April 2003
NSF 02/03/WQPC-SWP

Environmental Technology Verification Report

Reduction of Nitrogen in Domestic Wastewater from Individual Residential Homes

Waterloo Biofilter Systems, Inc.
Waterloo Biofilter® Model 4 Bedroom

Prepared by

NSF International

Under a Cooperative Agreement with
EPA U.S. Environmental Protection Agency

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**BIOLOGICAL WASTEWATER TREATMENT – NITRIFICATION AND DENITRIFICATION FOR NITROGEN REDUCTION**
APPLICATION:	**REDUCTION OF NITROGEN IN DOMESTIC WASTEWATER FROM INDIVIDUAL RESIDENTIAL HOMES**
TECHNOLOGY NAME:	**WATERLOO BIOFILTER® MODEL 4-BEDROOM**
COMPANY:	**WATERLOO BIOFILTER SYSTEMS, INC.**
ADDRESS:	**143 DENNIS ST., P.O. BOX 400** **ROCKWOOD, ONTARIO, N0B 2K0** **CANADA**
	PHONE: (519) 856-0757 **FAX: (519) 856-0759**
WEB SITE:	http://www.waterloo-biofilter.com
EMAIL:	info@waterloo-biofilter.com

NSF International (NSF) operates the Water Quality Protection Center (WQPC) under the U.S. Environmental Protection Agency's Environmental Technology Verification (ETV) Program. The WQPC evaluated the performance of a fixed film trickling filter biological treatment system for nitrogen removal for residential applications. This verification statement provides a summary of the test results for the Waterloo Biofilter Systems, Inc. Waterloo Biofilter® Model 4-Bedroom system. The Barnstable County (Massachusetts) Department of Health and the Environment (BCDHE) performed the verification testing.

The U.S. Environmental Protection Agency (EPA) created the Environmental Technology Verification (ETV) Program to facilitate deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by substantially accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, stakeholder groups consisting of buyers, vendor organizations, and permitters, and the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and verifiable quality are generated and that the results are defensible.

The accompanying notice is an integral part of this verification statement.

ABSTRACT

Verification testing of the Waterloo Biofilter Systems (WBS), Inc. Waterloo Biofilter® Model 4-Bedroom system was conducted over a thirteen month period at the Massachusetts Alternative Septic System Test Center (MASSTC) located at Otis Air National Guard Base in Bourne, Massachusetts. Sanitary sewerage from the base residential housing was used for the testing. An eight-week startup period preceded the verification test to provide time for the development of an acclimated biological growth in the Waterloo® system. The verification test included monthly sampling of the influent and effluent wastewater, and five test sequences designed to test the unit response to differing load conditions and power failure. The Waterloo® system proved capable of removing nitrogen from the wastewater. The influent total nitrogen (TN), as measured by TKN, averaged 37 mg/L with a median of 37 mg/L. The effluent TN (TKN plus nitrite/nitrate) concentration averaged 14 mg/L over the verification period, with a median concentration of 13 mg/L, which included an average TKN concentration of 3.7 mg/L and a median concentration of 1.6 mg/L. The system operating conditions (on-demand pump and float settings) remained constant during the test. Routine maintenance and system checks were performed for most of the test, except when media (foam cubes) was added after four months of operation. Adding media may be part of on-going maintenance, especially in the first few months according to the WBS Design, Installation, and Service Manual.

TECHNOLOGY DESCRIPTION

The Waterloo Biofilter® Model 4-Bedroom system is a two stage treatment technology, based on a fixed film trickling filter, using patented foam cubes to achieve treatment. The first stage of treatment occurs in the primary tank (normally a 1,500 gallon two compartment septic tank, a single compartment tank was used for the test) in which the solids are settled and partially digested. The second stage, the Biofilter® unit, is a separate system that provides secondary wastewater treatment. Microorganisms present in the wastewater attach to the Waterloo® patented foam media, and use the nutrients and organic materials provided by the constant supply of fresh wastewater to form new cell mass. The system does not have a fan, as passive aeration to support the microorganisms is provided by openings in the Biofilter® housing and the characteristics of the foam material, allowing air to freely pass through the media.

The Waterloo Biofilter® system is designed to remove total nitrogen from the wastewater by nitrification and denitrification. Nitrification occurs in the aerobic Biofilter® unit, where ammonia nitrogen is converted to nitrite and nitrate (predominately nitrate), while denitrification occurs in the anaerobic/anoxic primary tank, where the nitrite/nitrate is converted to nitrogen gas.

The verification testing was performed using a full scale, commercially available unit, which was received as a self-contained system ready for installation. Primary tank effluent flowed by gravity through an effluent screen (Zabel filter) to the pump/collection chamber. A pump in the chamber transferred the primary tank effluent to the Biofilter® spray nozzles located above the foam media, which was contained in baskets. The pump operated as an on-demand system, with a level control switch turning the pump on whenever the pump chamber accumulated six gallons of wastewater. The system had a gravity recycle line that recirculated approximately 50 percent of the treated effluent and any solids (if present) from the underflow of the Biofilter® back to the primary tank. The spray system and media were housed in an above grade, lined wooden enclosure.

VERIFICATION TESTING DESCRIPTION

Test Site

The MASSTC site, initially funded by the State of Massachusetts and operated by BCDHE, is located at the Otis Air National Guard Base in Bourne, Massachusetts. The site uses domestic wastewater from the base residential housing and sanitary wastewater from other military buildings in testing. A chamber located in the main interceptor sewer to the base wastewater treatment facility provides a location to obtain untreated wastewater.

The raw wastewater, after passing through a one-inch bar screen, is pumped to a dosing channel at the test site. This channel is equipped with four recirculation pumps that are spaced along the channel length to ensure mixing, such that the wastewater is of similar quality at all locations along the channel. Wastewater is dosed to the test unit using a pump submerged in the dosing channel. A programmable logic controller (PLC) is used to control the pumps and the dosing sequence or cycle.

Methods and Procedures

All methods and procedures followed the *ETV Protocol for Verification of Residential Wastewater Treatment Technologies for Nutrient Reduction,* dated November 2000. The Biofilter® was installed by a contractor, in conjunction with the BCDHE support team, in May 1999 as part of an earlier test program. The unit was installed in accordance with the Design, Installation, and Service Manual supplied by WBS. In order to prepare for ETV testing, the entire Waterloo® system was emptied of wastewater and cleaned. Solids were removed from the primary tank, and all pumps, lines, and associated equipment were cleaned. The foam filter media was replaced with new media.

In early January 2001, fresh water was added to the unit and the system was cycled for several days to make sure the unit was operating properly, the dosing pumps were calibrated, and the PLC was working properly. An eight-week startup period, following the startup procedures in the WBS Design, Installation, and Service Manual, allowed the biological community to become established and allowed the operating conditions to be monitored. Startup of the cleaned Biofilter® system began on January 15, 2001, when the primary tank was filled with wastewater from the dosing channel. The dosing sequence was then started, with the unit's pump and level switches set in accordance with the WBS Manual.

The system was monitored during the startup period, including visual observation, routine calibration of the dosing system, and collection of influent and effluent samples. Six sets of samples were collected for analysis. Influent samples were analyzed for pH, alkalinity, temperature, BOD_5, TKN, NH_3, and TSS. Effluent samples were analyzed for pH, alkalinity, temperature, $CBOD_5$, TKN, NH_3, TSS, dissolved oxygen, NO_2, and NO_3.

The verification test consisted of a thirteen-month test period, incorporating five sequences with varying stress conditions simulating real household conditions. The five stress sequences were performed at two-month intervals, and included Washday, Working Parent, Low Load, Power/Equipment Failure, and Vacation test sequences. Monitoring for nitrogen reduction was accomplished by measurement of nitrogen species (TKN, NH_3, NO_2, NO_3). Biochemical oxygen demand (BOD_5) and carbonaceous biochemical oxygen demand ($CBOD_5$) and other basic parameters (pH, alkalinity, TSS, temperature) were monitored to provide information on overall system treatment performance. Operational characteristics, such as electric use, residuals generation, labor to perform maintenance, maintenance tasks, durability of the hardware, and noise and odor production, were also monitored.

The Biofilter® system has a design capacity of 440 gallons per day. The verification test was designed to load the system at design capacity (± 10 percent) for the entire thirteen-month test, except during the Low Load and Vacation stress tests. The Biofilter® system was dosed 15 times per day with approximately 29-30 gallons of wastewater per dose. The unit received five doses in the morning, four doses mid-day, and six doses in the evening. The dosing volume was controlled by adjusting the pump run time for each cycle, based on twice weekly pump calibrations.

The sampling schedule included collection of twenty-four hour flow weighted composite samples of the influent and effluent wastewater once per month under normal operating conditions. Stress test periods were sampled on a more intense basis with six to eight composite samples being collected during and following each stress test period. Five consecutive days of sampling occurred in the twelfth month of the verification test. All composite samples were collected using automatic samplers located at the dosing channel (influent sample) and at the discharge of the Biofilter® unit. Grab samples were collected on each sampling day to monitor the system pH, dissolved oxygen, and temperature.

All samples were cooled during sample collection, preserved, if appropriate, and transported to the laboratory. All analyses were in accordance with EPA approved methods or Standard Methods. An established QA/QC program was used to monitor field sampling and laboratory analytical procedures. QA/QC requirements included field duplicates, laboratory duplicates and spiked samples, and appropriate equipment/instrumentation calibration procedures. Details on all analytical methods and QA/QC procedures are provided in the full Verification Report.

PERFORMANCE VERIFICATION

Overview

Evaluation of the Waterloo Biofilter® Model 4-Bedroom system at MASSTC began on January 15, 2001, when the Biofilter® pump was activated, and the initial dosing cycles activated. Flow was set at 440 gpd, resulting in 15 doses per day with a target of 29.33 gallons per dose. Six samples of the influent and effluent were collected during the startup period, which continued until March 13, 2001. Verification testing began at that time and continued for 13 months until April 17, 2002. The extra month of dosing and sampling (13 months versus the planned 12 months) was added to the test to obtain data on the system response as the temperatures began to rise in the spring. During the verification test, 53 sets of samples of the influent and effluent were collected to determine the system performance.

Startup

Overall, the unit started up with no difficulty. The startup instructions in the Manual were easy to follow and provided the necessary instructions to get the unit up and operating. No changes were made to the unit during the startup period, and no special maintenance was required. Regular observation showed that biological growth was established on the media during the startup period.

The Biofilter® system performance for $CBOD_5$, TSS, and TN appeared good during the first three weeks of operation, but did not continue to improve over the next five weeks. Effluent $CBOD_5$ varied between 23 and 66 mg/L, with the higher value at the end of the startup period. There was some initial indication that TN removal was occurring, with effluent concentrations of 18 to 31 mg/L during the first three weeks, compared with influent concentrations of 34 to 41 mg/L. However, after eight weeks it did not appear that the nitrifying organisms had established themselves in the system, with low wastewater and ambient temperatures considered the primary reasons for the slow trend toward improved reduction in both $CBOD_5$ and TN. The temperature of the effluent wastewater was about 4 °C when the unit was started and remained in the 5 to 8 °C range through March 13. After startup, and early in the verification test in late April, it was discovered that the foam media had settled and short-circuiting was occurring in both media baskets. Foam media was added to the unit (a simple process) in accordance with the WBS instructions. The WBS maintenance recommendations and checklist include a regular check of the foam media and the addition of media, if needed.

Verification Test Results

The daily dosing schedule was designed for 15 doses to be applied every day, except during the Low Load (September 2001) and Vacation stress (February 2002) periods. In September, it was discovered that only 14 doses were being delivered because of a timing issue with the PLC. The issue was resolved and 15 doses were delivered for the last eight months of the test. Volume per dose and total daily volume varied only slightly during the test period. The daily volume, averaged on a monthly basis, ranged from 401 to 444 gallons per day. This was within the range allowed in the protocol for the 440 gallons per day design capacity.

The sampling program emphasizes sampling during and following the major stress periods. This results in a large number of samples being clustered during five periods, with the remaining samples spread over the remaining months (monthly sampling). Therefore, impacts of a stress test or an upset condition occurring during concentrated sampling periods can have an impact on the calculation of average values. Both average and median results are presented, as the median values compared to average values can help in analyzing these impacts. In the case of the Biofilter® results, the median concentrations are somewhat lower than the average concentrations due to an upset condition following the Vacation stress test.

The TSS and BOD_5/$CBOD_5$ results for the verification test, including all stress test periods, are shown in Table 1. The influent wastewater had an average BOD_5 of 210 mg/L and a median BOD_5 of 200 mg/L. The TSS in the influent averaged 150 mg/L and had a median concentration of 130 mg/L. The Biofilter® effluent showed an average $CBOD_5$ of 10 mg/L with a median $CBOD_5$ of 7.4 mg/L. The average TSS in the effluent was 7 mg/L and the median TSS was 5 mg/L. $CBOD_5$ concentrations in the effluent typically ranged from 1 to 10 mg/L, and TSS ranged from 1 to 20 mg/L.

Table 1. BOD_5/$CBOD_5$ and TSS Data Summary

	BOD_5	**$CBOD_5$**		**TSS**		
	Influent (mg/L)	**Effluent (mg/L)**	**Percent Removal**	**Influent (mg/L)**	**Effluent (mg/L)**	**Percent Removal**
Average	210	10	95	150	7	95
Median	200	7.4	96	130	5	97
Maximum	370	43	99	340	55	>99
Minimum	67	1.0	71	61	<1	51
Std. Dev.	73	9.0	6.0	66	8	8

NOTE**:** The data in Table 1 are based on 53 samples.

The nitrogen results for the verification test, including all stress test periods, are shown in Table 2. The influent wastewater had an average TKN concentration of 37 mg/L, with a median value of 37 mg/L, and an average ammonia nitrogen concentration of 23 mg/L, with a median of 23 mg/L. Average TN concentration in the influent was 37 mg/L (median of 37 mg/L), based on the assumption that the nitrite and nitrate concentrations in the influent were negligible. The Biofilter® effluent had an average TKN concentration of 3.7 mg/L and a median concentration of 1.6 mg/L. The average NH_3-N concentration in the effluent was 2.4 mg/L and the median value was 0.7 mg/L. The nitrite concentration in the effluent was low, averaging 0.19 mg/L. Effluent nitrate concentrations averaged 10 mg/L with a median of 10 mg/L. Total nitrogen was determined by adding the daily concentrations of the TKN (organic plus ammonia nitrogen), nitrite, and nitrate. Average TN in the Biofilter® effluent was 14 mg/L (median 13 mg/L) for the thirteen month verification period. The Biofilter® system averaged a 62 percent reduction of TN for the entire test, with a median removal of 65 percent.

Table 2. Nitrogen Data Summary

	TKN (mg/L)		**Ammonia (mg/L)**		**Total Nitrogen (mg/L)**		**Nitrate (mg/L)**	**Nitrite (mg/L)**	**Temperature (°C)**
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Effluent	Effluent	Influent
Average	37	3.7	23	2.4	37	14	10	0.19	15
Median	37	1.6	23	0.7	37	13	10	0.14	15
Maximum	45	31	29	24	45	45	33	0.84	24
Minimum	24	<0.5	18	<0.2	24	6.8	0.6	<0.05	5.2
Std. Dev.	4.1	5.5	2.4	4.0	4.2	6.0	5.0	0.20	5.9

NOTE: The data in Table 2 are based on 53 samples, except for Temperature, which is based on 51 samples.

Verification Test Discussion

In late March and early April 2001, when temperatures began to increase, there was evidence of a more established biological population on the foam media. In late April, when it was discovered that the foam media had settled and wastewater was short-circuiting through the media, media was added to the unit. With the increasing temperatures and the elimination of the short-circuiting, the nitrifying population clearly became established, as indicated by the decrease in the TKN and ammonia concentrations in the effluent, and an increase in effluent nitrate concentration. TN concentration in the effluent began to decrease indicating that the denitrification population was becoming established in the primary tank. During May and June, the TN reduction was typically in 65 to 80 percent range. The Washday stress test performed in May 2001 did not appear to have a negative impact on nitrogen reduction. Likewise, in July 2001, the Working Parent stress test was performed and the performance of the unit remained steady during and following the stress period. The Biofilter® system continued to reduce the total nitrogen concentration on a steady basis (60-80 percent reduction) until February 2002. During this period, which included the Low Load and Power/Equipment Failure stress sequences, nitrification was very effective, with ammonia nitrogen and TKN being reduced to less than 1 mg/L. The denitrification process during this period was effective in removing nitrate produced during the nitrification step, but not as efficient or complete as the nitrifying step. The total nitrogen in the effluent ranged from 6.2 to 13 mg/L during the August to January period.

The Vacation stress test was started on February 4 and was completed on February 13, 2002. The sample taken before the stress test showed some signs that the denitrification process was slowing, while the nitrification process, as measured by TKN (1.6 mg/L) and ammonia (1.5 mg/L), was still consistent. Effluent $CBOD_5$ and TSS concentrations continued to be low, with values of 4.4 and 8 mg/L, respectively. On the first day after the Vacation stress test ended, the effluent nitrate value jumped to 33 mg/L, the ammonia level increased to 10 mg/L, total nitrogen went to 45 mg/L, and $CBOD_5$ and TSS increased. It would appear that both the nitrification and denitrification processes were impacted during this time by the lack of wastewater application to the media (no flow for eight days). The use of the “on-demand” pumping approach results in no application of wastewater to support the biological population on the Biofilter® when there is no flow to the system. The timing of the Vacation stress test also coincided with the coldest time of the year, with the temperature of the effluent dropping to 5 ^{o}C from 7 ^{o}C on first day after the stress period ended.

Performance began to improve almost immediately after the flow returned to normal conditions. In general, the effluent nitrogen concentrations were nearly back to pre-stress levels within one to two weeks of the resumption of dosing. Likewise, $CBOD_5$ and TSS concentrations returned to levels close to those prior to the stress. The overall performance of the system was slightly lower during the weeks following the Vacation stress test, as compared to the October to December 2001 period, showing effluent TN concentrations of 15 to 17 mg/L versus 9 to 11 mg/L.

The last sample collected in April 2002 indicated that the both the nitrifying and denitrifying processes had recovered, and the TN concentration in the effluent was 11 mg/L. TKN and ammonia concentrations were 3.5 mg/L and 1.1 mg/L, respectively, only slightly higher than the less than 1 mg/L levels achieved in previous summer and fall periods. The nitrate concentration was 7.1 mg/L, which was actually on the low side of the levels found in the summer and fall. The verification test provided a sufficiently long test period to collect data that included both a long run of steady performance by the Biofilter® system and a period of an apparent upset following the Vacation stress test. While the system was apparently impacted by the Vacation stress test and probably by the low temperatures, recovery was rapid with TN removal on the order of 60 percent (55-70 percent measured) being established within two to four weeks.

Operation and Maintenance Results

Noise levels associated with mechanical equipment were measured once during the verification period using a decibel meter. Measurements were made one meter from the unit, and one and a half meters above the ground, at 90° intervals in four (4) directions. The average decibel level was 47.6, with a minimum of 44.8 and maximum of 50.5. The background level was 37.7 decibels.

Odor observations were made monthly for the last eight months of the verification test. The observations were qualitative based on odor strength (intensity) and type (attribute). Observations were made during periods of low wind velocity (<10 knots), at a distance of three feet from the treatment unit, and recorded at 90° intervals in four directions. There were no discernible odors during any of the observation periods. The unit has two charcoal filters to help control odors. No maintenance was required on these units during the test.

Electrical use was monitored by a dedicated electric meter serving the Biofilter® system. The average electrical use was 1.3 kW/day with a maximum of 2.5 kW/day. The Biofilter® system does not require or use any chemical addition as part of the normal operation of the unit.

During the test, no problems were encountered with the operation of the system. The screen on the outlet from the septic tank (influent to the pump chamber) required periodic cleaning. During the test, the filter was cleaned after eight months (two months of startup and six months of testing) in accordance with the WBS recommendation. The distribution plates near the nozzles were cleaned when the outlet screen was cleaned to help maintain a uniform spray pattern over the media. No changes or adjustments were needed to the float switches or the pump. Media was added one time after four months of operation. No additional media was added for the duration of the test.

The treatment unit itself proved durable for the duration of the test and appears to generally be a durable design. The piping is standard PVC that is appropriate for the applications. Pump and level switch life is always difficult to estimate, but the equipment used is made for wastewater applications by a reputable and known manufacturer. The lined wooden box used as housing did attract ants that bore through the wood. This was solved by liberal application of borax in the area of the unit.

WBS recommends a minimum of once per year maintenance checks, and the sample maintenance contract is designed for twice per year maintenance of the unit. Based on fifteen months of observation, BCHDE staff believes that quarterly maintenance checks would seem appropriate to ensure the system is in good operating condition. It is possible that a knowledgeable homeowner could perform certain routine quarterly checks, after the system has been in operation for several months, and routinely checked by a trained operator. Homeowner involvement in routine cleaning and system checks might be able to reduce the scheduled contractor maintenance to a semi-annual frequency. Maintenance activities should include checking the filter media for subsidence, adding media if needed, checking the nozzles and distribution plates for clogging and cleaning if needed, and checking the pump, alarms, and floats for proper operation. The primary tank should be checked for sludge depth and the primary tank effluent screen should be cleaned. Replacement of the activated carbon located on the air openings should be part of routine maintenance, but the carbon life may be long, and replacement only needed if odor becomes a problem.

Quality Assurance/Quality Control

QA audits of the MASSTC and BCDHE laboratory were completed by NSF International during testing. NSF personnel completed a technical systems audit to assure the testing was in compliance with the test plan, a performance evaluation audit to assure that the measurement systems employed by MASSTC and the BCDHE laboratory were adequate to produce reliable data, and a data quality audit of at least 10 percent of the test data to assure that the reported data represented the data generated during the testing. In addition to quality assurance audits performed by NSF International, EPA QA personnel conducted a quality systems audit of NSF International's QA Management Program, and accompanied NSF during audits of the MASSTC and BCDHE facilities.

Original signed by *Hugh W. McKinnon* *5/30/03*	*Original signed by* *Gordon E. Bellen* *6/3/03*
Hugh W. McKinnon Date Director National Risk Management Research Laboratory Office of Research and Development United States Environmental Protection Agency	Gordon E. Bellen Date Vice President Research NSF International

NOTICE: Verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and NSF make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate as verified. The end user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of corporate names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products. This report in no way constitutes an NSF Certification of the specific product mentioned herein.

Availability of Supporting Documents

Copies of the *ETV Protocol for Verification of Residential Wastewater Treatment Technologies for Nutrient Reduction,* dated November 2000, the Verification Statement, and the Verification Report are available from the following sources:

1. ETV Water Quality Protection Center Manager (order hard copy)
   NSF International
   P.O. Box 130140
   Ann Arbor, Michigan 48113-0140
2. NSF web site: http://www.nsf.org/etv (electronic copy)
3. EPA web site: http://www.epa.gov/etv (electronic copy)

(NOTE: Appendices are not included in the Verification Report. Appendices are available from NSF upon request.)

