kcf/d)	36.9	12.3	54.3	26.1	108.3	38.4	130.7	43.2	106.4	28.1
Temperature (^oC)	12.4	1.5	10.6	2.8	11.6	0.8	10.9	0.4	10.4	1.0
Influent Flow (gpm)	6		8		10		12		14	
Backwash Frequency	100		100		72		48		48	

BOD loadings to BAF #2 were increasing from Phase II through the first time period of Phase IV because of increasing influent BOD concentrations and increasing influent flows. The effluent BOD concentrations of BAF #2 are consistently lower than the performance goal of 10 mg/L (90th Percentile). BAF #2 is capable of handling an average BOD (uninhibited) load of 131 lb/kcf/d while consistently meeting the effluent requirement of less than 10 mg/L (90th Percentile).

- The average CBOD loading to the system in the second time period of Phase IV was 91.8 lb/kcf/d (standard deviation of 38.6 lb/kcf/d). BAF #2 could only produce an effluent BOD concentration of less than 10 mg/L for 83% of the time, but that is very close to the target goal of less than 10 mg/L BOD for 90% of the time.

TSS and Turbidity Removal Performance

- As shown in Table 9, with the slight exception during the first time period of Phase IV, TSS loadings to BAF #2 generally increased from Phase II through the second time period of Phase IV. The effluent TSS concentration of BAF #2 was unable to meet the performance goal of 10 mg/L (90th Percentile) except in the second time period of Phase II. However, the average effluent TSS concentrations in all test phases were lower than 10 mg/L. Also, the percentage of time in each test phase during which the effluent TSS concentration was lower than 10 mg/L ranged from 66% to higher than 90%. Therefore, it is concluded that although effluent TSS concentrations could not meet the target goal consistently during the pilot study, the effluent TSS quality was of acceptable quality. If higher TSS removal is deemed necessary, a downstream filtration process is needed.

Table 9. Summary of Average Influent and Effluent TSS Concentrations at Different Test Phases

Parameters	Phase IIA 11/7/01 to 12/5/01		Phase IIB 12/6/01 to 12/17/01		Phase III 12/18/01 to 1/9/02		Phase IVA 1/10/02 to 1/25/02		Phase IVB 1/26/02 to 2/27/02	
	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.
TSS in (mg/L)	16.1	12.4	19.0	8.3	24.1	6.7	17.9	5.8	26.4	8.0
TSS out (mg/L)	6.9	7.1	5.0	2.1	8.7	2.3	7.8	4.1	9.3	5.9
90th Percentile TSS out (mg/L)	14.3		7.8		11.7		12.9		16.6	
Percentage of Time TSS out Less Than 10 mg/L	81%		>90%		75%		78%		66%	
TSS Loading (lb/kcf/d)	25.7	15.9	48.2	19.0	81.1	23.8	67.4	22.3	110.0	38.2
Temperature (°C)	12.4	1.5	10.6	2.8	11.6	0.8	10.9	0.4	10.4	1.0
Influent Flow (gpm)	6		8		10		12		14	
Backwash Frequency	100		100		72		48		48	

The highest average TSS loading of 110 lb/kcf/d occurred in the second time period of Phase IV and was roughly 60% of the Ondeo maximum TSS design loading of 188 lb/kcf/d.

- An energetic backwash was conducted on December 18, 2001 and on February 14, 2002. However, unlike the BAF #1 performance, the TSS removal performance of BAF #2 did not improve after the energetic backwashes. The impact of backwash frequency on nitrification efficiency was not established. It is speculated that a higher frequency of backwash would potentially improve TSS removal but might remove the slow growing nitrifiers from the system at a rate faster than they could recover, potentially causing a negative effect on nitrification.

- Table 10 shows the turbidity removal performance during the pilot study.

Table 10. Summary of Average Influent and Effluent Turbidities at Different Test Phases

Parameters	Phase IIA 11/7/01 to 12/5/01		Phase IIB 12/6/01 to 12/17/01		Phase III 12/18/01 to 1/9/02		Phase IVA 1/10/02 to 1/25/02		Phase IVB 1/26/02 to 2/27/02	
	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.
Turbidity in (NTU)	6.8	0.2	6.9	0.2	6.9	0.1	6.9	0.1	6.9	0.1
Turbidity out (NTU)	2.2	1.0	2.1	0.9	2.8	0.6	2.1	0.8	4.6	1.6
Projected Turbidity (90^{th} Percentile)	3.5		3.2		3.7		3.1		6.6	
Temperature (^{o}C)	12.4	1.5	10.6	2.8	11.6	0.8	10.9	0.4	10.4	1.0
Influent Flow (gpm)	6		8		10		12		14	
Backwash Frequency	100		100		72		48		48	

The average influent turbidity was approximately 7 NTU throughout the whole test period from October 22, 2001 to February 27, 2002, while the average influent TSS fluctuated from 16.1 mg/L to 26.4 mg/L.

- Throughout the whole test period, the effluent turbidity was consistently lower than the performance goal which was a maximum of 10 NTU (90^{th} percentile).

NH4-N Removal Performance

- As shown in Table 11, NH4-N loadings to BAF #2 were increasing from Phase II through the second time period of Phase IV. The NH4-N loading in the second time period of Phase IV was marginally higher than in the first time period of Phase IV and could be considered equal to it. The effluent NH4-N concentration (90^{th} Percentile) has been consistently meeting and better than the performance goal of 2 mg/L (90^{th} Percentile). The effluent NH4-N concentration (90^{th} Percentile) was 1.7 mg/L in the second time period of Phase IV, which was three to eight times higher than the effluent NH4-N concentrations in other test phases, indicating a decreased nitrification performance. The BAF #2 may be at its maximum NH4-N loading capacity at a BOD loading of 91.8 lb/kcf/d, a TSS loading of 110 lb/kcf/d, and an average test temperature of 10.4 ^{o}C.

Table 11. Summary of Average Nitrification Efficiencies at Different Test Phases

Parameters	Phase IIA 11/7/01 to 12/5/01		Phase IIB 12/6/01 to 12/17/01		Phase III 12/18/01 to 1/9/02		Phase IVA 1/10/02 to 1/25/02		Phase IVB 1/26/02 to 2/27/02	
	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.
NH4-N in (mg/L)	4.41	5.75	4.82	2.92	4.38	3.37	7.95	3.76	7.57	3.46
NH4-N out (mg/L)	0.15	0.13	0.20	0.09	0.23	0.3	0.09	0.05	0.78	0.92
90th Percentile NH4-N out (mg/L)	0.29		0.31		0.49		0.16		1.68	
NH4-N Loading (lb/kcf/d)	5.4	5.0	12.8	7.9	14.9	11.6	30.2	14.4	32.6	16.0
NH4-N Removal	94%	4%	94%	5%	95%	4%	99%	1%	91%	10%
90th Percentile Removal	89%		90%[1]		89%		97%		79%	
Percentage of Time with >90% Removal	75%		90%[1]		85%		97%		50%	
NO3-N in (mg/L)	2.1	0.6	2.0	0.4	2.3	1.0	2.4	0.4	2.1	0.9
NO3-N out (mg/L)	9.0	3.1	7.6	2.5	8.3	2.8	11.7	1.3	9.3	1.4
Alkalinity in (mg/L $CaCO_3$)	78.3	40.1	66.8	30.6	87.9	30.7	93.2	21.4	94.7	23.9
Alkalinity out (mg/L $CaCO_3$)	46.7	4.7	45.0	4.0	50.5	8.8	43.3	4.6	50.6	8.3
pH out	7.0	0.2	6.9	0.1	6.9	0.2	5.7[2]	2.2	6.9	1.0
Temperature (°C)	12.4	1.5	10.6	2.8	11.6	0.8	10.9	0.4	10.4	1.0
Influent Flow (gpm)	6		8		10		12		14	
Backwash Frequency	100		100		72		48		48	

[1] Due to small sample size, projected log normal values less than minimum value in sample set. Projected value with actual data range used.

[2] Only two pH data points (4.1 and 7.2) were collected in this time period. On the day the pH data point of 4.1 was collected, no NH4-N, and NO3-N data were collected.

- The NH4-N loading during the second time period of Phase IV testing was roughly 33% of the Ondeo maximum NH4-N design loading, and during this time period the unit showed signs of decreased nitrification performance. This is attributed to low temperature: the Ondeo maximum NH4-N design loading corresponds to a design temperature of 25 °C, while the average wastewater temperature during this time was 10.4 °C. There would be a reduction in treatment capacity due to reduction in biological activity at a lower temperature. In general, an 80% reduction in biological activity could be anticipated when the temperature drops from 25 °C to 10 °C (Table 11-15 in Metcalf & Eddy, Wastewater Engineering Treatment Disposal Reuse, 3rd Edition, McGraw-Hill, 1991)

- As shown in Table 11, the average NH4-N removal percentage exceeded 90% throughout all phases of the test. The NH4-N removal was 90% or higher for 90% of the time from Phase II through the first time period of Phase IV. Average temperature in all the test phases was fairly constant and ranged from 10.4 °C to 12.4 °C. In the second time period of Phase IV, the NH4-N removal percentage fell to 79% (90th percentile). This time period also corresponds to a high CBOD loading and higher TSS loading. It is hypothesized that the BOD loading in conjunction with the TSS loading during this time period increased heterotrophic growth, which out-competed the slower growing nitrifiers. The competition for oxygen inhibits nitrifiers and decreases nitrification efficiency. At the same time, the wastewater temperature during this time period was low, further decreasing nitrifier activity.

Backwash Volume

The volume of treated water used per backwash cycle was not monitored during the pilot testing. Therefore, the ratios of backwash volume to effluent production by BAF #2 per filter run were estimated based on backwash sequence settings and backwash frequency (filter run time) settings (Table 12). Similar to BAF #1, there were two triggers for the initiation of a backwash. The first backwash trigger was a timer. Backwash would be initiated if the filter run exceeded a preset duration of filter run time. The second backwash trigger was differential pressure across the media. As the filter run progressed, differential pressure across the media increased as a result of solids captured by the media and the growth of biomass as a result of consumption of organics. If the differential pressure exceeded the pressure setting before the preset filter run time was reached, a backwash was initiated regardless of the actual filter run time.

Table 13 summarizes the backwash sequence settings. The filter would be offline during the entire backwash sequence. Therefore there would be no effluent production during this time. However, only during the water wash time does the unit use treated effluent from the backwash water storage tank.

Volume of water used per backwash was approximately 600 gallons. This was estimated by multiplying the actual time setting for water wash (24 minutes) in the backwash sequence by the backwash rate setting of 25 gpm.

The percentage of backwash water use was less than 2 % of effluent treated when the BAF unit was operated under conditions similar to the pilot testing conditions in Phase IV testing (average CBOD loading of 92 lb/kcf/d, TSS loading of 110 lb/kcf/d, NH4-N loading of 33 lb/kcf/d, hydraulic loading of 4.5 gpm/ft^2, and backwash frequency of once every 48 hours). If backwash frequency were increased to once every 24 hours, the percentage of backwash water use would still be less than the target maximum of 8% of the treated water.

Table 12. Ratio of Backwash Volume Used to Effluent Volume Produced Per Filter Run

Time Period	Filter Run Duration Setting (hr)	Average Influent Flow (gpm)	Average Filter Online Time (min)	Estimated Volume of Water Treated per Filter Run (gallon)	Percentage of Backwash Water
11/1/01 to 11/6/01	72	5.9	4277	25505	2.4%
11/7/01 to 12/5/01	100	5.9	5957	35104	1.7%
12/6/01 to 12/17/01	100	8.1	5957	48412	1.2%
12/18/01 to 1/9/02	72	10.8	4277	46487	1.3%
1/10/02 to 1/25/02	48	12.0	2837	34615	1.8%
1/26/02 to 2/27/02	48	13.5	2837	38884	1.6%

Table 13. BAF #2 Backwash Sequence

Backwash Step	Approximate Duration
Quick Drain	1 min
Air Cushion	1 min
Air Scour	1 min
First Air + Water Wash	1 min
Second Quick Drain	1 min
Second Air + Water Wash	3 min
First Water Only Wash	2 min
Third Quick Drain	1 min
Third Air + Water Wash	3 min
Second Water Only Wash	2 min
Fourth Quick Drain	1 min
Fourth Air + Water Wash	7 min
Air Cushion Relief	1 min
Air Scour off	1 min
Third Water Only Wash	5 min
Backwash Complete	1 min
Filter to Waste	10 min
Return Filter to Online	1 min
Total Filter Offline Time	43 min
Total Water Wash Time	24 min

TSS Wastage

The concentration of TSS in spent backwash water was not sampled during the pilot testing.

Idle Test

Two idle tests were conducted to simulate the idle mode of a full-scale BAF unit. The purpose of the idle tests was to evaluate how much time would be required to stabilize nitrification when the filter unit was put back online after an idle period. Samples were collected at 10- to 20-minute intervals for two hours after the unit was put back online to monitor the NH4-N, NO2-N, and NO3-N concentrations.

The first idle test was initiated at 1:00 PM on February 27, 2002. The influent pump was turned off and the air blower was left on at 6 scfm to simulate the idle mode. The unit was left in simulated idle mode for 45.5 hours. On March 1, 2002, the unit was restarted at 10:30 AM and effluent samples were collected at 10 to 20 minute intervals for two hours.

The second idle test was initiated 5.5 hours after it was restarted after the first idle test. At 4:00 PM on March 1, 2002, the influent pump was turned off and the air blower was left on with reduced airflow of around 3 scfm to simulate the idle mode. The unit was left in simulated idle mode for 67 hours. On March 4, 2002, the unit was restarted at 11:00 AM, and effluent samples were collected at 10- to 20-minute intervals for two hours.

Figure 7 through Figure 10 show the results of the first and second idle test.

General Observations

The upstream BAF #1 for BOD removal and the downstream BAF #2 for nitrification were put into idle mode at the same time. After an idle period, BAF #2 was put back online using BAF #1 effluent that had been stored for at least one day.

BAF #2 was put into simulated idle mode by stopping the influent pump and keeping the air blower on during the test period. In a full-scale system, the air blower would be turned on intermittently for 5 to 10 minutes per hour to keep the filter media aerobic. The over aeration in the pilot unit caused the biofilm to dry out.

First Idle Test (February 27, 2002 to March 1, 2002)

It was originally planned that BAF #2 would be left in idle mode for one day during the first test trial. However, at the originally scheduled time of restart, there was not enough stored BAF #1 effluent in the storage tank, and BAF #2 was started up one day later. BAF #1 was put back into operation on February 28, 2002 to produce effluent to send to the storage tank that would be used to restart BAF #2 the following day.

On March 1, 2002, BAF #2 was restarted with BAF #1 effluent produced after BAF #1 was restarted on the day before. It was observed that BAF #2 media had dried up during the idle period. It was hypothesized that continuous aeration might have dried up the media. It took approximately 10 minutes to fill up BAF #2. The initial flush of water was highly turbid, possibly due to the amount of solids that might have sloughed off as the media dried up during the idle period. As shown in Figure 7, the effluent turbidity was approximately 130 NTU at the time of system re-start. The effluent turbidity stabilized at approximately 20 NTU approximately 70 minutes after re-start.

