THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

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®

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 ^oC when the unit was started and remained in the 5 to 8 ^oC 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

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

Original signed by
Hugh W. McKinnon *5/30/03*

Hugh W. McKinnon Date
Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Original signed by
Gordon E. Bellen *6/3/03*

Gordon E. Bellen Date
Vice President
Research
NSF International

NOTICE:

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.

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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.

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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	EPAdlc -4.562AHra.0082 Tc 0.0395 Tw 4..TN

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.

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Superior Court House (P.O. Box 427)
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The Verification Report was prepared by Scherger Associates.

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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
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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
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Mr. Sean Foss, Facility Operations Manager:
Barnstable County Department of Health and the Environment
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Dr. Thomas Bourne, Laboratory Manager
Barnstable County Department of Health and the Environment Laboratory
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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
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- Provide funding for verification testing.

The key contact for WBS is:

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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 oc1_0nt Pthe sa11 1 Tf -0.0034Ced wastewater g

1.3 Background – Nutrient Reduction

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.

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

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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 loa

[redacted]

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

[redacted]

Figure

The wastewater was pumped to the Biofilter® through 1 inch schedule 40 PVC pipe to a manifold with downward faci

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

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 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

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

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.

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 e5 -1.187 Td (week.")c 0.19day 6i0 -0.0041 Taa391ore, therv surrounding Bu5 stress91oreeheek

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, asasasasasasaprm 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[7en[7en

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 <u>Electric Use</u>

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 <u>Chemical Use</u>

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

3.4.5.3 <u>Noise</u>

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

[redacted]

[redacted]

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

Mon/Year	Target Gallon/dose	Doses/day	Ave Monthly 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