EPA's Office of Wastewater Management has published a number of documents to assist purchasers, community planners and regulators in the proper selection, operation and management of onsite wastewater treatment systems. Two relevant documents and their sources are:

1. *Handbook for Management of Onsite and Clustered Decentralized Wastewater Treatment Systems* http://www.epa.gov/owm/onsite
2. *Onsite Wastewater Treatment Systems Manual* http://www.epa/gov/owm/mtb/decent/toolbox.htm

Environmental Technology Verification Report

Nutrient Reduction in Domestic Wastewater From Individual Residential Homes

Waterloo Biofilter Systems, Inc.
Waterloo Biofilter® Model 4-Bedroom

Prepared for

NSF International
Ann Arbor, MI 48105

Prepared by

Scherger Associates
In cooperation with
Barnstable County Department of Health and Environment

Under a cooperative agreement with the U.S. Environmental Protection Agency

Raymond Frederick, Project Officer
ETV Water Quality Protection Center
National Risk Management Research Laboratory
Water Supply and Water Resources Division
U.S. Environmental Protection Agency
Edison, New Jersey 08837

April 2003

Notice

The U.S. Environmental Protection Agency (EPA) through its Office of Research and Development has financially supported and collaborated with NSF International (NSF) under a Cooperative Agreement. The Water Quality Protection Center, Source Water Protection area, operating under the Environmental Technology Verification (ETV) Program, supported this verification effort. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release.

Foreword

The following is the final report on an Environmental Technology Verification (ETV) test performed for NSF International (NSF) and the United States Environmental Protection Agency (EPA) by the Barnstable County Department of Health and Environment (BCDHE). Scherger Associates prepared the Verification Report in cooperation with BCDHE. The verification test for Waterloo Biofilter® System was conducted from January 2001 through April 2002 at the Massachusetts Alternative Septic System Test Center (MASSTC) test site in Bourne, Massachusetts.

Throughout its history, the EPA has evaluated the effectiveness of innovative technologies to protect human health and the environment. A new EPA program, the Environmental Technology Verification Program was developed to verify the performance of innovative technical solutions to environmental pollution or human health threats. ETV was created to substantially accelerate the entrance of new environmental technologies into the domestic and international marketplace. Verifiable, high quality data on the performance of new technologies are made available to end users regulators, developers, consulting engineers, and those in the public health and environmental protection industries. This encourages rapid availability of approaches to better protect the environment.

The EPA has partnered with NSF, to verify performance of various treatment systems designed to remove pollutants and protect water used as a source for drinking water and other uses under the Source Water Protection (SWP) area of the Water Quality Protection Center (WQPC). NSF is an independent, not-for-profit testing and certification organization dedicated to public health, safety and protection of the environment. A goal of verification testing is to enhance and facilitate the acceptance of small treatment systems and equipment by state regulatory officials and consulting engineers, while reducing the need for testing of equipment at each location where the equipment's use is contemplated. NSF meets this goal by working with manufacturers and NSF-qualified Testing Organizations (TO) to conduct verification testing under the approved protocols. The Barnstable County Department of Health and Environment is one such TO.

NSF is conducting the WQPC-SWP with participation of manufacturers, under the sponsorship of the EPA Office of Research and Development, National Risk Management Research Laboratory, Urban Watershed Management Branch, Edison, New Jersey. It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF or "accepted" by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations for those conditions tested by the TO.

Table of Contents

List of Appendices

List of Tables

List of Figures

Glossary of Terms

Accuracy - a measure of the closeness of an individual measurement or the average of a number of measurements to the true value and includes random error and systematic error.

Bias - the systematic or persistent distortion of a measurement process that causes errors in one direction.

Commissioning – the installation of the nutrient reduction technology and start-up of the technology using test site wastewater.

Comparability – a qualitative term that expresses confidence that two data sets can contribute to a common analysis and interpolation.

Completeness – a qualitative and quantitative term that expresses confidence that all necessary data have been included.

Precision - a measure of the agreement between replicate measurements of the same property made under similar conditions.

Protocol – a written document that clearly states the objectives, goals, scope and procedures for the study. A protocol shall be used for reference during Vendor participation in the verification testing program.

Quality Assurance Project Plan – a written document that describes the implementation of quality assurance and quality control activities during the life cycle of the project.

Residuals – the waste streams, excluding final effluent, which are retained by or discharged from the technology.

Representativeness - a measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point, a process condition, or environmental condition.

Standard Operating Procedure – a written document containing specific procedures and protocols to ensure that quality assurance requirements are maintained.

Technology Panel - a group of individuals established by the Verification Organization with expertise and knowledge in nutrient removal technologies.

Testing Organization – an independent organization qualified by the Verification Organization to conduct studies and testing of nutrient removal technologies in accordance with protocols and test plans.

Vendor – a business that assembles or sells nutrient reduction equipment.

Verification – to establish evidence on the performance of nutrient reduction technologies under specific conditions, following a predetermined study protocol(s) and test plan(s).

Verification Organization – an organization qualified by EPA to verify environmental technologies and to issue Verification Statements and Verification Reports.

Verification Report – a written document containing all raw and analyzed data, all QA/QC data sheets, descriptions of all collected data, a detailed description of all procedures and methods used in the verification testing, and all QA/QC results. The Verification Test Plan(s) shall be included as part of this document.

Verification Statement – a document that summarizes the Verification Report and is reviewed and approved by EPA.

Verification Test Plan – A written document prepared to describe the procedures for conducting a test or study according to the verification protocol requirements for the application of nutrient reduction technology at a particular test site. At a minimum, the Verification Test Plan includes detailed instructions for sample and data collection, sample handling and preservation, and quality assurance and quality control requirements relevant to the particular test site.

Abbreviations and Acronyms

ANSI	American National Standards Institute
BDCHE	Barnstable County Department of Health and the Environment
Biofilter®	Waterloo Biofilter® Model 4-Bedroom
BOD_5	Biochemical Oxygen Demand (five day)
$CBOD_5$	Carbonaceous Biochemical Oxygen Demand (five day)
COC	Chain of Custody
DO	Dissolved Oxygen
DQI	data quality indicators
DQO	data quality objectives
ETV	Environmental Technology Verification
GAI	Groundwater Analytical, Inc.
gal	gallons
gpm	gallons per minute
MASSTC	Massachusetts Alternative Septic System Test Center
mg/L	milligrams per liter
mL	milliliters
NIST	National Institute of Standards and Technology
NH_3/NH_4	Ammonia Nitrogen
NO_2	Nitrite Nitrogen
NO_3	Nitrate Nitrogen
NSF	NSF International
NRMRL	National Risk Management Research Laboratory
O&M	Operation and maintenance
ORD	Office of Research and Development, EPA
OSHA	Occupational Safety and Health Administration
QA	Quality assurance
QAPP	Quality assurance project plan
QC	Quality control
QMP	Quality management plan
RPD	Relative percent difference
SAG	Stakeholders Advisory Group
SOP	Standard operating procedure
SWP	Source Water Protection Area, Water Quality Protection Center
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TO	Testing Organization
EPA	United States Environmental Protection Agency
VO	Verification Organization
VR	Verification Report
VTP	Verification Test Plan
WBS	Waterloo Biofilter Systems, Inc.
WQPC	Water Quality Protection Center

Acknowledgments

The Testing Organization (TO), the Barnstable County Department of Health and the Environment, was responsible for all elements in the testing sequence, including collection of samples, calibration and verification of instruments, data collection and analysis, and data management. Mr. George Heufelder was the Project Manager for the Verification Test.

Barnstable County Department of Health and the Environment
Superior Court House (P.O. Box 427)
Barnstable, MA 02630
(508) 375-6616
Contact: Mr. George Heufelder, Project Manager
Email: gheufeld@capecod.net

The Verification Report was prepared by Scherger Associates.

Scherger Associates
3017 Rumsey Drive
Ann Arbor, MI 48105
(734) 213-8150
Contact: Mr. Dale A. Scherger
Email: Daleres@aol.com

The laboratories that conducted the analytical work for this study were:

Barnstable County Department of Health and the Environment Laboratory
Superior Court House (P.O. Box 427)
Barnstable, MA 02630
(508) 375-6606
Contact: Dr. Thomas Bourne
Email: bcdhelab@cape.com

Groundwater Analytical, Inc. (GWI)
228 Main St.
Buzzards Bay, MA 02532
(508) 759-4441
Contact: Mr. Eric Jensen

The Manufacturer of the Equipment was:

Waterloo Biofilter Systems, Inc.
143 Dennis Street, P.O. Box 400
Rockwood, Ontario, N0B 2K0 Canada
(519) 856-0757
Contact: Dr. E. Craig Jowett, Ph.D., P.Eng.
Email: craig@waterloo-biofilter.com

The TO wishes to thank NSF International, especially Mr. Thomas Stevens, Project Manager, and Ms. Maren Roush, Project Coordinator, for providing guidance and program management.

1.0 Introduction

1.1 ETV Purpose and Program Operation

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of innovative, improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholders groups which consist of buyers, vendor organizations, consulting engineers, and regulators; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory (as appropriate) testing, collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF), in cooperation with the EPA, operates the Water Quality Protection Center (WQPC), one of six Centers under ETV. Source Water Protection (SWP) is one area within the WQPC. The WQPC-SWP evaluated the performance of the Waterloo Biofilter Systems, Inc. (WBS) Waterloo Biofilter® Model 4-Bedroom (Biofilter®) for the reduction of nitrogen compounds (TKN, NH_3, NO_2, NO_3), present in residential wastewater. WBS sells the Biofilter® to treat wastewater from single-family homes. Other models of the Biofilter® are available for small commercial businesses, and similar applications, but this evaluation does not address those models. The unit is designed to work in conjunction with conventional septic tank systems and to provide nitrogen reduction in addition to the removal of organics and solids present in these wastewaters. The Biofilter® system is based on fixed film trickling filter technology, using a patented aerobic foam medium. This report provides the verification test results for the WBS Waterloo Biofilter® Model 4-Bedroom System, in accordance with the *Protocol for the Verification for Residential Wastewater Treatment Technologies for Nutrient Reduction,* November 2000(1).

1.2 Testing Participants and Responsibilities

The ETV testing of the Biofilter® was a cooperative effort between the following participants:

NSF International
Massachusetts Alternative Septic System Test Center
Barnstable County Department of Health and Environment Laboratory

Groundwater Analytical, Inc.
Scherger Associates
Waterloo Biofilter Systems, Inc.
EPA

1.2.1 NSF International - Verification Organization (VO)

The Water Quality Protection Center of the ETV is administered through a cooperative agreement between EPA and NSF International (NSF). NSF is the verification partner organization for the WQPC and the Source Water Protection (SWP) area within the center. NSF administers the center, and contracts the Testing Organization to develop and implement the Verification Test Plan (VTP).

NSF's responsibilities as the Verification Organization included:

- Review and comment on the site specific VTP;
- Coordinate with peer-reviewers to review and comment on the VTP;
- Coordinate with the EPA Project Manager and the technology vendor to approve the VTP prior to the initiation of verification testing;
- Review the quality systems of all parties involved with the Testing Organization and subsequently, qualify the companies making up the Testing Organization;
- Oversee the technology evaluation and associated laboratory testing;
- Carry out an on-site audit of test procedures;
- Oversee the development of a verification report and verification statement;
- Coordinate with EPA to approve the verification report and verification statement; and,
- Provide QA/QC review and support for the TO

Key contacts at NSF for the Verification Organization are:

Mr. Thomas Stevens, Program Manager
(734) 769-5347 email: stevenst@nsf.org

Ms. Maren Roush, Project Coordinator
(734) 827-6821 email: mroush@nsf.org

NSF International
789 N. Dixboro Road
Ann Arbor, Michigan 48105
(734) 769-8010

1.2.2 U.S. Environmental Protection Agency

The EPA Office of Research and Development, through the Urban Watershed Management Branch, Water Supply and Water Resources Division, National Risk Management Research Laboratory (NRMRL), provides administrative, technical, and quality assurance guidance and oversight on all ETV Water Quality Protection Center activities. The EPA reviews and approves each phase of the verification project. The EPA's responsibilities with respect to verification testing include:

- Verification Test Plan review and approval;
- Verification Report review and approval; and,
- Verification Statement review and approval.

The key EPA contact for this program is:

Mr. Ray Frederick, Project Officer, ETV Water Quality Protection Center
(732)-321-6627 email: frederick.ray@epa.gov

U.S. EPA, NRMRL
Urban Watershed Management Branch
2890 Woodbridge Ave. (MS-104)
Edison, NJ 08837-3679

1.2.3 Testing Organization

The Testing Organization (TO) for the verification testing was the Barnstable County Department of Health and Environment (BCDHE). Mr. George Heufelder of the BCDHE was the project manager. He had the responsibility for the overall development of the Verification Test Plan (VTP), oversight and coordination of all testing activities, and compiling and submitting all of the test information for development of this final report.

Mr. Dale Scherger of Scherger Associates was contracted by NSF to work with BCDHE to prepare the Verification Report (VR) and Verification Statement (VS).

The BCDHE Laboratory and its subcontractor, Groundwater Analytical, Inc. (GAI), provided laboratory services for the testing program and consultation on analytical issues addressed during the verification test period.

The responsibilities of the TO included:

- Prepare the site specific Verification Test Plan;

- Conduct Verification Testing, according to the Verification Test Plan;
- Install, operate, and maintain the Biofilter® in accordance with the Vendor's O&M manual(s);
- Control access to the area where verification testing was carried out;
- Maintain safe conditions at the test site for the health and safety of all personnel involved with verification testing;
- Schedule and coordinate all activities of the verification testing participants, including establishing a communication network and providing logistical and technical support on an "as needed" basis;
- Resolve any quality concerns that may be encountered and report all findings to the Verification Organization;
- Manage, evaluate, interpret and report on data generated by verification testing;
- Evaluate and report on the performance of the technology; and,
- If necessary, document changes in plans for testing and analysis, and notify the Verification Organization of any and all such changes before changes are executed.

The key personnel and contacts for the TO are:

Mr. George Heufelder, Project Manager
Barnstable County Department of Health and the Environment
Superior Court House (P.O. Box 427)
Barnstable, MA 02630
(508) 375-6616
Email: gheufeld@capecod.net

Mr. Sean Foss, Facility Operations Manager:
Barnstable County Department of Health and the Environment
Superior Court House (P.O. Box 427)
Barnstable, MA 02630
(508) 563-6757
Email: sfoss@capecod.net.

Dr. Thomas Bourne, Laboratory Manager
Barnstable County Department of Health and the Environment Laboratory
Superior Court House (P.O. Box 427)
Barnstable, MA 02630
(508) 375-6606
Email: bcdhelab@cape.com

Mr. Eric Jensen
Groundwater Analytical, Inc. (GAI)
228 Main St.
Buzzards Bay, MA 02532
(508) 759-4441

Scherger Associates was responsible for:

- Preparation of the Verification Report; and,
- Preparation of the Verification Statement

The key contact at Scherger Associates is:

Mr. Dale A. Scherger
Scherger Associates
3017 Rumsey Drive
Ann Arbor, MI 48105
(734) 213-8150
Email: Daleres@aol.com

1.2.4 Technology Vendor

The nitrogen reduction technology evaluated was the Waterloo Biofilter® Model 4-Bedroom System manufactured by WBS. WBS was responsible for supplying all of the equipment needed for the test program, and supporting the TO in ensuring that the equipment was properly installed and operated during the verification test. Specific responsibilities of the vendor include:

- Initiate application for ETV testing;
- Provide input regarding the verification testing objectives to be incorporated into the Verification Test Plan;
- Select the test site;
- Provide complete, field-ready equipment and the operations and maintenance (O&M) manual(s) typically provided with the technology (including instructions on installation, start-up, operation and maintenance) for verification testing;
- Provide any existing relevant performance data for the technology;
- Provide assistance to the Testing Organization on the operation and monitoring of the technology during the verification testing, and logistical and technical support as required;
- Review and approve the site-specific VTP;
- Review and comment on the Verification Report; and,

- Provide funding for verification testing.

The key contact for WBS is:

Dr. E. Craig Jewett, Ph.D., P.Eng.
Waterloo Biofilter Systems, Inc.
143 Dennis Street, P.O. Box 400
Rockwood, Ontario, N0B 2K0 Canada
(519) 856-0757
(519) 856-0759 (Fax)
Email: craig@waterloo-biofilter.com

1.2.5 ETV Test Site

The Massachusetts Alternative Septic System Test Center (MASSTC) was the host site for the nitrogen reduction verification test. MASSTC was initially funded by the State of Massachusetts. The Barnstable County Department of Health and the Environment operates and provides the staff for the center. The MASSTC is located at Otis Air National Guard Base, Bourne, MA. The site was designed as a location to test septic treatment systems and related technologies. MASSTC provided the location to install the technology and all of the infrastructure support requirements to collect domestic wastewater, pump the wastewater to the system, operational support, and maintenance support for the test. Key items provided by the test site were:

- Logistical support and reasonable access to the equipment and facilities for sample collection and equipment maintenance;
- Wastewater that is "typical" domestic, relative to key parameters such as BOD_5, TSS, Total Nitrogen, and phosphorus;
- A location for sampling of raw or screened wastewater and a sampling arrangement to collect representative samples;
- Automatic pump systems capable of controlled dosing to the technology being evaluated to simulate a diurnal flow variation and to allow for stress testing. Sufficient flow of wastewater to accomplish the required controlled dosing pattern;
- An accessible but secure site to prevent tampering by outside parties; and,
- Wastewater disposal of both the effluent from the testing operation and for any untreated wastewater generated when testing is not occurring.

1.2.6 Technology Panel

Representatives from the Technology Panel assisted the Verification Organization in reviewing and commenting on the Verification Test Plan.

1.3 Background – Nutrient Reduction

Domestic wastewater contains various physical, chemical and bacteriological constituents, which require treatment prior to release to the environment. Various wastewater treatment processes exist which provide for the reduction of oxygen demanding materials, suspended solids and pathogenic organisms. Reduction of nutrients, principally phosphorus and nitrogen, has been practiced since the 1960's at treatment plants where there is a specific need for nutrient reduction to protect the water quality and, hence, the uses of the receiving waters, whether ground water or surface water. The primary reasons for nutrient reduction are to protect water quality for drinking water purposes (drinking water standards for nitrite and nitrate have been established), and to reduce the potential for eutrophication in nutrient sensitive surface waters by the reduction of nitrogen and/or phosphorus.

The reduction of nutrients in domestic wastewater discharged from single-family homes, small businesses and similar locations within watersheds is desirable for the same reasons as for large treatment facilities. First, reduction of watershed nitrogen inputs helps meet drinking-water quality standards for nitrate and nitrite; and second, the reduction of both nitrogen and phosphorus helps protect the water quality of receiving surface and ground waters from eutrophication and the consequent loss in ecological, commercial, recreational and aesthetic uses of these waters.

Several technologies and processes can remove nutrients in on-site domestic wastewater. The Biofilter® process is based on the fixed film (trickling filter) biological process for nitrification and the anoxic conditions in the septic tank for biological denitrification. A brief discussion of these processes is given below.

1.3.1 Fixed Film Trickling Filter - Biological Nitrification

The EPA has published a fact sheet describing the nitrification process in trickling filter systems, *Wastewater Technology Fact Sheet Trickling Filter Nitrification,* EPA September 2000(2). This fact sheet provided the information presented below. A more comprehensive source of information is the EPA Manual for Nitrogen Control (EPA/625/R-93/010)(3).

Nitrification is a process carried out by bacterial populations (*Nitrosomonas* and *Nitrobacter)* that oxidize ammonium to nitrate with intermediate formation of nitrite. These organisms are considered autotrophic, because they obtain energy from the oxidation of inorganic nitrogen compounds. The two steps in the nitrification process and their equations are as follows:

1) Ammonia is oxidized to nitrite (NO_2^-) by *Nitrosomonas* bacteria.

$$2\ NH_4^+ + 3\ O_2 = 2\ NO_2^- + 4\ H^+ + 2\ H_2O$$

2) The nitrite is converted to nitrate (NO_3^-) by *Nitrobacter* bacteria.

$$2\ NO_2^- + O_2 = 2\ NO_3^=$$

Since complete nitrification is a sequential reaction, systems must be designed to provide an environment suitable for the growth of both groups of nitrifying bacteria. These two reactions essentially supply the energy needed by nitrifying bacteria for growth. Several major factors influence the kinetics of nitrification, including organic loading, hydraulic loading, temperature, pH, and dissolved oxygen concentration.

1. Organic loading: The efficiency of the nitrification process is affected by the organic loadings. Although the heterotrophic biomass is not essential for nitrifier attachment, the heterotrophs (organisms that use organic carbon for the formation of cell tissue) form biogrowth to which the nitrifiers adhere. The heterotrophic bacteria grow much faster than nitrifiers at high BOD_5 concentrations. As a result, the nitrifiers can be over grown by heterotrophic bacteria, which can cause the nitrification process to cease. Before nitrification can take place, the soluble BOD must be sufficiently reduced to eliminate this competition, generally down to 20-30 mg/L.

2. Hydraulic loading: Wastewater is normally introduced at the top of the attached growth reactor and trickles down through a medium. The value chosen for the minimum hydraulic loading should ensure complete media wetting under all influent conditions. Hydraulic and organic loadings are not independent parameters, because the wastewater concentration entering the plant cannot be controlled. The total hydraulic flow to the filter can be controlled to some extent by recirculation of the treated effluent. Recirculation also increases the instantaneous flow at points in the filter and reduces the resistance to mass transfer. This also increases the apparent substrate concentration and the growth and removal rate. The third major benefit of recirculation in nitrifying trickling filters is the reduction of the influent BOD_5 concentration, which makes the nitrifiers more competitive. This in turn increases the nitrification efficiency and increases the dissolved oxygen concentration.

3. Temperature: The nitrification process is very dependent on temperature and occurs over a range of approximately 4 to 45 °C (39 to 113 °F). Typically, at temperatures below 10 °C, nitrification rates slow dramatically, and may stop altogether at around 5 °C. Above 10 °C, the nitrification rate increases with temperature, and reaches a maximum at 30 to 35 °C. Higher nitrification rates are expected to be more affected by temperature than lower rates of nitrification.

4. pH: The nitrification process produces acid. The acid formation lowers the pH and can cause a reduction in the growth rate of the nitrifying bacteria. The optimum pH for *Nitrosomonas* and *Nitrobacter* is between 7.5 and 8.5. At a pH of 6.0 or less nitrification normally will stop. Approximately 7.1 pounds of alkalinity (as $CaCO_3$) are destroyed per pound of ammonia oxidized to nitrate.