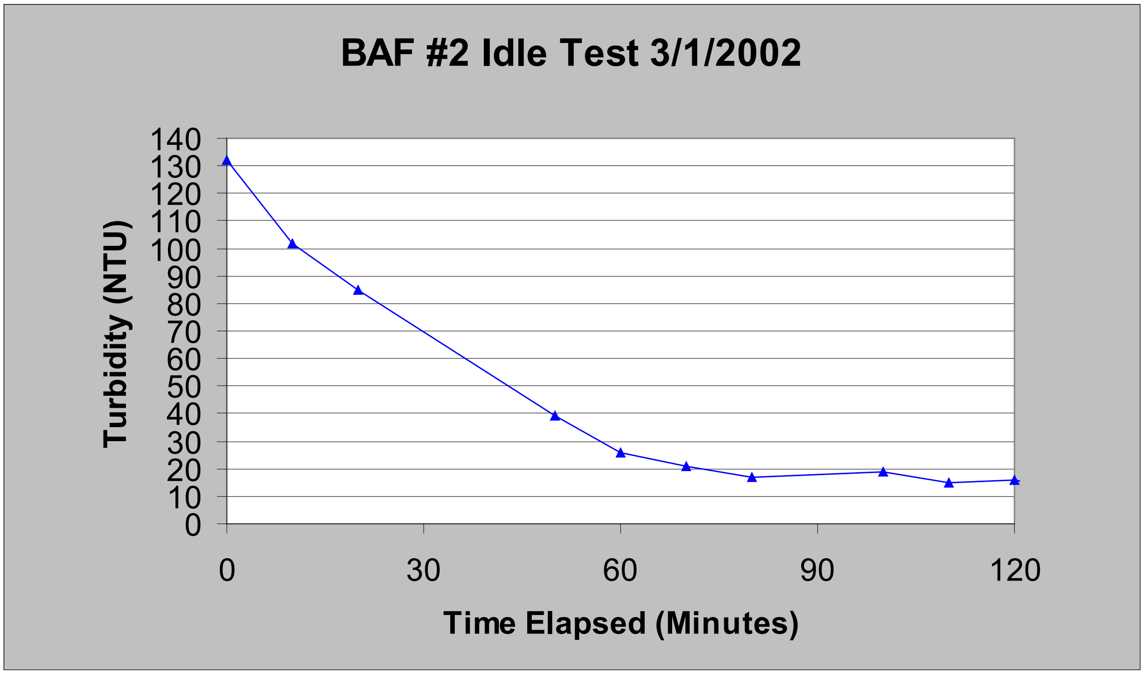

Figure 7. Results of First Idle Test - Turbidity (3/1/2002)

During the idle period, most of the NH4-N in the water remaining inside BAF #2 would have been converted to NO3-N by the nitrifiers under the aerobic idle condition. Therefore, the NO3-N concentration in the effluent immediately after restart would have been high and should have approached the influent NH4-N concentration of approximately 15 mg/L. As shown in Figure 8, the combined nitrogen concentration (NH4-N + NO2-N + NO3-N) was approximately 22.5 mg/L immediately after restart, higher than expected. This value confirms the expectation that NO3-N would be very high after restart.

Nitrification stabilized approximately 30 minutes after restart as shown in Figure 8.

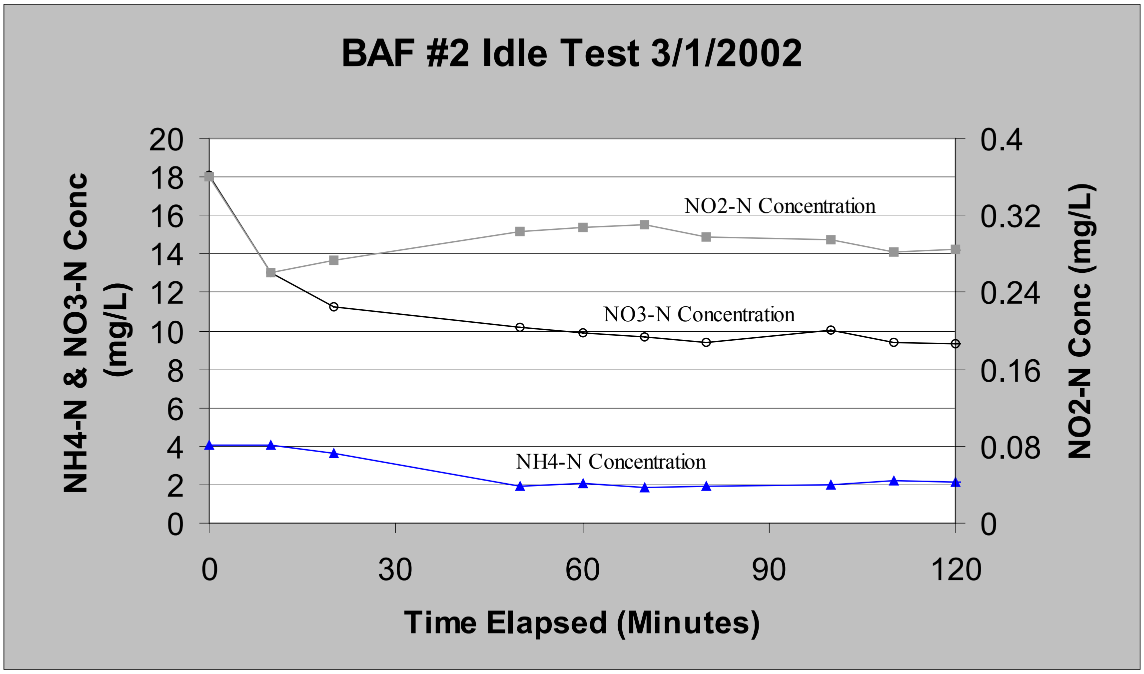

Figure 8. Results of Idle Test - NH4-N, NO3-N, & NO3-N (3/1/2002)

Second Idle Test (March 1, 2002 to March 4, 2002)

At 4:00 PM on March 1, 2002, BAF #2 was put back into idle mode a second time, approximately 5.5 hours after the restart from the first idle test. It was restarted at 11:00 AM on March 4, 2002, after approximately three days of simulated idle mode. Stored effluent produced by BAF #1 between February 28, 2002 and March 1, 2002 was used to restart BAF #2. This quality of the effluent would be similar to the effluent used in the first BAF #2 re-start. BAF #1 was still in idle mode when BAF #2 was re-started during the second idle test.

The top portion of the filter media dried out again, but the rest of the filter media remained moist. This time it only took about one minute to fill up BAF #2.

As shown in Figure 9, effluent turbidity only reached 18 NTU immediately after re-start and stabilized at approximately 8 NTU, roughly 80 minutes after re-start. This satisfactory effluent turbidity level indicated that most of the filter media remained moist during the second idle test and less solids were sloughed off compared to the first idle test.

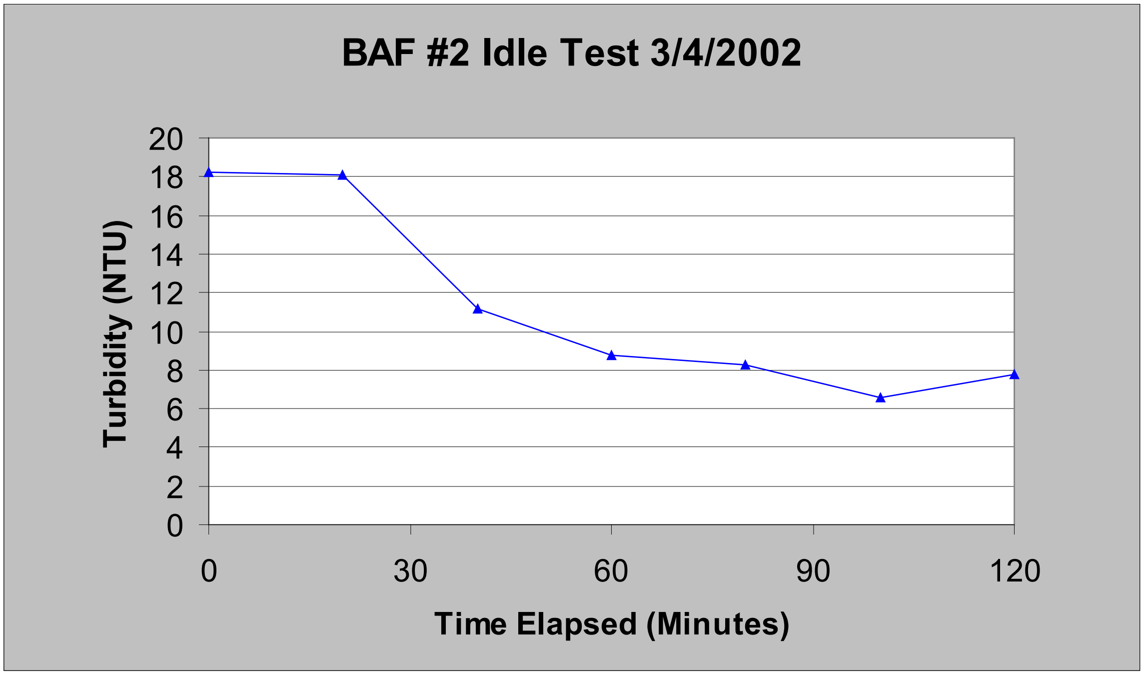

Figure 9. Results of Second Idle Test - Turbiditiy (3/4/2002)

Figure 10 shows the effluent NH4-N concentration increased significantly approximately 20 minutes after restart. However, the samples collected immediately at restart represented the quality of the water that was inside the BAF during the idle time. After one hydraulic retention time (roughly 10 to 20 minutes), the effluent quality would start to represent the performance of the BAF after restart. The effluent NH4-N concentration jumped from 2 mg/L to 12 mg/L in the sample collected at 20 minutes after restart. Therefore, we suspect that nitrification was lost immediately after restart. It was reported that the airflow was set at 2 to 3 scfm during the simulated idle mode and was not restored to 6 scfm during the restart. As a result, nitrification was lost, probably due to lack of aeration.

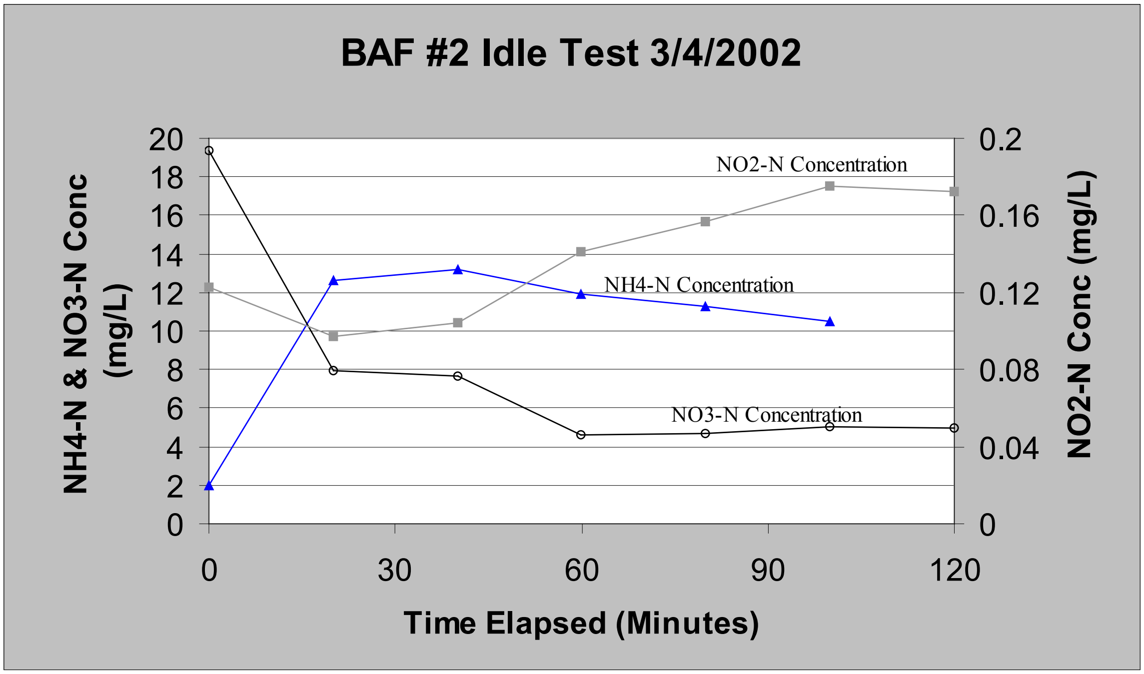

Figure 10. Results of Second Idle Test - NH4-N, NO2-N, & NO3-N (3/4/2002)

Conclusions from Idle Test

- The results of the first idle test show that a nitrification BAF unit could be put into idle mode for two days and nitrification could be restored approximately 30 minutes after restart.
- Care should be taken to prevent the media from drying up during idle mode. When the media dried up during the idle mode in the first test, solids sloughed off the media and resulted in extremely high effluent turbidity immediately after re-start. If this occurs in a full-scale facility, the initially produced effluent could be sent to waste to avoid the highly turbid effluent.

Evaluation of Pilot Results

Evaluation of Effectiveness of Technology to Meet Project Objectives

Table 14 shows the performance of the BAF #2 relative to the performance objectives established by the project team.

Table 14. Comparison of Performance Goals and Results for Primary Treatment

Performance Goal	BAF2 Performance
♦ Effluent NH4-N < 2 mg/L (90th percentile)	♦ Met performance goal in all test phases during pilot study.
♦ Effluent NH4-N >90% NH4-N Removal	♦ Met performance goal during Phase IIB and Phase IVA of the pilot study. ♦ Removal percentage (90th percentile) range from 79% to 97%.
♦ Effluent TSS < 10 mg/L (90th percentile)	♦ Met performance goal only during Phase IIB. ♦ Effluent TSS < 10 mg/L at 50th percentile level (i.e. average).
♦ Effluent BOD < 10 mg/L (90th percentile)	♦ Met performance goal in all test phases except in Phase IVB. ♦ The effluent BOD was 11.4 mg/L at 90th percentile during Phase IVB.
♦ Effluent Turbidity <10 NTU (90th percentile)	♦ Met performance goal in all test phases.
♦ Backwash <8% of treated flow	♦ Met performance goal in all test phases.

Operational and Reliability Considerations

Throughout the operation of BAF #2, a number of operational issues were reported by the operation staff. They can be grouped in the following categories:

- Loss of feed caused by:
  - Upstream unit offline
  - Upstream storage tank offline
  - Plugging of the influent screen
  - Feed pump failure
- False measurement of high differential headloss across media causing shutdown or cycling of unit.
- Pilot unit design
  - Control panel user interface not user friendly
  - Same pump was used for both backwash and feeding
  - Solenoid valve stuck in open position allowing mixing of feed and backwash water
  - Unsteady airflow rate.
  - Failure of feed line control valve

Some of the more significant operational issues are discussed in more detail below:

Loss of Feed

During the pilot testing period, BAF #2 used the effluent from BAF #1 as the influent feed. When BAF #1 was shut down due to various operational problems, BAF #2 would be shut down at the same time due to loss of feed water. However, in a full-scale facility, multiple first-stage BAF units would operate at the same time. In the event of a first-stage unit shutdown, there would still be other units in operation, and this would prevent the unnecessary shutdown of the second-stage

Blinding of influent screen caused BAF #2 shutdown or backwash cycling. After cleaning the fine screen, the process was stabilized. BAF #1 experienced similar problems at a higher frequency. A full-scale facility therefore would require a fine screen with sufficient capacity and self-cleaning capability. Clogging of the influent screen due to algal growth was experienced in the full-scale BAF facility in Roanoke, VA. The feed distribution channel to the second-stage BAF units in a full-scale facility could be enclosed or covered to minimize algal growth. Operational staff should also routinely perform visual field checks of the condition of the influent fine screen.

BAF #2 was shut down once when the feed pump failed and was shut down at a separate time when the pump failed during backwash. A BAF complex should have backup feed pumps, backwash pumps, and blower capacity, programmed to start up automatically in the event of a failure in the main feed pump, backwash pump, or blower.

False Measurement of High Differential Headloss Across Media Causing Shutdown Or Cycling Of Unit

Measurement of the differential pressure across the filter media was unreliable. This was probably caused by accumulation of air bubbles in the pressure-sensing line causing the false reading. This problem was solved by the operation staff manually bleeding air off the pressure sensing line. In a full-scale facility, the pressure sensing line should be designed so that there would be no localized high point to trap air. Also, air release valves could be installed on the pressure sensing lines to automatically bleed air from the pressure sensing lines.

Pilot Unit Design

The control panel of the pilot unit was not user friendly. This is probably due to the age of the pilot unit. A full-scale plant would come with a more user-friendly control panel and SCADA system.

In the pilot unit, the same pump was used for both influent feed and backwash. When the pump failed, the pilot unit had to be shut down. In a full-scale BAF complex, there would be different dedicated pumps for influent feed and backwash. As discussed previously, a full-scale BAF complex should have backup feed pumps, and backwash pumps, programmed to start up automatically in the event of a failure of the main feed pump, or backwash pump.

The problem of a solenoid valve stuck in the open position allowing mixing of feed and backwash water is unique to the pilot unit. The solenoid valve was required in the pilot unit since the same pump was used for both influent feed and backwash. In a full-scale system, there would be separate pumps for influent feed and backwash, eliminating the need of the solenoid valve and hence the associated problems.

The airflow to the pilot unit was controlled by adjusting how much the control valve was opened for bleeding air out. However, as the differential pressure increased in the system, the air pressure dropped and resulted in lower airflow rates. During the pilot study, the airflow had to be re-adjusted almost everyday. This operation issue was due to the older design of the pilot unit equipment. In a full-scale plant, the aeration system would be set up to automatically adjust the control valve to a constant pre-set rate regardless of differential pressure across the filter media.

The pilot plant operation was also interrupted when the control valve on the feed line failed. In a full-scale system, it would be prudent to install a high quality control valve with reliable and long lasting actuators to minimize operational problems due to control valve failure.

Implementation

Design Criteria

Table 15 shows the typical design criteria published by Ondeo and criteria established by this pilot study.