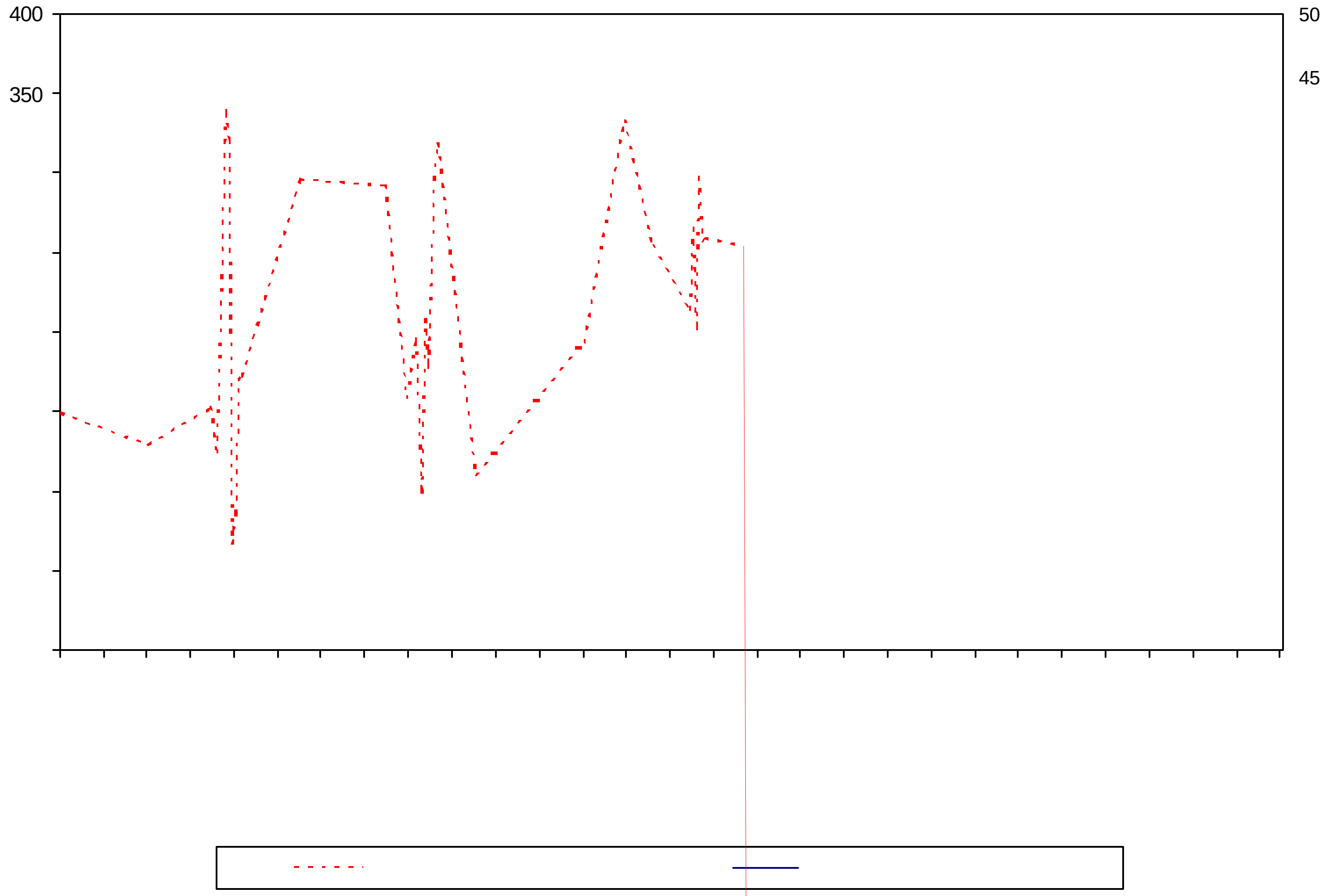
(1) The timer and PLC issue was fixed on September 6. Fifteen doses were delivered beginning on September 7, 2001.
(2) September/October – Low Load test run in September and October; average flow data for September and October does not include the low flow days. Only normal flow days are