September 2003
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# Environmental Technology Verification Report

## Reduction of Nitrogen in Domestic Wastewater from Individual Residential Homes

**Bio-Microbics, Inc.
RetroFAST® 0.375 System**

Prepared by

NSF International

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

ETV ETV ETV

**THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM**

**U.S. Environmental Protection Agency**

**NSF International**

# ETV Joint Verification Statement

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| TECHNOLOGY TYPE: | **BIOLOGICAL WASTEWATER TREATMENT – NITRIFICATION AND DENITRIFICATION FOR NITROGEN REDUCTION** |
| APPLICATION: | **REDUCTION OF NITROGEN IN DOMESTIC WASTEWATER FROM INDIVIDUAL RESIDENTIAL HOMES** |
| TECHNOLOGY NAME: | **RETROFAST® 0.375 SYSTEM** |
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NSF International (NSF) operates the Water Quality Protection Center (WQPC) under the U.S. Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) Program. The WQPC evaluated the performance of a submerged attached-growth biological treatment system for nitrogen removal for residential applications. This verification statement provides a summary of the test results for the Bio-Microbics, Inc. RetroFAST® 0.375 System (RetroFAST®). NovaTec Consultants, Inc. (NovaTec) performed the verification testing.

EPA created the 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 accelerating the acceptance and use of improved and 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.

## ABSTRACT

Verification testing of the RetroFAST® was conducted over a twelve-month period at the Mamquam Wastewater Technology Test Facility (MWTTF) located at the Mamquam Wastewater Treatment Plant (WWTP), which serves the District of Squamish, British Columbia, Canada. An eight-week startup period preceded the verification test to provide time for the development of an acclimated biological growth in the RetroFAST®. 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 RetroFAST® proved capable of removing nitrogen from the wastewater. The influent total nitrogen (TN) mean concentration was 39 mg/L, with a median of 36 mg/L. The effluent TN (total Kjeldahl nitrogen (TKN) plus nitrite/nitrate ($NO_2^-$/$NO^-_3$)) mean concentration was 19 mg/L over the verification period, with a median concentration of 18 mg/L. During the first two months of testing, an apparent upset condition occurred. During investigation of the upset, Bio-Microbics determined that the blower setting of 30 minutes on and 30 minutes off was incorrect. The blower was changed to continuous operation and the verification test continued for eleven months. The mechanical components of the RetroFAST® (blower, airlift, and optional alarm) operated properly throughout the test. No maintenance or operational changes were required during the final eleven months of the verification test.

## TECHNOLOGY DESCRIPTION

The following technology description is provided by the vendor and does not represent verified information.

The RetroFAST® 0.375 System is a submerged attached-growth treatment system, which is inserted as a retrofit device into the outlet side of new or existing septic tanks. The RetroFAST® has a rated capacity of 375 gallons per day (gpd), and is designed to treat wastewater from a single-family home with four to six persons. The only mechanical component is a remotely housed air blower, which provides air for oxygen supply and mixing to the aerated chamber. The media used is PVC or polyethylene cross-flow media, with a total installed packed volume of 12 cubic feet. A small control panel with an alarm designed to activate if the blower fails is available as an option.

Wastewater enters the septic tank in the primary treatment zone, which can be a separate compartment (the verification test used a two-compartment septic tank) or an area that extends from the inlet pipe to the forward bulkhead of the insert. The quiescent condition in the primary zone allows the heavy solids in the wastewater to settle to the bottom of the chamber, where they are gradually digested under anaerobic conditions. The wastewater then flows into the aerobic zone (either the second compartment or the area of the tank containing the RetroFAST® insert). The organic constituents in the wastewater serve as food for the aerobic bacteria that are attached to the honeycomb media in the RetroFAST® unit and present in the suspended solids (mixed liquor) in the liquid phase within the unit. An external blower supplies air to a draft tube located in a central chamber in the submerged media. The draft tube acts as an airlift pump to draw wastewater from below the media and distribute it over the media surface by a splash plate above the water line. The draft tube induces a circulation of wastewater down through the media and provides oxygen to the wastewater. Nitrified wastewater flows through the bottom of the central chamber into the surrounding anoxic zone, where solids settle to the bottom of the second chamber. Denitrification occurs in the anoxic zone in this chamber. The clarified effluent is discharged by gravity, flowing through an opening (notch) that separates the discharge water from the aeration zone and exiting via a discharge pipe.

## VERIFICATION TESTING DESCRIPTION

### *Test Site*

The MWTTF site is located at the wastewater treatment plant serving the District of Squamish, British Columbia, Canada. Wastewater is supplied from a sanitary sewer collection system serving a catchment consisting of primarily residential houses, with minor commercial sources. After passing through the WWTP screens and grit-removal processes, wastewater is pumped through a 2.5-inch diameter manifold pipeline to the test site, at a rate of approximately 53 gallons per minute (gpm) (3.4 liters per second [L/s]). During dosing periods, wastewater is constantly circulated through the manifold pipeline to ensure solid material contained in the wastewater does not settle. Excess flow in the manifold is discharged to the headworks of the WWTP. Dosing at each test unit is regulated by a pneumatic gate valve that is controlled by a programmable logic controller (PLC). The PLC enables operators to monitor the operating status of the test facility and the individual test units, and to change any of the dosing parameters (e.g., dosage volume, frequency of dosage, duration of dosing period, etc.).

### *Methods and Procedures*

The RetroFAST® was installed by the MWWTP operators with the assistance of Bio-Microbics staff on June 6, 2001. The unit was installed in the second compartment of a two-compartment septic tank in accordance with the installation instructions supplied by Bio-Microbics. On July 6, 2001, the septic tank was filled with one-third wastewater and two-thirds potable water, and the dosing sequence began. An eight-week startup period allowed the biological community to become established and the operating conditions to be monitored. The standard dosing sequence was used for the entire startup period.

The system was monitored during the startup period, including visual observation of the system and routine calibration of the dosing system. Several influent samples were collected and analyzed for pH, alkalinity, temperature, five-day biochemical oxygen demand ($BOD_5$), TKN, ammonia nitrogen ($NH_3$-N), $NO_2^-$, $NO_3^-$, and total suspended solids (TSS). Effluent samples were analyzed for pH, alkalinity, temperature, five-day carbonaceous biochemical oxygen demand ($CBOD_5$), TKN, $NH_3$-N, TSS, dissolved oxygen (DO), $NO_2^-$, and $NO_3^-$.

The thirteen-month verification test period incorporated 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. Nitrogen reduction was monitored by measuring nitrogen species (TKN, $NH_3$-N, $NO_2^-$, $NO_3^-$). Other basic parameters ($BOD_5$, $CBOD_5$, pH, alkalinity, TSS, temperature) were monitored to provide information on overall system 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 verification test was designed to load the RetroFAST® at design capacity (375 gpd ± 10%) for the entire test, except during the low load and vacation stress tests. The RetroFAST® was dosed 100 times per day with approximately 3.7 gallons of wastewater per dose. The unit received 35 doses in the morning, 25 doses mid-day, and 40 doses in the evening. The dosing volume was controlled by the length of time the pneumatic valve was open for each cycle. Dosing volumes were verified once per week.

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 more intensely, with six to eight composite samples being collected during and after each stress test period. Five consecutive days of sampling occurred in the last month of the verification test. All composite samples were collected using automatic samplers located at the dosing manifold pump location (influent sample) and at the discharge of the unit. Grab samples at each sample location were collected on each sampling day to monitor the system pH, DO, and temperature.

All samples were cooled during sample collection; preserved, if appropriate; and transported to the laboratory. All analyses were completed in accordance with EPA-approved methods or Standard Methods. An established quality assurance/quality control (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 RetroFAST® began on July 6, 2001, when the septic tank was filled and the wastewater dosing started. Flow was set at 375 gpd based on delivering 80 doses per day with a target of 4.7 gallons per dose. Samples of the influent and effluent were collected during the startup period, which continued until September 4, 2001. The dosing sequence was adjusted in September to delivery 100 doses per day with a delivery of 3.7 gallons per dose. Verification testing began September 5, 2001, and continued until October 25, 2002. Sampling and equipment problems in October and November 2001 resulted in the verification test being extended to fourteen months in order to obtain a full set of valid data. During the verification test, 60 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 installation instructions were easy to follow, and installation proceeded without difficulty. No changes were made to the unit during the startup period, and no special maintenance was required.

The RetroFAST® was removing $CBOD_5$ and TSS within the first three weeks of operation. At the end of the eight-week startup, effluent $CBOD_5$ was 8 mg/L and TSS was 6 mg/L. The effluent TN concentration was 12 mg/L at the end of the startup period, ranging from 6 to 12 mg/L in the final four weeks of startup. Influent TN concentration ranged from 30 to 37 mg/L during this time. Both the nitrification and denitrification processes appeared established at the end of the startup period, as indicated by the difference between influent and effluent TN. The blower was set to operate 30 minutes on and 30 minutes off during this period.

### *Verification Test Results*

The daily dosing schedule was adjusted slightly at the beginning of the verification test. The dose sequence was set for 100 doses of 3.7 gallons per dose to be applied every day, except during the low load (May to June 2002) and vacation stress (September 2002) periods. Volume per dose and total daily volume varied only slightly during the verification test. The daily volume, averaged on a monthly basis, ranged from 366 to 380 gpd, within the range allowed in the protocol for the 375 gpd design capacity.

The sampling program emphasized sampling during and after the major stress periods. This resulted in a large number of samples being clustered during five periods, with the remaining monthly samples spread over the remaining months. Both mean and median results were calculated, because comparing median values to mean values can help evaluate the impacts of the stress periods. The RetroFAST® results showed median concentrations for $NH_3$-N that were somewhat lower than the mean concentrations due to reduced nitrification efficiency in the December 2001 to January 2002 and July to August 2002 periods, which impacted the mean concentration.

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 a mean $BOD_5$ of 150 mg/L and a median $BOD_5$ of 150 mg/L. The TSS in the influent had a mean concentration of 180 mg/L and a median concentration of 170 mg/L. The RetroFAST® effluent showed a mean $CBOD_5$ of 12 mg/L with a median $CBOD_5$ of 12 mg/L. The mean TSS in the effluent was 28 mg/L and the median TSS was 24 mg/L.

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

| | $BOD_5$ Influent (mg/L) | $CBOD_5$ Effluent (mg/L) | Percent Removal | TSS Influent (mg/L) | TSS Effluent (mg/L) | TSS Percent Removal |
|---|---|---|---|---|---|---|
| Mean | 150 | 12 | 91 | 180 | 28 | 84 |
| Median | 150 | 12 | 92 | 170 | 24 | 88 |
| Maximum | 210 | 28 | 98 | 440 | 170 | 98 |
| Minimum | 65 | 2 | 79 | 110 | 3 | 14 |
| Std. Dev. | 30 | 5.9 | 4.4 | 56 | 25 | 15 |

Note: Data in Table 1 are based on 60 samples.

The nitrogen results for the verification test, including all stress test periods, are shown in Table 2. The influent wastewater had a mean TKN concentration of 39 mg/L, with a median value of 36 mg/L, and a mean $NH_3$-N concentration of 28 mg/L, with a median of 28 mg/L. The mean TN concentration in the influent was 39 mg/L (median of 36 mg/L). The RetroFAST® effluent had a mean TKN concentration of 11 mg/L and a median concentration of 6.2 mg/L. The mean ammonia concentration in the effluent was 5.9 mg/L and the median value was 3.4 mg/L. The nitrite concentration in the effluent was low, averaging 0.46 mg/L. The mean effluent nitrate concentration was 8.0 mg/L with a median of 9.1 mg/L. Total nitrogen was determined by adding the daily concentrations of the TKN (organic plus ammonia nitrogen), nitrite, and nitrate. The mean TN in the RetroFAST® effluent was 19 mg/L (median 18 mg/L) for the verification period. The RetroFAST® showed a mean TN reduction of 51%, with a median removal of 50%.

**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 | Effluent |
| Mean | 39 | 11 | 28 | 5.9 | 39 | 19 | 8.0 | 0.46 | 12.8 |
| Median | 36 | 6.2 | 28 | 3.4 | 36 | 18 | 9.1 | 0.46 | 14.5 |
| Maximum | 64 | 44 | 42 | 30 | 64 | 44 | 18 | 1.2 | 20.2 |
| Minimum | 28 | 1.7 | 19 | 0.15 | 28 | 6.4 | 0.06 | 0.04 | 4.90 |
| Std. Dev. | 9.0 | 10 | 3.9 | 7.0 | 9.0 | 7.5 | 5.0 | 0.31 | 4.75 |

Note: The data in Table 2 are based on 60 samples, except for nitrite and nitrate, which are based on 58 samples.

***Verification Test Discussion***

During the first two months of the verification test, September and October 2001, the nitrification and denitrification processes, which had been established during startup, were upset, and only small amounts of ammonia or TN were removed by the RetroFAST® system. TSS levels in the effluent were variable ranging from 8 to 59 mg/L. The ETV test team investigated possible causes for the upset condition despite no apparent changes in the influent wastewater quality. On November 14 during a system check by Bio-Microbics, it was determined that the blower setting of 30 minutes on and 30 minutes off was not correct for the system. On November 14, Bio-Microbics changed the blower setting to operate continuously, after which the RetroFAST® began to recover. Due to some difficulties at the test site and sampling problems during the first stress test in November, it was agreed that the verification stress test sequence would be restarted in December, and that the November data would be reported but excluded from the verification test data summaries.

The $NH_3$-N concentration in the effluent began to decrease at the end of November and nitrate concentrations increased. TN removal approached 50%. The washday stress test was performed from December 24 to December 28, 2001. The $NH_3$-N and TKN began to rise at the end of the stress test, and nitrate decreased. By the end of the post-stress test monitoring on January 3, 2002, the data showed no removal of TN by the system. The washday stress test appears to have upset the system. It should be noted that the temperature of the wastewater was also decreasing during this time, and there was a one-day spike in influent TSS near the end of the monitoring period. These factors may have contributed to the system performance.

During the next six weeks, the RetroFAST® system re-established the nitrifying population. Effluent TN concentration dropped to 13 mg/L and ammonia nitrogen to 0.3 mg/L. The working parent stress test was performed from February 25 through March 1, 2002. The $NH_3$-N concentration in the effluent increased during the stress period (4.8 mg/L), but was lower at the end of the stress period and during the post-stress monitoring. Nitrate levels, however, remained in the 13 to 15 mg/L range. TN removal was above 50% for most days, with concentrations ranging from 19 to 22 mg/L in the post-stress monitoring period. The working parent stress test did not appear to have a major impact on the nitrification process. During the next two months, the data show that more than 80% of the ammonia was being removed. However, nitrate levels increased to 17 to 18 mg/L, indicating the denitrification process was not able to convert all of the additional nitrate to nitrogen gas. The DO level in the effluent was in the 9.5 to 11 mg/L during this time.

The low load stress test began on May 6 and continued until May 26, 2002. Both the nitrification and denitrification processes appeared to improve during and after this stress test. Ammonia concentrations dropped below 1 mg/L, nitrate levels decreased to the 9 to 11 mg/L range, and TN nitrogen removal was 46 to 61% after the first ten days of the stress test. The lower daily volume of wastewater (50% of the rated capacity) being processed through the unit may be a factor in the improved performance of the unit.

During the June and July test period, which included the power failure test on July 22, the effluent TN concentration ranged from 11 to 17 mg/L. Ammonia concentrations increased each day during the post-stress test monitoring and reached a maximum of 12 mg/L on August 1. At the same time, the nitrate concentrations decreased, although the actual removal of nitrate by the system (assuming all ammonia removed is converted to nitrate) remained in the 14 to 19 mg/L range. It does appear that the power failure stress test had an impact on the system, which might be expected because the nitrification system is dependent on oxygen supplied by the blower. Late in the post-stress test monitoring period, ammonia removal performance began to deteriorate and did not appear to recover until September.

The vacation stress test started on September 23 and ended on October 2, 2002. During this period, there was no influent flow to the system. Following the resumption of flow on October 2, ammonia concentrations in the effluent were generally less than 1 mg/L, similar to the levels found during the low load test. Nitrate levels increased, but denitrification continued to remove 14 to 20 mg/L of nitrate from the system. The vacation stress test did not appear to have a negative impact on the system.

The system performance remained consistent for the duration of the verification test. The TKN and $NH_3$-N effluent concentrations were low and similar to the data from the period after the low load stress test. The nitrate levels remained in the 10 to 13 mg/L range, and the TN concentration from 15 to 18 mg/L, representing 49 to 61% removal.

The RetroFAST® system showed variable results during the verification test, with TN removal varying from zero to 86% removal. There were at least two apparent upset periods, one at the start of the verification test (possibly caused by the blower setting) and another during the washday stress test. A smaller upset in the nitrification process may have occurred at the end of the power failure post-stress-monitoring period in July 2002. During the last six months of the verification test, the system appeared more stable and performance was more consistent. During these last six months of operation, the TN concentration in the effluent had a mean concentration of 15 mg/L (range of 6 to 21 mg/L).