Table 15. Comparison of Typical Design Criteria and Pilot Study Results

Parameters	Ondeo Maximum Design Load for Nitrification (Design Temperature of 25 °C)	Pilot Study Conclusion (Design Temperature of 10 °C)
Hydraulic Loading, gpm/ft^2	1.6 to 8.2	<4.5
(m/h)	(4 to 20)	(<10.9)
Process Air, scfm/ft^2	0.2 to 1.9	1.9
(m/h)	(4 to 35)	(35)
TSS Loading, lb/kcf/d	188	110[1] & [3]
(kg/m^3/d)	(3)	(1.8)
BOD_5 Loading, lb/kcf/d	188	90[2] & [3]
(kg/m^3/d)	(3)	(1.4)
N-NH_4 Loading, lbkcf/d	100	33[3]
(kg/m^3/d)	(1.6)	(0.5)
Backwash Rate, gpm/ft^2	4.1 to 12.1	8.0
(m/h)	(10 to 29.5)	(19.5)
Backwash Duration, minutes	43	43
Backwash Frequency	NA	Minimum once every 48 hours
Backwash TSS Concentration (mg/L)	NA	NA

[1] Pilot unit was unable to produce effluent TSS (90th Percentile) of less than 10 mg/L throughout the test period. 110 lb/kcf/d was the highest TSS loading tested during the test period.

[2] Only known uninhibited BOD loading during the test period was 91.8 lb/kcf/d.

[3] At a NH4-N loading of approximately 33 lb/kcf/d in the second test period of Phase IV testing, the effluent NH4-N concentration was 1.7 mg/L (90th Percentile). This approached the target treatment level of 2 mg/L (90th Percentile). This NH4-N loading should be regarded as the maximum NH4-N loading if the BOD loading approaches 90 lb/kcf/d, TSS loading approaches 110 lb/kcf/d, and a water temperature of 10 °C.

Design Features

A two-stage BAF system would be able to consistently produce an effluent BOD concentration of less than 10 mg/L for 90% of the time. It is not able to produce an effluent TSS concentration of less than 10 mg/L for 90% of the time, but could produce an effluent TSS concentration of less than 15 mg/L for 90% of the time at conditions similar to those used in this pilot study. A two-stage BAF system would be able to consistently produce an effluent turbidity of less than 10 NTU for 90% of the time. If a higher degree of TSS and/or turbidity treatment is needed, a downstream filtration system could be used as required to produce Class A reuse water. The nitrification capacity of a BAF is severely hampered by low operating temperatures. The reduction in nitrification capacity is compounded by high BOD and TSS loading.

Control, monitoring, special

- Individual turbidity meters should be installed for each filter unit to provide real time monitoring of the performance of the filter.
- The minimum size of the backwash storage reservoir should be large enough to store sufficient water for two consecutive backwashes.

Pretreatment requirements

- A self cleaning 2.5 mm pore size fine screen (per Ondeo recommendation) with a backup unit would be required to treat the influent to the second stage BAF unit to prevent potential damage to filter media and clogging of the influent nozzles.

Residual treatment

- Volume of spent backwash water generated is estimated to be approximately 2% to 4% of the treatment plant capacity.
- Backwash TSS was not measured in this pilot study. However, based on the BAF #1 pilot study results, it is expected that the backwash TSS from a nitrification BAF would be dilute (200 to 1000 mg/L) and will require thickening.
- For satellite wastewater reuse plants, the spent backwash water containing waste TSS would be returned to the sewer for downstream treatment at the centralized wastewater treatment plant.

Issues not Resolved by Pilot Test Program

- The effect of backwashing more frequently than once every 48 hours on TSS removal and nitrification efficiency was not investigated.
- The effect of BOD loading above 90 lb/kcf/d and TSS loading above 110 lb/kcf/d on nitrification was not determined. During the last time period of Phase IV testing, the effluent NH4-N concentration (90^{th} Percentile) increased to 1.7 mg/L. This was three to eight times higher than the effluent NH4-N concentrations in other test phases, showing a decrease in nitrification rate under the test conditions of the last time period of Phase IV testing. It is uncertain if backwashing more frequently than once every 48 hours would have any beneficial effect on nitrification performance.
- TSS concentrations in spent backwash, the actual frequency of backwashes, and the actual volumes of backwashes were not measured during the pilot study. This information is important in sizing the backwash storage reservoir and would also be important in sizing a solids-treatment facility for a regular full-scale wastewater treatment plant. If the BAFs are used in satellite reuse plants, the solids generated would be sent to sewer, and there would probably not be an on-site solids treatment facility.
- The performance of BAF under intermittent peak loading and reduced airflow conditions was not tested during the pilot study.

Appendix A – Test Plan

Appendix B – Operator Log

Appendix C – Trend Plots and Phase Summaries

Appendix D – Pilot Unit Photos

Appendix A – Modifications to BAF #2 Test Plan During Course of Pilot Testing

Test Stages vs Test Phases

- In the test plan (last modified in early December 2001), the pilot study would be divided into three distinct test stages. However to avoid confusion with treatment process stages (one-stage BAF treatment vs two-stage BAF treatment), Test Stages were renamed Test Phases in pilot study report.

Changes to Stage 1 Testing – Start Up, and Stage 2 Testing – Determination of Maximum Sustainable TSS, BOD, and NH4-N Loading

- Backwash frequency became an important performance operating criteria. The Stage 1 Testing, and Stage 2 Testing in the test plan could be combined and re-divided into four test phases based on different backwash frequencies. Phases I, II, and III testing in the report could be regarded as the equivalent to Stage 1 testing in the test plan. Phase IV testing in the report could be regarded as the equivalent to Stage 2 testing in the test plan. Refer to the "Test Plan" section in the report for the operating conditions under different test phases.
- The highest influent flow tested at the end of Phase III testing was 10 gpm and Phase III testing was terminated on January 9, 2002, two days after the original end date of Stage 1 testing per December 2001 edition of test plan.
- Per the test plan, Stage 2 testing would be conducted in January 2002. However, Phase IV testing was conducted in both January and February 2002 due to the need to provide feed to the downstream MF unit.
- It was anticipated in the test plan that the highest influent flow that will be tested in Stage 2 would be 15 gpm. During the pilot testing, the highest influent flow tested was 14 gpm in Phase IV testing.

Changes to Stage 3 Testing – Additional Testing

- In the test plan, it was anticipated that if time allows, Stage 3 Testing – Additional Testing would be conducted in the last month of pilot testing. However, due to the requirement to feed BAF #2 effluent to the downstream unit, Stage 2 testing was extended into the last month of the pilot testing.
- Additional testing would include intermittent peak loading test, reduced air flow test, and idle test. Due to time limitation, only idle test was conducted.
- The test plan envisioned three idle tests. Only two idle tests were conducted in late February 2002 and early March 2002. Refer to report for details of idle tests.

King County Water Reuse Demonstration Project

Biological Aerated Filter Nitrification Test December 2001

The Biofor biological aerated filter for nitrification (BAF #2), manufactured by Ondeo Degrémont, is one of the eight treatment processes to be tested during the Demonstration Project. The demonstration testing facilities are configured to convey effluent from the Biofor for BOD removal (BAF #1) to BAF #2. The focus of the testing will be to evaluate the Biofor for nitrification. A separate test plan had been prepared for testing the BOD removal capability of Biofor using BAF #1.

In the initial test plan, it was anticipated that BAF #2 could be used in conjunction with BAF #1 to test for the denitrification capability in the last month of testing. It was anticipated that a portion of the nitrified effluent from BAF #2 would be recycled to the front end of BAF #2. An anoxic zone is formed by turning off part of the air supply in the front end of the filter for denitrification using methanol as a carbon source. However, according to the manufacturer, this may not be feasible for a number of reasons. First, all Biofor units are designed to have the aeration system at the bottom of the filter media. It would be physically impossible to turn off air to part of the media to form an anoxic zone for denitrification. Second, according to the manufacturer, the design philosophy behind Biofor is that denitrification, if needed, would be conducted in a stage separate from all other aerobic units (i.e. all BOD removal and nitrification units). Third, for best results, according to the manufacturer, a different type of filter media should be used for a denitrification unit.

Alternatively, BAF #1 could potentially be reconfigured to provide BOD removal and nitrification in one unit. BAF #2 could then be used to denitrifiy the effluent from BAF #1 using methanol as carbon source. However, to achieve both BOD removal and nitrification in BAF #1, it would require a significant lowering in the BOD loading to the unit. A high BOD loading to the unit would shift the population dynamics towards faster growing BOD removal heterotrophs and the slower growing nitrifiers would not be able to compete. Consequently, a lower flow rate to accommodate the nitrifiers may not provide sufficient flow to fully investigate the maximum hydraulic loading of a denitrification unit. Also, it would take 4 to 6 weeks (or more) to convert the biology in BAF #1 to perform nitrification. After the successful conversion of BAF #1, then the start up of BAF #2 for denitrification could proceed. It may take another 4 to 6 weeks (or more) before the biology of BAF #2 is ready for full post denitrification. There is not enough time available in the last month of testing for this alternative. Therefore, the option of testing denitrifcation capability of the Biofor would not be considered at this time.

Full Scale Plant Design Philosophy

Similar to a BOD removal only Biofor system, a full scale Biofor treatment process for nitrification would be designed with multiple cells. Each cell would be sized to operate at the optimum TSS, BOD, and NH_4^+ loading rate to promote growth of nitrifiers. The number of units in operation at any given time would be dependent on the total influent flow to the treatment plant. The number of cells in operation would be increased or decreased to match the flow so that the TSS, BOD, and NH_4^+ loading to each cell would remain relatively constant and optimum. Cells that are put in idle mode at any given time would be aerated intermittently (5 to 10 minutes per hour) to keep the unit aerobic. Idle cells would be cycled back into operation mode by alternating with active cells to limit the duration of inactivity. This will allow the biological activity to resume quickly in units that have been put into idle mode previously.

In order to collect sufficient data to facilitate full scale plant design, it is necessary to determine the maximum sustainable TSS, BOD, and NH_4^+ loading rate, the reaction of the BAF unit to intermittent peak loading, and the maximum duration of the idle mode without severely affecting the treatment efficiency when put back into operation. Of note, in a full scale plant design, the number of operating cells is proportional to influent flow. Therefore, the fluctuation in peak loading would be less than that seen in an activated sludge plant. Also, for reuse purpose, it is not necessary to design the system to handle all the primary or secondary effluent from a wastewater treatment plant. It would be possible to just treat a portion of the flow for reuse and discharge the rest without tertiary treatment. This would reduce the peak loading to the BAF treatment process. Therefore, the intermittent peak to be tested for reuse treatment would be lower than that of the intermittent peak for a regular wastewater treatment plant. The full scale reuse plant should be designed to handle the intermittent peak flow caused by one BAF unit taken offline for backwash. The rest of the remaining units in operation would have to handle the increased in flow that was originally handled by the unit in backwash mode. It was anticipated that the full scale unit would have four BAF units online during normal operation. Only one unit would be allowed to backwash at any given time. Therefore, the system should be designed to handle a 32% intermittent increase in flow.

Test Goals

Performance goals for BAF #2 are as follows:

- NH4 removal: >90% or less than 2 mg/L
- Effluent TSS: < 10 mg/L, 90th percentile
- Effluent BOD: <10 mg/L, 90th percentile
- Effluent turbidity: < 10 NTU, 90th percentile
- Backwash flow: < 8% of treated flow

The testing of BAF #2 would be dedicated to the following two objectives:

- What is the maximum sustainable TSS, BODs, and NH_4^+ loading rate to BAF #2?
- What is the response of BAF #2 to intermittent peak loading?
- What is the response of BAF #2 to reduced airflow?
- How long can the BAF unit be put into the idle cycle and return to full operation mode with little loss of treatment efficiency?

The stage 3 testing (intermittent peak loading test, reduced airflow test, and/or idle period test) of BAF #2 will coincide with stage 3 testing of BAF #1 and will take place after BAF #2 has been successfully started up. Depending on the time required to determine the maximum operational TSS, BODt, and NH_4^+ loading rate, the duration of testing of intermittent peak loading and idling cycle could be modified accordingly

Test Stages

There will be up to three stages in the evaluation. They are defined below.

Stage 1 – Start Up

The flow rate to BAF #2 would be initially set at a low value and gradually increased over 4 to 10 weeks to accommodate the gradual growth of the nitrifiers on the filter media.

Stage 2 – Determination of Maximum Sustainable TSS, BOD, and NH_4^+ Loading

After start up, the flow rate would be gradually increased to determine the maximum sustainable TSS, BOD, and NH_4^+ loading to the unit for nitrification.

The data collected would be used to develop the design criteria for a full scale nitrifcation BAF treatment system.

Stage 3 – Additional Testing

If time allows, this stage will be used to observe the reaction of the BAF process to intermittent peak loading condition, reduced airflow condition, and determination of idle period.

During the intermittent peak loading test, the online effluent turbidity meter would be used to provide an indication of the dynamic response of the process to intermittent peak loading.

During the reduced airflow condition test, the BAF would be operated at the maximum sustainable flow rate and the airflow to the unit would be gradually reduced to determine the lowest possible airflow without severely affecting treatment performance.

The idle period testing would be designed to determine how long a BAF unit could be left idle during a low flow situation and switched out of the idle mode quickly when flow increases. The PLC might have to be reprogrammed to provide automatic intermittent aeration to keep the unit aerobic.

The stage 3 tests of BAF #2 would coincide with the stage 3 tests of BAF #1.

Test Schedules, Conditions and Sampling

The test conditions and number of samples for laboratory analyses for the three proposed test stages are listed in Table 1. The proposed overall test schedule for BAF #1 and BAF #2 is shown in Table 2.

Sampling

- Influent – Sampler #6. Composite samples by automatic sampler
- Effluent – Sample #7. : Composite samples by automatic sampler
- Spent Backwash Water – Sample #7g. Grab sample only. Hand composite during backwash by taking three equal aliquots at start, midway, and at end of backwash cycle.

Other analytical and process parameters and frequency of measurements are as follows:

- Influent Turbidity (NTU) – twice a day
- Influent Temperature (^oC) – once a day
- Influent pH – once a day
- DO (mg/L) – once a day
- Effluent Turbidity (NTU) – twice a day
- Effluent Turbidity Flow (Lpm) – twice a day
- Effluent Temperature (^oC) – once a day
- Effluent pH – once a day
- Filter Differential Pressure (inH_2O) – twice a day
- Media Pressure (inH_2O) – twice a day
- Plenum Pressure (inH_2O) – twice a day
- Filter water Level (in) – twice a day
- Influent Flow (gpm) – twice a day
- Backwash Frequency
- Process Air Flow (scfm) – twice a day
- Filter Differential Pressure Before Backwash – once a day
- Filter Differential Pressure After Backwash – once a day

Test Conditions

Stage 1 – Start Up

BAF # 2 will initially receive a flow of 5 gpm from the effluent of BAF #1. This corresponds to a hydraulic loading rate (HLR) of 1.6 gpm/sf, a TSS, BODt, and NH_4^+ loading of 0.88, 0.88, and 0.25 kg/m^3 of filter media/day. The NH_4^+ loading is calculated assuming a NH_4^+ concentration of 10 mg/L in the BAF #1 effluent. The flow rate to BAF #2 would be gradually increased to 10 gpm (i.e. HLR of 3.2 gpm/sf) over a period of 4 to 10 weeks to allow the gradual growth of nitrifiers on the filter media.

Stage 2 – Determination of Maximum Sustainable TSS, BOD, and NH_4^+ Loading Rate

Gradually increase flow rate weekly from 10 gpm (i.e. HLR of 3.2 gpm/sf) until it reaches 12 gpm (i.e. HLR of 3.8 gpm/sf). The corresponding TSS, and BODt range from 1.77 to 2.12 kg/m^3 of filter media/day. The corresponding NH_4^+ loading ranges from 0.5to 0.61 kg/m^3 of filter media/day. Increase blower output in proportion per manufacturer suggestion. Increase the flow rate further to reach 15 gpm (i.e. HLR of 4.8 gpm/sf) if performance of BAF #2 allows. Nitrification is highly dependent on temperature. The full scale system should be designed using the lower nitrification rate in winter temperature.

Stage 3 – Additional Testing

In this test stage, three different groups of additional testing would be conducted depending on the available time. The three groups of tests are intermittent peak loading testing, reduced airflow testing, and idle period testing.

In the intermittent peak loading test, unless determined otherwise, increase the flow rate from the steady state value of 12 gpm (i.e. TSS and BODt loading of 2.12 kg/m^3 of filter media/day and NH_4^+ loading of 0.5 kg/m^3 of filter media/day) to 15.8 gpm (i.e. TSS and BODt loading of 2.79 kg/m^3 of filter media/day and NH_4^+ loading of 0.8 kg/m^3 of filter media/day) and sustain the peak loading rate for four hours. The online turbidimeter would be used to monitor the dynamic response of the process to peak loading. After the peak testing period, the flow rate would be resumed back to the original value for a day until the next period of testing. Take effluent samples during steady state for base line performance info and during peak loading period to capture the peak turbidity. A total of three intermittent peak loading tests per week should be conducted.