included. During 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 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 b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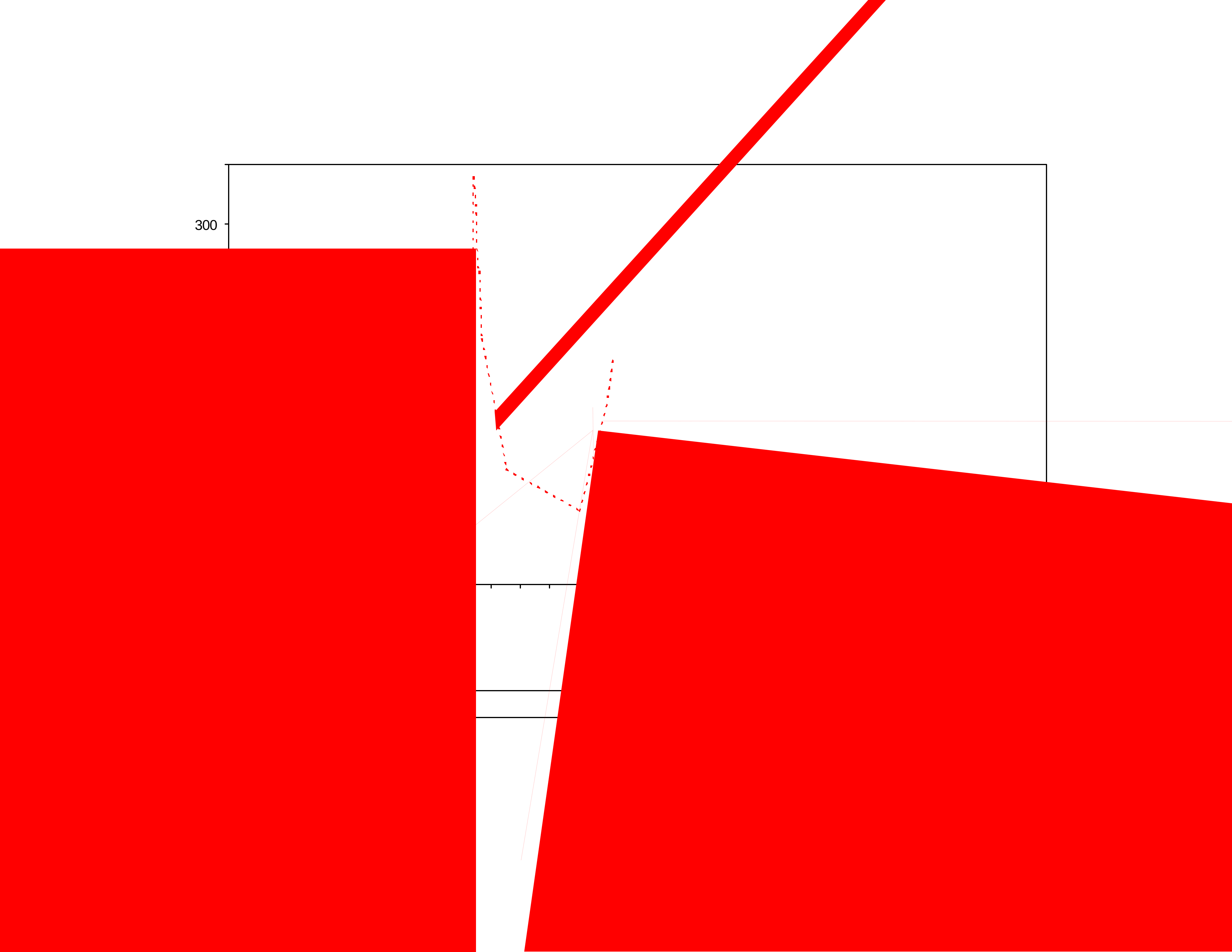
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Table 4-5. Waterloo Biofilter® BOD_5/$CBOD_5$ and TSS Results