5. Dissolved Oxygen (DO): The concentration of dissolved oxygen affects the rate of nitrifier growth and nitrification in biological waste treatment systems. The DO concentration at which nitrification is limited can be 0.5 to 2.5 mg/L in either suspended or attached growth systems under steady state conditions, depending on the degree of mass-transport or diffusional resistance and the solids retention time. The maximum nitrifying growth rate is reached at a DO concentration of 2 to 2.5 mg/L. However, it is not necessary to grow at the maximum growth rate to get effective nitrification if there is adequate contact time in the system. As a result there is a broad range of DO values where DO becomes rate limiting. The intrinsic growth rate of *Nitrosomonas* is not limited at DO concentrations above 1.0 mg/L, but DO concentrations greater than 2.0 mg/L may be required in practice. Nitrification consumes large amounts of oxygen with 4.6 pounds of O_2 being used for every pound of ammonia oxidized.

1.3.2 Biological Denitrification

Denitrification is an anoxic process where nitrate serves as the source of oxygen for bacteria and the nitrate is reduced to nitrogen gas. Denitrifying bacteria are facultative organisms that can use either dissolved oxygen or nitrate as an oxygen source for metabolism and oxidation of organic matter. If both dissolved oxygen and nitrate are present, the bacteria will tend use the dissolved oxygen first. Therefore, it is important to keep dissolved oxygen levels as low as possible.

Another important aspect of the denitrification process is the presence of organic matter to drive the denitrification reaction. Organic matter can be in the form of raw wastewater, methanol, ethanol, or other organic sources. When these sources are not present, the bacteria may depend on internal (endogenous) carbon reserves as organic matter. The endogenous respiration phase can sustain a system for a time, but may not be a consistent enough source of carbon to drive the reaction to completion or to operate at the rates needed to remove the elevated nitrate levels present in nitrified effluent.

The denitrifying reaction using methanol as a carbon source can be represented as follows:

$$6NO_3^{=} + 5CH_3OH = 5CO_2 + 3N_2 + 7H_2O + 6OH^-$$

Several conditions affect the efficiency of the denitrification process including the anoxic conditions, the temperature, presence of organic matter, and pH.

1. Dissolved oxygen - The level of dissolved oxygen has a direct impact on the denitrifying organisms. As dissolved oxygen increases, denitrification rate decreases. Dissolved oxygen concentrations below 0.3-0.5 mg/L in the anoxic zone are typically needed to achieve efficient denitrification.

2. Temperature affects the growth rate of denitrifying organisms with higher growth rates occurring at higher temperatures. Denitrification normally occurs between 5 and 35 °C (41 to 95 °F). As in the case of nitrification, denitrifying rates drop significantly as temperature falls below 10 °C.

3. Organic matter – The denitrification process requires a source of organic matter. Denitrification rate varies greatly depending upon the source of available carbon. The highest rates are achieved with addition of an easily assimilated carbon source such as methanol. Somewhat lower denitrification rates are obtained with raw wastewater or primary effluent as the carbon source. The lowest denitrification rates are observed with endogenous decay as the source of carbon.

pH and alkalinity – The optimum pH range for most denitrifying systems is 7.0 to 8.5. The process will normally occur in a wider range, pH 6 – 9, but denitrifying rates may be impacted near the extremes of the range. Acclimation of the population can lower the impact of pH on growth rates. An advantage of the denitrification process is the production of alkalinity that helps buffer the decrease in alkalinity in the nitrification process. Approximately 3.6 pounds of alkalinity is produced for each pound of nitrate nitrogen removed.

2.0 Technology Description and Operating Processes

2.1 Technology Description

The WBS Waterloo Biofilter® System uses a fixed film trickling filter process in conjunction with a conventional septic tank for wastewater treatment. The septic tank provides solid liquid separation and anaerobic conditions for organic treatment and denitrification. The trickling filter consists of a bed of highly permeable and absorbent media over which wastewater is applied and allowed to trickle through, providing aerobic conditions for organic removal and nitrification. The Biofilter® uses a patented foam material as the medium. Microorganisms present in the wastewater attach inside the media, and use the nitrogen and organic materials provided by the constant supply of fresh wastewater to form new cell mass. The open spaces between the media pieces allow air to freely pass through the bed, providing oxygen to support the microorganisms.

In the trickling filter, the organic material in the wastewater is degraded by microorganisms attached to the media in the form of a biological film. According to WBS, the upper 40 cm of the medium typically provides most of the treatment for solids and organics. The lower section of the filter provides conditions conducive to growth of nitrifying organisms. Nitrogen compounds, organic nitrogen and ammonia, are converted to nitrite and nitrate in the lower section of the Biofilter®. A portion of the treated effluent (approximately 50 percent of flow) is recycled to the septic tank to enhance the removal of nitrogen by reduction of the nitrate under anoxic conditions in the septic tank.

2.2 Waterloo Biofilter® Equipment and Process Description

A complete treatment system has two stages of treatment. Raw sewage flows to the septic tank where it undergoes initial organics treatment and separation of solids and liquids. The septic tank effluent drains by gravity through an effluent screen into a pump chamber, normally constructed below grade near the septic tank. The effluent screen is designed to ensure that large solids remain in the septic tank and do not clog the pump or the nozzles downstream. The screened effluent is pumped from the pump chamber to the Biofilter® unit using an on demand approach (i.e., the pump activates when there is a rise in the pump chamber due to incoming flow.)

The Biofilter® unit consists of the foam medium supplied as two to three inch cubes piled randomly into two self-contained baskets. The system relies on natural air circulation through the bed to supply oxygen to the biomass. No fan is used to supply air to the unit. The baskets are housed in a free draining shed with vents to allow natural air convection through the foam medium. The container box had two openings for air exchange that were supplied with a small amount of activated charcoal for odor control. The carbon filter was a loosely packed meshed placed in the conduit between the inside and outside of the housing unit. The outside opening had a screen affixed to it to prevent the intrusion of insects. The bag could be slid in/out from the inside. These carbon filters were apparently adequate to control odor as no discernable odors were noted during the test period. A neoprene seal between the hinged top of the foam filter and the container itself likewise prevented escape of odor.

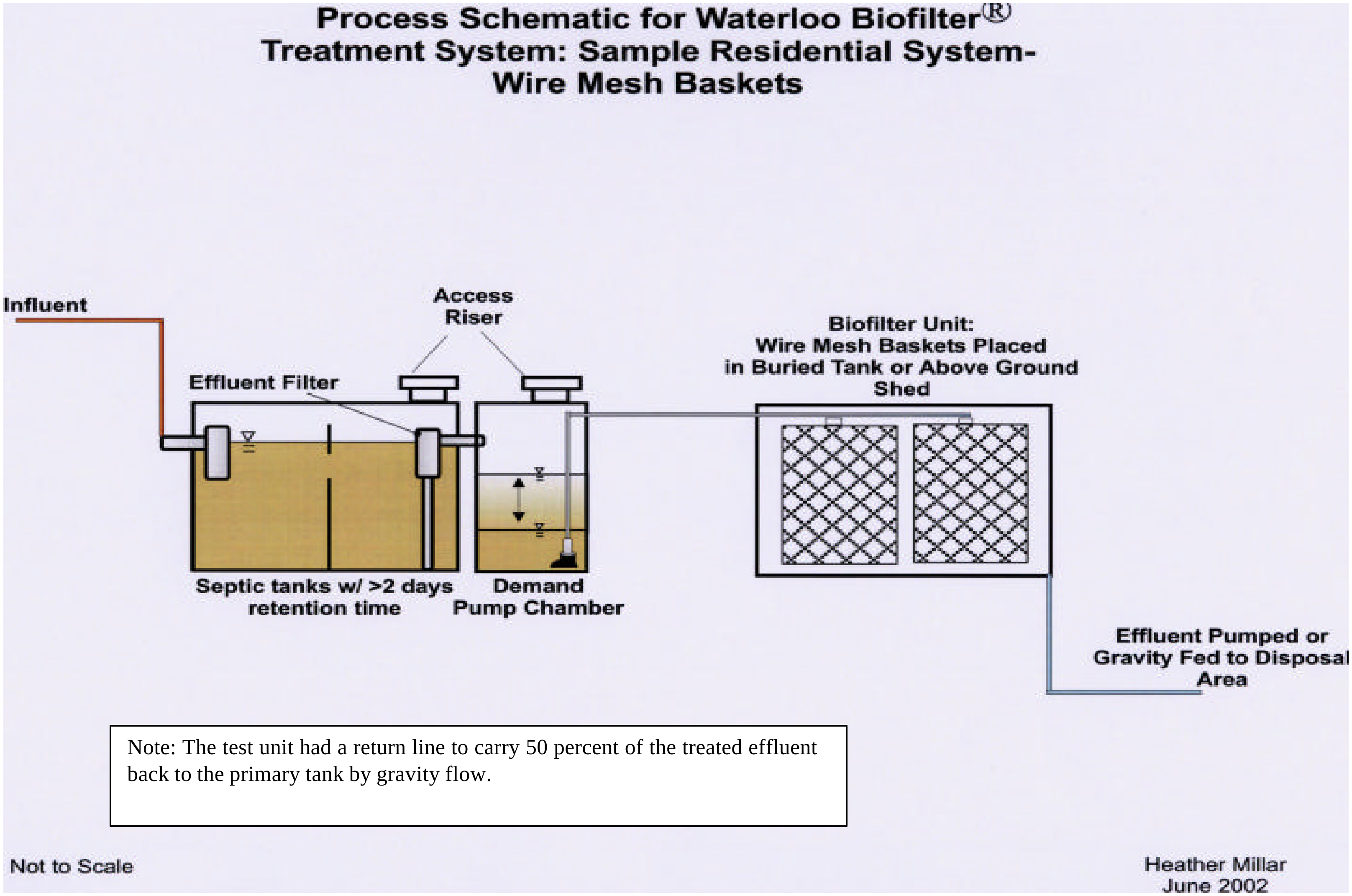
The Biofilter® Design, Installation, and Service Manual (Appendix A) lists several alternative containment systems for the foam medium, including below grade systems. Distribution nozzles spray the wastewater over the foam surface. The bottom of the container is partitioned to allow approximately 50 percent of the flow to return to the septic tank by gravity. The remaining 50 percent of flow is discharged by gravity from the system. In a normal installation, the discharge water flows to a tile field or other suitable disposal location. For this test, the treated effluent discharged through a sampling location, and then to the base sewer system.

Figures 2-1 through 2-3 show the basic system flow diagram and schematic representation of the Biofilter® system. The system operated for this test is designed to handle 440 gpd. Additional detailed information on the unit is presented in the Design, Installation, and Service Manual in Appendix A.

In a typical residential application, raw wastewater flows by gravity into a 1,200 to 1,500 gallon, two-compartment septic tank. The tank is baffled so that the flow does not channel directly through the tank and to promote settling of solids. The system tested in this verification uses a 1,500 gallon single compartment primary tank. All Biofilter® Systems use an effluent screen on the gravity discharge from the septic tank. Residential applications use a Zabel Model A 300 effluent filter attached to the outlet pipe of the septic tank to prevent solids from entering the pump chamber. The filter provides one-eighth to one-sixteenth inch (1/8 – 1/16) screening of the septic effluent.

The standard design for the pump chamber is a narrow diameter (18 to 24 inch) chamber that receives the screened effluent. The pump chamber for the test unit was 20 inches in diameter. The effluent pump is located on a slab to raise it off the floor. The on demand system uses two pump control switches, with the lower on-off switch operating the pump. The lower switch is set so that only approximately 23 liters (6 gallons) is dosed to the Biofilter® at any time. The upper switch is the high water alarm with no over ride capability. This alarm activates if the water is accumulating in the chamber due to pump failure, clogging of the nozzles, or if the incoming flow rate exceeds the pumping rate.

The key, according to WBS, to the Biofilter® high efficiency is the absorbent foam medium, which allows bacterial-microbial growth on the interior surfaces of the foam where they are protected and can grow out into the large open pore spaces in the foam. Wastewater slowly percolates down through the foam pieces and out the bottom. The unit for the ETV test consisted of two 44-inch diameter by 54-inch high PVC coated, wire mesh baskets, containing a total of 95.4 ft^3 (2.7 m^3) of two to three inch foam cubes. The design loading rate was 4.6 US $gpd/ft^3_{(foam)}$ at an influent dosing rate of 440 gallons per day. The baskets were housed in a free-draining wooden waterproof (cedar and pressure treated wood) shed with vents to allow natural air convection through the foam medium. The shed was insulated with waterproof hardened foam insulation. The bottom of the shed has a floor that was partitioned to send approximately half of the treated water from each basket back to the inlet to the septic tank. The balance of the treated water discharged by gravity through the sampling station.



Note: The test unit had a return line to carry 50 percent of the treated effluent back to the primary tank by gravity flow.

Figure 2-1. Waterloo Biofilter® Schematic Representation

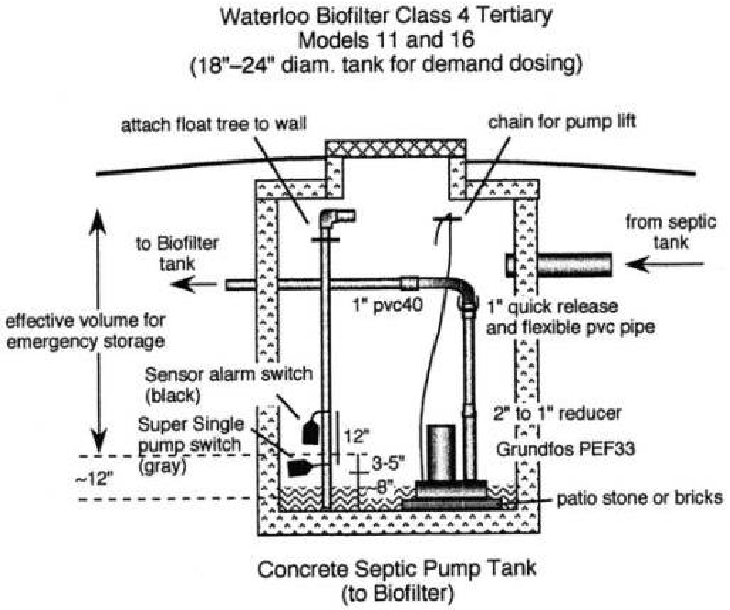


Figure 2-2. Waterloo Biofilter® System Pump Chamber

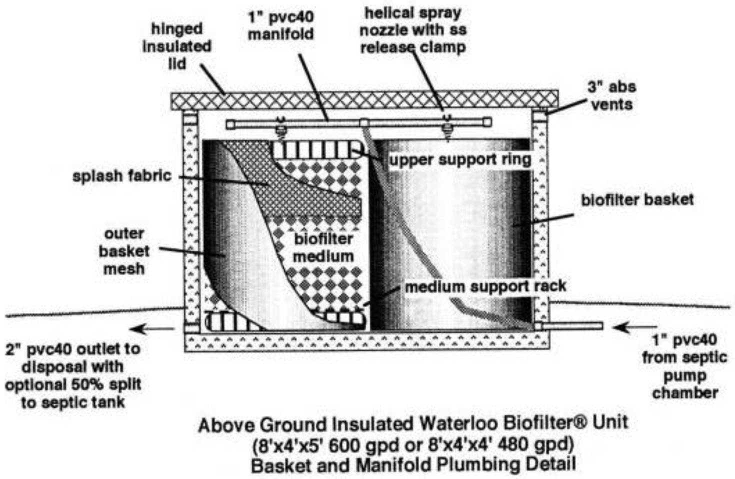


Figure 2-3. Waterloo Biofilter® Filter Schematic

The wastewater was pumped to the Biofilter® through 1 inch schedule 40 PVC pipe to a manifold with downward facing nozzles. The two nozzles (one over each basket) are standard fire sprinkler type nozzles, which distribute the spray over the foam in an even manner. The distribution system is sized to provide 10-15 psi at the nozzle head.

The Biofilter® Design, Installation, and Service Manual (Manual) provides additional details for the system and alternative configurations. A copy of the Manual is presented in Appendix A.

2.3 Equipment Specifications

The specifications for the Waterloo Biofilter® System are summarized in Table 2-1. All of the piping used in the systems is either schedule 40 PVC pipe or flexible hose.

Table 2-1. Waterloo Biofilter® Specifications

Item	Quantity
Zabel A 300 effluent filter	1
Grundfos pump EF33 1/3 hp 110 VAC	1
Float switches	2
PVC distribution system	1
Bete fog nozzles	2
Wire mesh baskets 44" D x 54"H	2
Foam medium	95.4 ft^3
Wooden shed (8'L X 4'W X 5'H)	1
Control panel	1
Technical Manual	1
Padlocks	1
Key	1

2.4 Operation and Maintenance

WBS provides an informational booklet to homeowners with important information about the Biofilter® System. The Design, Installation, and Service Manual is provided to installers and service companies. A copy of this Manual is presented in Appendix A. The Manual provides installation, startup, operation and maintenance descriptions for the unit. WBS also provides a Maintenance Checklist, a set of maintenance procedures, and troubleshooting information. These lists are also presented in Appendix A. WBS strongly recommends that a service contract be arranged with a local company to provide periodic maintenance for their units. The homeowners booklet states that service should be performed at least annually, but the example service contact in the Manual recommends twice per year.

The semi-annual maintenance procedures recommended in the maintenance program include:

- Check pump and pump chamber
- Check that the pump control and alarm switches operate properly
- Check and clean spray nozzles
- Check condition of biomass and foam medium
- Check the quality of the effluent (visual, odor)
- Check control panel
- Inspect the septic tank

2.5 Vendor Claims

Waterloo Biofilter Systems, Inc. (WBS) claims the Waterloo Biofilter® System can be designed to consistently remove nitrogen in wastewater on a year round basis. For a normal household, WBS claims effluent quality is less than 15 mg/L $CBOD_5$, less than 10 mg/L total suspended solids, and 20-60 percent reduction of total nitrogen. Using a 50 percent recirculation flow, WBS claims the total nitrogen removal can be increased to 50-60 percent on a healthy septic tank. WBS literature claims that foam filter medium has a life span of 20 to 30 years, and normally does not require cleaning for 10 years of operation. The foam medium life span was not part of this verification.

3.0 Methods and Test Procedures

3.1 Verification Test Plan and Procedures

A Verification Test Plan (VTP) was prepared and approved for the verification of the Waterloo Biofilter Systems, Inc., Waterloo Biofilter® Model 4-Bedroom System, and is included in Appendix B. The VTP, *Test Plan for The Massachusetts Alternative Septic System Test Center for the Verification Testing of the Waterloo Biofilter® Nutrient Reduction Technology* (4), February 2001 detailed the procedures and analytical methods to be used to perform the verification test. The VTP was prepared in accordance with the SWP protocol, *Protocol for the Verification of Residential Wastewater Treatment Technologies for Nutrient Reduction* (1), November 2000. The VTP included tasks designed to verify the nitrogen reduction capability of the Biofilter® unit and to obtain information on the operation and maintenance requirements of the Biofilter®. There were two distinct phases of fieldwork to be accomplished as part of the VTP, startup of the unit, and a one year verification test that included normal dosing and stress conditions. The Protocol requires twelve months of sampling, however, an extra month was added since the testing ended in a cold weather month (March). The extra one-month of data was collected to show the response of the system coming out of a cold weather period.

Each of the testing elements, performed during the technology verification, is described in this section. In addition to descriptions of sample collection methods, equipment installation, and equipment operation, this section also describes the analytical protocols. Quality Assurance and Quality Control procedures and data management approach are discussed in detail in the VTP.

3.2 MASSTC Test Site Description

The MASSTC site is located at Otis Air National Guard Base in Bourne, Massachusetts. The site is designed to provide domestic wastewater for use in testing various types of residential wastewater treatment systems. The domestic wastewater source is the sanitary sewerage from the base residential housing and other military buildings. The sewer system for the base flows to an on-base wastewater treatment facility. An interceptor chamber, located in the main sewer line to the base wastewater treatment facility was constructed when the MASSTC was built, and provides a location to obtain untreated wastewater. The raw wastewater passes through a bar screen (grate) located before the transfer pump. This bar screen has one inch spacing between the bars to remove large or stringy materials that could clog the pump or lines. The screened raw wastewater is pumped through an underground two-inch line to the dosing channel at the test site. The design of the interceptor chamber provides mixing of the wastewater just ahead of the transfer pump to ensure a well-mixed raw wastewater is obtained for the influent feed at the test site.

The screened wastewater is pumped to the dosing channel at a rate of approximately 29 gallons per minute (gpm) on a continuous basis for 18 hours per day, yielding at total flow of approximately 31,000 gallons per day (gpd). Wastewater enters the dosing channel, an open top concrete channel, sixty-five feet long by two feet wide by three feet deep, via two pipes midway in the channel. Approximately 4-6,000 gallons per day is withdrawn for test purposes in various treatment units. The excess wastewater flows by gravity to the base sanitary sewer and is treated at the base wastewater treatment plant. The dosing channel is equipped with four recirculation pumps. These pumps, spaced along the channel length, keep the wastewater in the channel constantly moving to ensure the suspension of solids, and to ensure that the wastewater is of similar quality at all locations along the channel.

Dosing of wastewater to the individual test units is accomplished by individual pumps submerged in-line along the dosing channel. The pumps are connected to the treatment technology being tested by underground PVC pipe. A custom designed, programmable logic controller (PLC) is used to control the pumps and the dosing sequence or cycle. Each technology feed pump can be controlled individually for multiple start and stop times, and for pump run time. For the Biofilter® system, the volumetric dosages were set to meet the dosing sequence described in the VTP. The test for the Biofilter® system was based on dosing 15 times per day with approximately 29 gallons of wastewater per dose. This dosing volume of 440 gallons per day was based on the Biofilter® rated capacity of 440 gpd. The individual dose volume was controlled by adjusting the pump run time for each cycle.

MASSTC maintains a small laboratory at the site to monitor basic wastewater treatment parameters. Temperature, dissolved oxygen, pH, specific conductance, and volumetric measurements are routinely performed to support the test programs at the site. These field parameters were performed at the site during the Biofilter® test.

The MASSTC has been in operation since 1999**.** Screened wastewater quality has been monitored as part of several previous test programs, as presented in Table 3-1. Influent wastewater monitoring was part of the startup and verification testing, and is described later in this section. Results of all influent monitoring during the verification test are presented in Chapter 4.

Table 3-1. Historical MASSTC Wastewater Data

Parameter	Average (mg/L)	Standard Deviation
BOD_5	180	61
TSS	160	59
Total Nitrogen	34	4.6
Alkalinity	170	28
pH	7.4	0.13

3.3 Installation and Startup Procedures

3.3.1 Introduction

WBS provided a Design, Installation, and Service Manual for the Biofilter®. This Manual is presented in Appendix A. The Biofilter® system had been installed at MASSTC in May 1999 as part of an on-going testing program. The existing system, a single compartment, 1,500 gallon septic tank, pump chamber, and a Biofilter® unit, were used for the startup and verification tests for the ETV program.

3.3.2 Objectives

The objectives of the installation and start-up phase of the VTP were to:

- Install the WBS Biofilter® in accordance with the Manual;
- Start-up and test the Biofilter® to ensure all processes were operating properly, the pump was set for proper automatic operation, and any leaks that occurred during the installation were eliminated;
- Make any modifications needed to achieve operation; and,
- Record and document all installation and start-up conditions prior to beginning the verification test.