In the reduced airflow test, the BAF would be operated at flow rate of 12 gpm (unless determined otherwise) and an airflow to be determined. The airflow would be reduced twice a week while keeping the influent flow at 12 gpm. Samples will be taken daily to monitor the performance of the system at different airflow and evaluate the lowest airflow required to maintain treatment performance.

In the idle period test, the pilot unit would be left idle for some period of time and then resumed back to operation for some period of time. If time allows, three sets of idle period test could be conducted. In the first two sets of tests, the filter will run for one day, followed by a one day of idle period, and then run for another day after the idle period. In the third set of test, the unit would be allowed to run for two days, followed by two days of idle period and then run for another two days after the idle period. Samples for each parameter (Inf CODt, Inf TSS, Inf NH_4^+, In Alk, Eff CODt, Eff TSS, Eff NH_4^+, Eff NO_3^-, Eff Alk, Backwash TSS) will be collected during the active run as base line performance info. Up to 3 sets of hourly samples per parameter would be collected during start up after each idle period to monitor the time for the biological treatment activity to resume back to target efficiency. There should be a backwash before the unit is put into idle mode.

The stage 3 tests for BAF #1 should coincide with the stage 3 tests for BAF #2.

CONTACTS

Since this testing is occurring in a very brief period, and many test conditions will be evaluated, it is important to maintain frequent, if not daily communications between the USFilter operators and staff, King County and the consultant team (HDR and Black & Veatch). The following is a list of the project team members.

King County

Bob Bucher
206-263-3883, bob.bucher@metrokc.gov

John Smyth
206-684-1774, john.smyth@metrokc.gov

HDR

JB Neethling
916-351-3830, jneethli@hdrinc.com

Mike Norton
425-450-6250, mnorton@hdrinc.com

Kenneth Hui
425-450-6236, khui@hdrinc.com

Black & Veatch

Cindy Wallis-Lage
913-458-3603, wallis-lagecl@bv.com

Ondeo Degrémont

Steve Tarallo
804-756-7761

Sudhakar
804-521-7474, Cell 804-240-4235

It is essential that the project team hold frequent conference calls as needed. Bob Bucher will coordinate the calls. At a minimum, they will include Steve Tarallo and/or Sudhakar from Ondeo Degrémont and JB Neethling or Kenneth Hui, HDR.

Table 1. Proposed Sampling Plan for Laboratory Analyses

	Flow Rate (gpm)	TSS Loading ($kg/m^3/d$)	BOD Loading ($kg/m^3/d$)	NH_4^+ Loading ($kg/m^3/d$)	Hydraulic Loading Rate (gpm/sf)	Influent								Effluent									BAF Backwash
						BODt	BODs	CODt	CODs	TKN	NH_4^+	Alk	TSS	BODt	BODs	CODt	CODs	TKN	NH_4^+	NO_3^-	Alk	TSS	TSS
Stage 1 Start Up (May be affected to Optional BAF #1 Stage 2b Test with Densedeg is conducted)																							
Week 1-11: 10/22/01 - 1/4/02						Note 1	Note 1	Note 1	Note 1	1	3	3	Note 1	1	1	3	3	1	3	3	3	3	1
Initial Flow	5	0.88	0.88	0.25	1.6																		
Target Flow	10	1.77	1.77	0.50	3.2																		
Stage 2 Determination of Maximum Sustainable TSS, BOD, and NH_4^+ Loading (Unless determined otherwise, BAF #1 will be operated at a flow rate of 19 gpm consistently)																							
Week 12: 1/7/02 - 1/11/02	12	2.12	2.12	0.61	3.8	Note 1	Note 1	2[Note 2]	2[Note 2]	1	3	3	2[Note 2]	1	1	3	3	1	3	3	3	3	1
Week 13: 1/14/02 - 1/18/02	13	2.30	2.30	0.66	4.1	Note 1	Note 1	2[Note 2]	2[Note 2]	1	3	3	2[Note 2]	1	1	3	3	1	3	3	3	3	1
Week 14: 1/21/02 - 1/25/02	14	2.47	2.47	0.71	4.5	Note 1	Note 1	2[Note 2]	2[Note 2]	1	3	3	2[Note 2]	1	1	3	3	1	3	3	3	3	1
Week 15: 1/28/02 - 2/1/02	15	2.65	2.65	0.76	4.8	Note 1	Note 1	2[Note 2]	2[Note 2]	1	3	3	2[Note 2]	1	1	3	3	1	3	3	3	3	1
Stage 3 Additional Testing (Exact Timing to be Determined)																							
Week 16: 2/4/02 - 2/8/02																							
Intermittent Peak Loading Test						Note 1	Note 1	Note 1	Note 1	2/test	2/test	2/test	Note 1	2/test	2/test	2/test	2/test	2/test	2/test	2/test	2/test	2/test	1/test
Steady State Flow	12	2.12	2.12	0.61	3.8																		
Peak Flow Condition	15.8	2.79	2.79	0.80	5.0																		
Week 17: 2/11/02 - 2/15/02																							
Reduced Airflow Test						Note 1	Note 1	Note 1	Note 1	3	3	3	Note 1	3	3	3	3	3	3	3	3	3	3
Airflow Range to be Determined	12	2.12	2.12	0.61	3.8																		
Week 18: 2/18/02 - 2/22/02 (Resume Operation on Tue 2/26/02)																							
Idle Period Test																							
Active Period (1, 2 days)	12	2.12	2.12	0.61	3.8	Note 1	Note 1	Note 1	Note 1	1	1	1	Note 1	1	1	1	1	1	1	1	1	1	1
Idle Period (1, 2 days)	0	0.00	0.00	0.00	0.0																		
Resume Operation	12	2.12	2.12	0.61	3.8	Note 1	Note 1	Note 1	Note 1	1	3	3	Note 1	3	3	3	3	1	3	3	3	3	

Note 1: Shares the same sample with BAF #1 effluent.

Note 2: Number of samples to be taken on top of BAF #1 effluent samples

Influent Assumptions

TSS = 35 mg/l

BOD = 35 mg/l

NH_4^+ = 10 mg/l

Table 2: Overall Schedule for BAF #1 and BAF #2

Week Beginning		10/1/2001	10/8/2001	10/15/2001	10/22/2001	10/29/2001	11/5/2001	11/12/2001	11/19/2001	11/26/2001	12/3/2001	12/10/2001	12/17/2001	12/24/2001	12/31/2001	1/7/2002	1/14/2002	1/21/2002	1/28/2002	2/4/2002	2/11/2002	2/18/2002	2/25/2002
BAF #1 Week #		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
BAF #1		Stage 1	Stage 2									Steady Run at 23 gpm								Stage 3 (To be Determined)			
BAF #1 Alternate Schedule		Stage 1	Stage 2				Stage 2b					Steady Run at 23 gpm								Stage 3 (To be Determined)			
BAF #2					Stage 1											Stage 2				Stage 3 (To be Determined)			
BAF # 2 Week #					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

BAF # 1 Schedule

Stage 1 - Determination of Maximum BOD_t Loading

Stage 2 - Class A Demonstration with Primary Effluent

Stage 2b - Class A Demonstration with Densedeg Effluent

Stage 3 - Additonal Testing (Intermittent Peak Loading, Reduced Airflow, and Idle Period)

BAF #2 Schedule

Stage 1 - Start Up

Stage 2 - Determinaton of Maximum TSS, BOD, NH_4^+ Loading

Stage 3 - Additonal Testing (Intermittent Peak Loading, Reduced Airflow, and Idle Period)

Date	Comments (ODS)	Comments (Log Book)	Comments (Weekly Report)
10/11/2001		Pilot unit arrived and offloaded by Shinn mech and West Point Maintenance Staff (WP crane used for locating pilot). Pilot anchored on existing conrete tank pad next to contractor trailer.	
10/12/2001		Shinn Mech and Prim elec completed install of pilot unit. Several hoses on back order… expect early next week. Storage tank 1 piping increased from 2 inches to 3 inches to supply to BAF1.	
10/13/2001		Shinn Mech and Prim elec completed install of pilot unit. Several hoses on back order… expect early next week. Storage tank 1 piping increased from 2 inches to 3 inches to supply to BAF1.	
10/14/2001		Shinn Mech and Prim elec completed install of pilot unit. Several hoses on back order… expect early next week. Storage tank 1 piping increased from 2 inches to 3 inches to supply to BAF1.	
10/15/2001		Shinn Mech and Prim elec completed install of pilot unit. Several hoses on back order… expect early next week. Storage tank 1 piping increased from 2 inches to 3 inches to supply to BAF1.	
10/16/2001		Shinn Mech and Prim elec completed install of pilot unit. Several hoses on back order… expect early next week. Storage tank 1 piping increased from 2 inches to 3 inches to supply to BAF1.	
10/17/2001		Shinn Mech and Prim elec completed install of pilot unit. Several hoses on back order… expect early next week. Storage tank 1 piping increased from 2 inches to 3 inches to supply to BAF1.	
10/18/2001		Shinn Mech and Prim elec completed install of pilot unit. Several hoses on back order… expect early next week. Storage tank 1 piping increased from 2 inches to 3 inches to supply to BAF1.	
10/19/2001		Shinn Mech and Prim elec completed install of pilot unit. Several hoses on back order… expect early next week. Storage tank 1 piping increased from 2 inches to 3 inches to supply to BAF1.	
10/20/2001		No comments.	
10/21/2001		No comments.	
10/22/2001		No comments.	
10/23/2001		No comments.	
10/24/2001		No comments.	
10/25/2001		Unit loaded with media. Approximately 1 bag of media consumed. Filled reactor with C2 water and will allow to soak over weekend.	
10/26/2001		No comments.	
10/27/2001		No comments.	
10/28/2001		No comments.	
10/29/2001		No comments.	
10/30/2001		All backordered hoses installed and unit checked out by Ondeo. Portland Engs (Francis) onsite to connect skid to DH+ network. Successfully checked out.	
10/31/2001		No comments.	
11/1/2001		At 1300 hrs unit strted up at following conditions: feed flow of 6.0 gpm; aeration flow of 6.0 scfm; wash interval of 72 hrs. Provided training on operator interface screen. Minimal graphics with simplified setpoint configuration. Aeration flow is only parameter requiring manual input in control loop. Still need to plumb effluent turbidity and sampler overflow bucket.	
11/2/2001		Continued operation under following conditions of feed flow of 6 gpm and aeration of 6 scfm.	
11/3/2001		Continued operation under following conditions of feed flow of 6 gpm and aeration of 6 scfm.	
11/4/2001		Continued operation under following conditions of feed flow of 6 gpm and aeration of 6 scfm.	
11/5/2001		Continued operation under following conditions of feed flow of 6 gpm and aeration of 6 scfm. Conference call with Ondeo, HDR and KC to discuss operation. Highlights include 20-40 gpm, assuming 12 mg/L NH4-N loading, will run 2-3 weeks at 6 gpm, then increased 1 gpm/week.	
11/6/2001	Loss of flow in evening due to BAF1 shutdown at 2000 hrs in aborted backwash.	Continued operation under following conditions of feed flow of 6 gpm and aeration of 6 scfm.	
11/7/2001	Shutdown, storage tank 1 empty.	Loss of flow to unit throughout day due to low storage tank 1 level. Aeration air maintained. Ondeo adjusted wash cycle time from 4,320 to 6000 minutes (to 100 hrs) to minimize potential for wasting out biomass during inconsistent feed flow conditions.	

Date	Comments (ODS)	Comments (Log Book)	Comments (Weekly Report)
11/8/2001	Flow secured with drain of storage tank 2.	No flow throughout day due to storage tank 1 cleaning. Aeration air maintained.	
11/9/2001	Secured until 11/10/01.	Flow reinitiated to unit.	
11/10/2001	At 0842 hrs reinitiated flow to unit from storage tank 1. At 0903 hrs restarted unit at operator screen, influent pump to auto, raw water pump in auto.	No comments.	
11/11/2001	No data recorded.	No comments.	
11/12/2001		No comments.	
11/13/2001	At 1027 accumulated time to backwash [min] 4405.	No comments.	
11/14/2001	At 0905 accumulated time to backwash [min] 5764. At 0918 accumulated time to backwash 1176.	Completed install of effluent sampler overflow bucket.	
11/15/2001	No feed flow during storage tank 1 cleaning from 0800 to 1700 hrs.	Plumbed effluent turbidity water. Turbidity measurement is now active. From 0700 to 1400 hrs loss of feed flow to unit during storage tank 1 cleaning.	
11/16/2001		No comments.	
11/17/2001		No comments.	
11/18/2001	At 1301 hrs still no flow to unit.	At 0845 hrs loss of feed flow discovered due to BAF1 shutdown. Expect flow lost since early morning.	
11/19/2001	At 0905 hrs BAF2 started up - no flow to turbidimeter yet.	Vendor forgot to restart unit; reestablished flow at approximately 0830 hrs.	
11/20/2001		No comments.	
11/21/2001	Cleaned skid fine screen.	At 0610 hrs low flow to unit "momentarily". Restarted unit from operator interface.	
11/22/2001		No comments.	
11/23/2001		No comments.	
11/24/2001		No comments.	
11/25/2001	No flow to turbidimeter.	No comments.	
11/26/2001	Set up and started autosampler at 1330 hrs.	No comments.	
11/27/2001	At 0929 hrs noted unit in ABSHTDN (abnormal shutdown) - cycled for the 3rd time (estimated) timer.	Unit was in abnormal shutdown (ABSHTDN) and was in low feed cycle. Clean the screen and increase flow to unit.	
11/28/2001	Noted at 1550 hrs that the air flow meter has water in it. Control valve closed - open CV 12% to get air flow ot 5 scfm.	At 1110 hrs unit was in stand-by mode. Earlier the unit received no flow, since BAF1 went into idle last night. When flow to BAF2 was resumed, restarted the unit at 1110 hrs. At 1600 hrs reestablished flow to turbidimeter. Air flow bleed valve was closed - turned it back on 12% on (PDI control, diff pressure" menu, air flow now 5 scfm.	
11/29/2001		No comments.	
11/30/2001	At 0817 hrs process air flow loop = changed CV % open from 12 to 11%.	No comments.	
12/1/2001		No comments.	
12/2/2001		No comments.	
12/3/2001		Cleaned skid fine screen. Cleaned turbidimeter and rotometer at 0930 hrs.	
12/4/2001		No comments.	
12/5/2001		No comments.	
12/6/2001		Clean the fine screen. At 15:52 hrs, increase flow from 6 gpm to 8 gpm. Air flow was less than 6 scfm (5 scfm), adjust to 6 scfm by decrease air CV from 11 to 9%.	
12/7/2001		Air flow too high (9 scfm) adjusted cv to 10%. Backwash pump tripped, unit shut itself down and re-started itself??? Influent flow was 24.5 gpm- the CV was 0% . Shut the unit down and re-started manually. Flow re-stabilized at 8 gpm, air flow 5.5 scfm.	
12/8/2001		No comments.	
12/9/2001		No comments.	
12/10/2001		No comments.	
12/11/2001		No comments.	
12/12/2001		No comments.	
12/13/2001		Air flow rate was 4 scfm. Adjusted air CV to 8%, flow increased to 6.5 scfm.	
12/14/2001		At 9:15 hrs loss of flow to unit due to BAF 1 shut down last evening at 22:56 hrs. Unit continued running, suspect stuck feed float switch. At 14:15 hrs, re-started BAF2 unit- flow across feed screen. At 16:00 hrs, cleaned turbidimeter. Cleaned overflow weir on top of pilot unit.	
12/15/2001		At 16:00 hrs, shift crew (Reymond) called to inform that unit was shutdown due to high headloss. Informed Reymond to leave unit as-is until tomorrow morning. Program setup to idle-aeration on for 5 min/1 hr.	
12/16/2001		At 9:45 hrs, restarted unit and adjusted the following: a)bled air from high side of differential pressure transducer was displaying -0.7 inch H_2O, b) adjust aeration flow by change PID CI from 8 to 11% Air flow was close to 9 scfm before change.	
12/17/2001		No comments.	