	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	$CBOD_5$				
	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	

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. T6.i Tc 0.0784 T(81rrTf 0 Tc 45 TD 6did2ammonia niTw 0 -1.187 TD

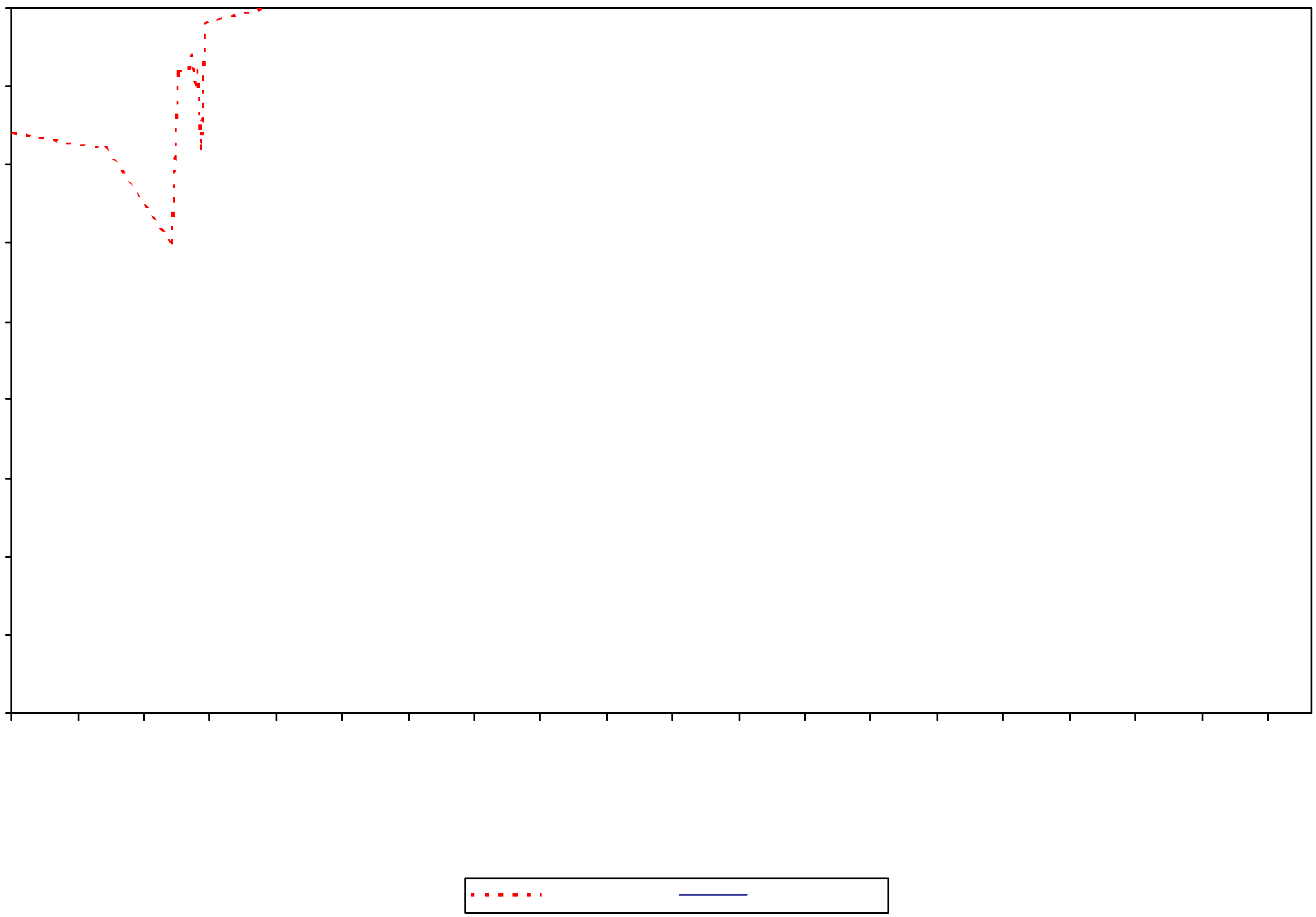
4.3.3.2 Discussion

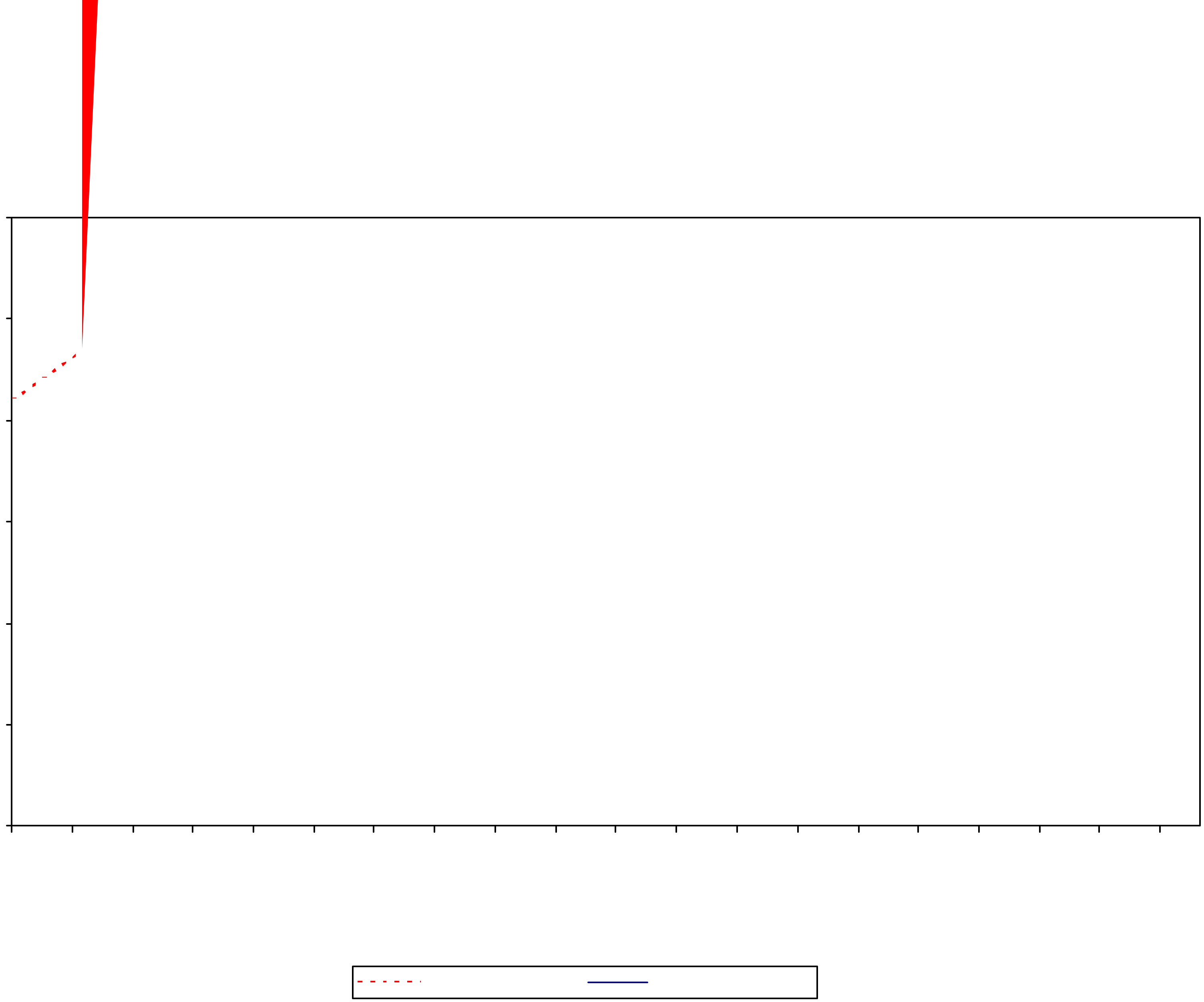
As discussed earlier in the startup section, at the end of the startup period (January 15 to March 12, 2001), the Biofilter® effluent was showing only negligible reduction of total nitrogen. Influent and effluent wastewater temperatures were in the 4 to 8 ^{o}C range. As shown in Table 4-6, beginning 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 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 ^{o}C from 7 ^{o}C on first day after the Vacation stress period ended.