3.3.3 Installation and Startup Procedures

The installation of the Biofilter® was performed by a contractor under the supervision of the BCDHE support team and supported by the WBS staff. The installation was performed in May 1999 as part of an earlier test program. In order to prepare for startup of the Biofilter® for the ETV verification, the entire Biofilter® system was emptied of wastewater and cleaned in December 2000. Solids were removed from the primary tank, and all pumps, lines, and associated equipment were cleaned. The foam media in the filter was removed and replaced with new media. At the end of the cleaning period, the system was in a “like new” condition.

The VTP and Protocol allow for an eight-week startup period. During the startup, the biological community is established and operating conditions are adjusted, if needed, for site conditions. The startup procedures in the Manual (Appendix A) were followed as written. The primary tank and filter system were filled with water and each component of the system checked for proper operation. The water was also used to check the dosing pump flow rates.

Startup of the cleaned Biofilter® system began on January 15, 2001. Raw wastewater from the dosing channel was added to the primary tank until it was full, resulting in a mixture of fresh water and raw wastewater in the tank.. The dosing sequence was started on January 15 with a setting of 15 doses of wastewater per day, with a target of 29.33 gallons of wastewater per dose. This dose setting provided a target total daily flow of 440 gallons per day.

The system was monitored during the startup period (January 15 through March 12, 2001) by visual observation of the system, routine calibration of the dosing system, and the collection of influent and effluent samples. Samples for analysis were collected six times over the eight week startup period. Influent samples were analyzed for pH, alkalinity, temperature, BOD_5, TKN, NH_3, and TSS analyses. The effluent was also analyzed for pH, alkalinity, temperature, $CBOD_5$, TKN, NH_3, TSS, dissolved oxygen, NO_2, and NO_3. Procedures for sample collection, analytical methods, and other monitoring procedures were the same procedures used during the one-year verification period. These procedures are described later in this section.

3.4 Verification Testing - Procedures

3.4.1 Introduction

The verification test procedures were designed to verify nitrogen reduction by the WBS Biofilter® treatment technology. The verification test consisted of a thirteen-month test period, incorporating five stress periods with varying stress conditions simulating real household conditions. Dosing volume was set based on the design capacity of the Biofilter® system. Monitoring for nitrogen reduction was accomplished by measurement of nitrogen species (TKN, NH_3, $NO_{2,}$ NO_3). Carbonaceous oxygen demand (CBOD) and other basic parameters (pH, alkalinity, TSS, Temperature) were monitored to provide information on overall treatment performance. Operational characteristics such as electric use, residuals generation, noise and odor were also monitored.

Verification results and observations are presented in Chapter 4 of this Verification Report.

3.4.2 Objectives

The objectives of the verification test were to:

- Determine nitrogen reduction performance of the Biofilter® system;
- Monitor removal of other oxygen-using contaminants (BOD_5 $CBOD_{5,}$ TSS);
- Determine operation and maintenance characteristics of the technology; and,
- Assess chemical usage, energy usage, generation of byproducts or residuals, noise and odors.

3.4.3 System Operation- Flow Patterns and Loading Rates

The flow and loading patterns used during the thirteen-month verification test were designed in accordance with the Protocol, as described in the VTP (Appendix B). The flow pattern was designed to simulate the flow from a "normal" household. Several special stress test periods were also incorporated into the test program.

3.4.3.1 Influent Flow Pattern

The influent flow dosed to Biofilter® was controlled by the use of timed pump operation. The dosing pump was set to provide 15 doses of equal volume (target - 29.3 gallons per dose) in accordance with the following schedule:

- 6 a.m. – 9 a.m. approximately 33 percent of total daily flow in 5 doses
- 11 a.m. – 2 p.m. approximately 27 percent of total daily flow in 4 doses
- 5 p.m. – 8 p.m. approximately 40 percent of total daily flow in 6 doses

The influent dosing pump was controlled by a programmable logic controller, which permitted timing of the fifteen individual doses to within one second. The pump flow rate and time setting was calibrated by sequencing the dosing pump for one cycle and collecting the entire volume of flow in a "calibrated" barrel. The barrel was initially calibrated by placing measured volume of water into it. The dosing flow volume was checked by this calibration method at least twice per week. Calibration results were recorded in the field logbook.

The initial total daily flow to the Biofilter® was targeted to be 440 gallons per day (29.3 gallons per dose). After each calibration test, the measured volume was compared to this target rate. If the volume was more than 10 percent above or below the target, the pump run time was increased or decreased to adjust the volume per dose back to the target volume. If the run time was changed, then a second calibration was performed to determine the total volume for the new timer setting. The QC requirement for the dosing volume was 100 ± 10 percent of the target flow (440 gallons per day) based on a thirty (30) day average, with the exception of periods of stress testing. All calibration tests were recorded in the field logbook.

In addition to the twice weekly direct calibrations, the PLC system results were checked on a daily basis. The PLC system recorded the number of doses delivered each day for each pump operated by the system. The PLC was checked to confirm that 15 doses were delivered each day. The PLC was also checked to ensure that the start and stop times were set properly. Any changes made to the settings or problems with dose cycles were recorded on the log.

Flow information was entered into a spreadsheet that showed each day of operation, the pump run time, the gallons pumped per dose, and the number of doses delivered to the unit.

3.4.3.2 Stress Testing Procedures

One stress test was performed during the verification test following every two months of operation at the normal design loading. Five stress scenarios were run during the thirteen month evaluation period. These special tests were designed to test the Biofilter® response to differing load conditions and a power/equipment failure.

Stress testing included the following simulations:

- Washday stress
- Working Parent stress

- Low Load stress
- Power/Equipment Failure stress
- Vacation stress

Washday stress simulation consisted of three (3) washdays in a five (5) day period, with each washday separated by a 24-hour period of dosing at the normal design loading rate. During a washday, the system received the normal flow pattern; however, during the course of the first two (2) dosing periods per day, the hydraulic loading included three (3) wash loads [three (3) wash cycles and six (6) rinse cycles]. The volume of wash load flow was 28 gallons per wash load. The hydraulic loading rate was adjusted so that the loading on washdays did not exceed the design loading rate. Common detergent (Arm and Hammer Fabri-care) and non-chlorine bleach was added to each wash load at the manufacturer recommended amount.

The Working Parent stress simulation consisted of five (5) consecutive days when the Biofilter® was subjected to a flow pattern where approximately 40 percent of the total daily flow was dosed between 6 a.m. and 9 a.m., and approximately 60 percent of the total daily flow was dosed between 5 p.m. and 8 p.m. This simulation also included one (1) wash load [one (1) wash cycle and two (2) rinse cycles] during the evening dose cycle. The hydraulic loading did not exceed the design loading rate during the stress test period.

The Low Load stress simulation consisted of testing the unit at 50 percent of the target flow (220 gallons per day) loading for a period of 21 days. Approximately 35 percent of the total daily flow was dosed between 6 a.m. and 11 a.m., approximately 25 percent of the flow was dosed between 11 a.m. and 4 p.m., and approximately 40 percent of the flow was dosed between 5 p.m. and 8 p.m.

The Power/Equipment Failure stress simulation consisted of a standard daily flow pattern until 8 p.m. on the day when the Power/Equipment Failure stress is initiated. Power to the Biofilter® was turned off at 9 p.m. and the flow pattern was discontinued for 48 hours. After the 48-hour period, power was restored and the system dosed with approximately 60 percent of the total daily flow over a three (3) hour period, which included one (1) wash load [one (1) wash cycle and two (2) rinse cycles].

The Vacation stress simulation consisted of a flow pattern where, on the day that the stress is initiated, approximately 35 percent of the total daily flow was dosed between 6 a.m. and 9 a.m. and approximately 25 percent of the total daily flow was received between 11 a.m. and 2 p.m. The flow pattern was discontinued for eight (8) consecutive days, with power continuing to be supplied to the technology. Between 5 p.m. and 8 p.m. of the ninth day, the technology was dosed with 60 percent of the total daily flow, which included three (3) wash loads [three (3) wash cycles and six (6) rinse cycles].

3.4.3.3 Sampling Locations, Approach, and Frequency

3.4.3.3.1 Influent Sampling Location

Influent wastewater was sampled from the dosing channel at a point near the Biofilter® dosing pump intake, approximately four to six inches from the channel floor. The influent sampling site selection was based on the layout of the dosing channel at the MASSTC facility. Screened wastewater enters the sixty-five foot long dosing channel via two pipes midway between the channel end and the channel outlet. Dosing pumps for individual systems are located in-line along the dosing channel. The influent wastewater-sampling site was located close to the WBS Biofilter® dosing pump to ensure a representative sample of wastewater was obtained.

3.4.3.3.2 WBS Biofilter® Effluent Sampling Location

For the Biofilter® effluent, the sampling site was located in the distribution box where the effluent pipe from the Biofilter® discharges. During installation and setup of the Biofilter®, a sampling point, consisting of a tee-cross with sump of sufficient size to retain sample volume for both grab and automated sampler, was installed in the effluent pipe. The sump was only large enough to retain approximately one liter of fluid and was readily flushed and replenished by the normal flow of treated effluent. The sump was located so that it could be cleaned of any attached and settled solids. Cleaning of the sampling location, by brushing to remove any accumulated solids, was performed on a regular basis prior to each sampling period.

3.4.3.3.3 Sampling Procedures

Both grab and 24-hour flow weighted composite samples were collected at the influent and effluent sampling locations. Grab samples were collected from both locations for the measurement of pH and temperature. Dissolved oxygen was measured at the treated effluent location when flow across the sampling point was occurring. The grab samples were collected by dipping a sample collection bottle into the flow at the same location as the automatic sampler used for composite sample collection. The sample bottle was labeled with the sampling location, time and date. All pH and temperature measurements were performed at the on-site laboratory immediately after sample collection.

Composite samples were collected using automated samplers at each sample collection point. The automated samplers were programmed to draw equal volumes of sample from the waste treatment stream at the same frequency and timing as influent wastewater doses. Samples taken in this manner were therefore flow proportional. The effluent sampler timing was delayed to correspond to the passage of a flow pulse through the Biofilter® system based on the influent dosing pump timer setting. The automatic samplers were calibrated before each use and the volume of sample collected was checked to ensure that the proper number of individual samples was collected in the composite container. Detailed sampling procedures are described in the MASSTC SOPs (Appendix C).

Table 3-2 shows a summary of the sampling matrix for the verification test.

Table 3-2. Sampling Matrix

		Sample Location		
PARAMETER	**SAMPLE TYPE**	**INFLUENT**	**FINAL EFFLUENT**	**TESTING LOCATION**
BOD$_5$	24 Hour composite	√		Laboratory
CBOD$_5$	24 Hour composite		√	Laboratory
Suspended Solids	24 Hour composite	√	√	Laboratory
pH	Grab	√	√	Test Site
Temperature (°C)	Grab	√	√	Test Site
Alkalinity (as CaCO$_3$)	24 Hour composite	√	√	Laboratory
Dissolved Oxygen	Grab		√	Test Site
TKN (as N)	24 Hour composite	√	√	Laboratory
Ammonia (as N)	24 Hour composite	√	√	Laboratory
Total Nitrate(as N)	24 Hour composite		√	Laboratory
Total Nitrite (as N)	24 Hour composite		√	Laboratory

3.4.3.3.4 Sampling Frequency

Table 3-3 shows a summary of the sampling schedule followed during the test. Sample frequency followed the VTP, and included sampling under design flow conditions on a monthly basis and more frequent sampling during the special stress test periods.

Normal Monthly Frequency

Samples of the influent and effluent were collected once per month for the thirteen-month test period (March 2001 – April 2002). The initial VTP was designed for a twelve-month test program; however, the test period was extended for one additional month to provide data for the month of April when temperatures were expected to be higher.

Stress Test Frequency

Samples were collected on the day each stress simulation was initiated and when approximately 50 percent of each stress sequence was completed. For the Vacation and Power/Equipment failure stresses, there is no 50 percent sampling. Beginning twenty-four (24) hours after the completion of Washday, Working Parent, Low Load, and Vacation stress scenarios, samples were collected for six (6) consecutive days. Beginning forty-eight (48) hours after the completion of the Power/Equipment Failure stress, samples were collected for five (5) consecutive days.

Final Week

Samples were also collected for five (5) consecutive days at the end of the yearlong evaluation period.

The decision was made to extend the test period of one additional month to monitor changes in the system that would be influenced by the temperature of the wastewater. Therefore, there was one additional set of samples (April 17, 2002) collected after the five-day sampling of the “final week.”

3.4.3.3.5 Sample Handling and Transport

Samples collected in the automatic samplers were collected with ice surrounding the sample bottle to keep the sample cool. The composite sample container was retrieved at the end of the sampling period, shaken vigorously, and poured into new bottles that were labeled for the various scheduled analysis. Sample bottles used for TKN and ammonia analyses were supplied by the laboratory with preservative. Sample container type, sample volumes, holding times, and sample handling and labeling procedures were detailed in the VTP (Appendix B) and in the MASSTC SOP, Attachment I (Appendix C).

BCDHE personnel transported the samples to the BCDHE laboratory via automobile. The samples were packed in coolers with ice to maintain the temperature of all transported samples at 4 ^{o}C. Subsample containers analyzed at the GAI laboratory were transported from BCDHE laboratory to GAI by GAI personnel. Travel time to BCDHE was approximately 40 minutes. Travel time from BCDHE to GAI was approximately 45 minutes.

Table 3-3. Sampling Schedule for Waterloo Biofilter® System

Month/Day	Sampling Event
Jan 23 and 31, 2001	Startup – 2 sampling events
February 14 and 28, 2001	Startup – 2 sampling events
March 7 and 13, 2001	Startup – 2 sampling events
March 21, 2001	Normal monthly sample
April 18, 2001	Normal monthly sample
May 8,10, and 13-18, 2001	Washday stress - 8 samples
June 6, 2001	Normal monthly sample
July 3, 2001	Normal monthly sample
July 10 and 13-20, 2001	Working Parent stress – 8 samples
August 1, 2001	Normal monthly sample
September 5, 2001	Normal monthly sample
September 18, 27 and October 9-14, 2001	Low Load stress – 8 Samples
October 31, 2001	Normal monthly sample
November 28, 2001	Normal monthly sample
December 3, and 9-13, 2001	Power/Equipment Failure stress – 6 samples
December 28, 2001	Normal monthly sample
January 16, 2002	Normal monthly sample
February 4 and 14-19, 2002	Vacation Stress – 7 samples
March 4-8, 2002	Final week sampling – 5 samples
April 17, 2002	Additional monthly sample

3.4.3.4 Residuals Monitoring and Sampling

Byproducts or residuals generated by the Biofilter® system are returned to the primary tank, as part of the return flow from the unit. Solids settle in this tank and accumulate slowly over time. Measurements of solids depth in the primary tank were made twice near the end of the testing period, in the thirteenth and fourteenth months after startup. A coring solids measurement tool (Core Pro) was used to estimate the depth of sludge/solids and the scum layer in the 1,500 gallon primary tank. The sampling device is a clear tube with a check valve on the bottom. The tube is pushed through the solids to the bottom of the tank. The valve closes and the entire sample column, water and solids, are removed from the tank. The column height is checked to ensure that no sample has leaked from the device. The solids depth is then determined by measuring the height of the solids in the clear tube using a tape measure or ruler. This approach gives a direct measurement of the depth of solids. The thickness of any scum layer present is measured by ruler or tape also. Three measurements of solids depth were made at each of the two access manholes.

Samples of solids were recovered from the Core Pro during the final measurement period by emptying the probe contents into a clean container and sending the sample to the BCDHE laboratory for VSS and TSS analysis. This sample included both the solids and the water present in the tube. Thus, the concentration measurements for solids represent the concentration as if the entire contents of the tank were mixed. To estimate the solids concentration in the settled material at the bottom of the tank, the depth of solids and the depth of water column need to be accounted for, and the ratio used to calculate an estimated solids percent.

3.4.4 *Analytical Testing and Record Keeping*

As shown in Table 3-3, fifty-three (53) samples of the influent and effluent for the Biofilter® unit were collected over the thirteen-month verification period. Table 3-2 presented the parameter list. Samples included grab and composite samples for each sampling day. Industry standard procedures (EPA Methods (5,6) or Standard Methods (7)) were used for all sample analysis. The methods used for each constituent are shown in Table 3-4. Temperature, dissolved oxygen and pH were measured onsite. All other analyses were performed by off site laboratories. The Barnstable County Department of Health and Environment Laboratory performed the analyses for alkalinity, total suspended solids, biochemical oxygen demand (BOD_5), carbonaceous biochemical oxygen demand ($CBOD_5$), nitrite, and nitrate. Groundwater Analytical, Inc. (GAI) was responsible for the analyses for Total Kjeldahl Nitrogen and ammonia.

Table 3-4. Summary of Analytical Methods and Precision and Accuracy Requirements

Parameter	Facility	Acceptance Criteria	Acceptance Criteria	Analytical Method
		Duplicates (%)	Spikes (%)	
pH	On-site	N/A	N/A	SM #423
Temperature (°C)	On-site	N/A	N/A	SM #2550
Dissolved Oxygen	On-site	N/A	N/A	SM #4500
Suspended Solids	BCDHE Laboratory	80-120	N/A	SM #2540 D
$CBOD_5$	BCDHE Laboratory	80-120	N/A	SM #5210 B
Alkalinity	BCDHE Laboratory	80-120	N/A	SM #2320
Total Nitrite (as N)	BCDHE Laboratory	90-110	60-140	EPA 353.3
Total Nitrate (as N)	BCDHE Laboratory	90-110	60-140	EPA 353.3
TKN (as N)	GAI Laboratory	80-120	80-120	EPA 351.4
Ammonia (as N)	GAI Laboratory	80-120	80-120	EPA 350.1

SM – Standard Methods – 19th Edition

A Quality Assurance Project Plan was developed as part of the VTP, and provided quality control requirements and systems to ensure the integrity of all sampling and analysis. Precision and accuracy limits for the analytical methods are shown in Table 3-4. The QAPP included procedures for sample chain of custody, calibration of equipment, laboratory standard operating procedures, method blanks, corrective action plan, etc. Additional details are provided in the VTP (Appendix B). Three laboratory audits were also performed during the verification test to confirm that the analytical work was being performed in accordance with the methods and the established QC objectives.

The results of all analyses from the off site laboratories were reported to the TO by hardcopy laboratory reports. The laboratory data are presented in Appendix D. The off site laboratories also provided QA/QC data for the data sets. This data is included in Appendix D with the laboratory reports. The on site laboratory maintained a laboratory logbook to record the results of all analyses performed at the site. Copies of the on-site laboratory logbook are presented in Appendix E.

The data received from the laboratories were summarized in an Excel spreadsheet by BCDHE personnel at the test site. The data were checked against the original laboratory reports by the site staff, and were checked by NSF to ensure the data was accurately entered. The spreadsheets are included in Appendix F.

3.4.5 Operation and Maintenance Performance

Both quantitative and qualitative performance of the Biofilter® unit was evaluated during the verification test. A field log was maintained that included all observations made during the startup of the unit and throughout the verification test. Observations regarding the condition of the system, any changes in setup or operation (influent wastewater timer adjustments, nozzle cleaning, etc.), or any problems that required resolution were recorded in the log by the field personnel.

Observation and measurement of operating parameters included electric use, chemical use, noise, odor, and evaluation of mechanical components, electrical/instrumentation components, and by-product volumes and characteristics.

3.4.5.1 Electric Use

Electrical use was monitored by a dedicated electric meter serving the WBS Biofilter®. The meter reading was recorded biweekly in the field log by BCDHE personnel. The meter manufacturer and model number and any claimed accuracy for the meter was recorded in the Field Log. At the end of the testing period, the electric meter was returned to the manufacturer for calibration and the calibration data entered in the Field Log.

3.4.5.2 Chemical Use

For this ETV testing, the Biofilter® did not use any process chemicals to achieve treatment.

3.4.5.3 Noise

Noise levels associated with mechanical equipment were measured once during the verification period, using a decibel meter to measure the noise level. Measurements were taken one meter from the unit and one and a half meters above the ground, at 90° intervals in four (4) directions. The meter was calibrated prior to use. Meter readings were recorded in the field log. Duplicate measurements at each quadrant were made to account for variations in ambient sound levels.

3.4.5.4 Odors

Odor observations were made during the final eight months of the verification test. The observation was qualitative based on odor strength (intensity) and type (attribute). Intensity was stated as not discernable; barely detectable; moderate; or strong. Observations were made during periods of low wind velocity (<10 knots). The observer stood upright at a distance of three (3) feet from the treatment unit, at 90° intervals in four (4) directions. All observations were made by the same BCDHE employee.

3.4.5.5 Mechanical Components

Performance and reliability of the mechanical components, such as wastewater pumps, were observed and documented during the test period. These observations included recording in the Field Log of equipment failure rates, replacement rates, and the existence and use of duplicate or standby equipment.

3.4.5.6 Electrical/Instrumentation Components

Electrical components, particularly those that might be adversely affected by the corrosive atmosphere of a wastewater treatment process, and instrumentation and alarm systems were monitored for performance and durability during the course of verification testing. Observations of any physical deterioration were noted in the Field Log. Any electrical equipment failures, replacements, and the existence and use of duplicate or standby equipment were recorded in the Field Log.

4.0 Results and Discussion

4.1 Introduction

Evaluation of the WBS Biofilter® at MASSTC began on January 15, 2001. The unit was filled with a mixture of fresh water and wastewater, the pumps were activated, and the initial dosing cycles started. Flow was set at 440 gpd resulting in 15 doses per day, with a target 29.3 gallons per dose. The startup period continued until March 12, 2001. Six samples of the influent and effluent were collected during the startup period. Verification testing began on March 13, 2001 and continued for 13 months, until April 17, 2002. The extra month of dosing and sampling (13 months versus the planned 12 months) was added to the test to obtain data on the system response as the temperatures began to rise in the spring. During the verification test, 53 sets of samples of the influent and effluent were collected to determine the system performance.

This chapter presents the results of the sampling and analysis of the influent and effluent to/from the unit, a discussion of the results, and observations on the operation and maintenance of the unit during startup and normal operation. Summary of results are presented in these sections. Complete copies of all spreadsheets with individual daily, weekly, or monthly results are presented in Appendix F.

4.2 Startup Test Period

The startup period provided time for the Biofilter® to develop a biological growth acclimated to the site-specific wastewater. The startup also provided an opportunity for the Biofilter® system to be adjusted, if needed, to optimize performance at the site. These first eight weeks of operation also provided site personnel an opportunity to become familiar with the Biofilter® operation and maintenance requirements. Samples were collected during weeks 2, 3, 5, 7, and 8 (2 sets) of the startup period.