***Operation and Maintenance Results***

Noise levels associated with blower system and airlift were measured twice 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 directions. The noise levels ranged from 58 to 64 decibels.

Qualitative odor observations based on odor strength (intensity) and type (attribute) were made six times during the verification test. 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 five of the six observation periods. On the final observation, the odor was logged as a barely discernable musty odor.

A dedicated electric meter, serving the RetroFAST®, was used to monitor electrical use for the period of continuous blower operation. The average electrical use was 2.1 kilowatts (kW) per day. This usage rate appears low for a one-fourth horsepower blower operating continuously, but was consistent during the verification test and checked with a second meter. The RetroFAST® did not require or use any chemical addition during normal operation.

During the test, the system experienced no mechanical problems. The only change made to the system was to alter the blower operation from an on/off cycle to continuous operation on November 14, 2001. No maintenance or cleaning was performed during the verification test.

The treatment unit appeared to be of durable design and proved to be durable during the test. The piping and construction materials used in the system meet the application needs. Although blower life is difficult to estimate, the equipment used operated continuously for eleven months with no downtime.

***Quality Assurance/Quality Control***

During testing, NSF completed a QA/QC audit of the MWTTF site and CanTest Laboratories Ltd. (CanTest), the analytical laboratory. This audit included: (a) a technical systems audit to assure the testing was in compliance with the test plan, (b) a performance evaluation audit to assure that the measurement systems employed by MWTTF and CanTest were adequate to produce reliable data, and (c) 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. EPA QA personnel also conducted a quality systems audit of NSF's QA Management Program.

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| *Original signed by*<br>*Lee A. Mulkey* *09/30/03* | *Original signed by*<br>*Gordon E. Bellen* *10/02/03* |
| Lee A. Mulkey Date<br>Acting Director<br>National Risk Management Research Laboratory<br>Office of Research and Development<br>United States Environmental Protection Agency | Gordon E. Bellen Date<br>Vice President<br>Research<br>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

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RetroFAST® 0.375 System

Prepared for

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Ann Arbor, MI 48105

Prepared by

Scherger Associates
In cooperation with
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Under a cooperative agreement with the U.S. Environmental Protection Agency

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## Notice

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# Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

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# Figures



# Tables

## Acronyms and Abbreviations

| | |
|---|---|
| ANSI | American National Standards Institute |
| Bio-Microbics | Bio-Microbics, Inc. |
| $BOD_5$ | Biochemical Oxygen Demand (five day) |
| $^oC$ | Degrees Celsius (temperature) |
| $CaCO_3$ | Calcium Carbonate |
| CanTest | CanTest Laboratories, Ltd. |
| $CBOD_5$ | Carbonaceous Biochemical Oxygen Demand (five day) |
| Cu ft | Cubic Feet |
| DO | Dissolved Oxygen |
| DQI | Data quality indicators |
| DQO | Data quality objectives |
| EPA | (U.S.) Environmental Protection Agency |
| ETV | Environmental Technology Verification |
| ft | Feet |
| gal | U.S. Gallons |
| gpm | (U.S.) Gallons Per Minute |
| hp | Horsepower |
| in | Inches |
| kW | Kilowatt |
| kW/d | Kilowatts per Day |
| MWTTF | Mamquam Wastewater Technology Test Facility |
| mg/L | Milligrams per liter |
| mL | Milliliters |
| NIST | National Institute of Standards and Technology |
| $NH_3$-N | Ammonia Nitrogen |
| $NO_2$ | Nitrite Nitrogen |
| $NO_3$ | Nitrate Nitrogen |
| NovaTec | NovaTec Consultants, Inc. |
| 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 |
| PVC | Polyvinyl Chloride |
| QA | Quality Assurance |
| QAPP | Quality Assurance Project Plan |
| QC | Quality Control |
| QMP | Quality management plan |
| RetroFAST® | RetroFAST® 0.375 System |
| RPD | Relative Percent Difference |
| SAG | Stakeholders Advisory Group |
| SCADA | Control Microsystems Micro16 SCADA System |
| SOP | Standard Operating Procedure |
| SWP | Source Water Protection Area (Water Quality Protection Center) |

| | |
|---|---|
| S.U. | Standard Units for pH |
| TKN | Total Kjeldahl Nitrogen |
| TN | Total Nitrogen |
| TO | Testing Organization |
| TS | Total Solids |
| TSS | Total Suspended Solids |
| VFA | Volatile fatty acids |
| VO | Verification Organization |
| VR | Verification Report |
| VSS | Volatile Suspended Solids |
| VTP | Verification Test Plan |
| WQPC | Water Quality Protection Center |
| WWTP | Mamquam Wastewater Treatment Plant |

# Acknowledgments

The Testing Organization (TO), NovaTec Consultants, Inc., 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. Dr. Troy Vassos was the Project Manager for the Verification Test. Ms. Lynn Mallett was the Project Coordinator.

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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.

# Chapter 1
# Introduction

## 1.1 ETV Purpose and Program Operation

EPA has created the ETV Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The ETV Program's goal 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 (TOs); stakeholders groups that consist of buyers, vendor organizations, consulting engineers, and regulators; 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 adequate quality are generated and that the results are defensible.

In cooperation with EPA, NSF 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 RetroFAST® 0.375 System for the reduction of total Kjeldahl nitrogen (TKN), ammonia nitrogen ($NH_3$-N), nitrite nitrogen ($NO_2$), and nitrate nitrogen ($NO_3$) present in residential wastewater. Bio-Microbics, Inc. (Bio-Microbics) sells the RetroFAST® 0.375 System as a retrofit system for wastewater treatment or as an enhancement for full-sized, soil-based systems at single-family homes. Other models of the system are available for larger residences, commercial businesses, and similar applications, but this evaluation does not address those models. The unit is designed to work in conjunction with a septic tank system to provide nitrogen reduction in addition to the removal of organics and solids present in these wastewaters. The RetroFAST® 0.375 System is based on attached submerged growth (fixed film) biological treatment. This report provides the verification test results for the RetroFAST® 0.375 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 RetroFAST® 0.375 System was a cooperative effort between the following participants:

- NSF
- NovaTec Consultants, Inc. (NovaTec)
- Mamquam Wastewater Technology Test Facility (MWTTF)
- CanTest Laboratories, Ltd.

- Scherger Associates
- Bio-Microbics
- EPA

### *1.2.1 NSF International - Verification Organization (VO)*

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

NSF's responsibilities as the VO 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 TO and, subsequently, qualify the companies making up the TO;
- 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 quality assurance/quality control (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, MI 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, NRMRL, provides administrative, technical, and QA guidance and oversight on all ETV WQPC activities. EPA reviews and approves each phase of the verification project. 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 TO for the verification testing was the NovaTec Consultants, Inc. (NovaTec). The project manager, Dr. Troy Vassos, was responsible for the overall development of the VTP, oversight and coordination of all testing activities, and compilation and submission all of the test information for development of this final report.

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

CanTest Laboratories, Ltd. 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 VTP;
- Conduct verification testing, according to the VTP;
- Install, operate, and maintain the RetroFAST® 0.375 System in accordance with the Vendor's operation and maintenance (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 as needed;
- Resolve any quality concerns that might be encountered and report all findings to the verification organization;

- Manage, evaluate, interpret, and report data generated by verification testing;
- Evaluate and report the performance of the technology; and,
- If necessary, document changes in plans for testing and analysis, and notify the VO of any and all such changes before changes are executed.

The key personnel and contacts for the TO are:

Dr. Troy Vassos, Project Manager
(604) 873-9262 email: tvassos@novatec.ca

Ms. Lynn Mallett, Project Coordinator
(604) 873-9262 email: lmallett@novatec.ca

NovaTec Consultants, Inc.
224 West 8th Avenue
Vancouver, BC, Canada V5Y 1N5

The laboratory that conducted the analytical work for this study was:

Mr. E. Jensen
(604) 734-7276 email: ejensen@cantest.com
CanTest Laboratories, Ltd.
4606 Canada Way
Burnaby, BC, Canada V5G 1K5

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
(734) 213-8150 email: Daleres@aol.com

Scherger Associates
3017 Rumsey Drive
Ann Arbor, MI 48105

### *1.2.4 Technology Vendor*

The nitrogen reduction technology evaluated was the RetroFAST® 0.375 System manufactured by Bio-Microbics, Inc. Bio-Microbics was responsible for supplying all 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 VTP;
- Select the test site;
- Provide complete, field-ready equipment and the O&M manual(s) typically provided with the technology (including instructions on installation, startup, operation, and maintenance) for verification testing;
- Provide any existing relevant performance data for the technology;
- Provide assistance to the TO 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 Bio-Microbics is:

Mr. Brian Jones
(913) 422-0707 email: bjones@biomicrobics.com

Bio-Microbics, Inc.
8450 Cole Parkway
Shawnee, KS 66227

### *1.2.5 ETV Test Site*

The Mamquam Wastewater Technology Test Facility (MWTTF, the host site for the nitrogen reduction verification test, is located at the Mamquam Wastewater Treatment Plant (WWTP), which serves the District of Squamish, British Columbia. The site is designed to test on-site wastewater treatment systems and related technologies. MWTTF provides the location to install the technology and all of the infrastructure support requirements to collect domestic wastewater, and pump the wastewater to the system, as well as operational and maintenance support for the test. Key items provided by the test site are:

- Logistical support and reasonable access to the equipment and facilities for sample collection and equipment maintenance;
- Primarily domestic wastewater that is representative of domestic wastewater relative to key parameters such as five-day biochemical oxygen demand ($BOD_{5}$), total suspended solids (TSS), total nitrogen (TN), and phosphorus;
- A location for sampling 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;
- Daily operation and observation of the test unit, including maintaining a daily logbook and collecting flow, electrical use, and related information;
- Setup of sampling equipment and collection of samples per the established schedule;
- 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 does not occur.

#### *1.2.6 Technology Panel*

Representatives from the Technology Panel assisted the VO in reviewing and commenting on the VTP.

### 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 that reduce oxygen-demanding materials, suspended solids, and pathogenic organisms. Reduction of nutrients, principally phosphorus and nitrogen, has been practiced since the 1960s at centralized wastewater treatment plants. Nutrient reduction is needed primarily to protect the quality of ground- or surface water for drinking (drinking-water standards for $NO_2$ and $NO_3$ have been established) and to reduce the potential for eutrophication in nutrient-sensitive surface waters and the consequent loss in ecological, commercial, recreational, and aesthetic uses.

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 RetroFAST® 0.375 System process is based on fixed film submerged growth biological treatment. According to Bio-Microbics, aerobic and anoxic conditions are maintained in separate sections of the RetroFAST® when inserted into the septic tank.

#### *1.3.1 Biological Nitrification*

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) Ammonium 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 (DO) concentration.

**Organic loading:** Organic loadings affect the efficiency of the nitrification process. 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 do at high $BOD_5$ concentrations. As a result, the nitrifiers can be overgrown by heterotrophic bacteria, which can cause the nitrification process to cease. In order for nitrification to take place, the organic loadings must be low enough to provide balance between the heterotrophic and nitrifying bacteria. In a submerged growth filter such as the RetroFAST® unit, the bacteria are attached to the filter and present as suspended growth biomass within the unit. The filter media provides a surface area for nitrifier attachment that may enhance the nitrification process as compared to suspended growth only systems.

**Hydraulic loading:** In a submerged growth filter system, wastewater normally flows through a highly specific area media that is submerged in the mixed liquor of the treatment system. The total hydraulic flow to the submerged media can be controlled by adjusting the recirculation rate of the wastewater flow through the media. Both hydraulic and organic loadings are important parameters that must be considered. Recirculation benefits nitrifying reactors by reducing the influent $BOD_5$ concentration, which makes the nitrifiers more competitive. Control of the food to microorganism ratio is important to maximize the nitrification process.

**pH:** The nitrification process produces acid, which lowers the pH and can reduce 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 calcium carbonate [$CaCO_3$]) are destroyed per pound of ammonia oxidized to nitrate.

**Dissolved Oxygen (DO):** The concentration of DO 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, the maximum growth rate is not needed for effective nitrification if there is adequate contact time in the system. As a result there is a broad range of DO values at which 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 oxygen equivalent (electron acceptor) for bacteria, and the nitrate is reduced to nitrogen gas. Denitrifying bacteria are facultative organisms that can use either DO or nitrate ($NO_3$) 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.

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

**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 to 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 during the nitrification process. Approximately 3.6 pounds of alkalinity is produced for each pound of nitrate nitrogen removed.

Additional information on various nitrogen control strategies can be found in the *Manual for Nitrogen Control*, USEPA, 1993, 625/R-93/010 [2].

# Chapter 2
# Technology Description and Operating Processes

## 2.1 General Technology Description

The Bio-Microbics RetroFAST® 0.375 System (RetroFAST®) is a submerged attached-growth (fixed film) treatment system, which is marketed by Bio-Microbics as a retrofit device into the outlet side of new or existing septic tanks. The RetroFAST® has a rated capacity of 375 gallons per day (gpd), and is designed to treat wastewater from a single-family home with four to six persons.

Wastewater enters the septic tank in the primary treatment zone, which can be a separate compartment (the verification test used a two-compartment septic tank) or an area that extends from the inlet pipe to the forward bulkhead of the insert. The quiescent conditions in the primary zone allows the heavy solids in the wastewater to settle to the bottom of the chamber where they are gradually digested under anaerobic conditions, releasing short-chain volatile fatty acids (VFAs) and ammonia to solution. These solubilized, first-stage, anaerobic digestion by-products, combined with fine colloidal particles (which do not readily settle) and soluble organic and inorganic materials contained in the influent wastewater, form the constituents of the primary effluent from the first compartment of the septic tank.

The primary effluent flows into the aerobic zone (either the second compartment or the area of the tank containing the RetroFAST® insert). The organic constituents serve as food for the aerobic bacteria, which are attached to the honeycomb media in the RetroFAST®, and are present in the suspended solids (mixed liquor) in the liquid phase with the unit. An external blower supplies air to a draft tube located in a central chamber in the submerged media. The draft tube acts as an airlift pump to draw wastewater from below the media and distribute it over the surface by a splash plate above the water line. The draft tube induces a circulation of wastewater down through the media and provides oxygen to wastewater. The aerobic bacteria consume organic material and convert ammonia to nitrite ($NO_2$) and then to $NO_3$. Nitrified wastewater flows through the bottom of the central chamber into the surrounding (un-aerated) anoxic zone, where solids settle to the bottom of the second chamber. Denitrification occurs in the anoxic zone in this chamber. The clarified effluent flows by gravity through a small opening in the wall that separates the aeration zone from the discharge zone, and exits the unit via a discharge pipe to the discharge location. For the ETV test, the treated effluent entered a sump, and the effluent was pumped back to the Mamquam wastewater treatment plant.