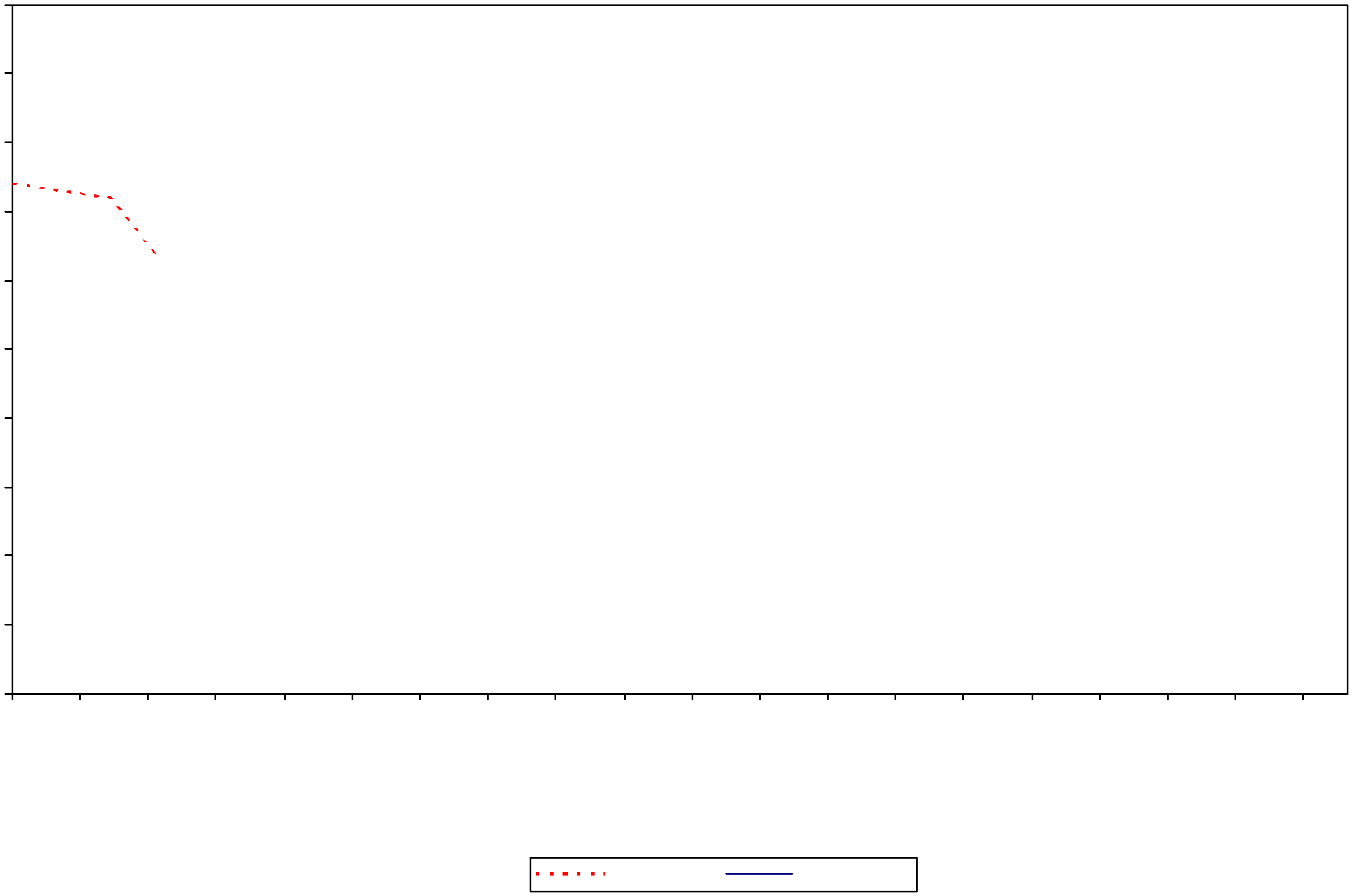
Performance began to improve almost immediately after the flow returned to normal conditions. $CBOD_5$ effluent concentrations began to trend downward and were below 10 mg/L within two weeks. Ammonia nitrogen concentrations also began to trend downward and were in the 1-3 mg/L range within a few days. 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.