4.2.1 Startup Flow Conditions

The flow conditions for the Biofilter® were established at the target capacity of 440 gallons per day in accordance with the VTP. The dosing pump was set to deliver 15 doses per day at approximately 29.3 gallons per dose. Five (5) doses were delivered between 6 a.m. and 9 a.m., four (4) doses between 11 a.m. and 2 p.m., and six (6) doses between 5 p.m. and 8 p.m. In early September, it was discovered that a PLC problem resulted in the actual dosing rate being 14 doses per day, as the first dose each morning was not occurring. Thus, for the startup period and approximately six months (March 13 to September 9) of the verification test, the unit received 14 doses per day, four (4) in the morning, four (4) mid day, and six (6) in the early evening. The average flow for the startup period was 408 gpd, which was within the ± 10 percent (396-484 gpd) of the design flow on a monthly basis specified for the test. The volume of wastewater dosed to the unit during the startup remained mostly constant and only minor adjustments to the dosing pump run time were required. Table 4-1 shows a summary of the flow volumes during the startup period. The daily flow records are in Appendix F.

Table 4-1. Flow – Volume Data during the Startup Period

Date	Average		Actual Daily Volume (Gallons)
	Doses/day	Gallons/dose	
Jan 15 – 21	14	29.3	410
Jan 22 - 27	14	28.0	392
Jan 28 – Feb 6	14	29.5	413
Feb 7 – 13	14	29.0	406
Feb 14 – 17	14	29.1	407
Feb 18 – 24	14	28.9	405
Feb 25 – Mar 3	14	30.0	420
Mar 4 - 6	14	28.5	399
Mar 7- 12	14	29.5	413

4.2.2 Startup Analytical Results

The results of the influent and effluent monitoring during the startup period are shown Tables 4-2 and 4-3. The first sets of samples were taken seven days after the unit was started. The initial data showed that the unit reduced the CBOD$_5$ and TSS to 23 mg/L and 6 mg/L, respectively, and the Biofilter® appeared to be removing some of the total nitrogen (34 mg/L in the influent, 18 mg/L in the effluent). Observations and additional sampling to determine the condition of the unit continued for the next eight weeks. No adjustments to the system were made. The treatment performance was lower in February with CBOD$_5$ increasing in the effluent to as high as 58 mg/L.

At the end of the eight weeks allotted for the startup, the verification test period began. The biological growth was not yet fully established or acclimated, as suggested by the elevated CBOD$_5$ in the effluent (48 to 66 mg/L). It is likely that the cold temperatures were slowing the development and acclimation process. WBS literature indicates that with a winter startup, nitrification can take several months to begin, but that once established nitrification will continue through subsequent winters. The temperature of the incoming wastewater was about 4 to 8 °C when the unit was started, and was 8 °C at the end of the startup period. Effluent temperature was lower at 5 to 6 °C. As will be seen in the next section, the unit showed rapid improvement in performance beginning in April and May when temperatures increased above 10 °C.

Table 4-2. Influent Wastewater Quality - Startup Period

Date	Alkalinity (mg/L)	BOD$_5$ (mg/L)	DO (mg/L)	Ammonia (mg/L)	pH (S.U.)	TKN (mg/L)	TN (mg/L)	TSS (mg/L)	Influent Temp. (°C)
01/23/01	180	150	0.2	26	7.6	34	34	120	8.2
01/31/01	170	280	1.2	24	7.2	41	41	280	8.0
02/14/01	190	180	N/S	26	7.5	42	42	190	N/S
02/28/01	200	200	0.8	28	7.7	46	46	190	7.1
03/07/01	160	180	1.4	23	7.4	34	34	130	7.4
03/13/01	180	160	1.1	25	7.4	40	40	130	7.8

N/S – no sample

Table 4-3. Waterloo Biofilter$^{®}$ Effluent Quality - Startup Period

Date	Alkalinity (mg/L)	CBOD$_5$ (mg/L)	DO (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	pH (S.U.)	TKN (mg/L)	TN (mg/L)	TSS (mg/L)	Discharge Temp (°C)
01/23/01	180	23	5.5	24	<0.1	<0.05	7.6	18	18	6	3.8
01/31/01	190	24	3.6	25	<0.1	<0.05	7.5	31	31	7	8.0
02/14/01	200	45	7.5	28	<0.1	<0.05	7.7	39	39	22	5.0
02/28/01	200	58	8.8	28	<0.1	0.07	7.6	38	38	26	5.8
03/07/01	190	48	8.6	27	<0.1	0.09	7.9	34	34	25	5.2
03/13/01	190	66	8.4	26	<0.1	<0.05	7.8	36	36	39	5.4

4.2.3 Startup Operating Conditions

The Biofilter$^{®}$ system was started according to the Manual. The on-off switch for the pump was set so that the pump would turn on and dose the media when the volume in the pump chamber was about 6 gallons of water. Since the pump operated as an on-demand system, there was no timer or automatic controls to set. The high water switch/alarm in the pump chamber was tested and the unit was placed into service. The startup instructions in the Manual (Appendix A) were easy to follow and provided the necessary instructions to get the unit up and operating. The effluent recirculation rate was preset by the divider in the bottom of the enclosure at approximately 50 percent for this evaluation.

No changes were made to the unit during the startup period. Regular observations showed that biological growth was slowly being established on the media. No maintenance was required during the startup period and there were no mechanical problems. Overall, the unit started up with no mechanical difficulty.

4.3 Verification Test

In accordance with the startup period set forth in the VTP and the Protocol, the verification test was started officially on March 13, 2001. A final startup sample was collected on March 12-13. All results for the balance of the test were considered part of the verification test period. The data presented for the verification results do not include data from the startup period. As stated above, there were no changes made to the basic operation of the system. All Biofilter® operating parameters (pumps, alarms, etc.) remained the same as during the initial startup period.

4.3.1 Verification Test - Flow Conditions

The dosing sequence (15 doses per day, 29.3 gallons per dose) was performed every day from March 13 through September 7, 2001, except during the stress periods. Volume per dose and total daily volume varied only slightly during this period. In September, it was discovered that while the PLC was set to deliver 15 doses per day and showed 15 doses being delivered, only 14 doses were actually being pumped to the unit. The first dose each morning was being missed because of a timer issue with the start of wastewater flow at the test site. Beginning September 7, 2001, the problem was resolved and daily flow was dosed 15 times per day as originally specified in the VTP. The lower flow being dosed to the unit for the first six months was still within the specification that flow be ± 10 percent of the design flow on a monthly average basis (design flow 440 gpd). Table 4-4 shows the average monthly volumes for the verification period. As this data shows, the actual wastewater volume dosed to the Biofilter® was very close to the targeted volume of 440 gallons per day for the last seven months of the test.

Table 4-4. Waterloo Biofilter® Influent Volume Summary

	Target		Ave Monthly	
Mon/Year	**Gallon/dose**	**Doses/day**	**Gallon/dose**	**Gallon/day**
Mar-01	29.33	14	28.8	403
Apr-01	29.33	14	29.5	413
May-01	29.33	14	28.7	401
Jun-01	29.33	14	29.9	421
Jul-01	29.33	14	30.2	423
Aug-01	29.33	14	29.2	408
Sep-01	29.33	15(1)	28.7	426(2)
Oct-01	29.33	15	29.6	444(2)
Nov-01	29.33	15	29.1	436
Dec-01	29.33	15	29.0	435(3)
Jan-02	29.33	15	29.3	439
Feb-02	29.33	15	29.4	434(4)
Mar-02	29.33	15	29.2	438
Apr-02	29.33	15	28.9	433
Average		**15**	**29.2**	**425**
Maximum			30.2	444
Minimum			28.7	401
Std. Dev.			0.4	14

(1) The timer and PLC issue was fixed on September 6. Fifteen doses were delivered beginning on September 7, 2001.

(2) September/October – Low Load test run in September and October; average flow data for September and October does not include the low flow days. Only normal flow days are included. During the Low Load test, flow was set at 50 percent of normal flow. Actual average flow during the Low Load test (September 17 to October 7) was 219 gpd.

(3) December – Power/Equipment Failure Test – no flow one day, low flow on second day. Average does not include the low/no flow days.

(4) February 2002 – Vacation test – 10-day test; no flow for 8 days,
Only nine doses on first and last day; Low or no flow days excluded from the calculation of monthly averages

4.3.2 BOD_5/$CBOD_5$ and Suspended Solids Results

Figures 4-1 and 4-2 show the results for BOD_5/$CBOD_5$ and total suspended solids (TSS) in the influent and effluent for the verification test. Table 4-5 presents same results with a summary of the data (average, median, maximum, minimum, standard deviation). $CBOD_5$ was measured in the effluent as required in the Protocol. The use of the $CBOD_5$ analysis was specified because the effluent from nutrient reduction systems was expected to be low in oxygen demanding organics, and have a large number of nitrifying organisms, which can cause nitrification to occur during the first five days of the test. The $CBOD_5$ analysis inhibits nitrification during the analysis, and provides a better measurement of the oxygen demanding organics in the effluent. The BOD_5 test was used for the influent, which had much higher levels of oxygen demanding organics, and was expected to have a very low population of nitrifying organisms. In the standard BOD_5 test, it is assumed that little nitrification occurs within the five days of the test. Therefore, the oxygen demanding organics are the primary compounds measured in the wastewater influent. Using the BOD_5 of the influent and the $CBOD_5$ in the effluent should provide a good comparison of the oxygen demanding organics removal of the system.

The verification test emphasizes sampling during and following the major stress periods. This results in a large number of samples being clustered during five periods with the remaining samples spread over the remaining months (monthly sampling). Therefore, impacts of the stress test or an upset condition occurring during the concentrated sampling can have an impact on the calculation of average values. Both average and median results are presented in Table 4-5, as the median values compared to average values can help in analyzing these impacts. In the case of the Biofilter® results, the effluent median values are lower than the average values due to the lower performance that occurred immediately following the Vacation stress test (February 14 to 19, 2002).

The influent wastewater had an average BOD_5 of 210 mg/L and a median BOD_5 of 200 mg/L. The average influent TSS was 150 mg/L with a median concentration of 130 mg/L. The Biofilter® effluent showed an average $CBOD_5$ of 10 mg/L and a median $CBOD_5$ of 7.4 mg/L. The effluent TSS concentration was 7 mg/L, with a median concentration of 5 mg/L. The Biofilter® system averaged 95 percent reduction of BOD_5/$CBOD_5$ with a median removal of 96 percent. TSS removal averaged 95 percent over the thirteen-month period, with a median removal of 97 percent. $CBOD_5$ concentrations in the effluent typically ranged from 1 to 20 mg/L, and TSS ranged from 1 to 10 mg/L, except for the first month after startup and for a short period in February 2002.

At the end of the startup period, the Biofilter® system was reducing TSS and $CBOD_5$, but had not yet achieved the level of performance anticipated by WBS and conducive to the establishment of nitrification. During the period of March 13 through April 18, 2001, wastewater effluent temperature began to increase quickly (see Figure 4-7) and the effluent concentration of TSS and $CBOD_5$ began to trend lower. At the end of April, it was also noted that the media had "settled", which was causing short-circuiting of the wastewater through the media. Checking the media level is part of the recommended routine maintenance for the unit. Additional media was poured into the top of the unit, as directed in the Manual. No additional media was needed or added for the duration of the test.

By the start of the first stress test, (Washday stress), the unit was producing effluent concentrations in the range of 7 to 18 mg/L for $CBOD_5$ and 3 to 13 mg/L for TSS. The Washday stress test was started on May 8 and concluded on May 11, with no significant impact on the $CBOD_5$ and TSS performance. Post stress period monitoring showed continued improvement in performance into June 2001. Both effluent $CBOD_5$ and TSS were 15 mg/L or less during the next two month period.

The Working Parent stress test was started on July 10 and was completed on July 13. By the start of the stress test, the unit was showing $CBOD_5$ and TSS below 10 mg/L. Performance continued to be good during the stress test and there was no apparent change in the effluent quality. From August 2001 through January 2002, the Biofilter® performance was consistent. Data collected during the Low Load stress test in September/October and the Power/Equipment Failure test in December showed no change in either $CBOD_5$ or TSS performance.

Following the Vacation stress test in February 2002, there was an increase in effluent $CBOD_5$ (16 to 27 mg/L range) and TSS (8 to 20 mg/L). These results are likely a result of the Vacation stress test, but also coincide with the water temperature in the system effluent dropping to its lowest point for the year (5 to 7 °C). During the Vacation stress test, there is an eight-day period with no flow to the system, although power is maintained. The Biofilter® system only pumps wastewater to the unit if there is a demand, so the biological growth on the media received no flow for eight days. It is likely that this period of no flow, combined with the low outside air and water temperatures, stressed the population. Whatever the cause of the increase in $CBOD_5$ and TSS in the effluent, the performance improved within two weeks of normal operation. By early March, effluent $CBOD_5$ and TSS were at or below 10 mg/L.

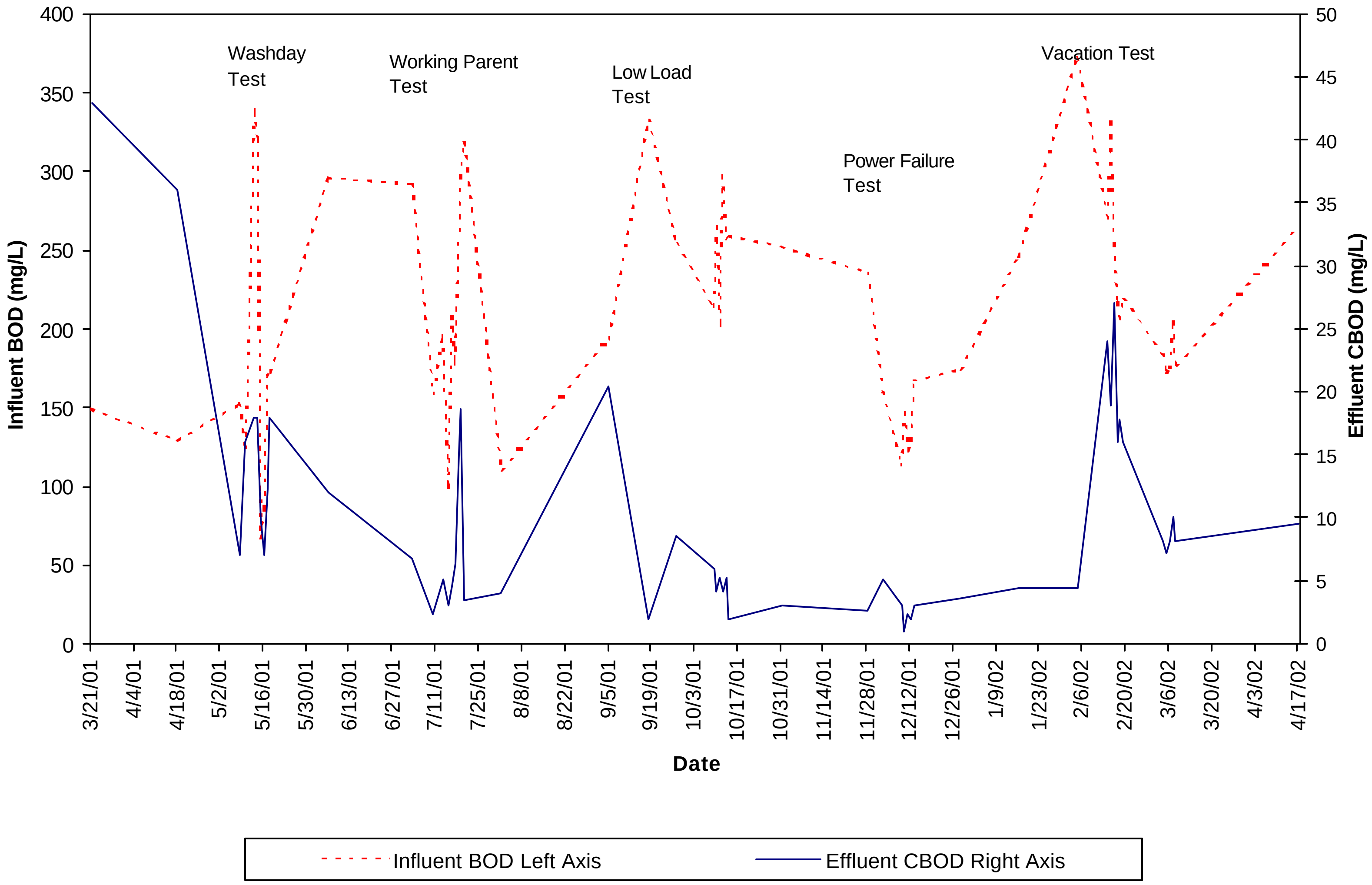


Figure 4-1. Waterloo Biofilter® BOD_5/$CBOD_5$ Results

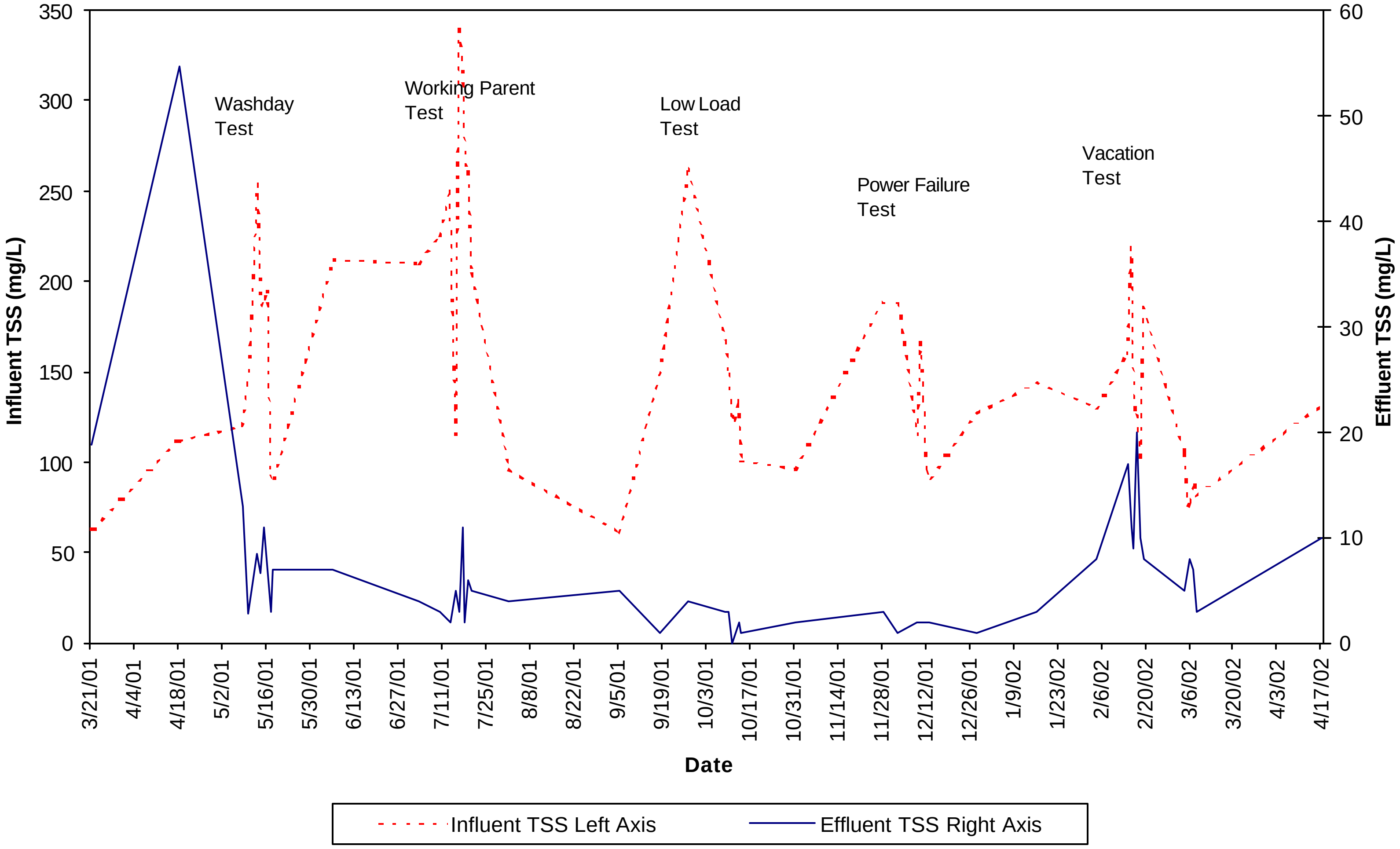


Figure 4-2. Waterloo Biofilter® Total Suspended Solids Results

Table 4-5. Waterloo Biofilter® BOD$_5$/CBOD$_5$ and TSS Results

	BOD$_5$	CBOD$_5$			TSS	
Date	Influent (mg/L)	Effluent (mg/L)	Removal (Percent)	Influent (mg/L)	Effluent (mg/L)	Removal (Percent)
03/21/01	150	43	71	63	19	70
04/18/01	130	36	72	110	55	51
05/08/01	150	7.1	95	120	13	89
05/10/01	120	16	87	150	3	98
05/13/01	340	18	95	250	9	97
05/14/01	320	18	94	190	7	96
05/15/01	67	9.9	85	190	11	94
05/16/01	86	7.0	92	200	7	96
05/17/01	170	12	93	92	3	97
05/18/01	170	18	90	90	7	92
06/06/01	300	12	96	210	7	97
07/03/01	290	6.7	98	210	4	98
07/10/01	160	2.3	99	230	3	99
07/13/01	200	5.1	97	250	2	99
07/15/01	99	3.1	97	120	5	96
07/16/01	210	4.5	98	340	3	99
07/17/01	180	6.3	96	320	11	97
07/18/01	240	15	94	260	2	99
07/19/01	300	19	94	260	6	98
07/20/01	320	3.5	99	200	5	98
08/01/01	110	4.0	96	96	4	96
09/05/01	190	20	89	61	5	92
09/18/01	330	2.0	99	150	1	99
09/27/01	250	8.6	97	260	4	98
10/09/01	210	6.0	97	170	3	98
10/10/01	260	4.2	98	150	3	98
10/11/01	200	5.3	97	120	<1.0	>99
10/12/01	300	4.1	99	120	1	99
10/13/01	260	5.2	98	130	2	99
10/14/01	260	2.0	99	100	1	99

Table 4-5. Waterloo Biofilter® BOD_5/$CBOD_5$ and TSS Results (continued)

	BOD_5	$CBOD_5$		TSS		
	Influent (mg/L)	Effluent (mg/L)	Removal (Percent)	Influent (mg/L)	Effluent (mg/L)	Removal (Percent)
10/31/01	250	3.1	99	96	2	98
11/28/01	240	2.7	99	190	3	98
12/03/01	160	5.1	97	190	1	99
12/09/01	110	3.1	97	120	2	98
12/10/01	150	<1.0	>99	170	2	99
12/11/01	120	2.4	98	140	2	99
12/12/01	130	1.9	99	95	2	98
12/13/01	170	3.1	98	91	2	98
12/28/01	170	3.6	98	130	1	99
01/16/02	250	4.4	98	140	3	98
02/04/02	370	4.4	99	130	8	94
02/14/02	270	24	91	160	17	89
02/15/02	330	19	94	220	11	95
02/16/02	250	27	89	130	9	93
02/17/02	220	16	93	130	20	84
02/18/02	210	18	91	100	10	90
02/19/02	220	16	93	190	8	96
03/04/02	180	8.2	96	100	5	95
03/05/02	170	7.2	96	76	7	91
03/06/02	180	8.1	95	78	8	90
03/07/02	200	10	95	87	7	92
03/08/02	180	8.2	95	81	3	96
04/17/02	260	9.5	96	130	10	92
Samples	53	53	53	53	53	53
Average	210	10	95	150	7	95
Median	200	7.4	96	130	5	97
Maximum	370	43	99	340	55	>99
Minimum	67	1	71	61	<1	51
Std. Dev.	73	9	6	66	8	8

Values below the detection limit are set to zero for concentration averages
Samples = Number of samples collected or used in the calculations

4.3.3 Nitrogen Reduction Performance

4.3.3.1 <u>Results</u>

Figures 4-3 through and 4-5 present the results for the TKN, ammonia, and total nitrogen (TN) in the influent and effluent during the verification test. Figure 4-6 shows the results for nitrite and nitrate in the effluent from the Biofilter® system. Table 4-6 presents all of the nitrogen results with a summary of the data (average, median, maximum, minimum, standard deviation).