Date	Comments (ODS)	Comments (Log Book)	Comments (Weekly Report)
12/18/2001		At 12:25 hrs, changed the flowrate from 8 gpm to 10 gpm. Adjusted air flowrate from 4 to 6 scfm. Changed BW frequency from 100 hrs to 72 hrs. Backwas acc. Clock was resetted to zero at 12:35 due to the unit shut down during parameters changing. At 14:13 hrs, performed energetic BW.	
12/19/2001		At 14:30 hrs, discovered unit cycling on/off. Suspected lack of feed flow. Performed the following: restarted unit (switch off/on); cleaned feed screen; adjusted feed ball valve next to the screen fully open.	
12/20/2001		At 7:30 hrs, noticed no flow to sample overflow bucket during sample collection. Found flow to turbidimeter directly connected to the turbidimeter, bypassing rotometer.	
12/21/2001		Cleaned skid screen. Cleaned turbidimeter suction line at 13:15 hrs, established flow.	
12/22/2001		No comments.	
12/23/2001		No comments.	
12/24/2001		No comments.	
12/25/2001		No comments.	
12/26/2001		No comments.	
12/27/2001		At 12:15 hrs, restarted the unit by cycling on and off. Suspect lake of water in feed through . Cleaned feed screen. At 12:30 hrs, cleaned effluent turbidimeter and sample overflow bucket.	
12/28/2001		Cleaned feed screen	
12/29/2001		No comments.	
12/30/2001		No comments.	
12/31/2001		No comments.	
1/1/2002		No comments.	
1/2/2002		At 14:00 hrs, troubleshooting cycling of pilot unit. Talked with Ondeo- suggested bleeding sense line to pressure diff transmitter. Potentially air in senseline is causing high pressure diff,, which triggers backwash. This would account for high headloss alarms recorded @ following times: 12/31, 15:28 hrs. At 14:07nhrs, nbled pressure diff. transmitter senseline.	
1/3/2002		No comments.	
1/4/2002		No comments.	
1/5/2002		No comments.	
1/6/2002		No comments.	
1/7/2002		No comments.	
1/8/2002		At 16:30 hrs, reconfigured pilot hosing (discharge) to fill ST2. Storage tank 2 is now in service.	
1/9/2002		No comments.	
1/10/2002		At 12:25 hrs, decreased BW frequency from every 72 hrs to 48 hours (2880 min). Increased flow to 12 gpm. Re-setted BW acc clock to zero, resetted unit (off/on). Adjusted air flow- CV from 8% to 7%.	
1/11/2002		No comments.	
1/12/2002		No comments.	
1/13/2002		No comments.	
1/14/2002		Lab not getting enough sample for all analyses. Requested more than 2 L. Need lots of volume for TKN. Put a new 8 L bottle in autosampler. Decanted from existing 2 L bottle to 8 L bottle. Reset F1 from 190 to 260, vol increase from 80 to 140 mL/sample. Increase P1 from 194 to 265. 12:30- first sample of larger volume.	
1/15/2002		No comments.	
1/16/2002		No comments.	
1/17/2002	At 9:20 hrs, cleaned turbidimeter	No comments.	
1/18/2002	Cleaned skid screen. At 13:30, adjusted control valve in air flow loop from 7% to 8%. At 15:30 hrs, found air flow = 4 scfm, therefore, adjusted CV back to 7%- air flow rate was 7 scfm. At 20:19 hrs, no flow over screen. AT 20:45, still no flow, 12 gpm. At 21:52 hrs, flow over screen 12 gpm.	No comments.	
1/19/2002		No comments.	
1/20/2002	Put unit in standbyuntil storage tank 1 level increased. BAF1 out of service since 3:20 hrs.	At 11:00 hrs, unit placed in standby until storage tank 1 level increase (See BAF1 log- unit out of service for several hours). Unit found running with no feed flow. Sespect feed trough float switch "hung-up". Will troubleshoot later. At 16:35 hrs, restarted BAF2.	
1/21/2002		No comments.	
1/22/2002		At 15:45 hrs, cleaned effluent turbidimeter and started S1 sampler.	

Date	Comments (ODS)	Comments (Log Book)	Comments (Weekly Report)
1/23/2002		At 10:00 hrs, Unit lost flow (for how long?). Feed pump wasn't operating. Stopped and restarted the unit. Adjusted air control valve from 7 to 8%.	
1/24/2002		At 16:00 hrs, connecyted final hose from storage tank 2 to FP2 suction side. Lleft DV-20 closed until ready to feed MF.	
1/25/2002		At 16:40 hrs, changed influent flow from 12 to 14 gpm	
1/26/2002		No comments.	
1/27/2002		No comments.	
1/28/2002		At 10:30 hrs, changed air CV from 8 to 9%.	
1/29/2002		No comments.	
1/30/2002		No comments.	
1/31/2002		No comments.	
2/1/2002	Cleaned skid screen and overflow bucket.	At 15:40 hrs, cleared line to effluent turbidimeter. No flow noted @ overflow	
2/2/2002		No comments.	
2/3/2002		At 11:00 to 12:00 hrs, cleaned effluent turbidimeter and sampler overflow bucket.	
2/4/2002		No comments.	
2/5/2002	At 11:50 cleaned skid screen. Influent flow was fluctuating between 5-20 gpm- unit still adjusting flow post bw. Wait for the flow to stabilize at 14 gpm and adjusted overflow rate to 1.5 gpm.	At 11:40 hrs, reduced BAF 2 overflow from 6 to 1.5 gpm. Flushed BW tank	
2/6/2002		At 9:00 hrs, only get 6 gpm feed flow, eventhough the set point was 14 gpm. CV was 100% opened. The feed was fluctuating from 0 to 25 gpm. At 15:00 hrs, found out that the control valve between the BW tank and feed pump was stuck opened. This allowed the mixing of the feed and BW water. Trid isolating BW tank by closing hand valve- left the unit to stabilize for an hour, but the flow would not stabilized. Stopped the unit for trouble shooting and cleaning the flow meter. Concluded that it was the instrument malfunction, Sudhakar (Ondeo) will order new parts. Started the unit back up.	
2/7/2002		At 9:00 hrs, the flow still fluctuating.	
2/8/2002		At 16:00 hrs, unit back in service with "steady" feed flowrate. Unit had been in IDLE for several hours this afternoon. Cleaned influeint feed screen box and check flow meter again. Not sure which solved the problem. Pump may have been cavitating due to clogged suction line??? At 16:10 hrs, cleaned turbidimeter.	
2/9/2002		No comments.	
2/10/2002		From 12:45 to 13:00 hrs, cleaned turbidimeter and sample overflow bucket. At 12:55 hrs, adjusted process air flow control loop. Was running at 14 scfm with cv = 0%. Resetted to achieve 7.5 scfm with cv= 6%.	
2/11/2002		No comments.	
2/12/2002		No comments.	
2/13/2002		No comments.	
2/14/2002		At 12:00, initiated energetic BW. Cleaned eff sample line and effluent turbidimeter	
2/15/2002		No comments.	
2/16/2002		No comments.	
2/17/2002		No comments.	
2/18/2002		No comments.	
2/19/2002		From 15:15 to 15:45 hrs, cleaned effluent turbidimeter and overflow bucket.	
2/20/2002		At 14:40 hrs, foam spilling out of the open pipe connected to the drain pipe (below the diff. Pressure meter) during BW cycle. From 18:10 to 18:25 hrs, cleaned the effluent turbidimeter.	
2/21/2002		No comments.	
2/22/2002		No comments.	
2/23/2002		No comments.	
2/24/2002		Around 15:15 hrs, cleaned the effluent turbidimeter. Noticed excess solides in sample overflow bucket. May want to investigate further.	
2/25/2002		No comments.	
2/26/2002		No comments.	

Date	Comments (ODS)	Comments (Log Book)	Comments (Weekly Report)
2/27/2002		1) At 13:00 hrs, attempted to put the unit into idle. After selecting "standby" from the filter status menu, the pump (inf) stopped briefly, th4en started up again. The sandby sequence screen didn't show that the unit was proceeding through stanby steps. 2) Tried shutting the unit down before selecting standby, didn't work either. 3) Misc timer didn't start counting (filtration or standby). 3) At 13:30 tried turning the feed off, hoping that the unit will go into standby. The unit shut itself down but went into BW. 4) Called Sudhakar, was told that the standby timer needed to be set-- couldn't find that menu- Sudhakar will contact the programmer. 5) Turned the influent pump off, let the air blower on-- not the normal standby condition, but shouldn't make much difference.	
2/28/2002		At 14:00 hrs, attempted to start the unit back up. However, the storage tank which feeds the unit had drained out due to a valve left opened. Closed the valve and let the unit fill up overnight, will resume the test tomorrow.	
3/1/2002		At 10:30, started the unit up. Noticed that the media had dried up. It tokk about 10 min. for the water to fill up to the weir. The water was very turbid, lots of solid. Constant aeration must have dried up the media. Cosulted vendor. Troy (Ondeo) suggested that the air can be turned down to 2-3 scfm. At 16:00 hrs, put the unit in idle by turning off the influent pump and reducing the air flow to about 2-3 scfm.	
3/2/2002		Unit in idle	
3/3/2002		Unit in idle	
3/4/2002		Around 11:00 hrs, started the unit back up. The water on top of the media had dried out again, but probably just the surface. Once the unit started, it took less than a minute for the water to appear on to of the media. The test was finished around 13:00 hrs. The unit was put into backwash twice.	
3/5/2002		The backwash tank was cleaned and filled up with clean water. Another backwash was initiated.	
3/6/2002		The unit was drained and the screen was rinsed.	

Trend Plots and Phase Summaries

This appendix contains summaries of the pilot testing and presents the data from the different test phases. The following items are shown:

- Performance tables for the various process components – for the overall testing and each individual test phase.
- Trend plots of the operational data
- Correlations of influent and effluent, as well as effluent quality versus loading rate.

Table 1. Overall Performance Summary (October 22, 2001 to February 27, 2002)

	Minimum	Average	Maximum	Standard Deviation	90th Percentile[1]	Target
Influent BODt, mg/L	14.0	26.7	53.0	9.6	39.4	NA
Effluent BODt, mg/L	3.0	6.7	12.0	2.4	9.8	<10.0 (90th Percentile)
BODt Loading[2], lb/kcf/d	26.4	92.3	190.7	43.8	>46.8 for 90% of the time	NA
Influent TSS, mg/L	4.0	21.4	50.0	9.6	33.9	NA
Effluent TSS, mg/L	1.0	7.9	25.0	4.9	14.0	<10.0 (90th Percentile)
TSS Loading[3], lb/kcf/d	7.5	71.7	185.4	42.2	>30.7 for 90% of the time	NA
Influent NH4-N, mg/L	0.30	7.15	20.00	5.00	13.19	NA
Effluent NH4-N, mg/L	0.01	0.34	2.60	0.56	0.76	<2
NH4-N Removal	77%	94%	100%	6%	>86% for 90% of the time; >90% for 75% of the time	>90%
NH4-N Loading[4], lb/kcf/d	0.6	20.0	58.9	16.2	>6.3 for 90% of the time	NA
Influent NO3-N, mg/L	0.2	2.1	3.9	0.8	3.1	NA
Effluent NO3-N, mg/L	1.7	9.1	14.1	2.6	12.4	NA
Influent Alkalinity[7], mg/L $CaCO_3$	33.0	92.7	208.0	37.1	139.0	NA
Effluent Alkalinity, mg/L $CaCO_3$	32.0	48.3	63.0	7.5	58.0	NA
Influent pH	No Data	No Data	No Data	No Data	No Data	NA
Effluent pH	4.1	6.8	7.2	0.5	7.1[6]	NA
Influent Turbidity, NTU	6.5	6.9	7.2	0.1	7.1	NA
Effluent Turbidity, NTU	0.6	3.0	7.7	1.5	4.9	<10.0 (90th Percentile)
Temperature, ^{O}C	6.7	11.2	14.6	1.6	>9.3 for 90% of the time	NA

[1] Projected log normal values

[2] Ondeo maximum design BODt loading of 188 lb/kcf/d

[3] Ondeo maximum design TSS loading of 188 lb/kcf/d

[4] Ondeo maximum design NH4-N loading of 100 lb/kcf/d

[5] NH4-N data on 12/16/2001, TSS data on 2/6/2002, and BODt data on 2/7/2002 were not included in statistical analyses. Effluent concentrations of the various parameters were larger than the influent concentrations.

[6] Due to small sample size, projected log normal values larger than maximum value in sample set. Projected actual data range used instead.

[7] On 2/7/02, influent alkalinity was recorded as 24 mg/L $CaCO_3$ while the effluent alkalinity was recorded as 63 mg/L $CaCO_3$. There was no influent NH4-N data and no pH data. The effluent NH4-N data was 0.53 mg/L. We speculated that the influent and effluent alkalinity had been switched accidentally and the alkalinity data points on this day were excluded from the statistical analysis.

Table 2. Phase IIA Performance Summary

	Minimum	Average	Maximum	Standard Deviation	90th Percentile[1]	Target
Influent BODt, mg/L	14.0	20.5	33.0	8.6	31.7	NA
Effluent BODt, mg/L	4.0	5.5	7.0	2.1	8.3	<10.0 (90th Percentile)
BODt Loading[2], lb/kcf/d	26.4	36.9	54.0	12.3	>27.4 for 90% of the time[5]	NA
Influent TSS, mg/L	4.0	16.1	50.0	12.4	30.6	NA
Effluent TSS, mg/L	1.0	6.9	23.0	7.1	14.3	<10.0 (90th Percentile)
TSS Loading[3], lb/kcf/d	7.5	25.7	71.1	15.9	>10.6 for 90% of the time	NA
Influent NH4-N, mg/L	0.30	4.41	20.00	5.75	9.63	NA
Effluent NH4-N, mg/L	0.03	0.15	0.40	0.13	0.29	<2
NH4-N Removal	89%	94%	99%	4%	>89% for 90% of the time[5]; >90% for 75% of the time[5]	>90%
NH4-N Loading[4], lb/kcf/d	0.6	5.4	17.2	5.0	>1.4 for 90% of the time	NA
Influent NO3-N, mg/L	1.2	2.1	3.0	0.6	2.8	NA
Effluent NO3-N, mg/L	5.5	9.0	14.1	3.1	13.0	NA
Influent Alkalinity, mg/L $CaCO_3$	41.0	78.3	172.0	40.1	129.7	NA
Effluent Alkalinity, mg/L $CaCO_3$	44.0	46.7	56.0	4.7	52.7	NA
Influent pH	No Data	No Data	No Data	No Data	No Data	NA
Effluent pH	6.8	7.0	7.2	0.2	7.2	NA
Influent Turbidity, NTU	6.5	6.8	7.2	0.2	7.1	NA
Effluent Turbidity, NTU	1.3	2.2	5.2	1.0	3.5	<10.0 (90th Percentile)
Temperature, ^{O}C	10.6	12.4	14.6	1.5	>10.6 for 90% of the time	NA

[1] Projected log normal values

[2] Ondeo maximum design BODt loading of 188 lb/kcf/d

[3] Ondeo maximum design TSS loading of 188 lb/kcf/d

[4] Ondeo maximum design NH4-N loading of 100 lb/kcf/d

[5] Due to small sample size, projected log normal values less than minimum value in sample set. Projected value with actual data range used instead.

Table 3. Phase IIB Performance Summary

	Minimum	Average	Maximum	Standard Deviation	90^{th} Percentile[1]	Target
Influent BODt, mg/L	14.0	21.2	37.0	9.0	32.9	NA
Effluent BODt, mg/L	5.0	6.6	8.0	1.1	8.1	<10.0 (90^{th} Percentile)
BODt Loading[2], lb/kcf/d	35.3	54.3	99.9	26.1	>37.1 for 90% of the time[5]	NA
Influent TSS, mg/L	11.0	19.0	35.0	8.3	29.7	NA
Effluent TSS, mg/L	2.0	5.0	8.0	2.1	7.8	<10.0 (90^{th} Percentile)
TSS Loading[3], lb/kcf/d	27.6	48.2	77.6	19.0	>28.5 for 90% of the time[5]	NA
Influent NH4-N, mg/L	1.45	4.82	6.70	2.92	8.44	NA
Effluent NH4-N, mg/L	0.13	0.20	0.30	0.09	0.31	<2
NH4-N Removal	88%	94%	98%	5%	>90% for 90% of the time[5]	>90%
NH4-N Loading[4], lb/kcf/d	3.8	12.8	18.1	7.9	>5.3 for 90% of the time	NA
Influent NO3-N, mg/L	1.7	2.0	2.5	0.4	2.5	NA
Effluent NO3-N, mg/L	4.6	7.6	10.1	2.5	9.8[5]	NA
Influent Alkalinity, mg/L $CaCO_3$	33.0	66.8	104.0	30.6	99.6[5]	NA
Effluent Alkalinity, mg/L $CaCO_3$	41.0	45.0	49.0	4.0	48.2[5]	NA
Influent pH	No Data	No Data	No Data	No Data	No Data	NA
Effluent pH	6.8	6.9	7.1	0.1	7.1	NA
Influent Turbidity, NTU	6.7	6.9	7.2	0.2	7.1	NA
Effluent Turbidity, NTU	0.6	2.1	3.4	0.9	3.2	<10.0 (90^{th} Percentile)
Temperature, ^{O}C	6.7	10.6	13.0	2.8	>7.4 for 90% of the time	NA

[1] Projected log normal values

[2] Ondeo maximum design BODt loading of 188 lb/kcf/d

[3] Ondeo maximum design TSS loading of 188 lb/kcf/d

[4] Ondeo maximum design NH4-N loading of 100 lb/kcf/d

[5] Due to small sample size, projected log normal values less than minimum value in sample set or larger than the maximum value in the sample set. Projected value with actual data range used instead.