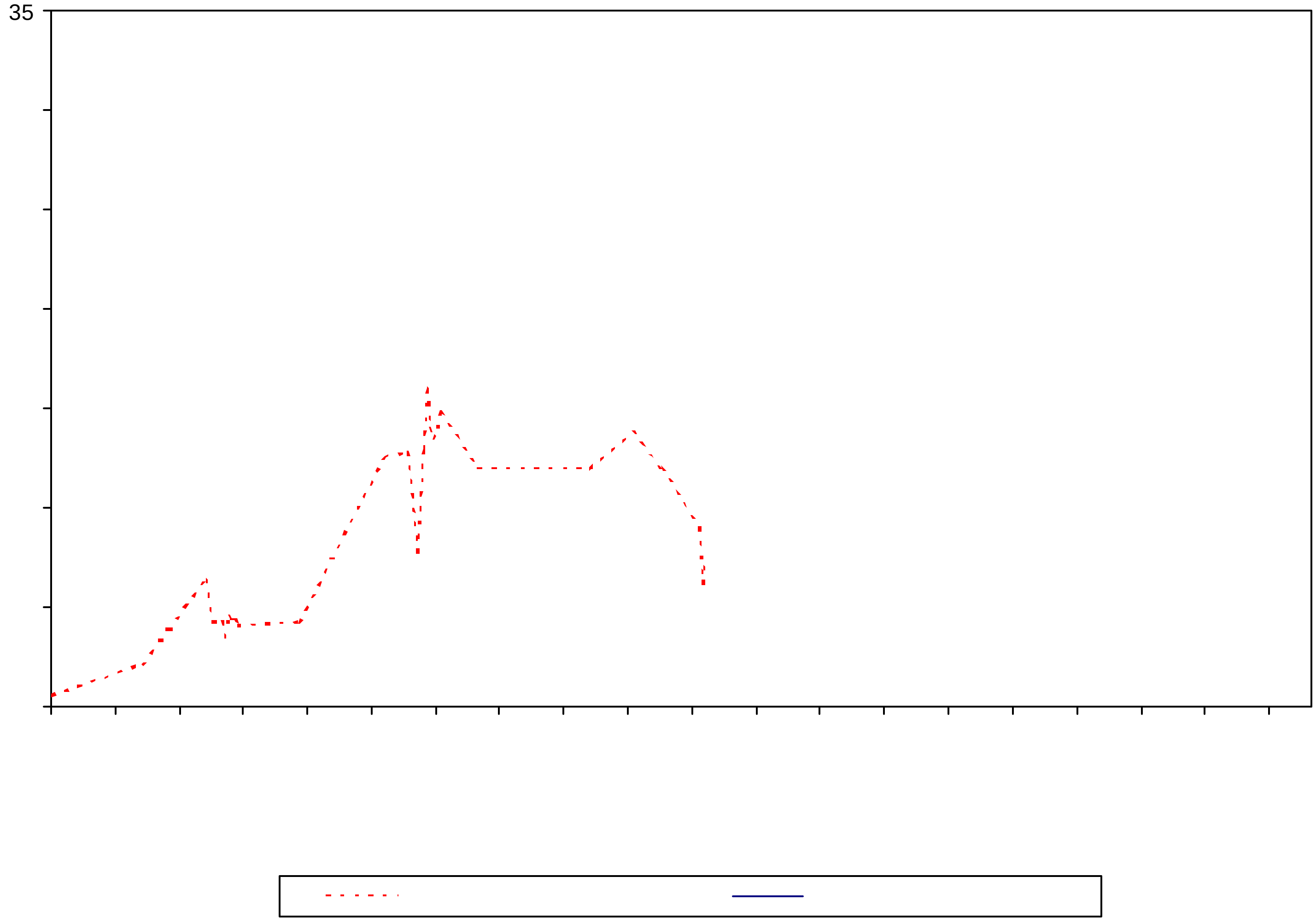
The last sample collected in April 2002 indicated that both the nitrifying and denitrifying processes had recovered, resulting in an effluent TN concentration of 11 mg/L. TKN and ammonia concentrations were 3.5 mg/L and 1.1 mg/L, respectively, only slightly higher than the less 1 mg/L levels achieved 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.