The influent wastewater had an average TKN concentration of 37 mg/L and an average ammonia nitrogen concentration of 23 mg/L, with median concentrations of 37 mg/L and 23 mg/L, respectively. Average TN concentration in the influent was 37 mg/L (median of 37 mg/L), based on the generally accepted assumption that the nitrite and nitrate concentration in the influent was negligible. The Biofilter® effluent had an average TKN concentration of 3.7 mg/L, with a median of 1.6 mg/L. The average ammonia nitrogen concentration in the effluent was 2.4 mg/L, with a median concentration of 0.7 mg/L. The nitrite concentration in the effluent averaged 0.19 mg/L, with a median concentration 0.14 mg/L. Effluent nitrate concentrations averaged 10 mg/L over the thirteen-month test, with a median concentration of 10 mg/L. Total nitrogen was determined by adding the concentrations of the TKN (organic plus ammonia nitrogen), nitrite and nitrate, resulting in an average TN in the Biofilter® effluent of 14 mg/L for the thirteen month verification period, with a median concentration of 13 mg/L. The Biofilter® system averaged 62 percent reduction of TN for the verification test period, with a median removal of 65 percent.

Alkalinity, pH, dissolved oxygen (DO), and temperature were measured during the verification test. These parameters can provide insight into the condition of the system and can impact total nitrogen removal. Table 4-7 shows the results for alkalinity, DO, and pH. Temperature measurements are shown in Figure 4-7 and Table 4-6.

The pH of the influent was very consistent throughout the test, ranging from pH 7.2 to 7.6. The effluent from the Biofilter® showed a slight decrease in pH, but in a similar range, consistently remaining in the pH 6.9 to 7.7 range. The alkalinity of the influent averaged 180 mg/L as $CaCO_3$ with a maximum concentration of 230 mg/L and minimum of 160 mg/L. The effluent alkalinity was consistently lower than the influent (as expected when nitrification/denitrification is occurring), with an average concentration of 82 mg/L and a median concentration 74 mg/L. The only time the effluent alkalinity did not decrease by at least 25 percent was during the first weeks after startup when the unit was not yet fully acclimated.

The Dissolved Oxygen in the influent wastewater was low, as would be expected. The average DO in the influent was 0.3 mg/L, and was less than 1.0 mg/L on all but one day of testing. The Biofilter® system is designed to operate as an aerobic system with the vents on the unit allowing air to move through the media. The DO in the effluent from the Biofilter® was normally in the range of 4 to 7 mg/L, and averaged 6.2 mg/L over the thirteen months of verification testing.

4.3.3.2 Discussion

As discussed earlier in the startup section, at the end of the startup period (January 15 to March 12, 2001), the Biofilter® effluent was showing only negligible reduction of total nitrogen. Influent and effluent wastewater temperatures were in the 4 to 8 °C range. As shown in Table 4-6, beginning in late March and early April, the temperatures began to increase. There was some indication that performance was improving, but $CBOD_5$ was still at 36 mg/L. TKN and ammonia concentrations were decreasing but performance was not at the level anticipated. In late April, it was discovered that the foam media had settled in the baskets and the wastewater was short-circuiting through the media. Media was added to the unit, as recommended in the Manual. With the increasing temperatures and the elimination of the short-circuiting, the nitrifying population clearly became established, as indicated by the decrease in the TKN and ammonia concentrations in the effluent, and an increase in nitrate concentration. TN concentration in the effluent began to decrease, indicating that the denitrification population was becoming established in the septic tank. During May and June, the TN reduction was typically in 65 to 80 percent range. The Washday stress test performed in May 2001 did not appear to have a negative impact on nitrogen reduction. Overall, given the conditions during the startup, which began in January, the system took approximately three to four months to develop a nitrifying and denitrifying population.

In July 2001, the Working Parent stress test was performed. The performance of the unit remained steady during and following this stress period. The Biofilter® system continued to reduce the total nitrogen concentration on a consistent basis (60-80 percent reduction) until February 2002. During this period, which included the Low Load and Power/Equipment Failure stress tests, nitrification was very effective, generally reducing the ammonia nitrogen and TKN to less than 1 mg/L. The denitrification process during this period was also effective in removing nitrate produced during the nitrification step, although nitrate removal was not as efficient or complete as the nitrifying step. The total nitrogen in the effluent ranged from 6.2 to 14 mg/L during the August to December period.

The Vacation stress test was started on February 4 and was completed on February 13, 2002. The sample taken before the stress test in early February showed some signs that denitrification process was slowing down, while the nitrification process, as measured by TKN and ammonia, was still consistent. Effluent $CBOD_5$ concentrations were low at 4.4 mg/L. The results showed somewhat higher effluent nitrate levels (increase from 10 to 15 mg/L), and TN removal was just over 50 percent (17 mg/L in the effluent). Also, the alkalinity (Table 4-7) was slightly lower in the effluent during this period. The lower alkalinity can be an indicator that the denitrification process is slowing down, as the nitrification process consumes alkalinity (approximately 7.1 mg for each mg of ammonia nitrogen removed), and the denitrification process produces alkalinity (approximately 3.6 mg per mg nitrate nitrogen removed).

On the first day after the Vacation stress test ended, the effluent nitrate concentration jumped to 33 mg/L, and the effluent ammonia concentration was higher at 10 mg/L. Total nitrogen increased to 45 mg/L, which was actually higher than the influent value of 35 mg/L. $CBOD_5$ and TSS also increased on the day after the stress test. It would appear that both the nitrification and denitrification processes were impacted during this time. The lack of wastewater application to the media (no flow for eight days) most likely had an impact on the biological population. The use of the "on-demand" pumping approach results in no application of wastewater to the Biofilter® when there is no flow. Also, the timing of the Vacation stress test coincided with the coldest time of the year, and the temperature of the effluent dropped to 5 °C from 7 °C on first day after the Vacation stress period ended.

Performance began to improve almost immediately after the flow returned to normal conditions. $CBOD_5$ effluent concentrations began to trend downward and were below 10 mg/L within two weeks. Ammonia nitrogen concentrations also began to trend downward and were in the 1-3 mg/L range within a few days. Nitrate concentrations decreased and total nitrogen removal reached 50 percent by February 19. Temperature of the effluent continued to climb over the next few weeks and the system performance continued to show improvement. The overall performance of the system was slightly lower during the weeks following the Vacation stress test (March 2002), as compared to the October to December 2001 period, showing effluent TN concentrations of 15 to 17 mg/L versus 9 to 11 mg/L.

The last sample collected in April 2002 indicated that both the nitrifying and denitrifying processes had recovered, resulting in an effluent TN concentration of 11 mg/L. TKN and ammonia concentrations were 3.5 mg/L and 1.1 mg/L, respectively, only slightly higher than the less 1 mg/L levels achieved in previous summer and fall periods. The nitrate concentration was 7.1 mg/L, which was actually on the low side of the levels found in the summer and fall. Alkalinity was higher than in February and March, indicating that the denitrifying population was active and adding to the alkalinity of the system.

The verification test provided a sufficiently long test period to collect data that included both a long run of steady performance by the Biofilter® system and a period of an apparent upset following the Vacation stress test. While the system appeared to be impacted by the Vacation stress test and low temperatures, recovery was rapid, with TN removal on the order of 60 percent (55-70 percent measured) being established within two to four weeks.