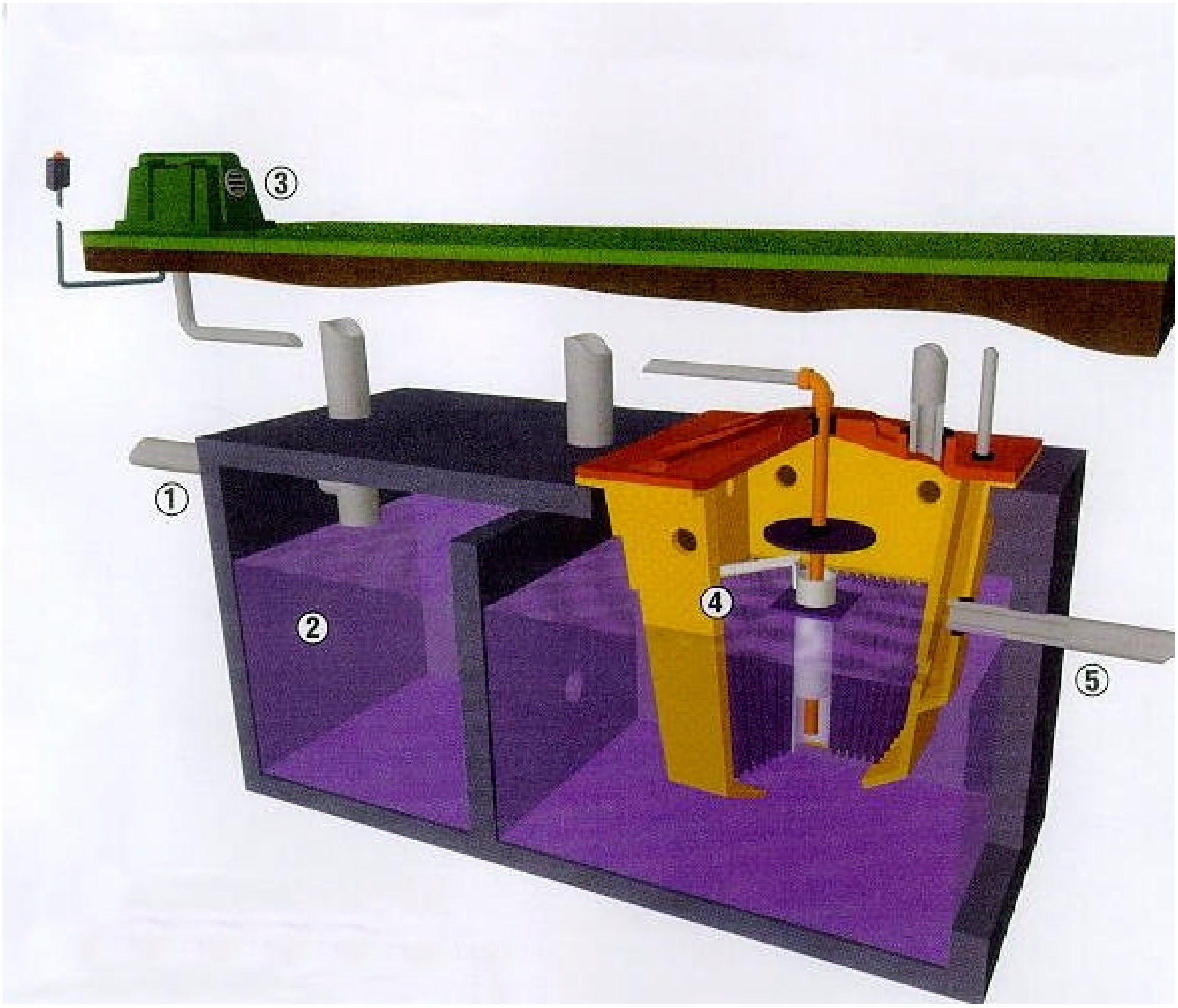
The septic tank used for the ETV testing program was a two-chamber 1,350 gallon tank. The first chamber volume was 880 gallons, and the second chamber was 470 gallons, separated by a concrete wall. Figure 2-1 shows a cut-away view of the RetroFAST® as installed in a septic tank. Wastewater from the first chamber flows to the second chamber through a pipe in the divider wall that has a tee on the end so that floating materials are retained in the first chamber. The treated effluent exits the RetroFAST® through a small opening that separates the mixed aerated wastewater from the effluent flowing to the three-inch exit pipe (See Figure 2-1 and 2-2). Flow is by gravity, and the exit flow rate is based on the influent flow rate. The only mechanical component is the remote air blower, which provides compressed air to the aerated chamber for oxygen supply and mixing. . The RetroFAST® utilizes a 1/4 hp regenerative blower producing 21 cubic feet per minute (cfm). Polyvinyl chloride (PVC) or polyethylene cross-flow media is used, with a total installed packed volume of 12 cubic feet (cu ft). The blower is contained in a remote housing. A small control panel with an alarm designed to activate if the blower fails is available as an option. Figure 2-2 show side and top views of the RetroFAST® insert and the blower assembly.

### 2.2 Equipment Specifications

The specifications for the RetroFAST® 0.375 System are summarized in Table 2-1. All of the piping used in the system is Schedule 40 PVC pipe to be supplied by the contractor completing the installation. Components of the system are shown in Figure 2-3.

**Table 2-1. RetroFAST® 0.375 System Specifications**

| Item | Quantity |
|---|---|
| RetroFAST® 0.375 Unit | 1 |
| Self contained with: | |
| Airlift system | |
| PVC cross flow media (12 cu ft) | |
| RetroFAST® blower system | 1 |
| ¼ hp regenerative blower | |
| Blower housing | |
| Control panel and blower alarm (Optional feature) | 1 |
| Operations and Maintenance Manual | 1 |




(1) Influent line from home – gravity feed to first compartment
(2) First compartment for solids separation and settling
(3) Remote blower to deliver air (oxygen) to the RetroFast® Insert
(4) RetroFast® unit – aerobic process with media for attached growth; air lift circulates water from bottom of compartment two to top of RetroFast®
(5) Effluent line to tile field or other receiving location, flow by gravity

**Figure 2-1. RetroFAST® 0.375 System general layout.**

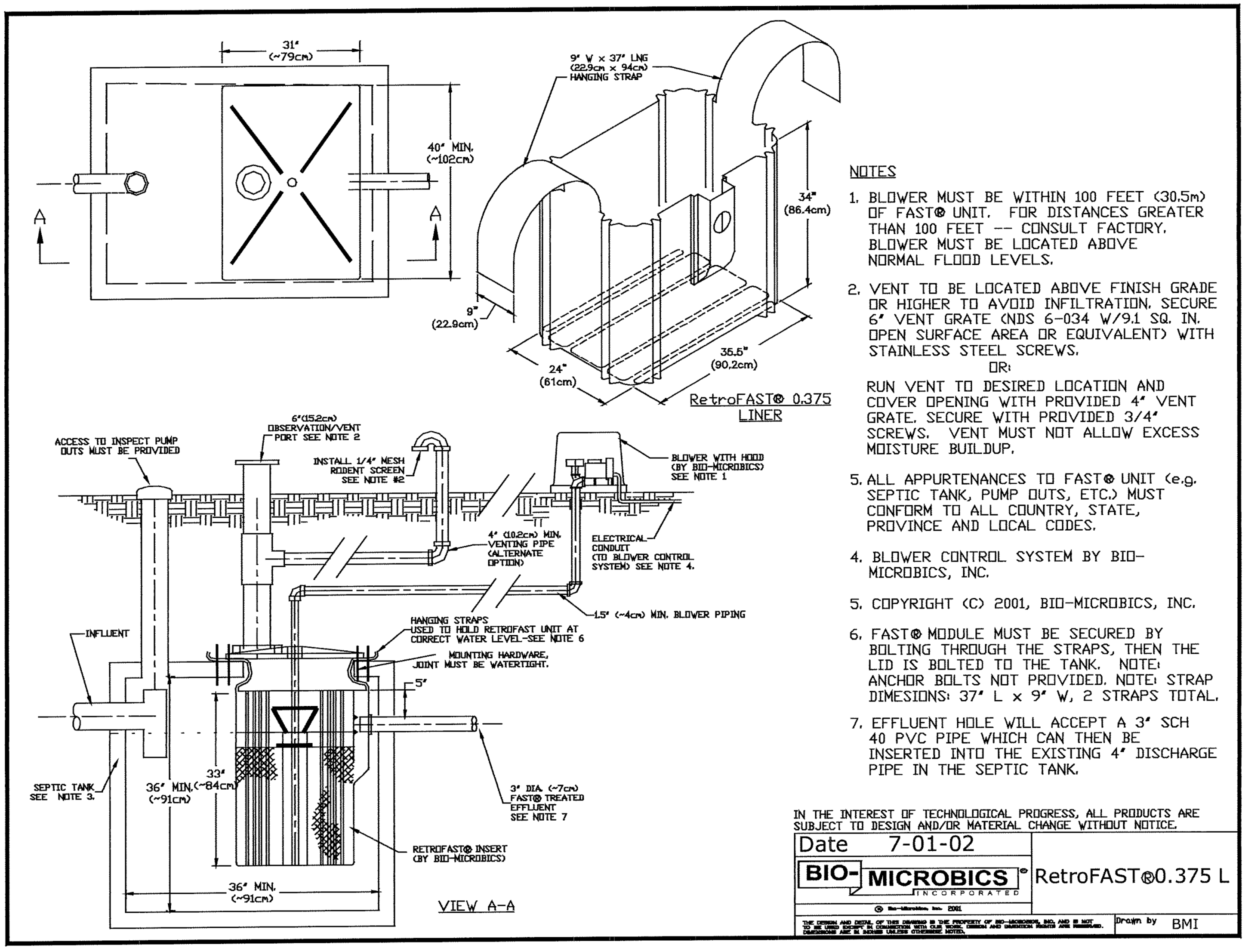



**Figure 2-2. RetroFAST® 0.375 System side and top view**

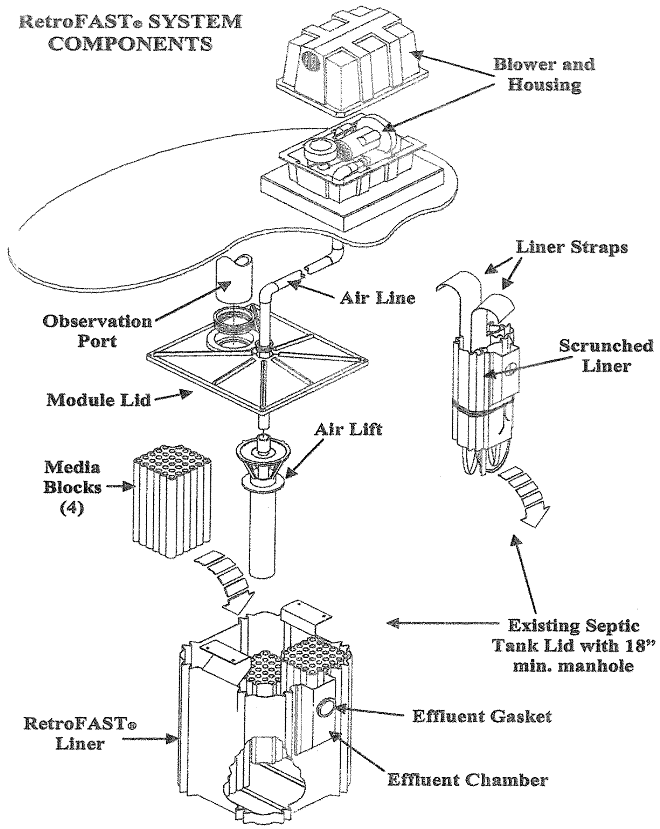



**Figure 2-3. RetroFAST® 0.375 System components.**

## 2.3 Operation and Maintenance

Bio-Microbics provides a Homeowners Manual (Manual) with important information about the RetroFAST® 0.375 System, including specific sizing and installation instructions, a basic overview of the treatment process, and a troubleshooting table covering common treatment and system problems. A copy of this information is presented in Appendix A. Maintenance is focused primarily on the blower system. Periodic cleaning of the screens on the blower housing and the openings on the vent system is recommended. Annual inspection and cleaning of the air intake filter is suggested to avoid blower damage. According to Bio-Microbics, no maintenance is required for any underground components in the RetroFAST® insert.

Each unit includes a two-year warranty for parts. Bio-Microbics does not specifically recommend that a service contract be arranged to provide periodic maintenance for their units, but does provide example service contracts that can be used by their suppliers. Bio-Microbics recommends that their suppliers maintain a spare parts inventory including two blowers, two control panels, and several air filters.

## 2.4 Vendor Claims

Bio-Microbics claims the RetroFAST® 0.375 System is designed to retrofit existing septic tanks or upgrade full-sized soil-based systems to reduce nitrogen, $BOD_5$, and TSS present in residential wastewater. No specific levels of treatment are indicated.

# Chapter 3
# Methods and Test Procedures

## 3.1 Verification Test Plan and Procedures

The VTP, *Test Plan for the Bio-Microbics RetroFAST® 0.375 Under the US Environmental Protection Agency Environmental Technology Verification Program at the Mamquam Wastewater Technology Test* [3], August 2001, prepared and approved for the verification of the Bio-Microbics, Inc., RetroFAST® 0.375 System, is included in Appendix B. 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 details the procedures and analytical methods to be used to perform the verification test. The VTP included tasks designed to verify the nitrogen reduction capability of the RetroFAST® 0.375 System and obtain information on the operation and maintenance requirements of the RetroFAST® 0.375 System. The VTP covered two distinct phases of fieldwork: startup of the unit and a one-year verification test that included normal dosing and stress conditions. The verification test was completed between September 2001 and October 2002.

This section describes each of the testing elements performed during technology verification, including sample collection methods, analytical protocols, equipment installation, and equipment operation. QA/QC procedures and data management approach are discussed in detail in the VTP.

## 3.2 MWTTF Test Site Description

MWTTF is located at the Mamquam WWTP, which serves the District of Squamish, British Columbia. Domestic wastewater is supplied from a sanitary sewer collection system serving a catchment consisting primarily of residential houses, with minor contributions from commercial sources.

Screened raw (influent) wastewater is pumped through a 2.5-inch diameter manifold pipeline to each test site, at a rate of approximately 53 gpm (3.4 L/s). During dosing periods, wastewater is constantly circulated through the manifold pipeline to ensure the influent wastewater being dosed to the test units is "fresh," and that solid material contained in the wastewater has not settled out. Once the wastewater has passed through the manifold pipeline, it is discharged to the headworks of the Mamquam WWTP. The pressure in the manifold system is regulated downstream of the pneumatic gate so that a constant pressure is maintained on the line to provide a steady flow rate through the pneumatic gate when it is open.

Dosing at each of the test sites is regulated by a pneumatic gate valve located at each of the testing sites, which is controlled by a Control Microsystems Micro16 SCADA system (SCADA). The SCADA system is monitored by a National Instruments LookOut interface, which displays and logs the status of all test system components including pumps, pneumatic valves, samplers, and analogue sensors. This SCADA system enables operators to monitor the operating status of the test facility and the individual test units, and to change any of the dosing parameters (e.g., dosage volume, frequency of dosage, duration of dosing period, etc.).

Dosing rates are verified by volumetric calibration checks (i.e., measuring the volume per dose), which are performed weekly at each test site. Daily dosage volumes are calculated by multiplying the dosage rate by the number of dosage events in a 24-hour period. The computer control program determines the number of dosage events by dividing the daily dose for each test unit by the calibrated dosage volume. The calculated daily dosage volume is verified by monitoring of the daily volume pumped from the individual test unit treated effluent sumps (i.e., multiplying the calibrated sump-pump pumping rate by the total pumping time per day).

MWTTF maintains a small laboratory at the site to monitor basic wastewater treatment parameters. Temperature, DO, pH, specific conductance, and volumetric measurements were performed at the site during the RetroFAST® 0.375 test.

Influent wastewater quality has been monitored as part of normal WWTP operations, and is within the requirements established in the Protocol for raw wastewater quality. These data are presented in Table 3-1. Influent wastewater monitoring was part of the startup and verification testing, and will be described later in this section. Results of all influent monitoring during the verification test are presented in Chapter 4.

**Table 3-1. Historical MWTTF Wastewater Data**

| Parameter | Average (mg/L) |
|---|---|
| $BOD_5$ | 180 |
| TSS | 160 |
| Total Nitrogen | 40 |
| $NH_3$-N | 29 |
| Alkalinity | 170 |
| pH | 7.4 |

## 3.3 Installation and Startup Procedures

### *3.3.1 Introduction*

The system delivered by Bio-Microbics consisted of a complete RetroFAST® 0.375 System (septic tank insert, blower assembly with housing, and control panel). This system was installed by the MWTTF staff with the assistance of Bio-Microbics personnel on June 6, 2001. The installation instructions provided by Bio-Microbics are presented in Appendix A.

### *3.3.2 Objectives*

The objectives of the installation and startup phase of the VTP were to:

- Install the RetroFAST® 0.375 System in accordance with the instructions;
- Startup and test the RetroFAST® 0.375 System to ensure all processes were operating properly;

- Make any modifications needed to achieve operation; and
- Record and document all installation and startup conditions prior to beginning the verification test.

### *3.3.3 Installation and Startup Procedure*

The VTP and Protocol allow for an eight-week startup period, during which the biological community was established and operating conditions were adjusted, if needed, for site conditions. Following the installation, the septic tank with the RetroFAST® inserted in the second compartment was filled with water, and each component of the system was checked for proper operation. This installation represented a retrofit configuration with the larger primary settling zone in the first compartment of a two-compartment septic tank. In a new system, a two-compartment tank would be installed with the smaller chamber as the primary settling zone. The blower system and control/alarm panel (an installed option) were checked and found to be operating properly.

Startup of the RetroFAST® began on July 6, 2001. The septic tank was filled with 1/3 wastewater and 2/3 tap water, and the dosing sequence was started with a target of 4.76 gallons of wastewater per dose to meet the targeted total daily flow of 375 gpd. The dosing sequence followed the Protocol, as described in Section 3.4.3.1. The blower system was set to operate for 30 minutes on and 30 minutes off. In November 2001, Bio-Microbics determined that this setting was not correct and adjusted the blower system to run continuously.

The system was monitored during the startup period (July 6 through September 5, 2001) by visual observation of the system, routine calibration of the dosing system, and the collection of influent and effluent samples several times over the eight-week startup period. Influent samples were analyzed for some or all of the following parameters: pH, alkalinity, temperature, $BOD_5$, five-day carbonaceous biochemical oxygen demand ($CBOD_5$), total Kjeldahl nitrogen (TKN), $NH_3$-N, and TSS analyses. The effluent was also analyzed for pH, alkalinity, temperature, $CBOD_5$, TKN, $NH_3$-N, TSS, DO, $NO_2$, and $NO_3$. The same procedures for sample collection, analytical methods, and monitoring were used during startup and the one-year verification period, as described in Section 3.4.3.3.