[6] NH4-N data on 12/16/2001 was not included in statistical analyses. Effluent concentration of NH4-N was larger than the influent concentration.

Table 4. Phase III Performance Summary

	Minimum	Average	Maximum	Standard Deviation	90th Percentile[1]	Target
Influent BODt, mg/L	26.0	32.0	53.0	10.6	45.6	NA
Effluent BODt, mg/L	8.0	8.6	9.0	0.6	9.3	<10.0 (90th Percentile)
BODt Loading[2], lb/kcf/d	85.2	108.3	185.1	38.4	>86.5 for 90% of the time[5]	NA
Influent TSS, mg/L	14.0	24.1	40.0	6.7	32.9	NA
Effluent TSS, mg/L	4.0	8.7	12.0	2.3	11.7	<10.0 (90th Percentile)
TSS Loading[3], lb/kcf/d	48.7	81.1	139.7	23.8	>53.8 for 90% of the time	NA
Influent NH4-N, mg/L	0.67	4.38	8.50	3.37	8.32	NA
Effluent NH4-N, mg/L	0.01	0.23	0.73	0.30	0.49	<2
NH4-N Removal	89%	95%	100%	4%	>89% for 90% of the time; >90% for 85% of the time	>90%
NH4-N Loading[4], lb/kcf/d	2.2	14.9	29.4	11.6	>4.9 for 90% of the time	NA
Influent NO3-N, mg/L	1.1	2.3	3.9	1.0	3.6	NA
Effluent NO3-N, mg/L	1.7	8.3	11.1	2.8	10.7	NA
Influent Alkalinity, mg/L $CaCO_3$	41.0	87.9	119.0	30.7	117.6[5]	NA
Effluent Alkalinity, mg/L $CaCO_3$	37.0	50.5	63.0	8.8	61.7	NA
Influent pH	No data	No Data	No Data	No Data	No Data	NA
Effluent pH	6.5	6.9	7.2	0.2	7.2	NA
Influent Turbidity, NTU	6.7	6.9	7.0	0.1	7.0	NA
Effluent Turbidity, NTU	1.9	2.8	4.2	0.6	3.7	<10.0 (90th Percentile)
Temperature, ^{O}C	10.3	11.6	12.3	0.8	>10.5 for 90% of the time	NA

[1] Projected log normal values

[2] Ondeo maximum design BODt loading of 188 lb/kcf/d

[3] Ondeo maximum design TSS loading of 188 lb/kcf/d

[4] Ondeo maximum design NH4-N loading of 100 lb/kcf/d

[5] Due to small sample size, projected log normal values less than minimum value in sample set or larger than the maximum value in sample set. Projected value with actual data range used instead.

Table 5. Phase IVA Performance Summary

	Minimum	Average	Maximum	Standard Deviation	90th Percentile[1]	Target
Influent BODt, mg/L	24.0	34.8	50.0	10.8	49.0	NA
Effluent BODt, mg/L	3.0	4.3	6.0	1.3	5.9	<10.0 (90th Percentile)
BODt Loading[2], lb/kcf/d	87.9	130.7	190.7	43.2	>88.6 for 90% of the time	NA
Influent TSS, mg/L	10.0	17.9	29.0	5.8	25.5	NA
Effluent TSS, mg/L	2.0	7.8	14.0	4.1	12.9	<10.0 (90th Percentile)
TSS Loading[3], lb/kcf/d	37.9	67.4	110.0	22.3	>42.2 for 90% of the time	NA
Influent NH4-N, mg/L	4.10	7.95	13.50	3.76	12.78	NA
Effluent NH4-N, mg/L	0.03	0.09	0.16	0.05	0.16	<2
NH4-N Removal	96%	99%	100%	1%	>97% for 90% of the time	>90%
NH4-N Loading[4], lb/kcf/d	15.6	30.2	51.5	14.4	>16.7 for 90% of the time[5]	NA
Influent NO3-N, mg/L	1.8	2.4	2.9	0.4	2.9[5]	NA
Effluent NO3-N, mg/L	9.5	11.7	12.6	1.3	12.6[5]	NA
Influent Alkalinity, mg/L $CaCO_3$	58.0	93.2	121.0	21.4	121.0	NA
Effluent Alkalinity, mg/L $CaCO_3$	39.0	43.3	52.0	4.6	49.3	NA
Influent pH	No Data	No Data	No Data	No Data	No Data	NA
Effluent pH[6]	4.1[7]	5.7	7.2	2.2	6.9[5]	NA
Influent Turbidity, NTU	6.9	6.9	7.0	0.1	7.0	NA
Effluent Turbidity, NTU	0.7	2.1	3.3	0.8	3.1	<10.0 (90th Percentile)
Temperature, ^{O}C	10.7	10.9	11.1	0.4	>10.5 for 90% of the time	NA

[1] Projected log normal values

[2] Ondeo maximum design BODt loading of 188 lb/kcf/d

[3] Ondeo maximum design TSS loading of 188 lb/kcf/d

[4] Ondeo maximum design NH4-N loading of 100 lb/kcf/d

[5] Due to small sample size, projected log normal values less than minimum value in sample set. Projected value with actual data range used instead

[6] Only two effluent pH data points available in the who test period.

[7] No influent and effluent BOD, TSS, NH4-N data were collected on the day when effluent pH of 4.1 was measured.

Table 6. Phase IVB Performance Summary

	Minimum	Average	Maximum	Standard Deviation	90th Percentile[1]	Target
Influent BODt, mg/L	17.0	24.5	39.0	6.8	33.6	NA
Effluent BODt, mg/L	3.0	7.2	12.0	3.3	11.4	<10.0 (90th Percentile)
BODt Loading[2], lb/kcf/d	75	106.4	173.4	28.1	>76.7 for 90% of the time[5]	NA
Influent TSS, mg/L	14.0	26.4	42.0	8.0	37.0	NA
Effluent TSS, mg/L	2.0	9.33	25.0	5.9	16.6	<10.0 (90th Percentile)
TSS Loading[3], lb/kcf/d	55.2	110.0	185.4	38.2	>71.3 for 90% of the time	NA
Influent NH4-N, mg/L	1.01	7.57	13.20	3.46	12.04	NA
Effluent NH4-N, mg/L	0.02	0.78	2.60	0.92	1.68	<2
NH4-N Removal	77%	91%	99%	10%	>79% for 90% of the time; >90% for 50% of the time	>90%
NH4-N Loading[4], lb/kcf/d	4.5	32.6	58.9	16.0	>16.2 for 90% of the time	NA
Influent NO3-N, mg/L	0.2	2.1	3.1	0.9	2.9[5]	NA
Effluent NO3-N, mg/L	6.9	9.3	10.8	1.4	10.7[5]	NA
Influent Alkalinity, mg/L $CaCO_3$	37.0	94.7	124.0	23.9	117.0[5]	NA
Effluent Alkalinity, mg/L $CaCO_3$	32.0	50.6	59.0	8.3	58.3[5]	NA
Influent pH	No Data	No Data	No Data	No Data	No Data	NA
Effluent pH	6.7	6.9	7.0	0.1	7.0	NA
Influent Turbidity, NTU	6.8	6.9	7.0	0.1	7.0	NA
Effluent Turbidity, NTU	1.8	4.6	7.7	1.6	6.6	<10.0 (90th Percentile)
Temperature, ^{O}C	9.2	10.4	12.0	1.0	>10.5 for 90% of the time	NA

[1] Projected log normal values

[2] Ondeo maximum design BODt loading of 188 lb/kcf/d

[3] Ondeo maximum design TSS loading of 188 lb/kcf/d

[4] Ondeo maximum design NH4-N loading of 100 lb/kcf/d

[5] Due to small sample size, projected log normal values less than minimum value in sample set or higher than maximum value in sample set. Projected value with actual data range used instead

[6] TSS data on 2/6/2002, and BODt data on 2/7/2002 were not included in statistical analyses. Effluent concentrations of the various parameters were larger than the influent concentrations.

[7] On 2/7/02, influent alkalinity was recorded as 24 mg/L $CaCO_3$ while the effluent alkalinity was recorded as 63 mg/L $CaCO_3$. There was no influent NH4-N data and no pH data. The effluent NH4-N data was 0.53 mg/L. We speculated that the influent and effluent alkalinity had been switched accidentally and the alkalinity data points on this day were excluded from the statistical analysis.