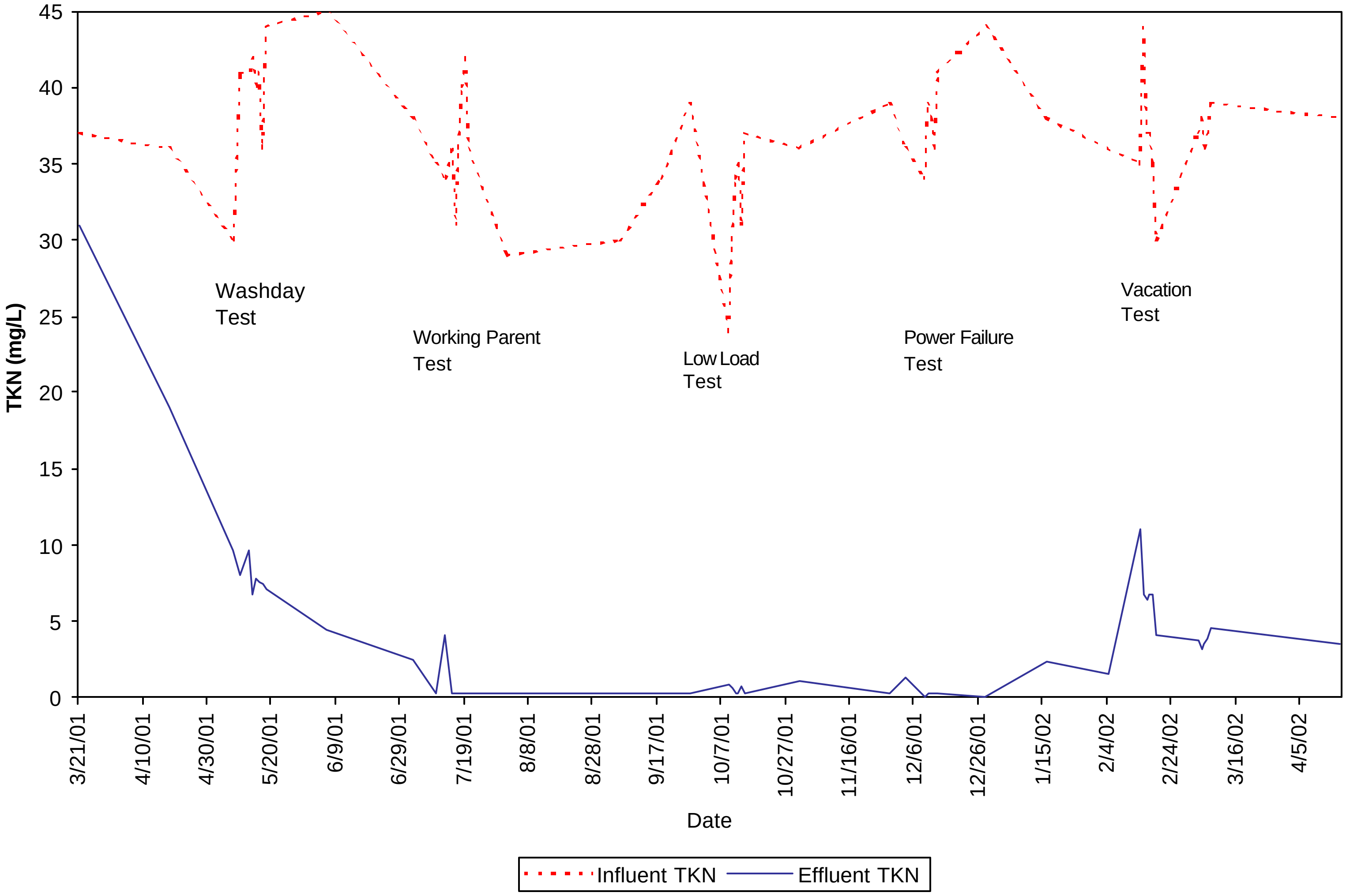


Figure 4-3. Waterloo Biofilter® Total Kjeldahl Nitrogen Results

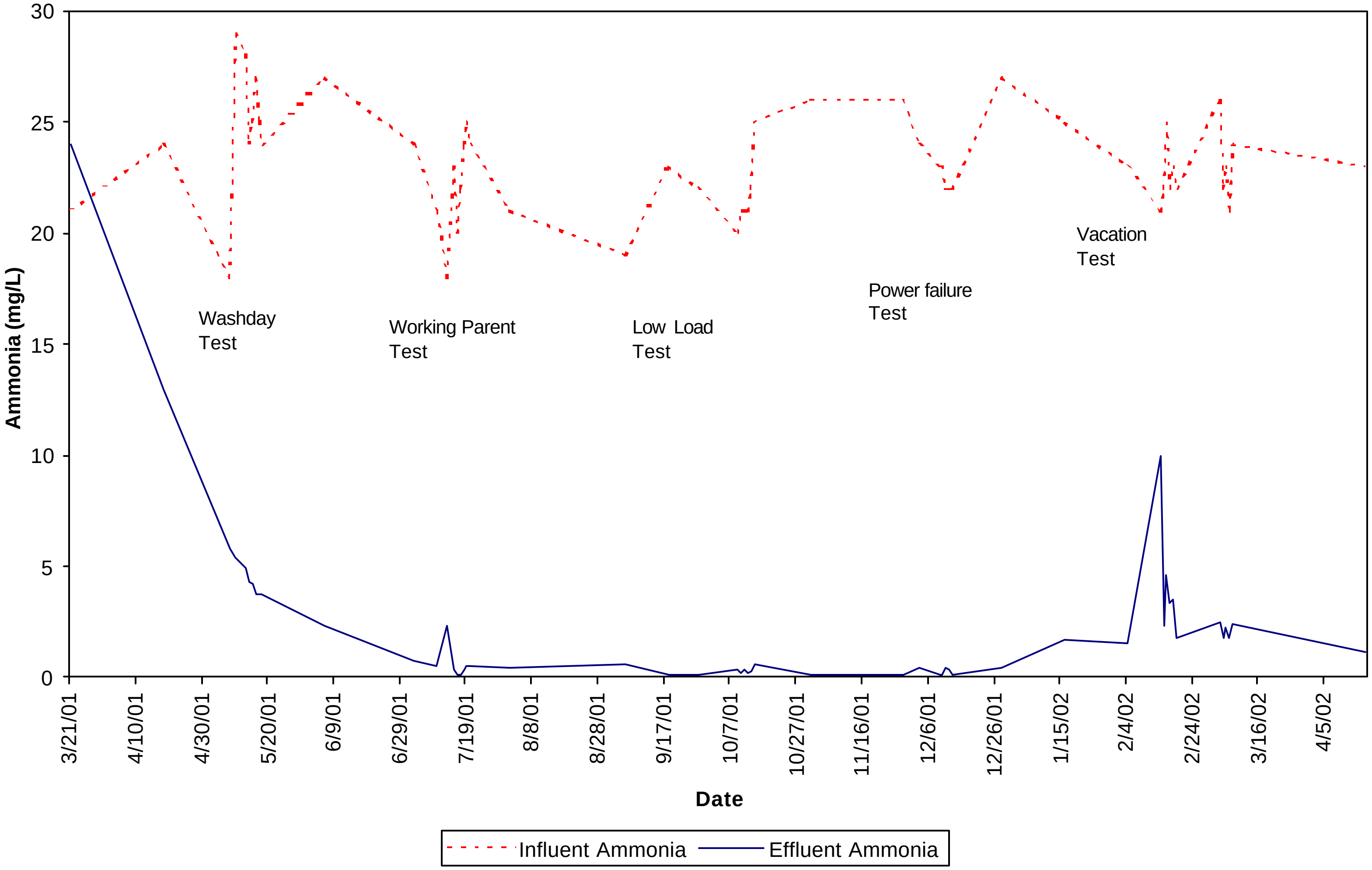


Figure 4-4. Waterloo Biofilter® Ammonia Nitrogen Results

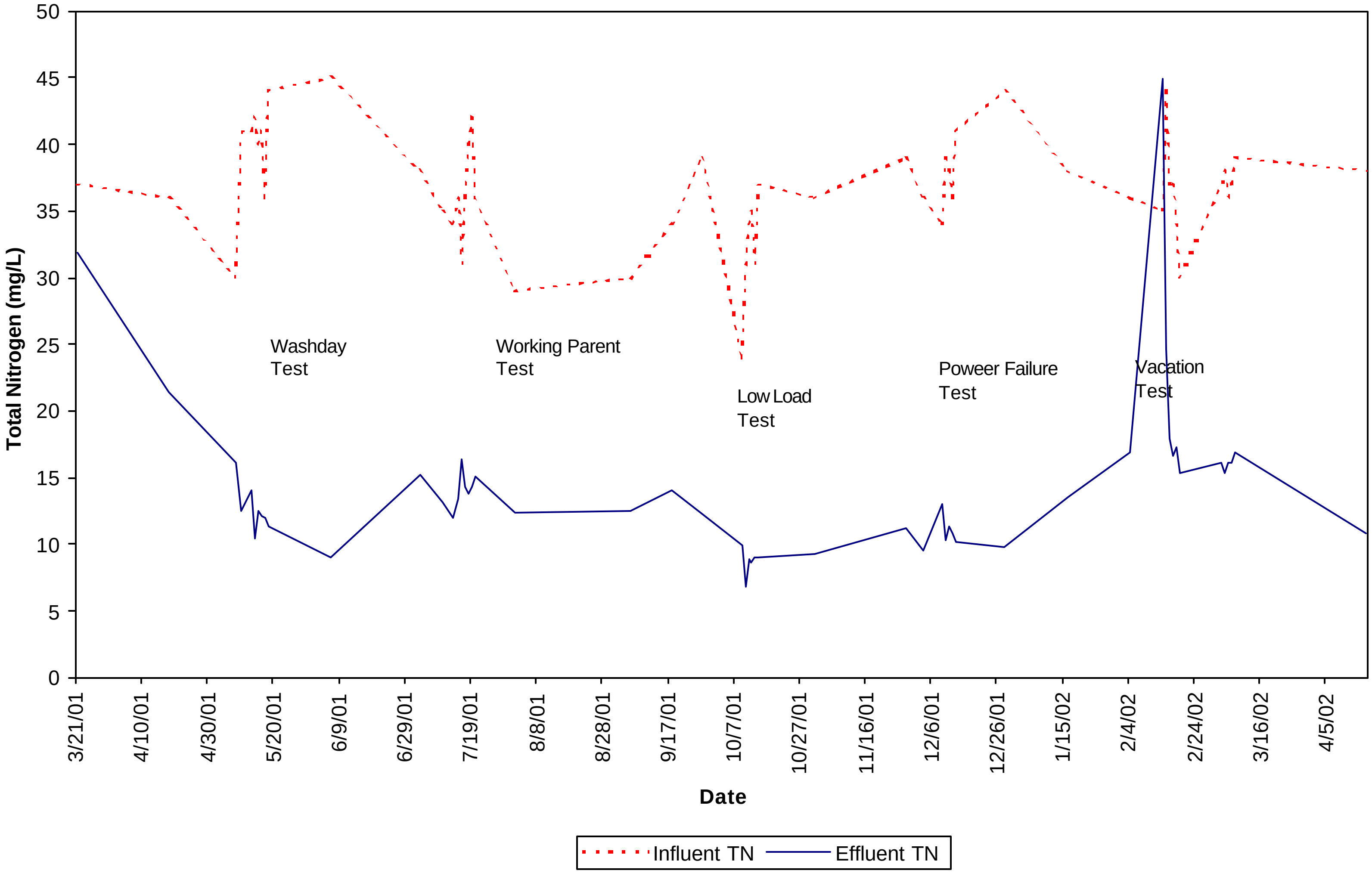


Figure 4-5. Waterloo Biofilter® Total Nitrogen Results

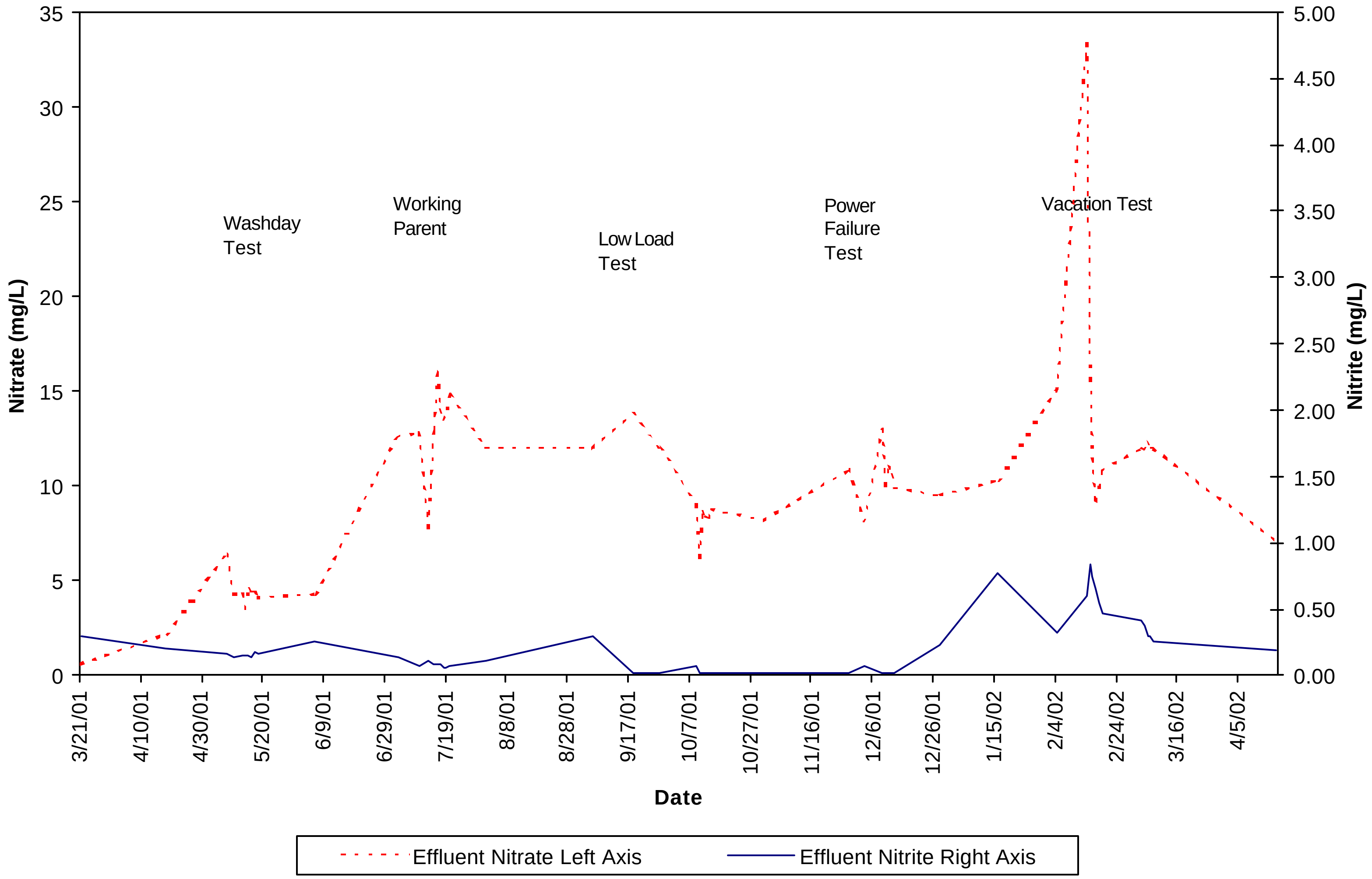


Figure 4-6. Waterloo Biofilter® Nitrite and Nitrate Effluent Concentrations

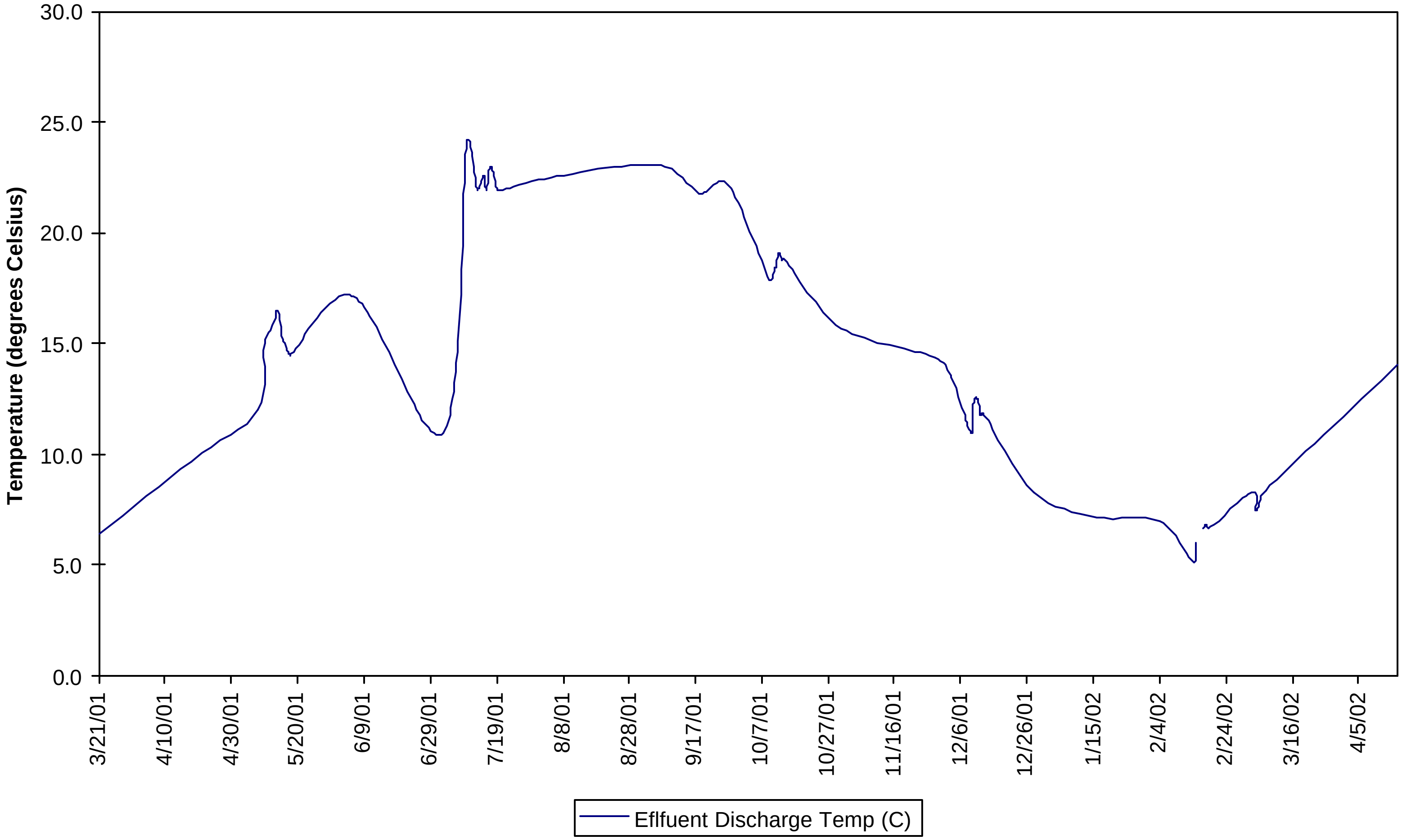


Figure 4-7. Waterloo Biofilter® Effluent Temperature

Table 4-6. Waterloo Biofilter® Influent and Effluent Nitrogen Data

	TKN (mg/L)		Ammonia (mg/L)		Total Nitrogen (mg/L)		Nitrate (mg/L)	Nitrite (mg/L)	Temperature (°C)
Date	Influent	Effluent	Influent	Effluent	Influent	Effluent	Effluent	Effluent	Influent
03/21/01	37	31	21	24	37	32	0.6	0.30	6.4
04/18/01	36	19	24	13	36	21	2.2	0.20	9.7
05/08/01	30	9.6	18	5.8	30	16	6.4	0.16	N/R
05/10/01	41	8.0	29	5.4	41	12	4.3	0.14	15
05/13/01	41	9.6	28	4.9	41	14	4.3	0.15	16
05/14/01	42	6.8	24	4.3	42	10	3.5	0.15	16
05/15/01	40	7.8	25	4.2	40	13	4.6	0.15	16
05/16/01	41	7.6	27	3.7	41	12	4.4	0.14	15
05/17/01	36	7.4	25	3.7	36	12	4.4	0.18	15
05/18/01	44	7.1	24	3.7	44	11	4.1	0.16	14
06/06/01	45	4.4	27	2.3	45	9	4.3	0.26	17
07/03/01	38	2.5	24	0.7	38	15	13	0.14	11
07/10/01	35	<0.5	21	0.5	35	13	13	0.07	24
07/13/01	34	4.1	18	2.3	34	12	7.8	0.12	22
07/15/01	36	<0.5	23	0.3	36	13	13	0.09	23
07/16/01	31	<0.5	20	<0.2	31	16	16	0.08	22
07/17/01	36	<0.5	22	<0.2	36	14	14	0.09	23
07/18/01	40	<0.5	24	0.3	40	14	14	0.06	23
07/19/01	42	<0.5	25	0.5	42	14	14	0.06	22
07/20/01	36	<0.5	24	0.5	36	15	15	0.07	22
08/01/01	29	<0.5	21	0.4	29	12	12	0.11	22
09/05/01	30	<0.5	19	0.6	30	13	12	0.29	23
09/18/01	34	<0.5	23	<0.2	34	14	14	<0.05	22
09/27/01	39	<0.5	22	<0.2	39	12	12	<0.05	22
10/09/01	24	0.9	20	0.3	24	10	9.0	0.07	18
10/10/01	30	0.6	21	0.2	30	6.8	6.2	<0.05	18
10/11/01	34	<0.5	21	0.3	34	8.9	8.6	<0.05	18
10/12/01	35	<0.5	21	0.2	35	8.7	8.4	<0.05	19
10/13/01	31	0.7	22	<0.5	31	9.0	8.3	<0.05	19
10/14/01	37	<0.5	25	0.6	37	9.1	8.8	<0.05	19

N/R – Not reported

Table 4-6. Waterloo Biofilter® Influent and Effluent Nitrogen Data (continued)

	TKN (mg/L)		Ammonia (mg/L)		Total Nitrogen (mg/L)		Nitrate (mg/L	Nitrite (mg/L)	Temperature (°C)
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Effluent**	**Effluent**	**Influent**
10/31/01	36	1.1	26	<0.2	36	9.3	8.2	<0.05	16
11/28/01	39	<0.5	26	<0.2	39	11	11	<0.05	14
12/03/01	36	1.3	24	0.4	36	9.5	8.1	0.07	14
12/09/01	34	<0.5	23	<0.2	34	13	13	<0.05	11
12/10/01	39	<0.5	23	<0.2	39	10	10	<0.05	12
12/11/01	38	<0.5	22	0.4	38	11	11	<0.05	12
12/12/01	36	<0.5	22	0.3	36	11	11	<0.05	12
12/13/01	41	<0.5	22	<0.2	41	10	9.9	<0.05	12
12/28/01	44	<0.5	27	0.4	44	10	9.5	0.23	8.3
01/16/02	38	2.4	25	1.7	38	13	10	0.77	7.2
02/04/02	36	1.6	23	1.5	36	17	15	0.32	7.0
02/14/02	35	11	21	10	35	45	33	0.60	5.2
02/15/02	44	6.7	22	2.3	44	25	17	0.84	6.0
02/16/02	37	6.4	25	4.6	37	18	11	0.74	N/R
02/17/02	37	6.8	22	3.3	37	17	9.2	0.65	6.7
02/18/02	35	6.8	23	3.5	35	17	9.9	0.55	6.8
02/19/02	39	4.1	22	1.8	30	15	11	0.47	6.7
03/04/02	37	3.7	26	2.5	37	16	12	0.41	8.3
03/05/02	38	3.1	22	1.8	38	15	12	0.38	7.5
03/06/02	36	3.5	23	2.2	36	16	12	0.29	7.7
03/07/02	37	3.8	21	1.8	37	16	12	0.30	8.2
03/08/02	39	4.6	24	2.4	39	17	12	0.26	8.4
04/17/02	38	3.5	23	1.1	38	11	7.1	0.19	14
Samples	53	53	53	53	53	53	53	53	51
Average	37	3.7	23	2.4	37	14	10	0.19	15
Median	37	1.6	23	0.7	37	13	10	0.14	15
Maximum	45	31	29	24	45	45	33	0.84	24
Minimum	24	<0.5	18	<0.2	24	6.8	0.6	<0.05	5.2
Std. Dev.	4.1	5.5	2.4	4.0	4.2	6.0	5.0	0.2	5.9

Values below the detection limit set equal to zero (0) for statistical calculations
N/R – not reported
Samples = Number of samples collected or used in the calculations

Table 4-7. Waterloo Biofilter® Alkalinity, pH, and Dissolved Oxygen Results

	Alkalinity (mg/L as $CaCO_3$)		Dissolved Oxygen (mg/L)		pH (S.U.)	
Date	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
03/21/01	200	200	0.4	8.3	7.6	7.7
04/18/01	190	150	1.9	8.2	7.6	7.6
05/08/01	160	110	N/R	N/R	7.3	7.4
05/10/01	190	130	0.6	6.0	7.4	7.5
05/13/01	180	120	0.4	5.0	7.5	7.6
05/14/01	170	120	0.7	5.0	7.5	7.6
05/15/01	180	120	0.5	5.8	7.4	7.5
05/16/01	180	110	0.4	6.2	7.4	7.5
05/17/01	180	110	0.3	6.0	7.5	7.6
05/18/01	190	110	0.3	6.4	7.6	7.6
06/06/01	180	88	0.4	6.6	7.6	7.4
07/03/01	190	73	0.4	3.3	7.3	7.1
07/10/01	180	88	0.8	5.2	7.5	7.4
07/13/01	170	110	0.7	5.2	7.4	7.3
07/15/01	190	90	0.1	4.3	7.6	7.2
07/16/01	200	86	0.1	4.0	7.6	7.6
07/17/01	180	80	0.1	3.6	7.4	7.2
07/18/01	190	76	0.2	4.7	7.2	7.0
07/19/01	200	66	0.2	4.9	7.2	7.1
07/20/01	190	66	0.1	4.7	7.4	7.3
08/01/01	170	60	0.3	4.7	7.5	7.3
09/05/01	170	74	0.3	4.3	7.3	7.1
09/18/01	180	64	0.3	5.8	7.4	7.4
09/27/01	190	70	0.1	6.2	7.3	7.3
10/09/01	170	74	0.2	7.2	7.5	7.4
10/10/01	180	78	0.0	7.4	7.4	7.3
10/11/01	190	76	0.0	6.7	7.3	7.2
10/12/01	180	79	0.1	6.7	7.2	7.1
10/13/01	180	78	0.1	6.8	7.4	7.3
10/14/01	190	68	0.0	7.1	7.4	7.4

N/R – Not Reported

Table 4-7. Waterloo Biofilter® Alkalinity, pH, and Dissolved Oxygen Results (continued)

Date	Alkalinity (mg/L as $CaCO_3$)		Dissolved Oxygen (mg/L)		pH (S.U.)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
10/31/01	200	74	0.3	7.7	7.4	7.3
11/28/01	190	66	0.2	7.5	7.4	7.1
12/03/01	170	66	0.1	8.3	7.3	7.1
12/09/01	180	60	0.2	6.4	7.5	7.2
12/10/01	190	62	0.1	8.0	7.5	7.3
12/11/01	180	60	0.1	8.0	7.4	7.2
12/12/01	180	60	0.4	8.2	7.4	7.2
12/13/01	190	62	0.4	7.8	7.6	7.2
12/28/01	230	62	0.3	7.6	7.5	7.4
01/16/02	190	70	0.2	8.4	7.6	7.2
02/04/02	180	48	0.2	5.1	7.4	6.9
02/14/02	170	72	0.2	7.0	7.4	6.9
02/15/02	200	64	0.2	6.8	7.3	7.0
02/16/02	190	86	0.2	6.9	7.4	7.1
02/17/02	180	86	0.2	7.3	7.4	7.2
02/18/02	170	82	0.1	5.6	7.5	7.0
02/19/02	180	76	0.4	5.4	7.4	7.1
03/04/02	170	60	0.8	4.5	7.5	7.3
03/05/02	160	56	0.5	7.0	7.4	7.0
03/06/02	170	58	0.6	5.6	7.4	6.9
03/07/02	180	56	0.2	5.7	7.4	6.9
03/08/02	180	60	0.5	6.0	7.4	6.9
04/17/02	190	86	0.1	5.6	7.4	7.1
Samples	53	53	52	52	53	53
Average	180	82	0.3	6.2	n/c	n/c
Median	180	74	0.2	6.2	7.4	7.3
Maximum	230	100	1.9	8.4	7.6	7.7
Minimum	160	48	0.0	3.3	7.2	6.9
Std. Dev	11	27	0.3	1.3	n/c	n/c

n/c – not calculated

Samples = Number of samples collected or used in the calculations

4.3.4 Residuals Results

During the treatment of wastewater in the Biofilter® system, solids accumulate in the primary tank. Inert solids are removed in the primary tank system just as in a normal septic system. Biological solids accumulate from the influent wastewater solids and from the recycle of effluent solids (approximately 50 percent recycle rate of treated effluent), and any solids that might slough from the media. Eventually, a buildup of solids reduces the capacity of the primary tank and the solids will need to be removed.

The approximate quantity of the residuals accumulated in the system was estimated by measuring the depth of solids in the primary tank. Measurement of solids depth was difficult in the primary tank (septic tank), as access to the unit is limited to manways in the top of the unit. Solids depth was estimated at three locations from each of the two manways using a Core Pro solids-measuring device. A column of water and solids is removed from the tank, and the undisturbed solids depth in the clear tube measured with a ruler. The measurements were made three times, once in June 2001, and twice near the end of the test, in February 2002 and in March 2002. The results are presented in Table 4-8.

Table 4-8. Solids/Scum Depth Measurement

	Primary Tank Solids/Scum Depth in Inches			
Manway Location	East	Middle	West	Average
June 20, 2001-Inlet	16	8	13	12
June 20, 2001 Outlet	6	10	19	12
June 20, 2002 Scum Depth Inlet	0	0	0	0
June 20, 2002 Scum Depth Outlet	0	0	0	0
February 4, 2002-Inlet	8	12	18	13
February 4, 2002-Outlet	12	7	7	9
February 4, 2002 Scum Depth Inlet	6	5	0	4
February 4, 2002 Scum Depth Outlet	7	4	6	6
March 8, 2002-Inlet	21	28	22	24
March 8, 2002-Outlet	9	10	9	9
March 8, 2002 Scum Depth Inlet	0	0	0	0
March 8, 2002 Scum Depth Outlet	7	4	6	6

Note: Measurement is estimated solids depth in the Primary Tank

In order to characterize the solids in the primary tank, total suspended solids and volatile suspended solids were measured in the samples collected in March. These data are presented in Table 4-9. These concentrations represent the solids concentration in the total sample collected, which includes the solids and water present in the sample tube. Based on an average of 16 inches of solids present in the tube in March, and an additional 44 inches of water (60 inch total depth in the septic tank), the concentration of solids must to be multiplied by a factor of 3.75 to estimate the actual solids concentration in the settled solids layer.

Table 4-9. TSS and VSS Results for the Waterloo Biofilter® Solids Sample

Date	Location	TSS (mg/L)	VSS (mg/L)
3/8/02	Primary Tank	6300	250

The mass of solids present in the septic tank can be estimated from these data. The average concentration of solids in the septic tank, 6,300 mg/L multiplied by the tank total volume of 1,500 gallons shows that the solids accumulated during the test was approximately 78 pounds.

The total mass of solids can also be estimated using the settled solids concentration and the tank dimensions. The primary tank holds a volume of approximately 25 gallons per inch of depth. Therefore, the solids volume, based on an average 16 inches depth (March data), was about 400 gallons. The settled solids concentration is estimated to be 2.4 percent (24,000 mg/L) using the ratio of total depth to solids depth described above (factor of 3.75). Based on a settled solids concentration of 24,000 mg/L, the weight of dry solids accumulated was approximately 80 pounds. The volatile solids represented 4 percent of the solids in the tank according to the laboratory results. These percentage of volatile solids seems very low, but could be checked or confirmed as the system was emptied before the laboratory data was received.

4.4 Operations and Maintenance

Operation and maintenance performance of the Biofilter® unit was monitored throughout the verification test. A field log was maintained that included all observations made over the thirteen-month test period. Data was collected on electrical and chemical usage, noise, and odor. Observations were recorded on the condition of the Biofilter®, any changes in setup or operation (pump adjustments, nozzle cleaning, etc.) or any problems that required resolution. A complete set of field logs is included in Appendix G.

4.4.1 Electric Use

Electrical use was monitored by a dedicated electric meter serving the Biofilter® system. The meter reading was recorded biweekly in the field log by BCDHE personnel. Table 4-10 shows a summary of the electrical use from startup through the end of the verification test. The complete set of electrical readings is presented in a spreadsheet in Appendix F. The average electrical use was 1.3 kilowatts per day based on the entire data set. The basic system tested used only one pump to dose the media and all other flow (recirculation, influent wastewater, effluent discharge) was by gravity. The unit tested did not have a fan for supplemental air supply to the filter. Options of adding a supplemental fan or the need to pump the discharge and/or recycle flow to the primary tank, in certain applications, would increase the electrical use.

Table 4-10. Summary of Waterloo Biofilter® Electrical Usage

	kW/day
Readings	188
Average	1.30
Maximum	2.50
Minimum	0.00
Std. Dev.	0.49

4.4.2 Chemical Use

The Biofilter® system did not require or use any chemical addition as part of the normal operation of the unit.

4.4.3 Noise

Noise levels associated with mechanical equipment were measured once during the verification period. A decibel meter was used to measure the noise level. Measurements were taken one meter from the unit and one and a half meters above the ground, at 90° intervals in four (4) directions. The meter was calibrated prior to use. Table 4-11 shows the results from this test.

Table 4-11. Waterloo Biofilter® Noise Measurements

Location	First Reading (decibels)	Second Reading (decibels)	Average
Background	37.5	38.0	37.7
Biofilter®			
East	47.6	45.5	46.8
South	49.5	49.3	49.4
West	50.5	49.3	49.5
North	44.8	44.8	44.8

Decibels are a log scale so averages are calculated on a log basis

4.4.4 Odor Observations

Monthly odor observations were made over the last eight months of the verification test. The observation was qualitative based on odor strength (intensity) and type (attribute). Intensity was stated as not discernable; barely detectable; moderate; or strong. Observations were made during periods of low wind velocity (<10 knots). The observer stood upright at a distance of three (3) feet from the treatment unit, and recorded any odors at 90° intervals in four (4) directions (minimum number of points). All observations were made by the same BCDHE employee. Table 4-11 summarizes the results for the odor observations. As can be seen, there were no discernible odors found during any of the observation periods.

The container box had two openings for air exchange that were supplied with a small amount of activated charcoal for odor control. The carbon filter was a loosely packed meshed placed in the conduit between the inside and outside of the housing unit. The outside opening had a screen affixed to it to prevent the intrusion of insects. The bag could be slid in/out from the inside. These carbon filters were apparently adequate to control odor as no discernable odors were noted during the test period. A neoprene seal between the hinged top of the foam filter and the container itself likewise prevented escape of odor. During the operation of the system, the odor of the media between doses (only discernable if the top was opened) was described as a mild musty odor.

Table 4-12. Odor Observations

Date	Number of Points observed	Observation
9/10/01	8	No discernable odor
10/20/01	8	No discernable odor
11/22/01	8	No discernable odor
12/09/01	8	No discernable odor
01/27/02	8	No discernable odor
02/17/02	8	No discernable odor
03/02/02	8	No discernable odor
03/31/02	8	No discernable odor

4.4.5 Operation and Maintenance Observations

The Waterloo Biofilter® is a trickling filter that uses as a proprietary open-cell foam media for the growth of bacteria for treatment combined with bacteria resident in the septic tank. The system is comprised of a septic tank, the filter media contained in baskets enclosed in an above grade housing, and a pump chamber. The operation of the system as configured during the test was by demand; that is, the activation of the pump serving the filter and the ultimate rate of forward flow was determined by the rate of wastewater supplied to the septic tank.

The operation of the system is described in detail in the Design, Installation and Service Manual (Appendix A). Septic tank effluent is distributed over baskets containing the open-cell foam. The bottom of the containers are partitioned to allow approximately 50 percent of the flow to return to the septic tank, while approximately 50 percent of the flow proceeds by gravity directly to the leaching facility or other distribution system (such as a pump chamber for low-pressure distribution to a leach field). The Biofilter® System, as tested, had only one pump, two spray nozzles, two level switches, a water level alarm, and a screen on the discharge from the septic tank. Therefore, in the opinion of the operating staff, the system is fairly simple and straightforward to operate and maintain (from a mechanical and electrical perspective).

During the test, very few problems were encountered with the operation of the system. The screen on the outlet from the septic tank (influent to the pump chamber) required periodic cleaning. During the test, the filter was cleaned after eight months (two months of startup and six months of testing) in accordance with the WBS recommendation. No changes or adjustments were needed to the float switches or the pump.