## 3.4 Verification Testing - Procedures

### *3.4.1 Introduction*

The verification test procedures were designed to verify nitrogen reduction by the RetroFAST® 0.375 System. 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 RetroFAST® 0.375 System. 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 (TN, TKN, $NH_3$-N, $NO_2$, $NO_3$) removal the RetroFAST® 0.375 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 by-products 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 RetroFAST® was controlled by the SCADA system. The doses were set to provide doses of equal volume (target – 3.8 gallons per dose) in accordance with the following schedule:

- 6 am – 9 am approximately 35% of the total daily flow
- 11 am – 2 pm approximately 25% of the total daily flow
- 5 pm – 8 pm approximately 40% of the total daily flow

The initial total daily flow to the RetroFAST® was targeted to be 375 gpd. The QC requirement for the dosing volume was 100 ± 10% of the target flow (375 gpd) based on a 30 day average, with the exception of periods of stress testing. After each weekly calibration test (described in Section 3.2), the measured volume was compared to this target rate. If the volume was more than 10% above or below the target, the SCADA was adjusted to reset the volume per dose back to the target volume. The QC requirement for the dosing volume was 100 ± 10% of the target flow (375 gpd) based on a thirty day average, with the exception of periods of stress testing. All calibration tests were recorded in the field logbook. Flow information for each day of operation was entered into a spreadsheet that showed the volume per dose, the total daily volume, and the deviation from the target volume.

#### 3.4.3.2 Stress Testing Procedures

During the verification test, one stress test was performed following every two months of operation at the normal design loading. Five stress scenarios were run during the evaluation period to test the RetroFAST® 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 washdays in a five-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 dosing periods per day, the hydraulic loading included three wash loads consisting of three wash cycles and six rinse cycles with a flow of 36 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 and non-chlorine bleach were added to each wash load at the manufacturer's recommended amount.

The working parent stress simulation consisted of five consecutive days when the RetroFAST® was subjected to a flow pattern where approximately 40% of the total daily flow was dosed between 6 a.m. and 9 a.m., and approximately 60% of the total daily flow was dosed between 5 p.m. and 8 p.m. This simulation also included one wash load of one wash cycle and two 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 tested the unit at 50% of the target flow (188 gpd) loading for a period of 21 days. Approximately 35% of the total daily flow was dosed between 6 a.m. and 11 a.m., approximately 25% of the flow was dosed between 11 a.m. and 4 p.m., and approximately 40% of the flow was dosed between 5 p.m. and 10 p.m.

The power/equipment failure stress simulation consisted of a standard daily flow pattern until 8 p.m. on the day the test was initiated. Power to the system was turned off at 9 p.m., and the flow pattern was discontinued for 48 hours. After this 48-hour period, power was restored and the system was dosed with approximately 60% of the total daily flow over a three- hour period, which included one wash load of one wash cycle and two rinse cycles.

The vacation stress simulation consisted of a flow pattern where, on the day that the stress is initiated, approximately 35% of the total daily flow was dosed between 6 a.m. and 9 a.m. and approximately 25% of the total daily flow was received between 11 a.m. and 2 p.m. The flow pattern was discontinued for eight 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% of the total daily flow, which included three wash loads of three wash cycles and six 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 same place as the influent pump feeding the test facility's manifold distribution pipe, which is located in a trench used to transfer wastewater from the WWTP screens and grit removal process to the aerated bioreactors. Composite sample and grab samples were collected at this location.

*3.4.3.3.2. RetroFAST® 0.375 System Effluent Sampling Location*

The RetroFAST® effluent sample was collected from the end of the three-inch discharge pipe that conveyed treated wastewater to the effluent sump. During installation and setup of the Bio-Microbics unit, a sampling point consisting of a tee-cross with a "J" pipe of sufficient size to retain sample volume for both grab and automated samples was installed on the discharge end of the test unit. The piping was large enough to retain approximately one liter of fluid and be readily flushed and replenished by the normal flow of treated effluent. The sump was accessible so that the "J" pipe could be cleaned of attached and settled solids on a regular basis prior to sampling dates. The sampling location in the discharge pipe was installed for the verification test only, and would not be present in a typical residential installation. Consequently, cleaning of the discharge pipe or "J" pipe would not be required in a normal system.

*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 to measure pH and temperature. The grab samples were collected by dipping a sample collection bottle into the flow. The sample bottles were labeled with the sampling location, time, and date. All pH and temperature measurements were performed at the on-site laboratory immediately after sample collection. DO was measured in the effluent as the treated water flowed into the effluent sump.

Composite samples were collected using automated samplers at each sample collection point that were programmed to draw equal volumes of sample from the influent and effluent streams. Given that the volume of flow for each dose was constant, equal volume sub-samples result a flow proportional composite sample. The influent sampler activation was timed to coincide with the midpoint of the dosing cycle (i.e., if the dose time is 12 seconds, the sampler is triggered to collect a sample at the 6-second mark). The effluent sampler timing was set to correspond to the passage of a dose through the RetroFAST® discharge line. This time was calibrated by determining the delay between the time flow entered the system and the time effluent began to flow from the system. The effluent sampler was then set to start after this delay period. The sample volumes collected by the automatic samplers were calibrated and verified by recording the total volume of sample collected for each sampling day.

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

**Table 3-2. Sampling Matrix**

| Parameter | Sample Type | Sample Location: Influent | Sample Location: Effluent | Testing Location |
|---|---|---|---|---|
| $BOD_5$ | Composite | X | | Laboratory |
| $CBOD_5$ | Composite | | X | Laboratory |
| Suspended Solids | Composite | X | X | Laboratory |
| pH | Grab | X | X | Test Site |
| Temperature (°C) | Grab | X | X | Test Site |
| Alkalinity (as $CaCO_3$) | Composite | X | X | Laboratory |
| DO | Grab | | X | Test Site |
| TKN (as N) | Composite | X | X | Laboratory |
| $NH_3$-N | Composite | X | X | Laboratory |
| Total $NO_3$ (as N) | Composite | X | X | Laboratory |
| Total $NO_2$ (as N) | Composite | X | X | 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 on a monthly basis under design flow conditions and more frequent sampling during the special stress test periods.

Normal Monthly Frequency

Samples of the influent and effluent were collected at least once per month for test period (September 2001 – October 2002).

Stress Test Frequency

Samples were collected on the day each stress simulation was initiated and when approximately 50% of each stress sequence was completed. For the vacation and power/equipment failure stresses, there was no midpoint sampling. Beginning 24 hours after the completion of washday, working parent, low load, and vacation stress scenarios, samples were collected for six consecutive days. Beginning 48 hours after the completion of the power/equipment failure stress, samples were collected for five consecutive days.

Final Week

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

**Table 3-3. Sampling Schedule for RetroFAST® 0.375 System**

| Month/Day | Sampling Event |
|---|---|
| July 23, 25, and August 1, 2001 | Startup – 3 sampling events ($CBOD_5$ and TSS) |
| August 8, 17, 22, 29, and September 5, 2001 | Startup – 5 sampling events (all parameters) |
| September 10 and 30, 2001 | Monthly sample – 2 samples |
| October 10, 26, and 29, 2001 | Monthly sample – 3 samples |
| December 14, 2001 | Monthly sample – 1 sample |
| December 24, 26, 29-31, 2001 and January 1-3, 2002 | Washday stress - 8 samples<br>Test started on December 24, 2001 |
| January 30, 2002 | Monthly sample – 1 sample |
| February 18, 2002 | Monthly sample – 1 sample |
| February 25, 27, and March 2-7, 2002 | Working parent stress – 8 samples<br>Test started on February 25, 2002 |
| April 3 and 29, 2002 | Monthly sample – 2 samples |
| May 6, 16, 27-31, and June 1-3, 2002 | Low load stress – 10 samples<br>Test started on May 6, 2002 |
| June 27, 2002 | Monthly sample – 1 sample |
| July 19, 2002 | Monthly sample – 1 sample |
| July 22, 27-31, and August 1, 2002 | Power/equipment failure stress – 7 samples<br>Test started on July 22, 2002 |
| August 28, 2002 | Monthly sample – 1 sample |
| September 16, 2002 | Monthly sample – 1 sample |
| September 23, 24, and October 3-8, 2002 | Vacation stress – 8 samples<br>Test started on September 23, 2002 |
| October 21-25, 2002 | Final week sampling – 5 samples |

*3.4.3.3.5. Sample Handling and Transport*

Samples were collected by automatic samplers into 2.5 gallon Nalgene containers, which were wrapped in a Cryopak ice blanket 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 $NH_3$-N 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).

The samples were packed in coolers with frozen ice packs provided by the laboratory to maintain a temperature of 4 $^{o}$C. Samples were transported to CanTest by courier or NovaTec personnel. Travel time from MWTTF to CanTest was approximately 75 minutes.

3.4.3.4 Residuals Monitoring and Sampling

Sludge depth in the tank was measured once at the end of the verification test. A coring sludge measurement tool called a Sludge-Judge was used to estimate the depth of sludge/solids in the first and second chamber of the 1,300 gallon septic tank. Depth of the solids deposits was recorded in the Field Log.

Samples of the residuals/solids retained in each compartment of the tank were recovered using the Sludge-Judge. The solids/residue portion of the sample from the Sludge-Judge, excluding the liquid phase in the top portion of the sample, was emptied into a clean container, and the sample analyzed for total solids (TS), TSS, and volatile suspended solids (VSS). An additional sample of the first chamber was collected after the contents were vigorously mixed using a large pump.

### *3.4.4 Analytical Testing and Record Keeping*

Table 3-2 presented the parameter list, and Table 3-3 presented the sampling schedule. The methods used for each constituent are shown in Table 3-4. Temperature, DO, and pH were measured on-site. All other analyses were performed by CanTest.

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

| Parameter | Facility | Acceptance Criteria Duplicates (%) | Acceptance Criteria Spikes (%) | Analytical Method |
|---|---|---|---|---|
| pH | On-site | 10 | N/A | SM #4500 B |
| Temperature ($^oC$) | On-site | 10 | N/A | SM #2550 |
| DO | On-site | N/A | N/A | SM #4500 |
| Suspended Solids | CanTest | 18 | N/A | SM #2540 D |
| $BOD_5$/ $CBOD_5$ | CanTest | 15 | N/A | SM #5210 B |
| Alkalinity | CanTest | 10 | 85-115 | SM #2320 |
| Total $NO_2$ (as N) | CanTest | 12 | 86-112 | EPA 353.3 |
| Total $NO_3$ (as N) | CanTest | 12 | 90-110 | EPA 353.3 |
| TKN (as N) | CanTest | 20 | 66-124 | EPA 351.4 |
| $NH_3$-N (as N) | CanTest | 20 | 80-120 | EPA 350.1 |

Industry standard procedures were used for all sample analysis, as described in *EPA Methods* [4] [5], or *Standard Methods* [6]

A Quality Assurance Project Plan (QAPP), developed as part of the VTP, provided QC 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, and so forth. Additional details are proved in the VTP (Appendix B). A laboratory audit was 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 laboratory were reported to the TO by hard-copy laboratory reports. The off-site laboratory also provided QA/QC data for the data sets. These data and the laboratory reports are included in Appendix C. The on-site laboratory maintained a laboratory logbook to record the results of all analyses performed at the site. A copy of the on-site laboratory logbook is presented in Appendix D.

The data received from the laboratory were summarized in a spreadsheet by NovaTec personnel. The data were checked against the original laboratory reports by the site staff, and checked by NSF to ensure the data were accurately entered. The spreadsheets are included in Appendix E.

### *3.4.5 Operation and Maintenance Performance*

The verification test evaluated both quantitative and qualitative performance of the RetroFAST®. A field log noted all observations made during the startup of the unit and throughout the verification test. Observations regarding the condition of the system, operation, or any problems that required resolution were recorded in the log by the field personnel. Copies of the field logs are presented in Appendix D.

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

#### 3.4.5.1 Electric Use

Electric use was monitored by a dedicated electric meter serving the RetroFAST®. The meter reading was recorded daily and recorded in the field log.

#### 3.4.5.2 Chemical Use

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

#### 3.4.5.3 Noise

Noise levels associated with mechanical equipment were measured twice during the verification test. Measurements were taken 1 meter (3 feet) from the source(s) at 1.5 meters above the ground, at 90° intervals in four directions. The meter was calibrated prior to use.

#### 3.4.5.4 Odors

The Mamquam WTTF operations personnel made periodic qualitative odor observations during the verification test. The observations included odor strength (intensity) and type (attribute). Intensity was noted as non-detectable, barely detectable, moderate, or strong. Observations were made during periods of low wind velocity (<10 knots) while standing upright at a distance of 1 meter (3 feet) from the treatment unit, at 90° intervals in four directions. All observations were made by the same Mamquam WTTF personnel, to the extent possible.

3.4.5.5 Mechanical Components

Performance and reliability of the mechanical components, such as blowers, were observed and documented in the Field Log during the test period. These observations recorded 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, as were any electrical equipment failures, replacements, and the existence and use of duplicate or standby equipment.

# Chapter 4
# Results and Discussion

## 4.1 Introduction

This chapter presents the results of the verification test for the RetroFAST® 0.375 System, including the data for influent and effluent samples, a discussion of the results, and observations on the operation and maintenance of the unit during startup and normal operation. Summaries of the results are presented here. Complete copies of all spreadsheets with individual daily, weekly, or monthly results are presented in Appendix E.

## 4.2 Startup Test Period

The startup period provided time for the RetroFAST® to develop a biological growth and acclimate to the site-specific wastewater, and to be adjusted, if needed, to optimize performance at the site. These first eight weeks of operation also allowed site personnel to become familiar with the RetroFAST® operation and maintenance requirements. Samples were collected and analyzed for $CBOD_5$ and TSS during the first three weeks of startup, and for all test parameters during the last five weeks of the startup period.

### *4.2.1 Startup Flow Conditions*

The flow conditions for the RetroFAST® were established at the target capacity of 375 gpd in accordance with the VTP. The SCADA was set to deliver approximately 4.7 gallons per dose. Doses were delivered between 6 a.m. and 9 a.m. (35% of total), between 11 a.m. and 2 p.m. (25% of total volume), and between 5 p.m. and 8 p.m. (40% of total). The volume of wastewater dosed to the unit during the startup was generally within ± 10% of the targeted volume (338 to 412 gpd). A raw feed pump failure and an electrical problem at the test facility were addressed during startup. These issues were resolved, and only four days were affected by these maintenance issues at MWTTP. The influent dose problems were test facility issues, and not related to the RetroFAST® unit. Table 4-1 shows a summary of the flow volumes during the startup. The daily flow records appear in Appendix E.

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

| Date (2001) | Average Gallons/dose | Average Daily Volume (Gallons) |
|---|---|---|
| July 5-17 | 4.7 | 371 |
| July 18-31 | 4.8 | 348(1) |
| August 1-8 | 4.9 | 291(2) |
| August 9-22 | 4.6 | 347 |
| August 23-29 | 4.5 | 376 |
| August 29 - September 4 | 4.5 | 378 |

(1) One day low volume of 181 gallons due to MWTTP pump failure; average without low volume day was 360 gpd

(2) Three days of lower volume due to electrical problems at MWTTP average without three low volume days was 355 gpd

### *4.2.2 Startup Analytical Results*

The results of the influent and effluent monitoring during the startup period are shown in Tables 4-2 and 4-3. After one month of operation, the data (August 1 and 8) show that the RetroFAST® was removing more than 90% of the $CBOD_5$ and TSS. The RetroFAST® was also establishing the nitrification and denitrification processes, removing TN (37 mg/L in the influent, 15 mg/L in the effluent). Observations and additional sampling to determine the condition of the unit continued for the next four weeks. No adjustments were made to the system.

At the end of the eight weeks allotted for the startup, the biological system was established. The $CBOD_5$ and TSS were <10 mg/L, and the unit was removing nitrogen from the wastewater (TN removal of 68%). These data show that nitrification was established in the unit, although the last sample in the startup period (September 5) showed an increase in $NH_3$-N in the effluent compared the previous two weeks. Denitrification was also occurring as shown by the $NO_3$, $NO_2$, and the TN concentrations in the effluent. The alkalinity data also indicate establishment of the nitrification and denitrification processes. Alkalinity in the effluent was lower than in the influent, as the nitrification and denitrification processes, when operating together, result in a drop in alkalinity. Theoretically, the nitrification process consumes 7.1 mg of alkalinity per 1 mg of $NH_3$-N converted to $NO_3$. The denitrification process produces alkalinity at the rate of 3.6 mg of alkalinity per mg of $NO_3$ reduced to nitrogen. The net effect is a reduction of alkalinity in the effluent wastewater.