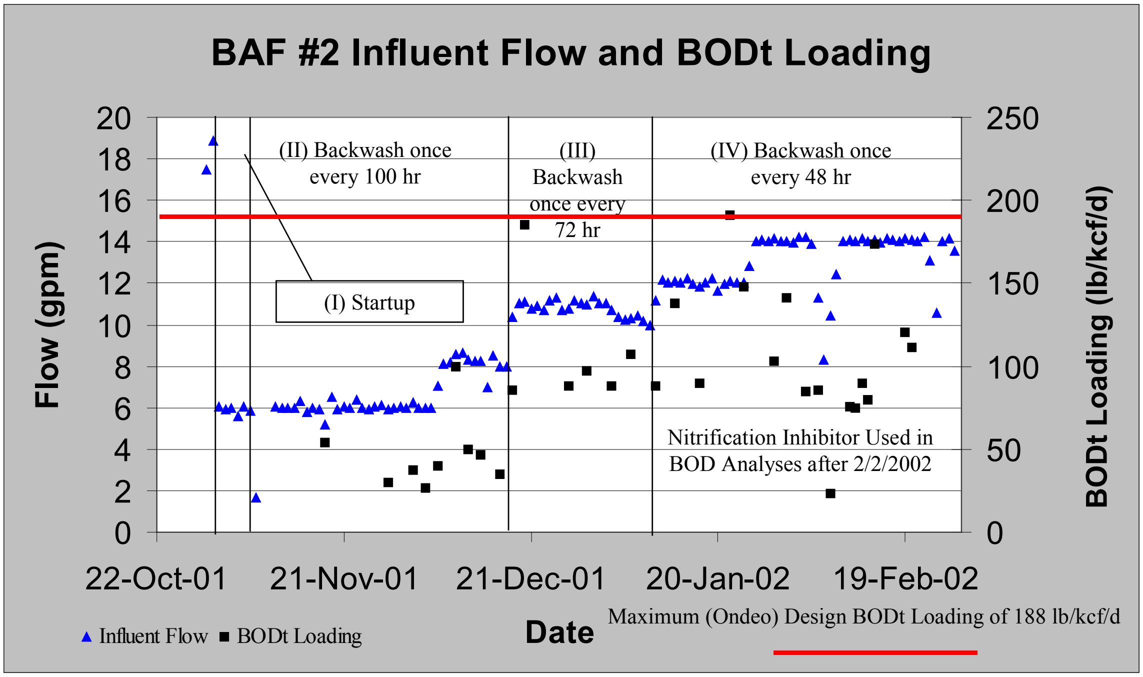

Figure 1. Influent Flow and BODt Loading During the Pilot Study

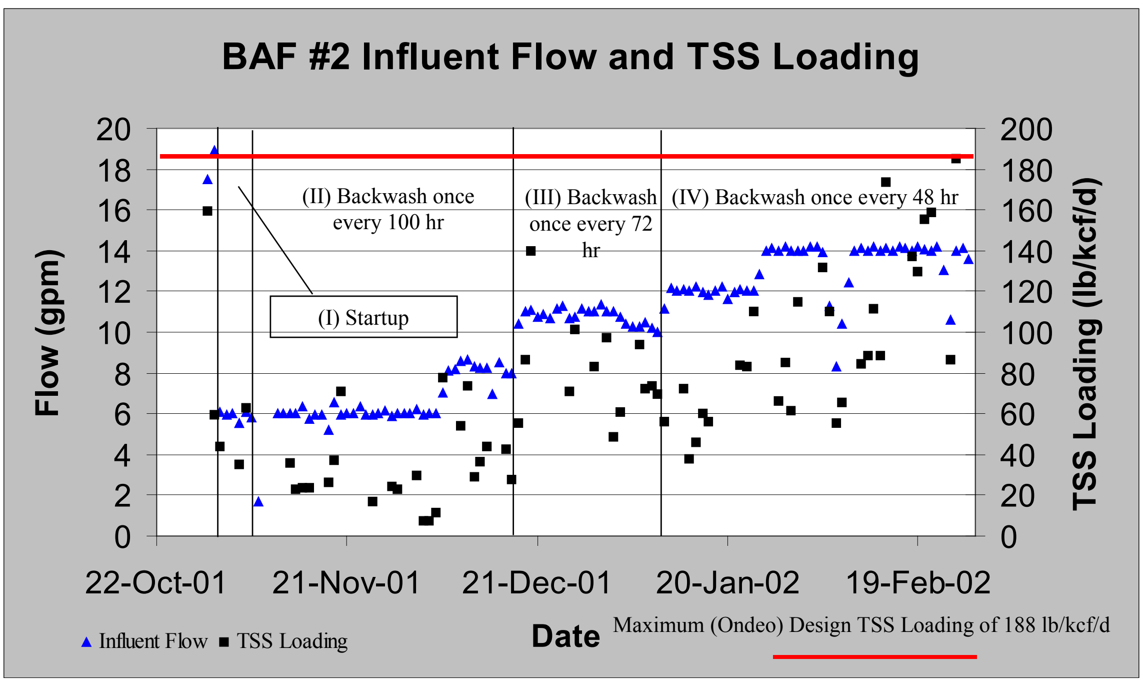

Figure 2. Influent Flow and TSS Loading During the Pilot Study

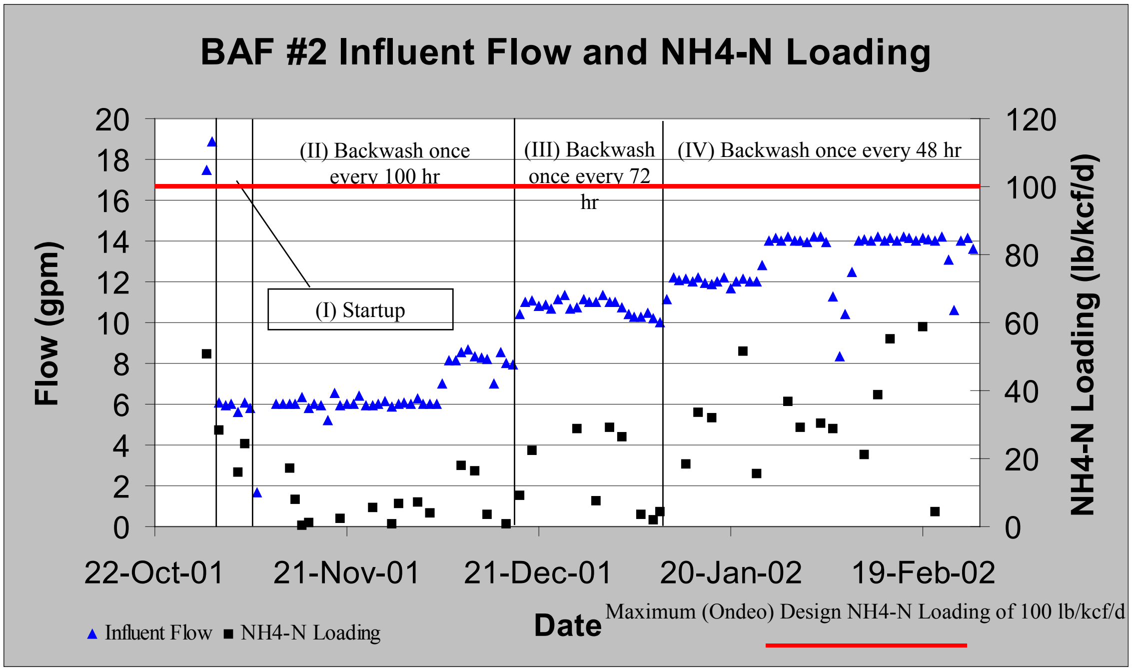

Figure 3. Influent Flow and NH4-N Loading During the Pilot Study

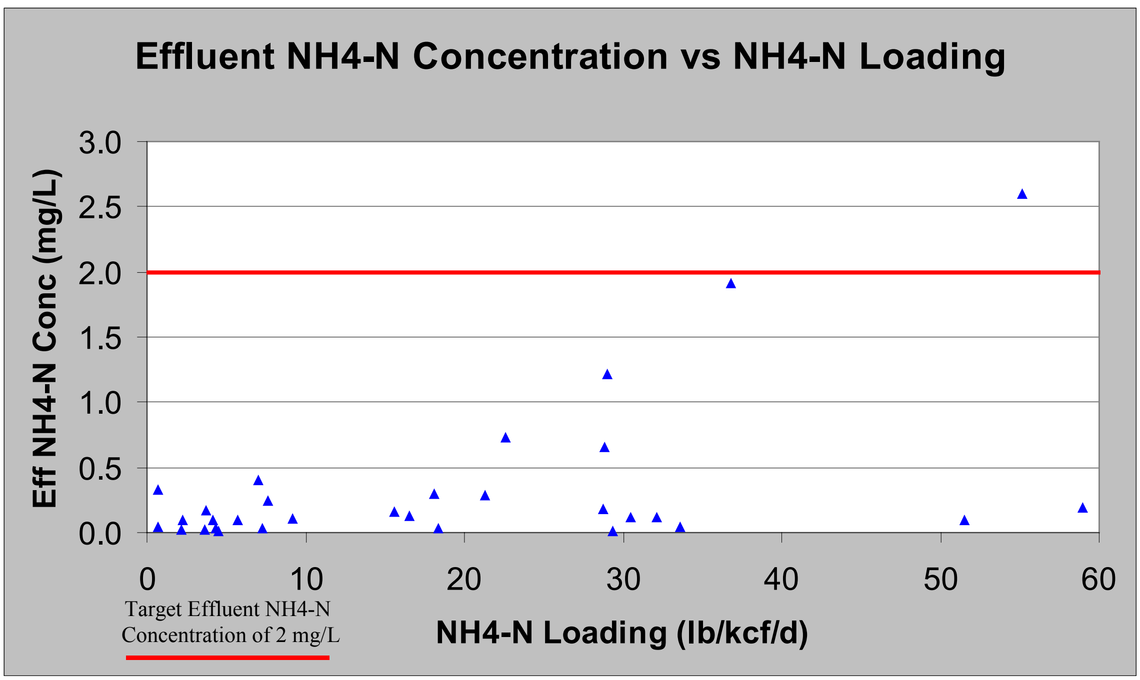

Figure 4. Effluent NH4-N Concentration vs NH4-N Loading During the Pilot Study

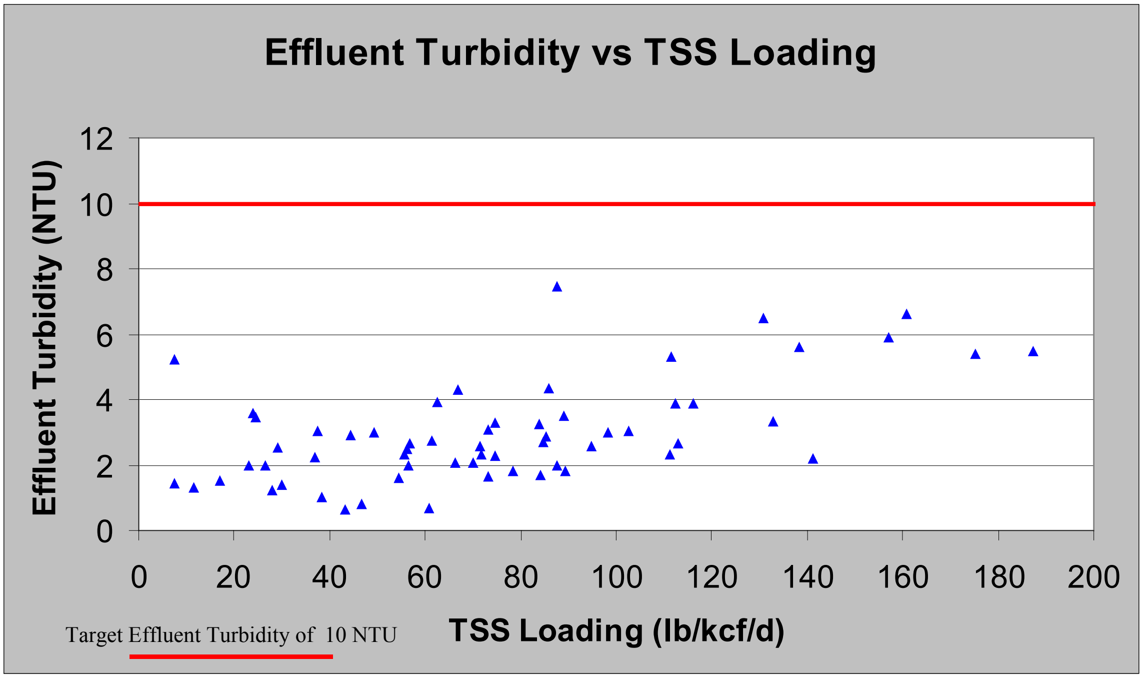

Figure 5. Effluent Turbidity vs TSS Loading During the Pilot Study

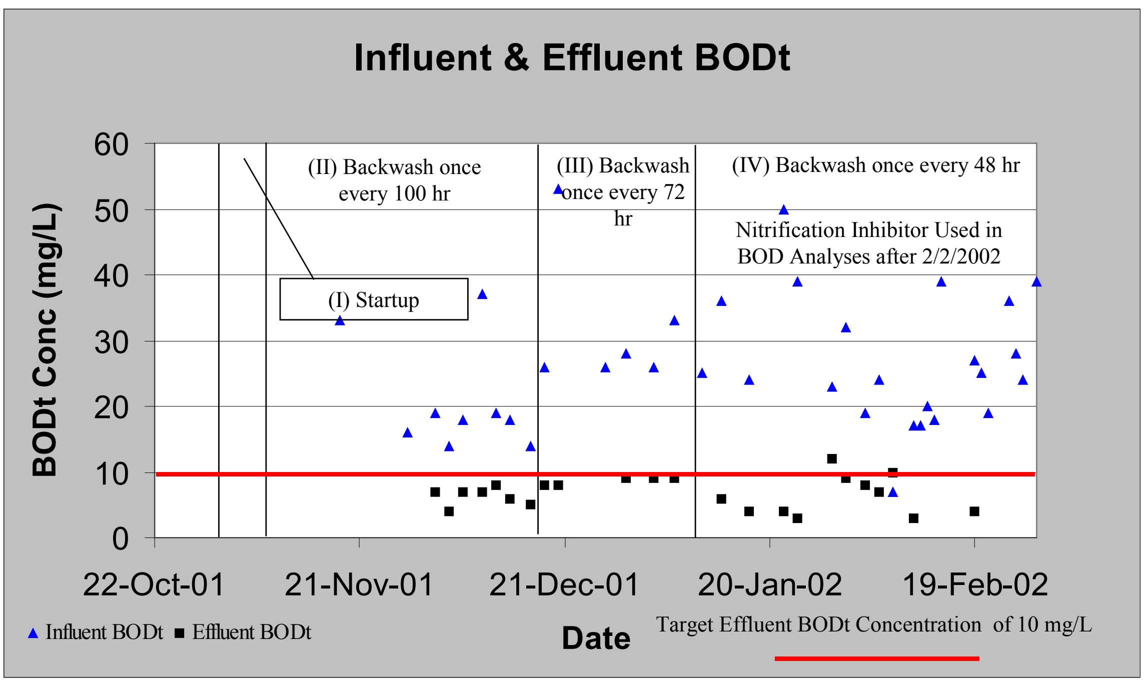

Figure 6. Influent and Effluent BODt During the Pilot Study

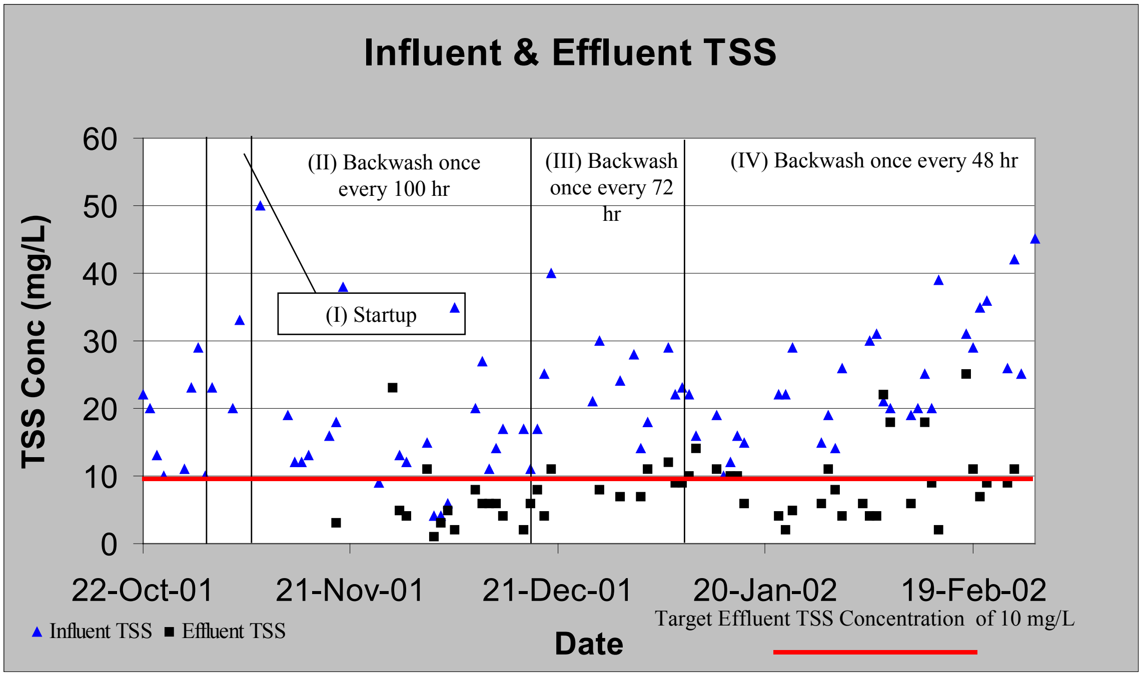

Figure 7. Influent and Effluent TSS During the Pilot Study

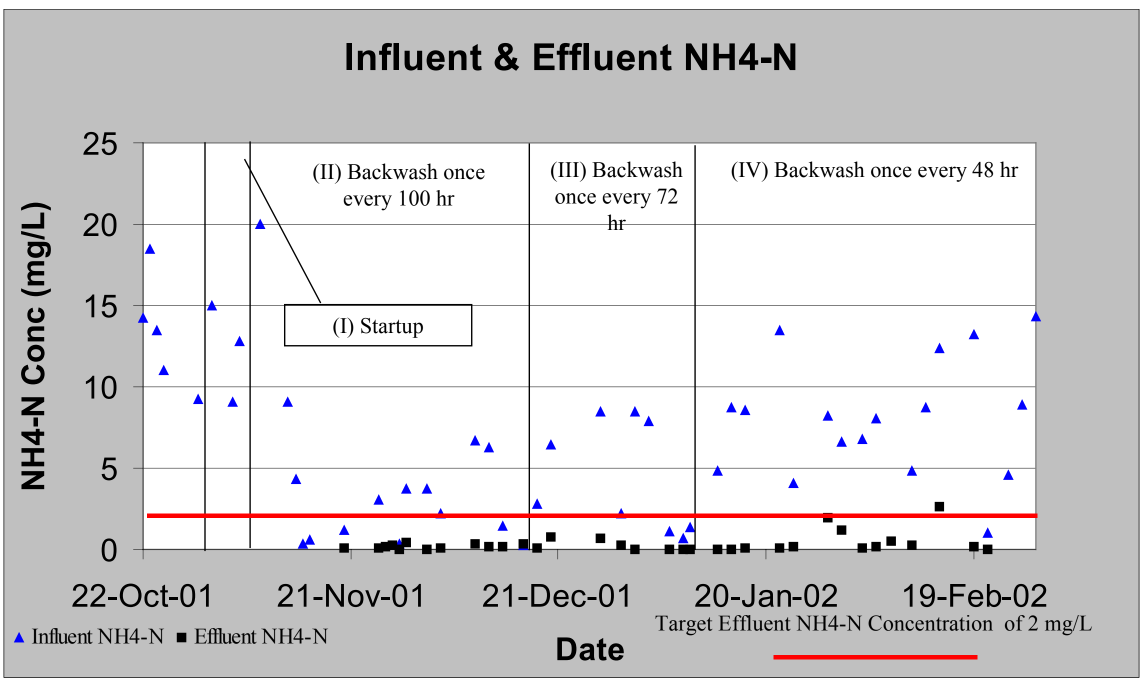

Figure 8. Influent and Effluent NH4-N During the Pilot Study

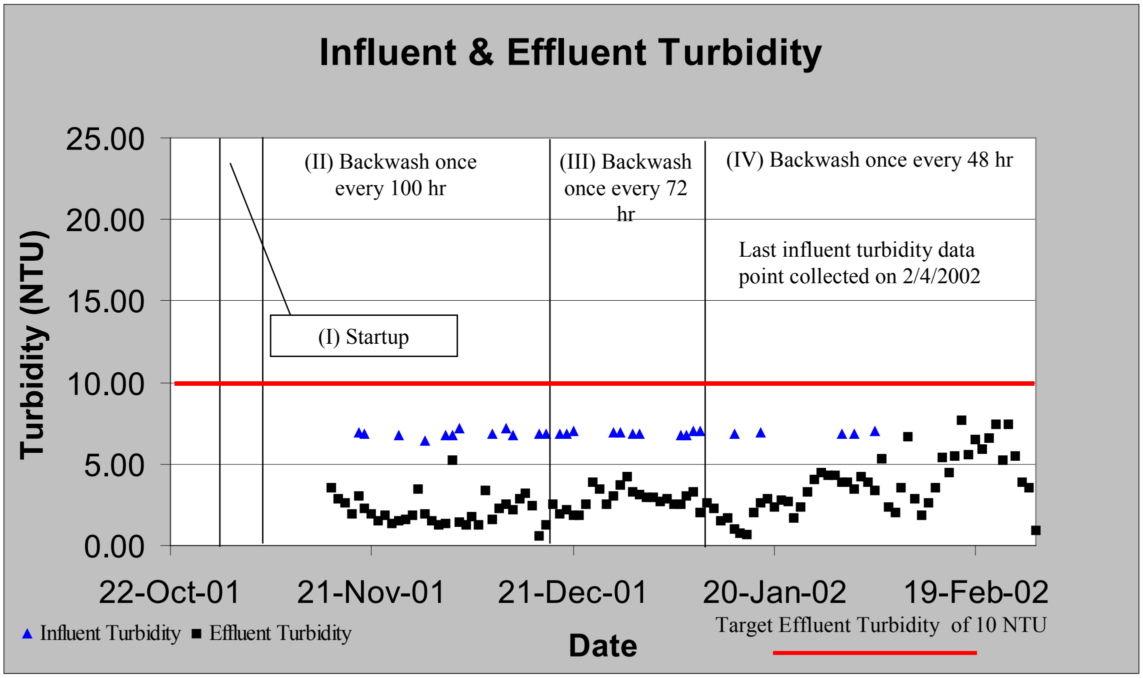

Figure 9. Influent and Effluent Turbidity During the Pilot Study

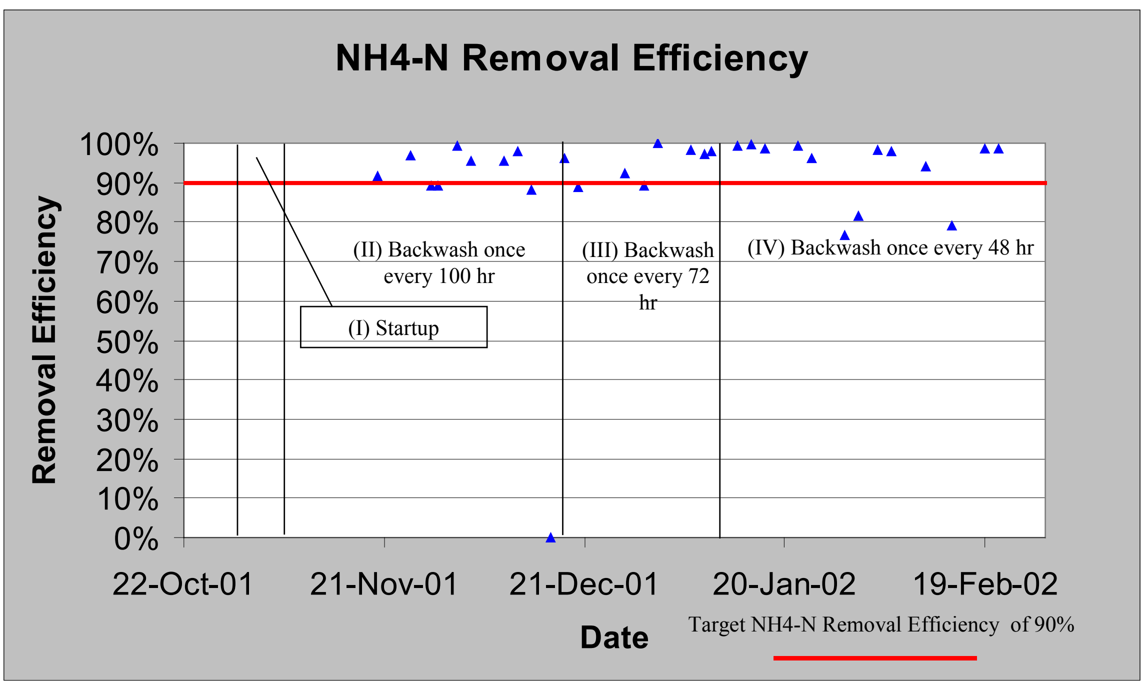