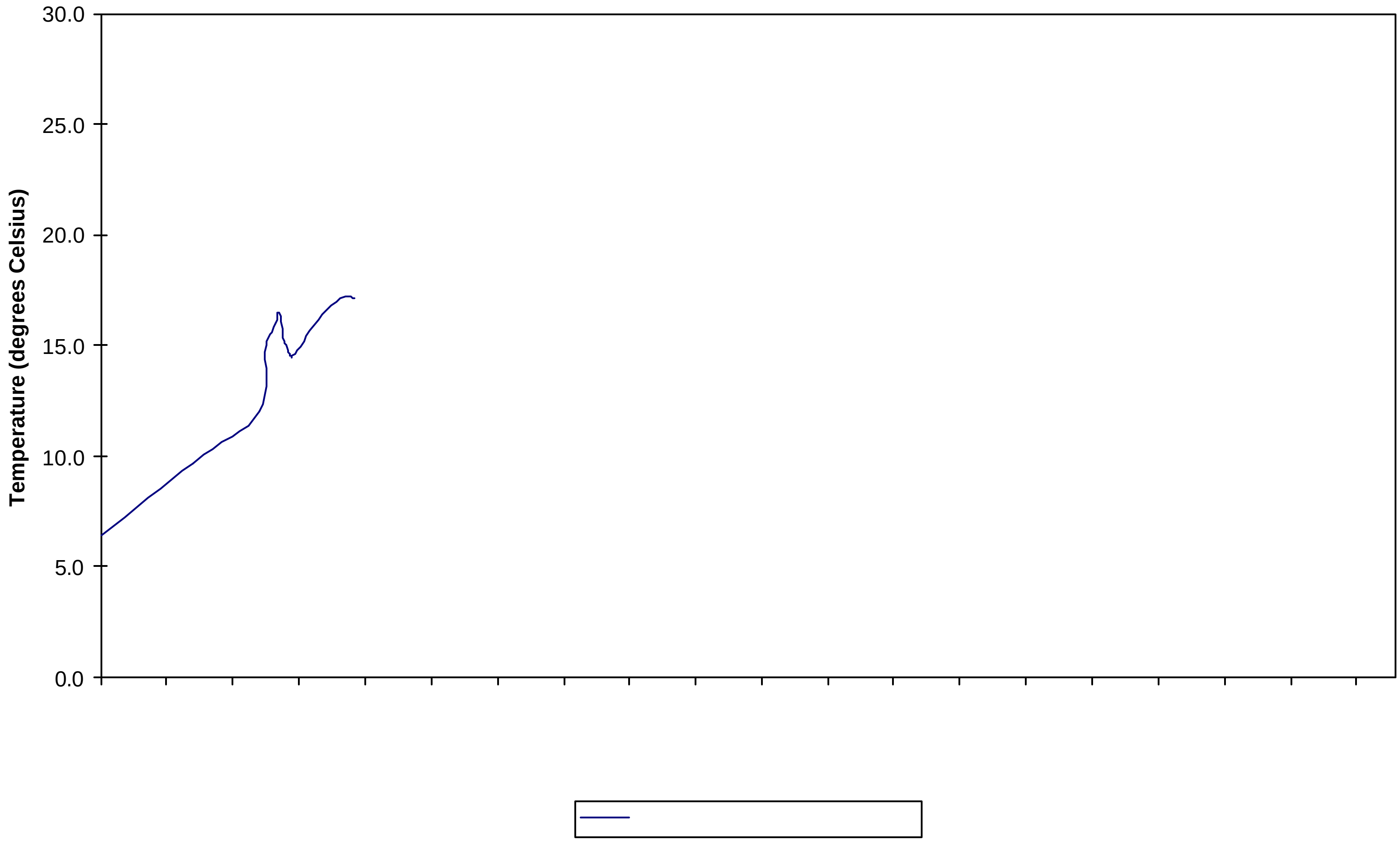
The verification test provided a sufficiently long test period to collect data that included both a long run of steady performance by the Biofilter® system and a period of an apparent upset following the Vacation stress test. While the system appeared to be impacted by the Vacation stress test and low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








35



30.0
25.0
20.0
15.0
10.0
5.0
0.0
Temperature (degrees Celsius)

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 (^oC)
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					

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), 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®

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)**
Background	37.5

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 etween mdCo2 to prr2 08 T i210.rdD2 0.0nrC 125a4 1 Tf -0.00581

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

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 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 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®

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	40 19ci7g8TDo760				

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

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	

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,