**Table 4-2. Influent Wastewater Quality – Startup Period**

| Date | $BOD_5$ (mg/L) | $CBOD_5$ (mg/L) | TSS (mg/L) | Alkalinity (mg/L) | pH (S.U.) | $NH_3$-N (mg/L) | TKN (mg/L) | TN (mg/L) | Influent Temp. (°C) |
|---|---|---|---|---|---|---|---|---|---|
| 07/23/01 | N/A | 200 | 310 | N/A | 7.4 | N/A | N/A | N/A | 15.5 |
| 07/25/01 | N/A | 95 | 72 | 170 | 7.4 | N/A | N/A | N/A | 15.2 |
| 08/01/01 | N/A | 150 | 100 | 200 | 7.4 | N/A | N/A | N/A | 14.7 |
| 08/08/01 | N/A | 160 | 95 | 200 | 6.9 | 31 | 32 | 32 | 17.2 |
| 08/17/01 | N/A | 190 | 190 | 160 | 7.2 | 21 | 34 | 34 | 19.3 |
| 08/22/01 | N/A | 160 | 110 | 120 | 6.6 | 23 | 30 | 30 | 17.8 |
| 08/29/01 | 100 | 120 | 420 | 150 | 6.8 | 25 | 37 | 37 | 18.5 |
| 09/05/01 | 110 | 110 | 340 | 150 | 6.6 | 23 | 37 | 37 | 17.2 |

N/A – not analyzed

**Table 4-3. RetroFAST® 0.375 System Effluent Quality – Startup Period**

| Date | $CBOD_5$ (mg/L) | TSS (mg/L) | Alkalinity (mg/L) | pH (S.U.) | $NH_3$-N (mg/L) | TKN (mg/L) | $NO_2$/ $NO_3$ (mg/L) | TN (mg/L) | DO (mg/L) | Discharge Temp (°C) |
|---|---|---|---|---|---|---|---|---|---|---|
| 07/23/01 | N/A | N/A | N/A | 7.4 | 16 | 21 | 0.5 | 22 | N/A | 19.4 |
| 07/25/01 | 17 | 6 | 160 | 7.4 | N/A | N/A | N/A | N/A | N/A | 20.6 |
| 08/01/01 | 2 | 27 | 160 | 7.4 | N/A | N/A | N/A | N/A | N/A | 18.4 |
| 08/08/01 | 7 | 9 | 130 | 7.2 | 12 | 13 | 1.8 | 15 | 4.3 | 18.3 |
| 08/17/01 | 15 | 4 | 77 | 6.9 | 0.5 | 2.4 | 7.9 | 10 | 3.8 | 20.0 |
| 08/22/01 | 14 | 5 | 81 | 6.9 | 1.5 | 3.0 | 3.0 | 6.0 | 4.4 | 18.8 |
| 08/29/01 | 12 | 6 | 96 | 6.9 | 5.4 | 7.7 | 1.0 | 8.7 | 3.2 | 18.5 |
| 09/05/01 | 8 | 6 | 100 | 7.0 | 10 | 10 | 1.5 | 12 | 4.0 | 18.3 |

N/A – not analyzed

#### *4.2.3 Startup Operating Conditions*

The RetroFAST® was started with the blower set to operate thirty minutes on and thirty minutes off. No changes were made to the unit during the startup period. Observations indicated that biological growth was being established, and the visual effluent quality was acceptable.

### 4.3 Verification Test

In accordance with the startup period set forth in the VTP and the Protocol, the verification test started officially on September 5, 2001. A last startup sample was collected on September 5. All results for the remainder of the verification test were considered part of the verification test period. The summary data presented for the verification results do not include data from the startup period.

#### *4.3.1 Verification Test - Flow Conditions*

The standard dosing sequence was performed every day from September 5, 2001 through October 25, 2002, except during the stress test periods. Table 4-4 shows the average monthly volumes for the verification period. As these data show, the actual wastewater volume dosed to the RetroFAST® was very close to the design capacity and targeted volume of 375 gpd for the entire verification test. All monthly averages meet the requirement of being within ± 10% of the target. Daily flow volumes are presented in Appendix E.

**Table 4-4. RetroFAST® 0.375 System Influent Volume Summary**

| | Average Monthly | |
|---|---|---|
| **Month-Year** | **Gallons/dose** | **Gallons/day** |
| Sep-01 | 4.13 | 366 |
| Oct-01 | 3.83 | 380 |
| Nov-01 | 3.84 | 372 |
| Dec-01 | 3.71 | 376 |
| Jan-02 | 3.67 | 373 |
| Feb-02 | 3.67 | 372 |
| Mar-02 | 3.66 | 372 |
| Apr-02 | 3.82 | 378 |
| May-02 | 3.72 | 375(1) |
| Jun-02 | 3.70 | 376 |
| Jul-02 | 3.79 | 367(2) |
| Aug-02 | 3.95 | 374 |
| Sep-02 | 3.99 | 379(3) |
| Oct-02 | 3.83 | 372(3) |
| Mean | 3.81 | 374 |
| Mean | 3.81 | 373 |
| Max | 4.13 | 380 |
| Min | 3.66 | 366 |
| Std Dev | 0.14 | 4.08 |

(1) May – Low load test run; average flow data does not include the low flow days. Only normal flow days are included. During the low load test, flow was set at 50% of normal flow. Actual average flow during the low load test (May 6 to May 26) was 188 gpd.
(2) July – During the power failure stress test there is one day with no flow and one day with reduced flow. These data point are not included in the monthly average.
(3) Sept-Oct – Vacation test, 10-day test with no flow for 8 days. Only nine doses applied on first and last day. Low or no flow days excluded from the calculation of monthly averages.

### *4.3.2 Verification Test Restart*

The first stress test was started in early November 2001, after two months of verification testing. Following the stress test completion, it was discovered that the sampling plan described in the VTP had not been followed. Several samples were missed, and the requirements for data completeness (a Data Quality Objective) were not met. Furthermore, in early November, water was found to be ponding near the blower, and the blower was raised by placing it on a cement block. Bio-Microbics and NSF were not informed of this change to the system until after the work was completed. Bio-Microbics arrived at the site on November 14 and checked the system. The blower, blower filter, piping, and insert were found to be in acceptable working order. However, Bio-Microbics determined that the blower operation setting (30 minutes on/30 minutes off) was not appropriate. Bio-Microbics changed the blower control to operate the blower continuously, thus supplying more air to the system. This setting was maintained for the remainder of the verification test.

Due to the incomplete data set and changes to the system, NSF, NovaTec, and Bio-Microbics agreed that the test would continue, but that the November data would not be used in the summary information for the verification report. September and October data would be used as the first two months of the test, and the incomplete washday stress test would be repeated. Wastewater continued to flow to the unit throughout November. The test resumed officially on December 1, 2001, providing a two-week period for the unit to stabilize following the aborted stress test and the changes to the blower operational setting. The washday stress test started in late December, and the remaining elements of the VTP were implemented based on the test plan schedule. This approach resulted in the collection of 13 months of data (September to October 2001, and December 2001 to October 2002) for the verification test.

### *4.3.3 $BOD_5$/$CBOD_5$ and TSS Results and Discussion*

Figures 4-1 and 4-2 show the influent and effluent $BOD_5$/$CBOD_5$ and TSS concentrations during the verification test. Table 4-5 presents the same results with a summary of the data (mean, 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 five days of the analysis. The $CBOD_5$ analysis inhibits nitrification 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. Comparing the $BOD_5$ of the influent and the $CBOD_5$ of the effluent demonstrates how effectively the system removes oxygen-demanding organics.

The influent wastewater had a mean $BOD_5$ of 150 mg/L with a range of 65 to 210 mg/L. The mean influent TSS was 180 mg/L, with a range of 110 to 440 mg/L. The RetroFAST® effluent had a mean $CBOD_5$ of 12 mg/L, varying from 2 mg/L to 28 mg/L. The mean effluent TSS concentration was 28 mg/L, ranging from 3 to 170 mg/L. The RetroFAST® achieve a mean reduction of 91% for $BOD_5$/$CBOD_5$ (range of 79 to 98%) and a mean reduction of 84% TSS (range of 14 to 98%).

Effluent data from the first two months of the verification test (September and October 2001) showed variable TSS concentrations (8 to 59 mg/L) with $CBOD_5$ concentrations of 2 to 18 mg/L. Bio-Microbics was concerned with the elevated and variable concentrations, but no changes were made to the system. As stated previously, the blower was set to continuous operation on November 14, 2001, and was not changed for the duration of the testing.

The washday stress test and working parent stress test were performed from December 24 through December 28, and February 25 through March 1, 2001, respectively. The data indicate that there were no specific impacts from these stress tests on system performance for TSS and $CBOD_5$. Effluent quality did vary during and after these stress periods, but was typically within the range of results found throughout the verification test.

Data collected during the low load stress test (May 6 to June 3) showed a possible short-term impact on TSS and $CBOD_5$, as the sample collected ten days into the test showed increases in TSS and $CBOD_5$. However, data collected at the end of the stress period (May 27) and during post-stress test monitoring showed TSS and $CBOD_5$ concentrations typical of the overall performance of the unit. The power/equipment failure test (July 22 to July 24) also showed an increase in TSS in the first sample after the stress test ended (July 27). However, subsequent samples appeared to be within the range of concentrations found during the entire verification test.

The vacation stress test started on September 23 and continued through October 2, 2002. There was an increase in effluent $CBOD_5$ (13 and 28 mg/L) and TSS (42 and 35 mg/L) in the two samples collected at the start of the test. In addition, the first sample collected after flow was restarted at the end of the stress test showed higher than average $CBOD_5$ (16 mg/L) and TSS (35 mg/L). These data were above the mean concentrations found during the verification test and were higher than the concentrations measured the week before the stress test. However, the concentrations are within the range of data found throughout the verification test. Any impact that might be caused by the vacation stress test (no flow for eight days) cannot be determined given variability exhibited by the RetroFAST® during the verification test.