Figure 10. NH4-N Removal Efficiency During the Pilot Study

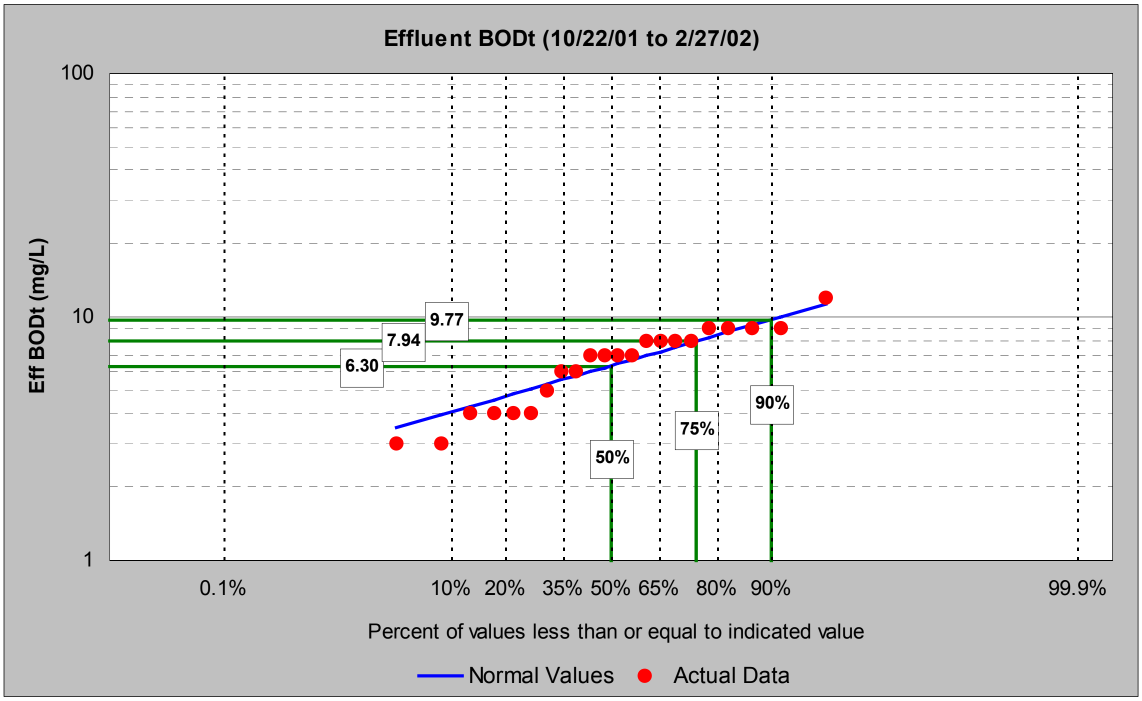

Figure 11. Effluent BODt Log Normal Percentile Plot During the Pilot Study

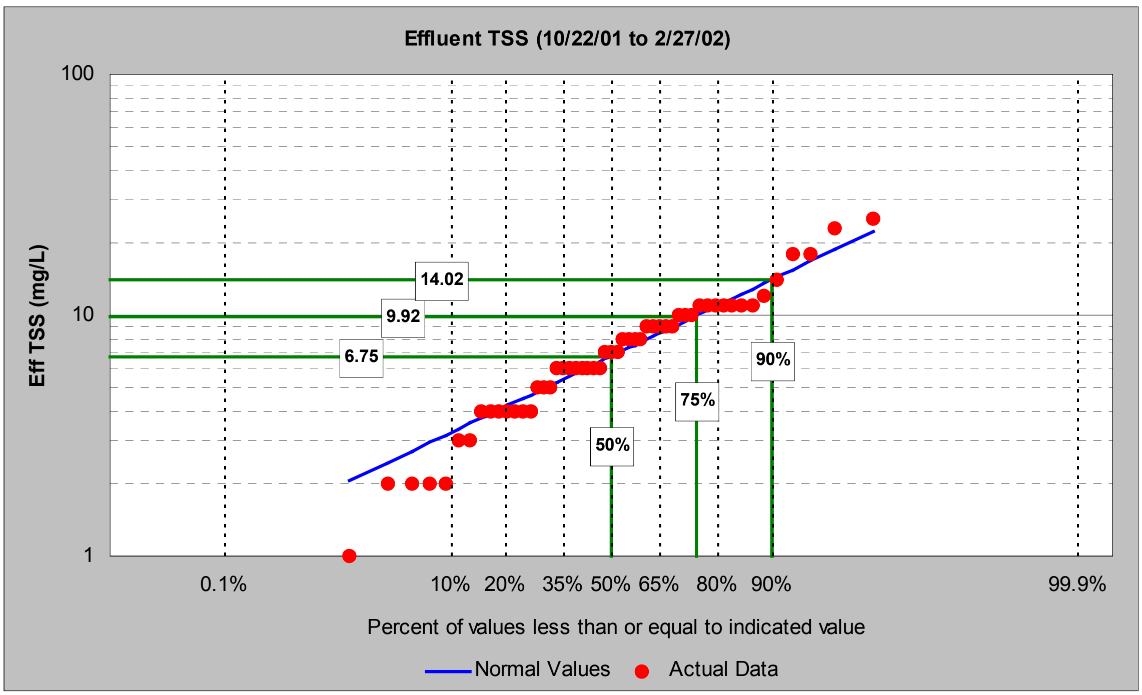

Figure 12. Effluent TSS Log Normal Percentile Plot During the Pilot Study

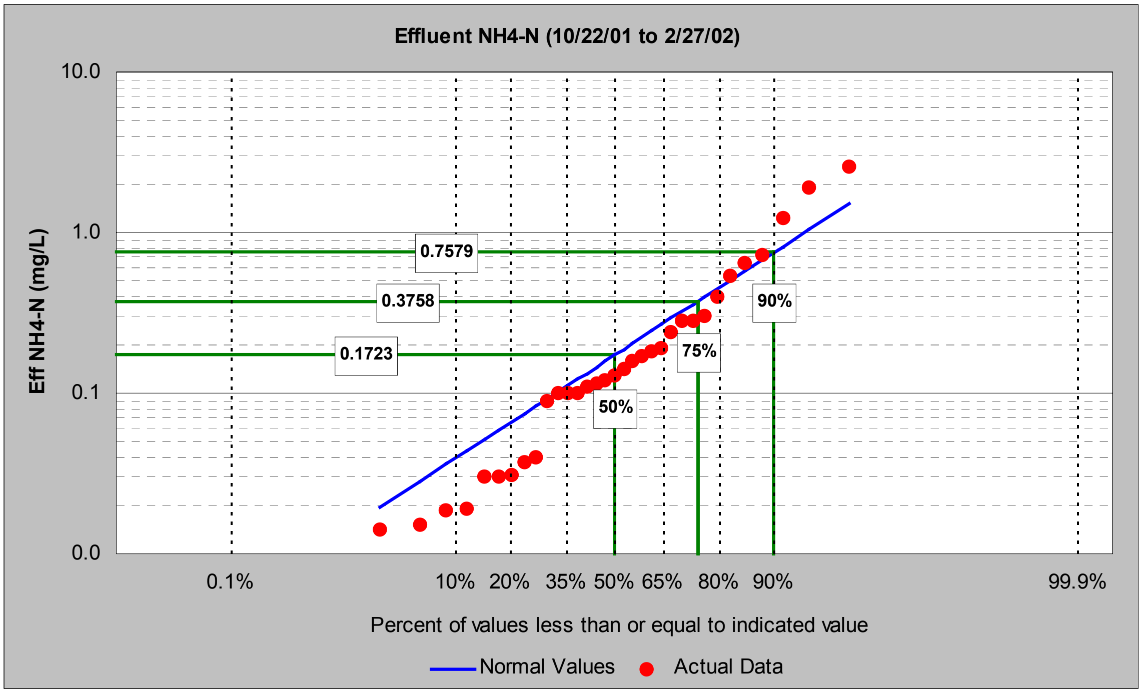

Figure 13. Effluent NH4-N Log Normal Percentile Plot During the Pilot Study

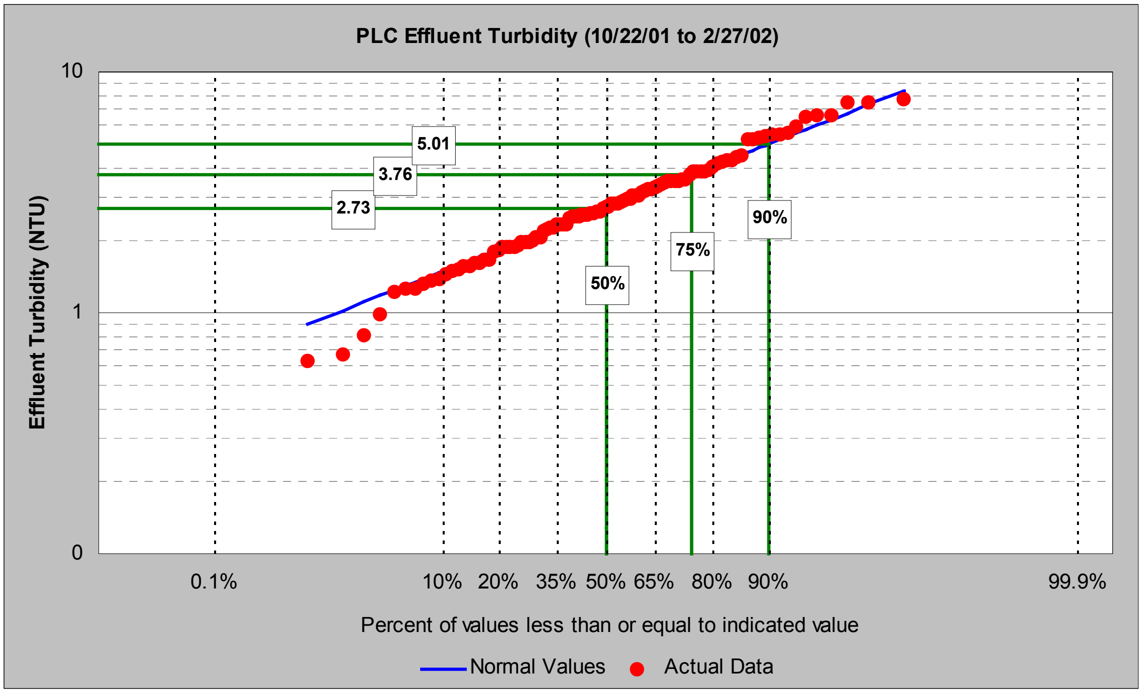

Figure 14. PLC Effluent Turbidity Log Normal Percentile Plot During the Pilot Study

BAF #2 Pilot Unit Photos

Introduction

The following is a series of photos of the Ondeo BIOFOR biological aerated filter pilot unit for nitrification (BAF #2) taken during the pilot testing. Each photo includes a caption and text boxes to point out key pieces of equipment.

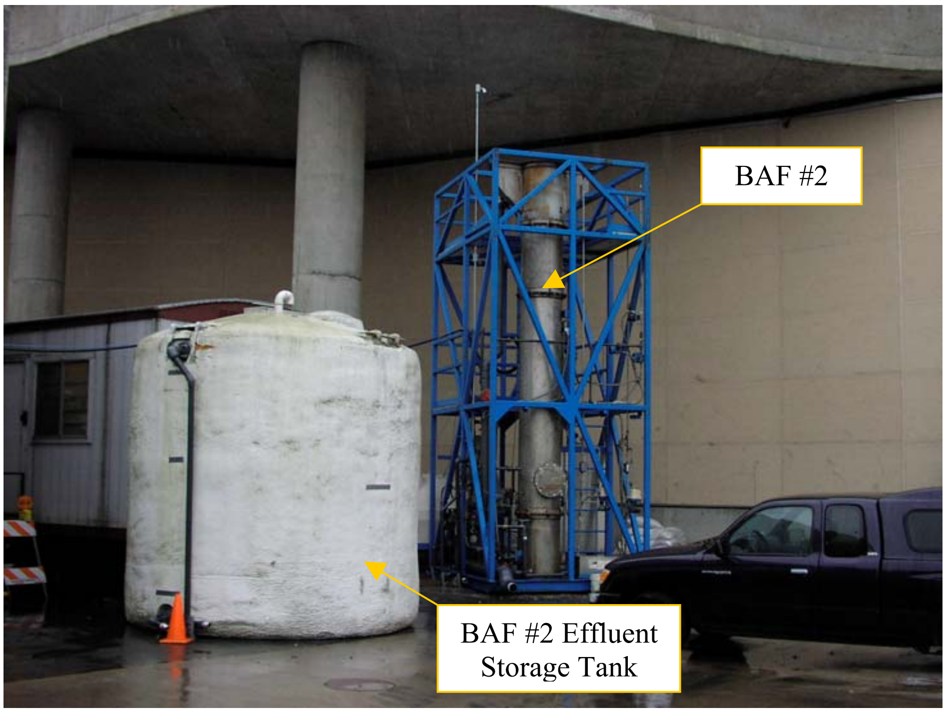

Figure 1. BAF #2 and Effluent Storage Tank

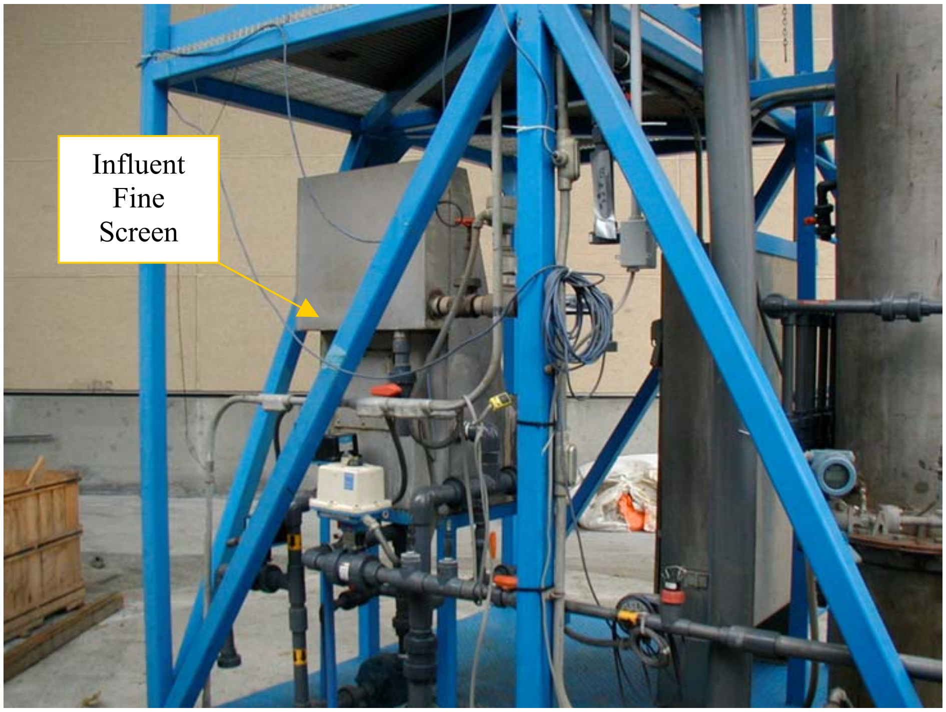

Figure 2. BAF #2 Influent Fine Screen

Figure 3. BAF #2 Effluent Automatic Sampler