According to WBS, "*after an initial period, which may extend approximately 2-6 months, likely depending on the organic loading, the height of the foam media should be checked for settling. This should not be confused with the start up period for performance, which is shorter in duration. Excessive settling of the media may cause a short-circuiting of the wastewater flow down the side of the container as the spray overtops the receded media. Foam media can easily be added at any point to prevent or anticipate this problem.*" The foam media condition and level was checked during the startup and periodically during the verification test. After approximately four months of operation (January 15 to April 27), it was noted that the effluent was somewhat cloudy and that the media had settled in the baskets. The settled media caused short-circuiting to occur in the unit. WBS directed the MASSTC staff to add media to the unit to fill the baskets. Media was added only once during the test.

During the test, the filter media was housed in a lined wooden box that was situated at least 80 percent above grade. The lining of the housing was comprised of waterproof hardened-foam insulation. Insects, notably boring-type ants, were found to infest the material and bored many tunnels in it, particularly in the top. Test Center personnel applied borax liberally in the area, which resulted in a near eradication of the ants. The hinged top of the container allowed access, but with use, the hinge arrangement proved inadequate as the fastening screws pulled out of the side of the wooden box. A lockable hasp provided adequate security from unauthorized access.

The effluent distribution nozzles are of a standard fire-sprinkler design and did not clog or prevent flow during the tests. Material exiting the orifice, however, did occasionally catch on the distribution plate features and periodically altered the spray pattern slightly. Cleaning this feature is a regular part of the maintenance of the system. The distribution plate was cleaned (a simple wiping of the plate) on the average of about once per quarter. While the cleaning may not be needed as frequently, checking and cleaning the plate on a regular basis to maintain an even flow distribution will help maintain optimum performance. This task is something that a homeowner could do in a few minutes time.

In general, the clarity of the liquid effluent can be described as clear, occasionally having a slight cloudy appearance. Any more extreme cloudiness signaled a problem, such as was observed when the foam media subsided and some short-circuiting of effluent occurred.

In the opinion of the test site operators, the system was easy to operate and maintain. The operators believe quarterly maintenance checks of the Waterloo Biofilter® would be adequate to address any anticipated problems. WBS recommends a minimum of once per year maintenance checks, and the sample maintenance contract is designed for twice per year maintenance of the unit. Based on fifteen months of observation, it is estimated that quarterly maintenance checks, requiring about one hour by a person knowledgeable of the system, would seem appropriate to ensure the system is in good operating condition. The skill level needed is the equivalent of a Class II Massachusetts treatment plant operator. It is possible that a knowledgeable homeowner could perform certain routine quarterly checks, after the system has been in operation for several months, and routinely checked by a trained operator. Homeowner involvement in routine cleaning and system checks might be able to reduce the scheduled contractor maintenance to a semi-annual frequency.

Maintenance activities should include checking the filter media for subsidence and adding media as needed. The biomass condition and the clarity of the effluent should be observed. The nozzles and distribution plates should be checked for clogging and be cleaned. The pump, alarms, and floats should be checked for proper operation. The primary tank should be checked for solids depth and the primary tank effluent screen (Zabel filter) should be cleaned. The activated carbon located on the air openings will have a finite life, although the testing provided no guidance on how long the carbon will last. It appears that carbon replacement should be part of routine maintenance, but the carbon life maybe long, and replacement only needed if odor becomes a problem.

The primary tank should be checked for solids depth and if solids have built up in the septic tank, pumping of the septic tank should be scheduled. There is no guidance on the solids depth in the septic tank that would indicate that the tank should be pumped. In a typical or standard residential septic tank system pumping can be expected to occur every 3 to 5 years. More frequent pumping of solids from the septic tank can be expected based on the additional solids load generated by the Biofilter® System. The regular maintenance checks should include measurement of solids level in the primary tank. When the level of solids buildup to 36 to 42 inches (60 inches of depth available to the outlet) in depth, the tank will need to be pumped to ensure that good solids separation continues in the tank.

The verification test ran for a period of thirteen months, which provided sufficient time to evaluate the overall performance of the unit. However, a much longer operational period would be needed to determine any impacts that repeated sloughing of solids from the media might have on the effluent loading to a receiving soil. The Biofilter® does not have a secondary clarifier or settling zone to remove biomass present in the treated effluent during sloughing periods. Fifty percent of the flow is returned to the primary tank, so during sloughing periods, half of the solids would be removed in the primary tank and half of the solids would be discharged. It is not possible to determine what, if any, long-term impacts that sloughed solids will have on the receiving soils. The Manual makes a statement that effluent samples collected from the system should be taken so that "no sloughed biomass is included." Collecting samples without "sloughed solids" may be appropriate to examine the clarity of the effluent, but are not appropriate to evaluate actual effluent concentrations. Samples taken during sloughing periods, which contain biomass, are more appropriate to obtain information on suspended solids concentrations, which would give some indication if a solids loading problem is occurring. If high solids are encountered on a regular basis, then close observation of the condition of the tile field or other receiving soil system should be part of the system checks.

No particular design considerations are necessary relative to placement, as the unit makes very little noise. Since approximately 80 percent of the Biofilter® unit protrudes out of the ground (four feet), some siting considerations based on this feature may be desired. The basic components of the system appear durable and should perform well under typical home wastewater conditions.

The Manual (Appendix A) provided by WBS is comprehensive and provides information for installation, startup, operation, and servicing of the Biofilter® system. The Manual includes information on the theory of biological treatment and descriptions of observations that can be made to visually check the condition of the biomass. The visual color inspection and assumptions guide in the maintenance checklist gives an indication of possible upset conditions. It should be noted that the "determination" of color and deciding that all "brown is bad" is probably stretching the science and the abilities of a maintenance person. However, providing this detail helps highlight the importance of observing the condition of the biomass in the unit.

4.5 Quality Assurance/ Quality Control

The VTP included a QA/QC Plan (QAPP) with critical measurements identified and several QA/QC objectives established. The verification test procedures and data collection followed the QAPP, and summary results are reported in this section. The full laboratory QA/QC results and supporting documentation are presented in Appendices D, E, and F.

4.5.1 Audits

Two audits of the MASSTC and Barnstable County Health Department Laboratory were conducted by NSF during the verification test. These audits, in August 2001 and January 2002, found that the field and laboratory procedures were generally being followed. Recommendations for changes or improvements were made and the responsible organizations responded quickly to these recommendations. The finding of these audits was that the overall approach being used in the field and the laboratory were in accordance with the established QAPP.

The only finding that needed immediate attention during the first lab audit in August 2001 was the lack of method blanks in the nitrite and nitrate tests at the proper frequency. The calibration standards gave a very good linear relationship and the analyses were considered valid. Corrective action was accomplished immediately. All other findings were paper work related, such as updating training records and SOPs. Recommendations were made to improve the detail placed in the field logs, and to be sure, that calibrations were documented and field duplicate samples collected as planned. The second audit in January 2002 found that recommendations had been implemented and no new findings were identified for immediate corrective action. The field and lab managers were reminded of activities that needed to be completed before the end of the test in accordance with the Test Plan.

A third audit was conducted at the end of the verification test. This audit reviewed the records and procedures that were used. A list of documents and data needed for the final report was prepared and discussed with the field and laboratory managers.

Internal audits of the field and laboratory operations were also conducted at least quarterly by BCDHE. These audits specifically reviewed procedures and records for the ETV project. Any shortcomings found during these internal audits were corrected as the test continued.

4.5.2 Daily Flows

One of the critical data quality objectives was to dose the unit on a daily basis to within 10 percent of the design flow. For the Biofilter® system the design flow was 440 gpd. The QC objective was to dose the unit at 440 gpd plus or minus 10 percent, based on a monthly average of the daily flows. The dose volume were calibrated twice per week and if the volume changed by more than ten percent the dosing pump run time was adjusted in the PLC. The objective was met for all 13 months of the verification test period. The monthly averages were presented in Table 4-4. The daily flows for all months are presented in spreadsheet format in Appendix F. The field logs in Appendix G provide the twice per week calibration data that is summarized in the spreadsheets.

4.5.3 Precision

Precision measurements were performed throughout the verification test by collection and analysis of duplicate samples. Field duplicates were collected to monitor the overall precision of the sample collection and laboratory analyses. There were three or four similar verification tests running simultaneously at the MASSTC. Field duplicates were generally collected on each sampling day, with the sample selected for replication rotating among the three or four technologies. The results for the field duplicates are presented in a spreadsheet in Appendix D. Summaries of the data are presented in Tables 4-13 through 4-15.

The precision for nitrogen compounds was generally excellent, particularly given the low levels of ammonia, TKN, and nitrate in some of the effluent samples. A few sample results were outside the target window of either 10 percent RPD (nitrite, nitrate) or 20 RPD percent (TKN, NH_3), but in most cases, the results were for samples that were very low in concentration. As an example, one set of data for TKN showed replicate one as 0.9 mg/L and replicate two as 0.5

mg/L with a detection limit of 0.5 mg/L. The calculated RPD for this sample is 57 percent. Even though the relative percent difference (RPD) is high, the data is reasonable given the low concentration found in the samples.

The test plan did not differentiate between laboratory precision and field precision. Typically, field precision targets are wider than laboratory goals to account for sampling variation, in addition to the laboratory variation. Also, the precision goals for nitrite and nitrate were set very tight (10 percent RPD), which would appear to be tighter than required for acceptable wastewater analysis and evaluation of these parameters. Using the 10 percent RPD criteria, 8 out of 49 field duplicates for nitrate exceeded the target, and 7 out of 50 duplicates for nitrite exceeded the window. TKN showed 10 out of 59 field duplicates exceeded the target of 20 percent RPD. Ammonia results were similar with 6 out of 60 samples above the target of 20 percent RPD, with all exceedances for samples having a concentration of less than 1 mg/L.

Table 4-13. Duplicate Field Sample Summary – Nitrogen Compounds

	TKN (mg/L)			Ammonia (mg/L)		
Statistics	Rep 1	Rep 2	RPD	Rep 1	Rep2	RPD
Number	60	60	59	60	60	60
Average	14	15	13	8.9	8.8	11
Median	7.5	8.1	6.5	5.0	5.0	4.5
Maximum	49	51	135	29	28	133
Minimum	<0.5	<0.5	0.0	<0.2	<0.2	0
Std. Dev.	14	14	22	9.1	9.0	21
	Nitrite (mg/L)			Nitrate (mg/L)		
Statistics	Rep 1	Rep 2	RPD	Rep 1	Rep2	RPD
Number	50	50	46	50	50	49
Average	0.32	0.33	5.3	6.9	6.9	6.3
Median	0.30	0.30	2.0	6.2	6.1	4.3
Maximum	0.95	1.1	33	15	15	36
Minimum	<0.05	<0.05	0.0	<0.1	0.70	0.0
Std. Dev.	0.20	0.22	8.4	4.1	4.2	8.3

Number = Number of analyses used in the calculations

Table 4-14. Duplicate Field Sample Summary – CBOD, BOD, Alkalinity, TSS

Statistics	$CBOD_5$ (mg/L)			BOD_5 (mg/L)		
	Rep 1	Rep 2	RPD	Rep 1	Rep2	RPD
Number	50	50	50	10	10	10
Average	10	10	20	220	210	10
Median	6.7	6.7	14	230	220	11
Maximum	60	54	110	280	270	23
Minimum	1.9	2.3	0.51	140	150	1.1
Std. Dev.	11	9.5	19	44	43	6.6
Statistics	TSS (mg/L)			Alkalinity (mg/L as $CaCO_3$)		
	Rep 1	Rep 2	RPD	Rep 1	Rep2	RPD
Number	60	60	59	60	60	60
Average	32	31	31	120	120	3.4
Median	7	9	12	110	100	1.8
Maximum	260	260	190	220	220	27
Minimum	1	<1	0	56	54	0
Std. Dev.	57	54	43	46	46	5.6

Number = Number of analyses used in the calculations

Table 4-15. Duplicate Field Sample Summary – pH, Dissolved Oxygen

Statistics	pH (S.U.)			Dissolved Oxygen (mg/L)		
	Rep 1	Rep 2	RPD	Rep 1	Rep2	RPD
Number	60	55	55	12	12	12
Average	7.4	7.4	0.4	5.9	5.9	0
Median	7.4	7.5	0.1	5.8	5.8	0
Maximum	8.0	8.0	3.8	9.9	9.9	0
Minimum	6.6	6.8	0	2.5	2.5	0
Std. Dev.	1.0	0.3	0.6	2.2	2.2	0
	Calculated using log scale			All replicates gave same value		

Number = Number of analyses used in the calculations

The $CBOD_5$ and TSS data tended to have poorer precision than the other analyses, because this data is based on treated effluent samples that are below 10 mg/L. Comparison of average values and median values shows that much of the TSS data is at low concentration. Both $CBOD_5$ and TSS have detection limits of 1 or 2 mg/L. TSS is generally reported to one significant figure at levels below 10 mg/L. It is expected that precision will be poorer at the lower concentrations and near the detection limit of the methods. Further, the influence of variability in sample collection can be seen in this data as well. The laboratory precision data presented in Table 4-17 shows a tighter precision for TSS (13 percent in lab versus 31 percent for field duplicates). The difficulty of getting a well-mixed sample for low level suspended solids undoubtedly added to the lower precision for the TSS test. Overall, the TSS results showed 26 out of 59 samples were outside the target of 20 percent RPD and 18 out of 50 samples were outside the target for $CBOD_5$. Only 2 out of 16 CBOD$_5$ samples exceeded the target when the concentration was above 10 mg/L. While this data indicates that precision is lower at the lower concentrations, the overall data set provides the needed information that showed the ability of the treatment unit to significantly reduce TSS and CBOD$_5$ in the wastewater. Laboratory procedures, calibrations, and data were audited and found to be in accordance with the published methods and good laboratory practice.

The laboratories performed lab duplicates on a frequency of at least one per batch or 10 percent of samples. The laboratory precision data is summarized in Tables 4-16 and 4-17. The various nitrogen analyses showed excellent precision, as did the alkalinity results. Nitrite results showed no samples (60 total) exceeded the very tight target of 10 percent RPD. Nitrate results showed 14 out 211 values exceeded the 10 percent RPD target, but only 1 result out 211 exceeded a 20 percent difference.

The CBOD$_5$ and TSS precision was generally within the target objective of 20 percent RPD, except when the concentrations were low. As discussed earlier, when effluent samples were below 10 mg/L the calculated percent differences were higher, as would be expected. The CBOD$_5$ and BOD$_5$ analyses used very similar procedures, and were performed together under the same conditions in the laboratory. The BOD$_5$ data showed much higher precision (average of 8 percent) than the CBOD$_5$ (average 15 percent). This is primarily due to the higher concentrations of BOD$_5$ (influent wastewater samples). In summary, 18 out of 57 results exceeded the CBOD$_5$ target of 20 percent RPD, but none of the samples over 10 mg/L exceeded the target (0 out of 17); BOD$_5$ results showed 7 out of 64 results were above the target; and 8 out of 44 TSS samples showed RPD above 20 percent. On-site audits and review of procedures and calibrations indicated that good laboratory practice was being followed. There were no identified, systematic errors that would account for the difference. The data for all analyses was judged acceptable and useable for evaluating the treatment efficiency.

Table 4-16. Laboratory Precision Data – Nitrogen Compounds

Statistics	Relative Percent Difference (RPD)			
	TKN	Ammonia	Nitrite	Nitrate
Number	59	53	67	211
Average	7.6	3.1	2.7	3.1
Median	4.7	0	0.0	2.1
Maximum	55	36	18	25
Minimum	0.0	0	0.0	0.0
Std. Dev.	11	6.6	4.3	3.7

Number = Number of analyses used in the calculations

Table 4-17. Laboratory Precision Data – CBOD$_5$, BOD$_5$, Alkalinity, TSS

	CBOD$_5$ (mg/L)			BOD$_5$ (mg/L)		
Statistics	Rep 1	Rep 2	RPD	Rep 1	Rep2	RPD
Number	57	57	57	64	64	64
Average	18	18	15	160	160	7.7
Median	5.9	6.7	7.6	170	170	4.4
Maximum	100	100	73	500	530	32
Minimum	<2.0	2.0	0	<2.0	<2.0	0
Std. Dev.	24	24	15	120	120	8.1
	TSS (mg/L)			Alkalinity (mg/L as CaCO$_3$)		
Statistics	Rep 1	Rep 2	RPD	Rep 1	Rep2	RPD
Number	44	44	44	48	48	48
Average	72	73	13	83	84	6.1
Median	52	54	5	80	80	1.8
Maximum	290	310	130	190	190	40
Minimum	1	4	0	2	2	0
Std. Dev.	73	72	24	58	59	12

Number = Number of analyses used in the calculations

4.5.4 Accuracy

Method accuracy was determined and monitored using a combination of matrix spikes and lab control samples (known concentration in blank water) depending on the method. Recovery of the spiked analytes was calculated and monitored during the verification test. Accuracy was in control throughout the verification test. All recoveries for all spiked samples for alkalinity, BOD$_5$, nitrite, and nitrate were within the established windows. Only 1 result out of 51 spiked samples was outside the recovery target for CBOD$_5$. Tables 4-18 and 4-19 show a summary of the recovery data. All quality control data is presented in Appendix D.

Table 4-18. Accuracy Results – Nitrogen Analyses

Statistics	TKN (% Recovery)		Ammonia (% Recovery)	
	Matrix Spike	Lab Control Sample	Matrix Spike	Lab Control Sample
Number	54	59	50	57
Average	95	100	99	107
Median	96	99	100	107
Maximum	137	114	112	120
Minimum	62	86	51	91
Std. Dev.	16	6.2	9.3	7.2

Statistics	Nitrite (% Recovery)		Nitrate (% Recovery)	
	Matrix Spike	Lab Control Sample	Matrix Spike	Lab Control Sample
Number	50	54	24	119
Average	104	99	98	99
Median	104	99	97	98
Maximum	123	120	113	116
Minimum	80	82	85	81
Std. Dev.	10	9.7	8.4	8.0

Number = Number of analyses used in the calculations

Table 4-19. Accuracy Results – CBOD, BOD, Alkalinity

Statistics	CBOD$_5$ (% Recovery)	BOD$_5$ (% Recovery)	Alkalinity (% Recovery
	Lab Control Sample	Lab Control Sample	Lab Control Sample
Number	51	54	61
Average	100	101	100
Median	101	101	100
Maximum	106	109	113
Minimum	77	84	93
Std. Dev.	5	4	3

Number = Number of analyses used in the calculations

The balance used for TSS analysis was calibrated routinely with weights that were NIST traceable. Calibration records were maintained by the laboratory and inspected during the on site audits. The temperature of the drying oven was also monitored using a thermometer that was calibrated with a NIST traceable thermometer. The pH meter was calibrated using a three-point calibration curve with purchased buffer solutions of known pH. Field temperature measurements were performed using a thermometer that was calibrated using a NIST traceable thermometer provided to the field lab by the BCDHE laboratory. The dissolved oxygen meter was calibrated daily using ambient air and temperature readings in accordance with the SOP. The noise meter was calibrated prior to use and all readings were recorded in the field logbook. All of these traceable calibrations were performed to ensure the accuracy of measurements.

4.5.5 Representativeness

The field procedures, as documented in the MASSTC SOPs (Appendix C), were designed to ensure that representative samples were collected of both influent and effluent wastewater. The composite sampling equipment was calibrated on a routine basis to ensure that proper sample volumes were collected to provide flow weighted sample composites. Field duplicate samples and supervisor oversight provided assurance that procedures were being followed. As discussed earlier, the challenge in sampling wastewater is obtaining representative TSS samples and splitting the samples into laboratory sample containers. The field duplicates showed that there was some variability in the duplicate samples. However, based on 60 sets of field duplicates, the overall average TSS of the replicates was very close (32 and 31 mg/L). This data indicated that while individual sample variability may occur, the long-term trend in the data was representative of the concentrations in the wastewater.

The laboratories used standard analytical methods and written SOP's for each method to provide a consistent approach to all analyses. Sample handling, storage, and analytical methodology were reviewed during the on-site and internal audits to verify that standard procedures were being followed. The use of standard methodology, supported by proper quality control information and audits, ensured that the analytical data was representative of the actual wastewater conditions.

4.5.6 Completeness

The VTP set a series of goals for completeness. During the startup and verification test, flow data was collected for each day and the dosing pump flow rate was calibrated twice a week as specified. The flow records are 100 percent complete. Electric meter records were maintained in the field logbook. Electric meter readings were performed twice a week and summarized in a spreadsheet. Only one electric meter reading was missed (the first reading at startup) during the startup and verification test. Out of 195 readings, one was incomplete giving a completeness of 99 percent complete.

The goal set in the VTP for sample collection completeness for both the monthly samples and stress test samples was 83 percent. All monthly samples were collected and all stress test samples were collected in accordance with the VTP schedule. Therefore, sample collection was 100 percent complete.

A goal of 90 percent was set for the completeness of analytical results from the BCDHE laboratory and GAI. All scheduled analyses for delivered samples were completed and found to be acceptable, useable data. Completeness is 100 percent for the laboratory.

5.0 REFERENCES

5.1 Cited References

(1) NSF International, *Protocol for the Verification of Residential Wastewater Treatment Technologies for Nutrient Reduction*, November 2000, Ann Arbor, Michigan.

(2) EPA, *Wastewater Technology Fact Sheet Trickling Filter Nitrification*, September 2000, Office of Water, Washington D.C., EPA 832-F-00-015

(3) EPA, *Manual for Nitrogen Control*, 1993, 625/R-93/010

(4) NSF International, *Test Plan for The Massachusetts Alternative Septic System Test Center for Verification Testing of AWT Biofilter Nutrient Reduction Technology*, January 2001

(5) United States Environmental Protection Agency: *Methods and Guidance for Analysis of Water*, EPA 821-C-99-008, 1999. Office of Water, Washington, DC.

(6) United States Environmental Protection Agency: *Methods for Chemical Analysis of Water and Wastes,* Revised March 1983, EPA 600/4-79-020

(7) APHA, AWWA, and WEF: *Standard Methods for the Examination of Water and Wastewater*, 19th Edition, 1998. Washington, DC.

5.2 Additional Background References

(8) United States Environmental Protection Agency: *Environmental Technology Verification Program - Quality and Management Plan for the Pilot Period (1995 – 2000)*, EPA/600/R-98/064, 1998. Office of Research and Development, Cincinnati, Ohio.

(9) NSF International, Environmental Technology Verification – *Source Water Protection Technologies Pilot Quality Management Plan*, 2000. Ann Arbor, Michigan.

(10) United States Environmental Protection Agency: *EPA Guidance for Quality Assurance Project Plans, EPA QA/G-5*, EPA/600/R-98-018, 1998. Office of Research and Development, Washington, DC

(11) United States Environmental Protection Agency, *Guidance for the Data Quality Objectives Process, EPA QA/G-4*, EPA/600/R-96-055, 1996. Office of Research and Development, Washington, DC.

(12) ANSI/ASQC: Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs (E4), 1994