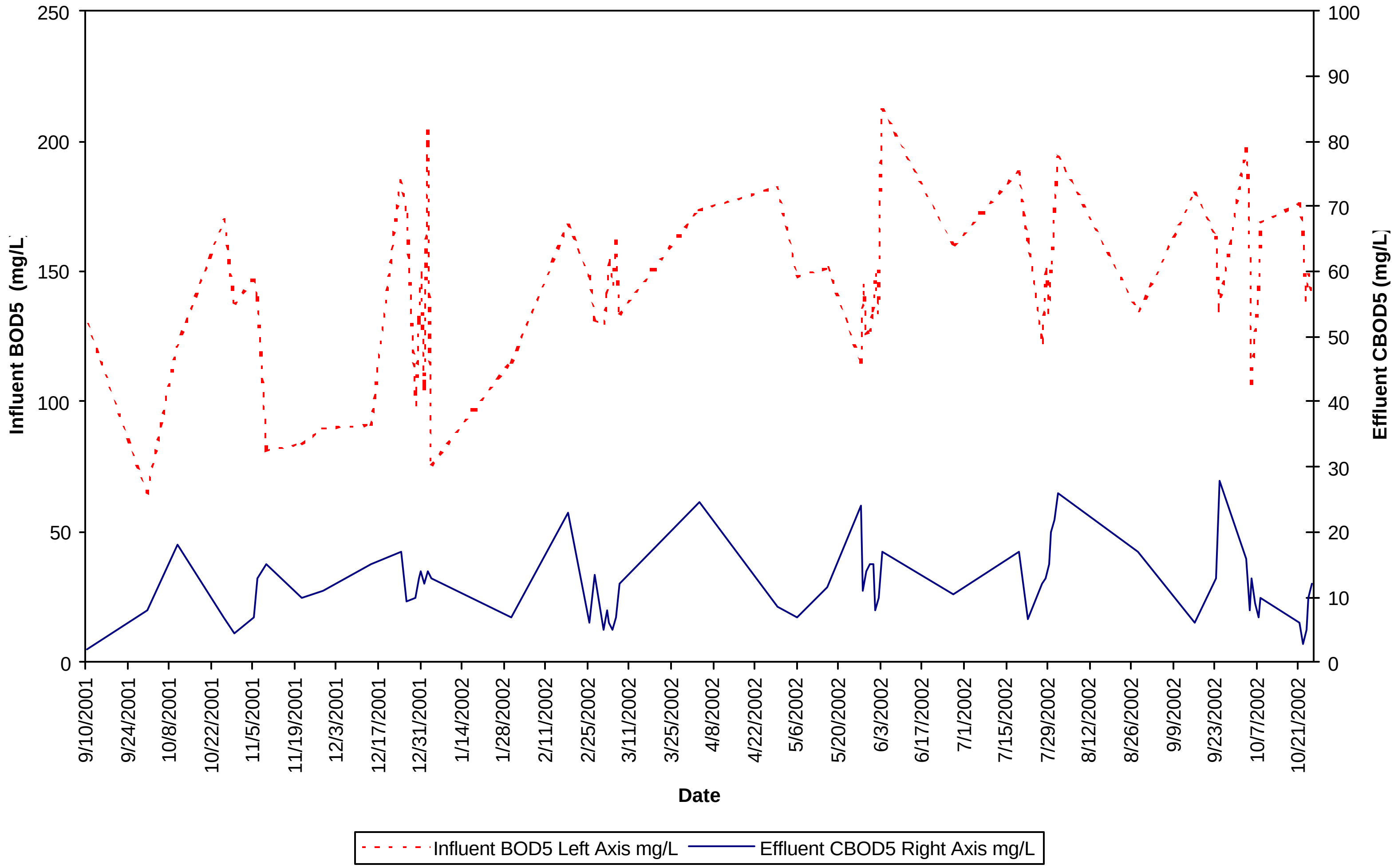



**Figure 4-1. RetroFAST® 0.375 System $BOD_5$/$CBOD_5$ results.**

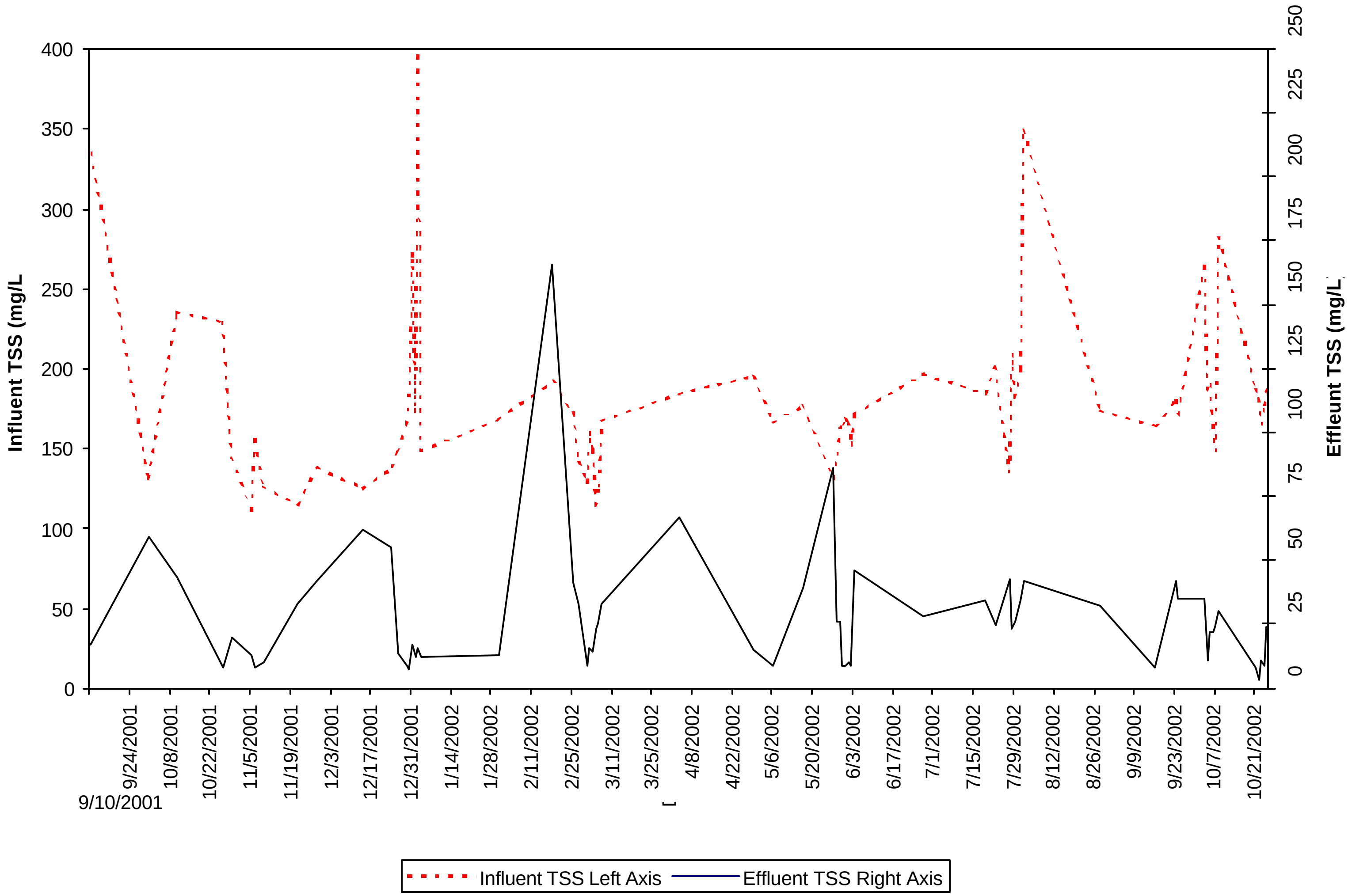



**Figure 4-2. RetroFAST® 0.375 System TSS results.**

**Table 4-5. RetroFAST® 0.375 System $BOD_5$/$CBOD_5$ and TSS Results**

| | $BOD_5$ | $CBOD_5$ | | TSS | | |
|---|---|---|---|---|---|---|
| Date | Influent (mg/L) | Effluent (mg/L) | Removal (%) | Influent (mg/L) | Effluent (mg/L) | Removal (%) |
| 09/10/01 | 130 | 2 | 98 | 340 | 17 | 95 |
| 09/30/01 | 65 | 8 | 88 | 130 | 59 | 55 |
| 10/10/01 | 120 | 18 | 85 | 240 | 44 | 81 |
| 10/26/01 | 170 | 7 | 96 | 230 | 8 | 97 |
| 10/29/01 | 140 | 5 | 97 | 140 | 20 | 86 |
| 11/05/01 | 150 | 7 | 95 | 110 | 13 | 88 |
| 11/06/01 | 140 | 13 | 91 | 160 | 8 | 95 |
| 11/09/01 | 81 | 15 | 81 | 130 | N/A | N/C |
| 11/21/01 | 84 | 10 | 88 | 120 | 33 | 71 |
| 11/28/01 | 90 | 11 | 88 | 140 | 42 | 70 |
| 12/14/01 | 91 | 15 | 84 | 120 | 62 | 50 |
| 12/24/01 | 180 | 17 | 91 | 140 | 55 | 60 |
| 12/26/01 | 170 | 10 | 94 | 150 | 14 | 91 |
| 12/29/01 | 99 | 10 | 90 | 160 | 9 | 95 |
| 12/30/01 | 130 | 13 | 90 | 190 | 7 | 96 |
| 12/31/01 | 150 | 14 | 91 | 270 | 17 | 94 |
| 01/01/02 | 100 | 12 | 89 | 170 | 12 | 93 |
| 01/02/02 | 200 | 14 | 93 | 440 | 16 | 96 |
| 01/03/02 | 76 | 13 | 83 | 150 | 12 | 92 |
| 01/30/02 | 120 | 7 | 94 | 170 | 13 | 92 |
| 02/18/02 | 170 | 23 | 86 | 190 | 170 | 14 |
| 02/25/02 | 150 | 6 | 96 | 170 | 41 | 76 |
| 02/27/02 | 130 | 14 | 90 | 140 | 33 | 77 |
| 03/02/02 | 130 | 5 | 96 | 130 | 9 | 93 |
| 03/03/02 | 140 | 8 | 94 | 160 | 16 | 90 |
| 03/04/02 | 150 | 6 | 96 | 150 | 14 | 91 |
| 03/05/02 | 140 | 5 | 97 | 110 | 23 | 80 |
| 03/06/02 | 160 | 7 | 96 | 130 | 25 | 80 |
| 03/07/02 | 130 | 12 | 91 | 170 | 33 | 80 |
| 04/03/02 | 170 | 25 | 86 | 180 | 67 | 64 |
| 04/29/02 | 180 | 9 | 95 | 200 | 15 | 92 |
| 05/06/02 | 150 | 7 | 95 | 170 | 9 | 95 |
| 05/16/02 | 150 | 12 | 92 | 180 | 39 | 78 |
| 05/27/02 | 120 | 24 | 79 | 130 | 86 | 34 |
| 05/28/02 | 140 | 11 | 92 | 150 | 26 | 82 |

N/A - not analyzed
N/C – not calculated

**Table 4-5. RetroFAST® 0.375 System $BOD_5$/$CBOD_5$ and TSS results (continued)**

| | $BOD_5$ | $CBOD_5$ | | TSS | | |
|---|---|---|---|---|---|---|
| | Influent (mg/L) | Effluent (mg/L) | Removal (%) | Influent (mg/L) | Effluent (mg/L) | Removal (%) |
| 5/29/02 | 130 | 14 | 89 | 160 | 26 | 84 |
| 5/30/02 | 130 | 15 | 88 | 160 | 9 | 95 |
| 5/31/02 | 140 | 15 | 89 | 170 | 9 | 95 |
| 6/1/02 | 150 | 8 | 95 | 170 | 10 | 94 |
| 6/2/02 | 130 | 10 | 93 | 150 | 9 | 94 |
| 6/3/02 | 210 | 17 | 92 | 170 | 46 | 73 |
| 6/27/02 | 160 | 11 | 93 | 200 | 28 | 86 |
| 7/19/02 | 190 | 17 | 91 | 180 | 34 | 82 |
| 7/22/02 | 160 | 7 | 96 | 200 | 25 | 88 |
| 7/27/02 | 120 | 12 | 90 | 140 | 43 | 68 |
| 7/28/02 | 150 | 13 | 91 | 210 | 23 | 89 |
| 7/29/02 | 130 | 15 | 89 | 180 | 26 | 86 |
| 7/30/02 | 150 | 20 | 87 | 190 | 29 | 85 |
| 7/31/02 | 170 | 22 | 87 | 200 | 34 | 83 |
| 8/1/02 | 190 | 26 | 87 | 350 | 42 | 88 |
| 8/28/02 | 140 | 17 | 87 | 170 | 32 | 82 |
| 9/16/02 | 180 | 6 | 97 | 160 | 8 | 95 |
| 9/23/02 | 160 | 13 | 92 | 180 | 42 | 77 |
| 9/24/02 | 140 | 28 | 79 | 170 | 35 | 80 |
| 10/3/02 | 200 | 16 | 92 | 260 | 35 | 87 |
| 10/4/02 | 180 | 8 | 95 | 190 | 11 | 94 |
| 10/5/02 | 110 | 13 | 88 | 190 | 22 | 88 |
| 10/6/02 | 130 | 9 | 93 | 160 | 22 | 87 |
| 10/7/02 | 140 | 7 | 95 | 150 | 24 | 84 |
| 10/8/02 | 170 | 10 | 94 | 280 | 30 | 89 |
| 10/21/02 | 180 | 6 | 97 | 190 | 8 | 96 |
| 10/22/02 | 160 | 3 | 98 | 180 | 3 | 98 |
| 10/23/02 | 140 | 5 | 96 | 160 | 11 | 93 |
| 10/24/02 | 150 | 10 | 93 | 180 | 9 | 95 |
| 10/25/02 | 140 | 12 | 92 | 190 | 24 | 87 |
| Number of Samples | 60 | 60 | 60 | 60 | 60 | 60 |
| Mean | 150 | 12 | 91 | 180 | 28 | 84 |
| Median | 150 | 12 | 92 | 170 | 24 | 88 |
| Maximum | 210 | 28 | 98 | 440 | 170 | 98 |
| Minimum | 65 | 2 | 79 | 110 | 3 | 14 |
| Std. Dev. | 30 | 5.9 | 4.4 | 56 | 25 | 15 |

Summary statistics do not include November 2001 data. See Section 4.3.2.
N/A - not analyzed
N/C – not calculated
Values below the detection limit are set to zero for concentration means

### *4.3.4 Nitrogen Reduction Performance*

4.3.4.1 Results

Figures 4-3 through 4-5 present the results for the TKN, $NH_3$-N, and TN in the influent and effluent during the verification test. Figure 4-6 shows the results for $NO_2$ and $NO_3$ in the effluent. Table 4-6 presents all of the nitrogen results with a summary of the data (mean, median, maximum, minimum, standard deviation). The summary statistics do not include the data from November 5 through November 28, when changes were made to the system and the sampling program was restarted.

The influent wastewater had a mean TKN concentration of 39 mg/L and a mean $NH_3$-N concentration of 28 mg/L. Mean TN concentration in the influent was 39 mg/L (the TKN concentration), based on the generally accepted assumption that the $NO_2$ and $NO_3$ concentration in the influent is negligible. The RetroFAST® effluent had a mean TKN concentration of 11 mg/L, and a mean $NH_3$-N concentration of 5.9 mg/L. The $NO_2$ mean concentration in the effluent was 0.46 mg/L, and $NO_3$ mean concentration was 8.0 mg/L. TN was determined by adding the concentrations of the TKN (organic plus ammonia nitrogen), $NO_2$ and $NO_3$ in the effluent. The mean TN in the RetroFAST® effluent was 19 mg/L for the thirteen-month verification period, with a median concentration of 18 mg/L. The RetroFAST® demonstrated a mean reduction of 51% in TN for the verification test period, with a median removal of 50%.

Alkalinity, pH, DO, and temperature were measured during the verification test. These parameters can impact TN removal and provide insight into the condition of the system. Table 4-7 shows the results for pH, alkalinity, DO, and wastewater temperature

The pH of the influent ranged from 6.4 to 7.8, and the effluent from the RetroFAST® was in a similar range of 6.5 to 8.0. The alkalinity of the influent averaged 150 mg/L as $CaCO_3$ with a maximum concentration of 180 mg/L and minimum of 130 mg/L. The effluent alkalinity was consistently lower than the influent when nitrification/denitrification was occurring, with a mean concentration of 83 mg/L and a median concentration 70 mg/L. The one exception was the December 29, 2001 through January 3, 2002 period, when the effluent alkalinity was very close to the influent concentration. The data suggest nitrification/denitrification was occurring, but there was no change in alkalinity. The data were checked and appeared to be correct, but these alkalinity data are considered suspect. The effluent alkalinity did vary based on the performance of the nitrification/denitrification process.

Bio-Microbics stated that the RetroFAST® is designed to operate as an aerobic and anoxic system. The wastewater is aerated to promote nitrification and then recycled to an anoxic quiescent zone prior to discharge. The DO in the effluent from the unit averaged 8.6 mg/L and was above 5 mg/L on all but three days. Measurement of the D.O. in the anoxic zone was not included in the verification test.

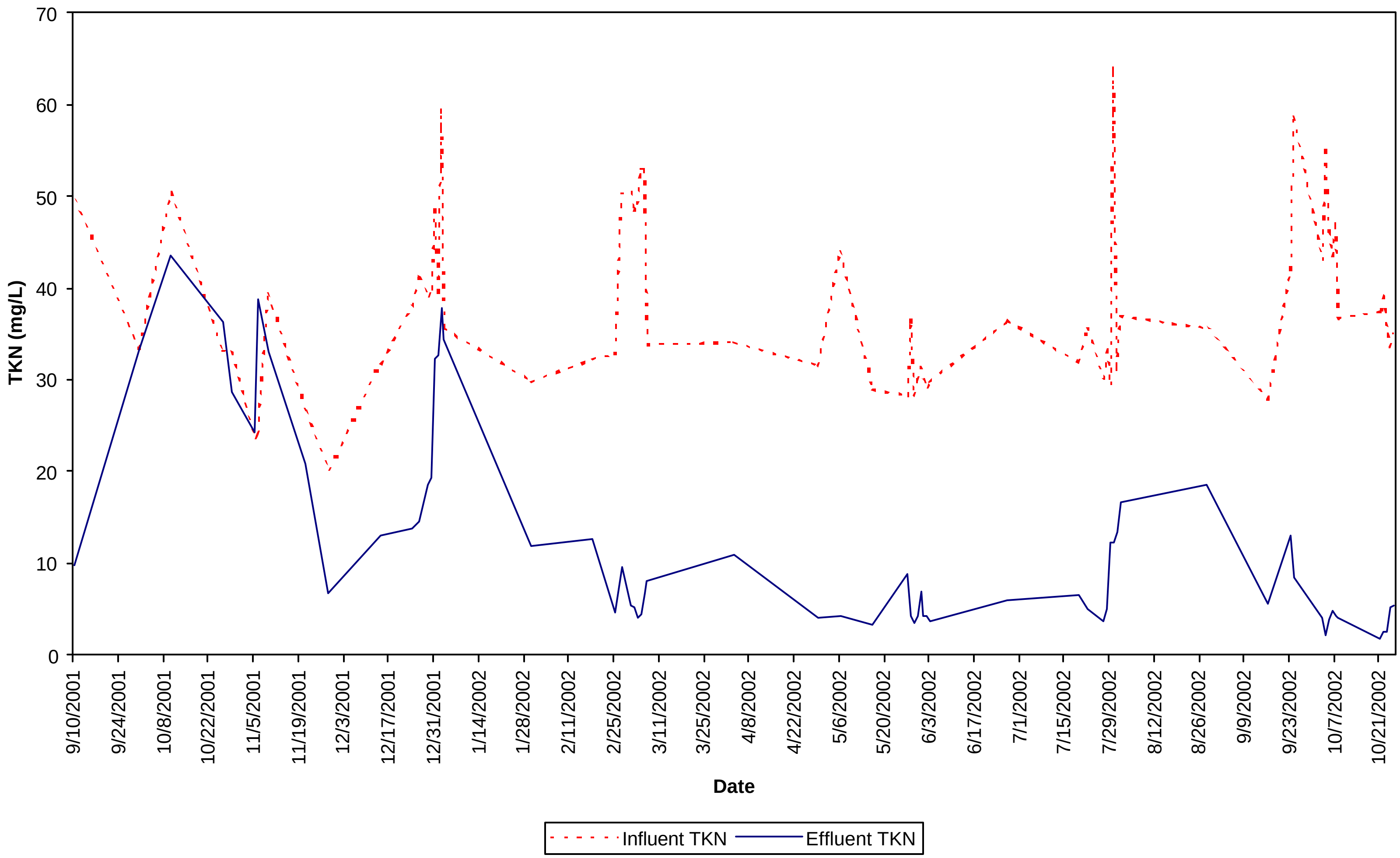



**Figure 4-3. RetroFAST® 0.375 System TKN results.**

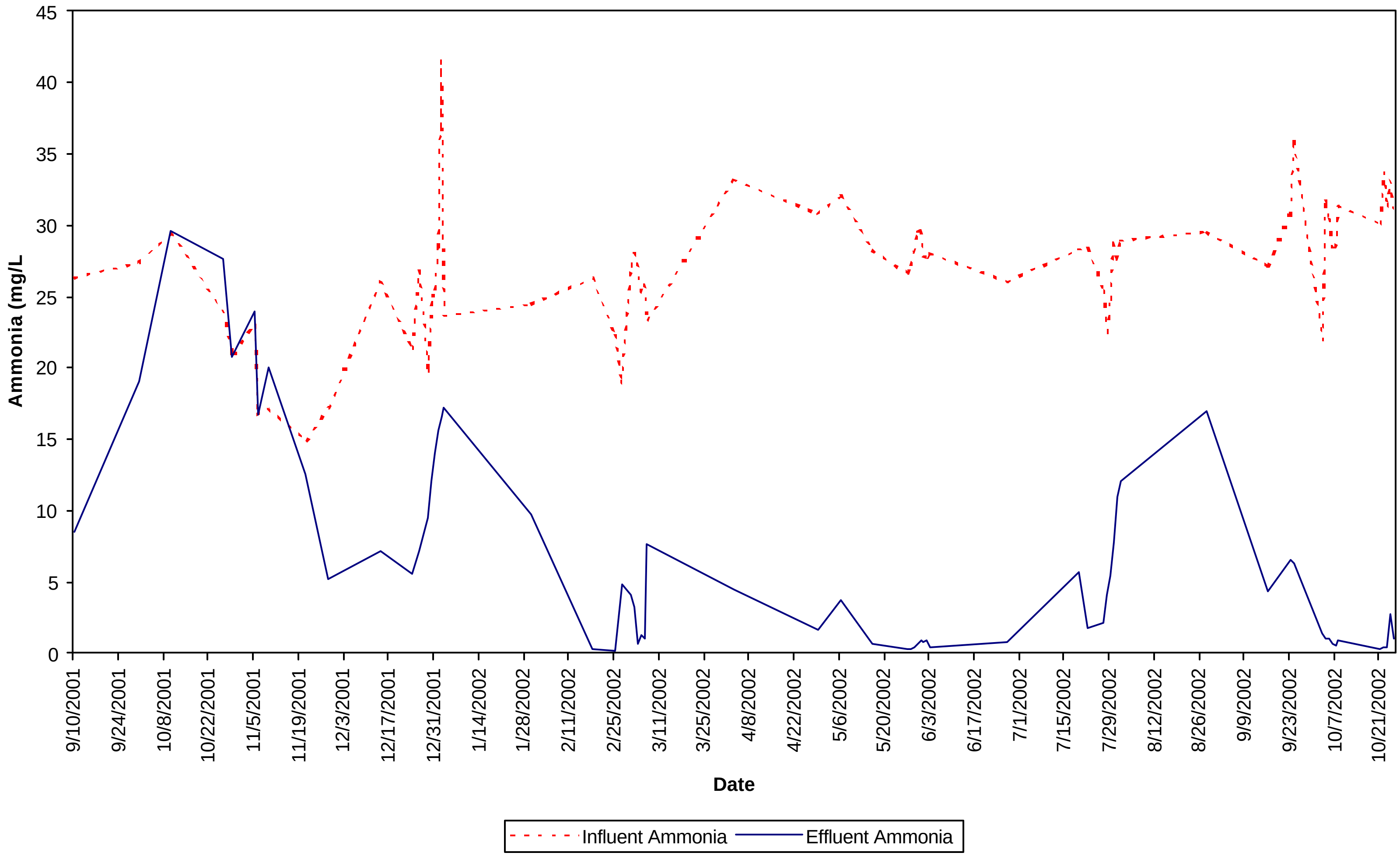



**Figure 4-4. RetroFAST® 0.375 System $NH_3$-N results.**

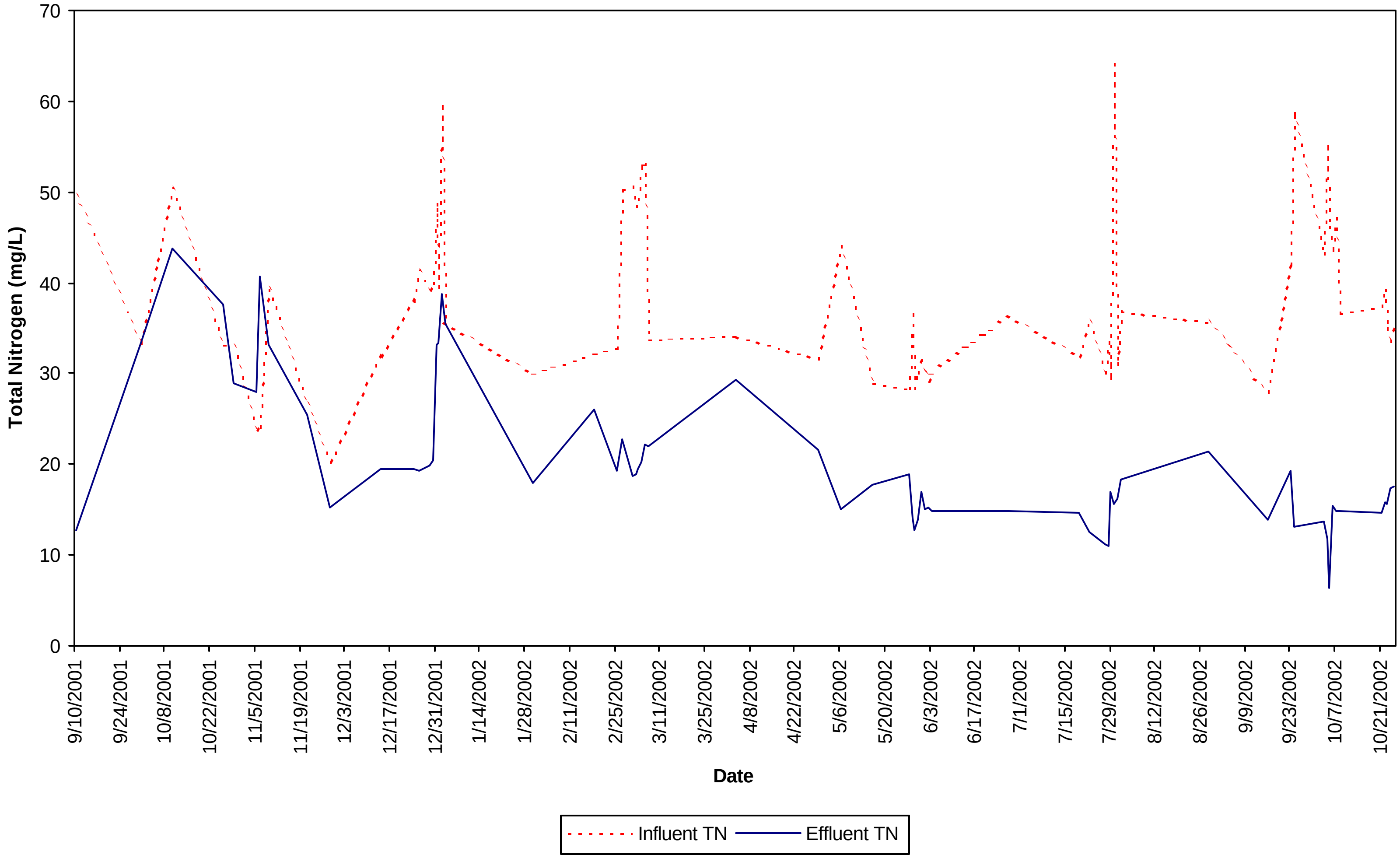



**Figure 4-5. RetroFAST® 0.375 System TN results.**

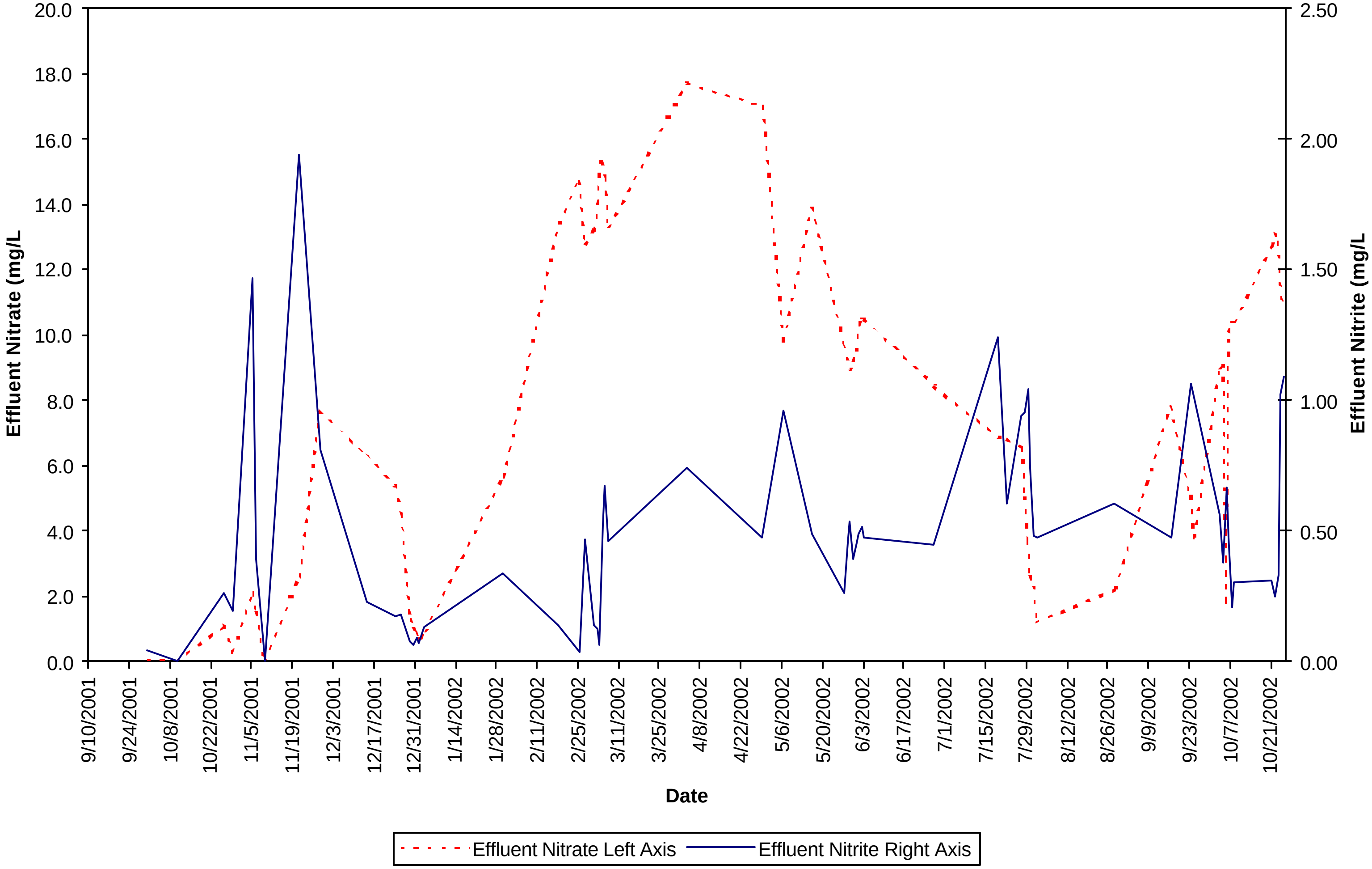



**Figure 4-6. RetroFAST® 0.375 System $NO_2$ and $NO_3$ effluent concentrations.**

**Table 4-6. RetroFAST® 0.375 System Influent and Effluent Nitrogen Data**

| | TKN (mg/L) | | $NH_3$-N (mg/L) | | TN (mg/L) | | $NO_3$ (mg/L) | $NO_2$ (mg/L) |
|---|---|---|---|---|---|---|---|---|
| Date | Influent | Effluent | Influent | Effluent | Influent | Effluent | Effluent | Effluent |
| 09/10/01 | 50 | 9.8 | 26 | 8.5 | 50 | 13 | N/A | N/A |
| 09/30/01 | 33 | 33 | 27 | 19 | 33 | 33 | 0.06 | 0.04 |
| 10/10/01 | 50 | 44 | 29 | 30 | 50 | 44 | N/A | N/A |
| 10/26/01 | 33 | 36 | 24 | 28 | 33 | 38 | 1.1 | 0.26 |
| 10/29/01 | 33 | 29 | 21 | 21 | 33 | 29 | 0.28 | 0.20 |
| 11/05/01 | 24 | 24 | 23 | 24 | 24 | 28 | 2.1 | 1.47 |
| 11/06/01 | 24 | 39 | 17 | 17 | 24 | 41 | 1.5 | 0.40 |
| 11/09/01 | 39 | 33 | 17 | 20 | 39 | 33 | N/A | N/A |
| 11/21/01 | 27 | 21 | 15 | 13 | 27 | 25 | 2.6 | 1.9 |
| 11/28/01 | 20 | 6.8 | 17 | 5.2 | 20 | 15 | 7.7 | 0.81 |
| 12/14/01 | 32 | 13 | 26 | 7.1 | 32 | 20 | 6.3 | 0.23 |
| 12/24/01 | 38 | 14 | 21 | 5.6 | 38 | 19 | 5.4 | 0.18 |
| 12/26/01 | 41 | 15 | 27 | 7.1 | 41 | 19 | 4.5 | 0.18 |
| 12/29/01 | 39 | 19 | 20 | 9.5 | 39 | 20 | 1.3 | 0.08 |
| 12/30/01 | 40 | 19 | 25 | 12 | 40 | 20 | 1.0 | 0.07 |
| 12/31/01 | 49 | 32 | 26 | 14 | 49 | 33 | 0.88 | 0.09 |
| 01/01/02 | 40 | 33 | 29 | 16 | 40 | 33 | 0.72 | 0.07 |
| 01/02/02 | 59 | 38 | 42 | 17 | 59 | 39 | 0.73 | 0.11 |
| 01/03/02 | 36 | 34 | 24 | 17 | 36 | 36 | 0.95 | 0.13 |
| 01/30/02 | 30 | 12 | 24 | 9.7 | 30 | 18 | 5.7 | 0.34 |
| 02/18/02 | 32 | 13 | 26 | 0.3 | 32 | 26 | 13 | 0.14 |
| 02/25/02 | 33 | 4.6 | 22 | 0.2 | 33 | 19 | 15 | 0.04 |
| 02/27/02 | 50 | 9.6 | 19 | 4.8 | 50 | 23 | 13 | 0.47 |
| 03/02/02 | 51 | 5.4 | 27 | 4.1 | 51 | 19 | 13 | 0.14 |
| 03/03/02 | 48 | 5.2 | 28 | 3.2 | 48 | 19 | 14 | 0.13 |
| 03/04/02 | 49 | 4.0 | 27 | 0.7 | 49 | 19 | 15 | 0.07 |
| 03/05/02 | 53 | 4.4 | 25 | 1.3 | 53 | 20 | 15 | 0.53 |
| 03/06/02 | 53 | 6.7 | 26 | 1.0 | 53 | 22 | 15 | 0.67 |
| 03/07/02 | 34 | 8.1 | 23 | 7.6 | 34 | 22 | 13 | 0.46 |
| 04/03/02 | 34 | 11 | 33 | 4.5 | 34 | 29 | 18 | 0.74 |
| 04/29/02 | 32 | 4.1 | 31 | 1.7 | 32 | 22 | 17 | 0.48 |
| 05/06/02 | 44 | 4.2 | 32 | 3.7 | 44 | 15 | 9.8 | 0.96 |
| 05/16/02 | 29 | 3.4 | 28 | 0.7 | 29 | 18 | 14 | 0.49 |
| 05/27/02 | 28 | 8.9 | 27 | 0.3 | 28 | 19 | 9.7 | 0.26 |
| 05/28/02 | 37 | 4.3 | 27 | 0.2 | 37 | 14 | 9.3 | 0.46 |

**Table 4-6. RetroFAST® 0.375 System Influent and Effluent Nitrogen Data (continued)**

| Date | TKN (mg/L) Influent | TKN (mg/L) Effluent | $NH_3$-N (mg/L) Influent | $NH_3$-N (mg/L) Effluent | TN (mg/L) Influent | TN (mg/L) Effluent | $NO_3$ (mg/L Effluent | $NO_2$ (mg/L) Effluent |
|---|---|---|---|---|---|---|---|---|
| 05/29/02 | 28 | 3.4 | 28 | 0.5 | 28 | 13 | 8.9 | 0.54 |
| 05/30/02 | 30 | 4.3 | 30 | 0.7 | 30 | 14 | 9.2 | 0.39 |
| 05/31/02 | 31 | 7.0 | 30 | 0.9 | 31 | 17 | 9.5 | 0.46 |
| 06/01/02 | 30 | 4.2 | 28 | 0.8 | 30 | 15 | 10 | 0.49 |
| 06/02/02 | 29 | 4.3 | 28 | 0.9 | 29 | 15 | 11 | 0.52 |
| 06/03/02 | 30 | 3.8 | 28 | 0.5 | 30 | 15 | 11 | 0.48 |
| 06/27/02 | 37 | 5.9 | 26 | 0.8 | 37 | 15 | 8.5 | 0.45 |
| 07/19/02 | 32 | 6.6 | 28 | 5.7 | 32 | 15 | 6.9 | 1.2 |
| 07/22/02 | 36 | 5.1 | 28 | 1.8 | 36 | 12 | 6.8 | 0.61 |
| 07/27/02 | 30 | 3.7 | 25 | 2.1 | 30 | 11 | 6.6 | 0.94 |
| 07/28/02 | 33 | 5.0 | 23 | 4.1 | 33 | 11 | 5.1 | 0.96 |
| 07/29/02 | 30 | 12 | 25 | 5.5 | 30 | 17 | 3.7 | 1.0 |
| 07/30/02 | 64 | 12 | 29 | 7.8 | 64 | 16 | 2.6 | 0.74 |
| 07/31/02 | 31 | 14 | 28 | 11 | 31 | 16 | 2.3 | 0.48 |
| 08/01/02 | 37 | 17 | 29 | 12 | 37 | 18 | 1.2 | 0.48 |
| 08/28/02 | 36 | 19 | 30 | 17 | 36 | 21 | 2.2 | 0.61 |
| 09/16/02 | 28 | 5.6 | 27 | 4.4 | 28 | 14 | 7.8 | 0.48 |
| 09/23/02 | 42 | 13 | 31 | 6.6 | 42 | 19 | 5.1 | 1.1 |
| 09/24/02 | 59 | 8.4 | 36 | 6.4 | 59 | 13 | 3.8 | 1.0 |
| 10/03/02 | 43 | 4.1 | 22 | 1.4 | 43 | 14 | 9.0 | 0.56 |
| 10/04/02 | 55 | 2.2 | 32 | 1.0 | 55 | 12 | 9.1 | 0.38 |
| 10/05/02 | 46 | 3.9 | 30 | 1.0 | 46 | 6 | 1.8 | 0.66 |
| 10/06/02 | 44 | 4.9 | 28 | 0.7 | 44 | 16 | 10 | 0.48 |
| 10/07/02 | 47 | 4.3 | 28 | 0.5 | 47 | 15 | 10 | 0.21 |
| 10/08/02 | 37 | 4.1 | 31 | 0.9 | 37 | 15 | 10 | 0.30 |
| 10/21/02 | 38 | 1.7 | 30 | 0.3 | 38 | 15 | 13 | 0.31 |
| 10/22/02 | 39 | 2.5 | 34 | 0.4 | 39 | 16 | 13 | 0.25 |
| 10/23/02 | 35 | 2.6 | 31 | 0.5 | 35 | 16 | 13 | 0.33 |
| 10/24/02 | 34 | 5.2 | 33 | 2.8 | 34 | 17 | 11 | 1.0 |
| 10/25/02 | 35 | 5.5 | 31 | 1.0 | 35 | 18 | 11 | 1.1 |
| No. Samples | 60 | 60 | 60 | 60 | 60 | 60 | 58 | 58 |
| Mean | 39 | 11 | 28 | 5.9 | 39 | 19 | 8.0 | 0.46 |
| Median | 36 | 6.2 | 28 | 3.4 | 36 | 18 | 9.1 | 0.46 |
| Maximum | 64 | 44 | 42 | 30 | 64 | 44 | 18 | 1.2 |
| Minimum | 28 | 1.7 | 19 | 0.15 | 28 | 6.4 | 0.06 | 0.04 |
| Std. Deviation | 9.0 | 10 | 3.9 | 7.0 | 9.0 | 7.5 | 5.0 | 0.31 |

Summary statistics do not include November 2001 data – See Section 4.3.2
N/A - not analyzed
N/C – not calculated
Values below the detection limit set equal to zero (0) for statistical calculations

**Table 4-7. RetroFAST® 0.375 System Alkalinity, pH, and DO Results**

| | DO (mg/L) | pH (S.U.) | | Alkalinity (mg/L as $CaCO_3$) | | Temperature ($^oC$) | |
|---|---|---|---|---|---|---|---|
| Date | Effluent | Influent | Effluent | Influent | Effluent | Influent | Effluent |
| 09/10/01 | 1.6 | 6.6 | 6.9 | 160 | 82 | 17.4 | 17.0 |
| 09/30/01 | 2.0 | 6.8 | 7.3 | 170 | 170 | 16.8 | 16.4 |
| 10/10/01 | 5.1 | 6.5 | 6.8 | 170 | 170 | 16.8 | 15.0 |
| 10/26/01 | 7.8 | 6.5 | 6.8 | 150 | 150 | 14.0 | 12.4 |
| 10/29/01 | 8.0 | 6.4 | 6.7 | 140 | 140 | 15.3 | 11.0 |
| 11/05/01 | 8.2 | 6.3 | 6.8 | 140 | 160 | 13.9 | 10.3 |
| 11/06/01 | 6.9 | 6.4 | 6.7 | 140 | 160 | 13.4 | 10.5 |
| 11/09/01 | 8.4 | 6.5 | 6.8 | 160 | N/A | 13.4 | 10.9 |
| 11/21/01 | 5.5 | 6.1 | 6.5 | 120 | 110 | 12.9 | 10.7 |
| 11/28/01 | 3.0 | 6.1 | 6.3 | 130 | 56 | 11.4 | 10.2 |
| 12/14/01 | 11 | 7.0 | 6.7 | 150 | 200 | 12.2 | 9.7 |
| 12/24/01 | 11 | 7.4 | 7.7 | 130 | 60 | 10.1 | 8.4 |
| 12/26/01 | 10 | 7.5 | 7.6 | 140 | 85 | 10.7 | 4.9 |
| 12/29/01 | 8.8 | 7.6 | 8.0 | 140 | 140 | 12.7 | 7.1 |
| 12/30/01 | 9.4 | 7.6 | 8.0 | 150 | 150 | 10.8 | 8.4 |
| 12/31/01 | 9.5 | 7.8 | 8.0 | 150 | 150 | 10.0 | 9.5 |
| 01/01/02 | 9.6 | 7.3 | 7.9 | 150 | 160 | 13.3 | 8.4 |
| 01/02/02 | 9.9 | 7.2 | 7.9 | 170 | 160 | 10.7 | 7.3 |
| 01/03/02 | 9.7 | 7.2 | 7.9 | 130 | 150 | 9.6 | 7.4 |
| 01/30/02 | 9.9 | 7.3 | 7.5 | 130 | 81 | 8.4 | 5.3 |
| 02/18/02 | 11 | 7.2 | 7.3 | 150 | 34 | 9.4 | 7.8 |
| 02/25/02 | 11 | 7.2 | 6.9 | 130 | 30 | 8.2 | 5.4 |
| 02/27/02 | 10 | 7.1 | 7.2 | 130 | 62 | 8.3 | 5.9 |
| 03/02/02 | 11 | 7.0 | 7.4 | 140 | 60 | 8.6 | 6.9 |
| 03/03/02 | 11 | 7.2 | 7.3 | 140 | 61 | 8.9 | 5.4 |
| 03/04/02 | 11 | 7.1 | 7.1 | 140 | 50 | 8.8 | 5.5 |
| 03/05/02 | 11 | 7.2 | 7.4 | 150 | 53 | 8.7 | 6.5 |
| 03/06/02 | 9.5 | 7.8 | 7.3 | 140 | 58 | 8.6 | 5.3 |
| 03/07/02 | 10 | 7.2 | 7.4 | 140 | 72 | 8.9 | 5.3 |
| 04/03/02 | 10 | 7.7 | 7.1 | 160 | 41 | 10.9 | 9.1 |
| 04/29/02 | 9.0 | 7.4 | 6.7 | 170 | 19 | 10.8 | 10.9 |
| 05/06/02 | 8.7 | 7.8 | 7.2 | 150 | 44 | 11.2 | 11.3 |
| 05/16/02 | 8.8 | 7.5 | 7.1 | 130 | 31 | 12.2 | 12.3 |
| 05/27/02 | 9.4 | 7.5 | 7.1 | 150 | 54 | 13.2 | 14.0 |
| 05/28/02 | 9.3 | 7.5 | 7.4 | 150 | 58 | 13.3 | 15.3 |

N/A – not analyzed

**Table 4-7. RetroFAST® 0.375 System Alkalinity, pH, and DO Results (continued)**

| Date | DO(mg/L) Effluent | pH (S.U.) Influent | pH (S.U.) Effluent | Alkalinity (mg/L as $CaCO_3$) Influent | Alkalinity (mg/L as $CaCO_3$) Effluent | Temperature ($^oC$) Influent | Temperature ($^oC$) Effluent |
|---|---|---|---|---|---|---|---|
| 05/29/02 | 8.0 | 7.3 | 7.3 | 150 | 59 | 13.5 | 14.8 |
| 05/30/02 | 8.0 | 7.2 | 7.2 | 140 | 55 | 13.2 | 14.4 |
| 05/31/02 | 8.0 | 7.3 | 7.1 | 140 | 54 | 12.9 | 14.5 |
| 06/01/02 | 8.3 | 7.2 | 7.0 | 140 | 45 | 13.0 | 14.1 |
| 06/02/02 | 8.2 | 7.2 | 7.0 | 140 | 42 | 13.5 | 14.2 |
| 06/03/02 | 8.6 | 7.1 | 6.8 | 140 | 38 | 13.4 | 14.7 |
| 06/27/02 | 7.4 | 6.9 | 6.9 | 150 | 57 | 15.6 | 18.9 |
| 07/19/02 | 8.2 | 6.8 | 7.2 | 140 | 75 | 18.0 | 20.2 |
| 07/22/02 | 7.8 | 7.2 | 7.0 | 150 | 65 | 16.1 | 20.1 |
| 07/27/02 | 7.5 | 7.0 | 7.3 | 150 | 80 | 16.7 | 18.7 |
| 07/28/02 | 7.6 | 7.4 | 7.4 | 150 | 88 | 17.9 | 19.6 |
| 07/29/02 | 7.0 | 6.7 | 7.0 | 160 | 98 | 16.7 | 20.2 |
| 07/30/02 | 7.3 | 6.8 | 6.8 | 150 | 100 | 16.1 | 19.3 |
| 07/31/02 | 7.3 | 6.7 | 7.0 | 150 | 110 | 16.3 | 17.9 |
| 08/01/02 | 7.2 | 6.8 | 6.8 | 160 | 120 | 15.8 | 18.1 |
| 08/28/02 | 7.0 | 7.5 | 7.3 | 160 | 130 | 17.8 | 18.4 |
| 09/16/02 | 7.6 | 7.6 | 7.7 | 170 | 79 | 16.7 | 16.9 |
| 09/23/02 | 7.9 | 7.6 | 7.7 | 160 | 91 | 16.2 | 15.7 |
| 09/24/02 | 7.4 | 7.8 | 7.5 | 180 | 110 | 16.2 | 15.6 |
| 10/03/02 | 8.6 | 7.4 | 7.9 | 160 | 77 | 16 | 15.4 |
| 10/04/02 | 8.3 | 7.6 | 7.6 | 160 | 76 | 16.4 | 16.8 |
| 10/05/02 | 8.3 | 7.7 | 7.3 | 180 | 72 | 17.2 | 16.9 |
| 10/06/02 | 8.1 | 7.6 | 7.4 | 180 | 72 | 16.8 | 16.2 |
| 10/07/02 | 8.4 | 7.4 | 7.2 | 180 | 70 | 16.9 | 15.9 |
| 10/08/02 | 8.4 | 7.6 | 7.5 | 180 | 75 | 16.5 | 16.3 |
| 10/21/02 | 8.4 | 6.9 | 6.5 | 170 | 51 | 16.1 | 15.7 |
| 10/22/02 | 8.4 | 7.2 | 7.2 | 170 | 55 | 15.3 | 14.6 |
| 10/23/02 | 7.9 | 7.3 | 7.0 | 170 | 56 | 14.2 | 13.3 |
| 10/24/02 | 8.0 | 7.4 | 7.0 | 170 | 61 | 16.1 | 15.4 |
| 10/25/02 | 9.1 | 7.5 | 7.1 | 170 | 43 | 15.3 | 11.7 |
| No. Samples | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| Mean | 8.6 | 7.2 | 7.2 | 150 | 83 | 14 | 12.8 |
| Median | 8.6 | 7.3 | 7.3 | 150 | 70 | 14 | 14.5 |
| Maximum | 11 | 7.8 | 8.0 | 180 | 200 | 18 | 20.2 |
| Minimum | 1.6 | 6.4 | 6.5 | 130 | 19 | 8.2 | 4.90 |
| Std. Deviation | 1.8 | 0.35 | 0.37 | 140 | 42 | 3.1 | 4.75 |

Summary statistics do not include November 2001 data – See Section 4.3.2
N/A - not analyzed

4.3.4.2 Discussion

During the first two months of the verification test, September and October 2001, the nitrification and denitrification processes, which had been established during startup, were upset, and only small amounts of $NH_3$-N or TN were removed by the RetroFAST® system. All members of the ETV test team were concerned about the problem and tried to determine what might have caused the upset condition. There were no apparent changes in the influent wastewater quality. During the November 14 system check by Bio-Microbics, it was determined that the blower setting of 30 minutes on and 30 minutes off was not correct for the system. Bio-Microbics indicated that the incorrect blower setting was the cause of the problem. Bio-Microbics changed the blower setting to operate continuously on November 14, and the verification test was officially continued in December. Following the change to the blower setting, the RetroFAST® began to recover. The ammonia nitrogen concentration in the effluent began to decrease at the end of November and nitrate concentrations increased, indicating the nitrification/denitrification processes were re-establishing. TN removal approached 50% at that time.

The washday stress test was performed from December 24 to December 28, 2001. The $NH_3$-N and TKN began to rise at the end of the stress test and $NO_3$ decreased. By the end of the post-stress test monitoring (January 3, 2002), the data showed no removal of TN by the system. The washday stress test appears to have upset the system. It should be noted that the temperature of the wastewater was decreasing during this time, and there was a one-day spike in TSS near the end of the monitoring period. These factors may have contributed to the system upset.

During the next six weeks, the RetroFAST® system re-established the nitrifying population, as shown by the drop in $NH_3$-N concentration. The February 18 sample showed $NH_3$-N of 0.3 mg/L and a TKN concentration of 13 mg/L (59% removal). The denitrification process also appears to have been re-established to some extent, with effluent $NO_3$ levels of 13 mg/L on February 18.

The working parent stress test was performed from February 25 through March 1, 2002. The $NH_3$-N concentration in the effluent increased during the stress period (4.8 mg/L), but was lower at the end of the stress period and during the post-stress monitoring. Nitrate levels, however, remained in the 13 to 15 mg/L range. TN removal was above 50% for most days, with concentrations ranging from 19 to 22 mg/L in the post-stress monitoring period. The working parent stress test did not appear to have a major impact on the nitrification process. During the next two months, the data show that more than 80% of the $NH_3$-N was being removed, but $NO_3$ levels increased to 17 to 18 mg/L as the denitrification process was not able to convert the $NO_3$ to nitrogen gas. The DO level in the effluent was in the 9.5 to 11 mg/L during this time.

The low load stress test began on May 6 and continued until May 26, 2002. Both the nitrification and denitrification processes appeared to improve during and following this stress test. $NH_3$-N concentrations dropped below 1 mg/L, $NO_3$ levels decreased to the 9 to 11 mg/L range, and TN removal was 46 to 61% after the first ten days of the stress test. The lower daily volume of wastewater being processed through the unit may be a factor in the improved and steadier performance of the unit.

During the June and July test period, which included the power failure test on July 22, the TN concentration in the effluent ranged from 11 to 17 mg/L. $NH_3$-N concentrations increased each day during the post-stress test monitoring and reached a maximum of 12 mg/L on August 1. At the same time, the $NO_3$ concentrations decreased, although the actual removal of $NO_3$ by the system (assuming all $NH_3$-N removed is converted to $NO_3$) remained in the 14 to 19 mg/L range. The power failure stress test appeared to have an impact on the system, which might be expected since the nitrification system is dependent on oxygen supplied by the blower. Late in the post-stress test monitoring period, $NH_3$-N removal performance began to deteriorate and did not recover until September.

The vacation stress test started on September 23 and ended on October 2, 2002. During this period, there was no influent flow to the RetroFAST® system. Following the resumption of flow on October 2, $NH_3$-N concentrations in the effluent were generally less than 1 mg/L, similar to the levels found during the low load test. Nitrate levels increased, but denitrification continued to remove 14 to 20 mg/L of $NO_3$ from the system. The vacation stress test did not have a negative impact on the system based on these data.

The system performance remained more consistent for the duration of the verification test. The TKN and $NH_3$-N effluent concentrations were low and similar to the data from the period after the low load stress test. The $NO_3$ levels remained in the 10 to 13 mg/L range, removing an estimated 17 to 21 mg/L of $NO_3$. The TN concentration in the effluent ranged from 15 to 18 mg/L, representing 49 to 61% removal.

The RetroFAST® system showed variable results during the verification test with TN removal varying from zero to 86%. There were at least two apparent upset periods, one at the start of the verification test (possibly caused by the blower setting discussed previously) and another during the washday stress test. A smaller upset in the nitrification process may have occurred in the late July 2002 period at the end of the power failure post-stress-monitoring period. During the last six months of the verification test, the system appeared more stable and performance was more consistent. During these last six months of operation, the TN concentration in the effluent averaged 15 mg/L (range of 6 to 21 mg/L).

#### *4.3.5 Residuals Results*

During the treatment of wastewater in the RetroFAST®, solids accumulate in the first and second compartment of the tank. Inert and biological solids accumulate from influent wastewater just as in a normal septic tank. Eventually, a buildup of solids reduces the capacity of the primary tank, and the solids need to be removed. Solids will also build up in the second compartment, as the section below the media is used as the settling zone for solids associated with the RetroFAST® treatment.

The approximate depth of the residuals accumulated in the system was estimated in each compartment of the septic tank at the end of the test period. Measurement of solids depth in a septic tank is always difficult, as access to the tank is limited to a manway in the top. For the verification testing, solids depth in the first compartment was estimated at nine locations accessible from the manway using a Sludge-Judge solids-measuring device. A single depth measurement was made in the second compartment, as access with the treatment unit in place was limited to a single small opening. In each case, a column of water and solids was removed from the tank, and the undisturbed solids depth in the clear tube was measured. The measurements were made after approximately sixteen months (July 5, 2001 to October 25, 2002) of operation. The results for the first compartment are presented in Table 4-8. Solids depth in the second compartment was 12 inches, measured at the single access point.

**Table 4-8. Solids Depth Measurement--First Compartment**

| Solids Depth - First Compartment (Inches) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Inlet Left | Inlet Center | Inlet Right | Center Left | Center Center | Center Right | Outlet Left | Outlet Center | Outlet Right |
| 33 | 27 | 33 | 6 | 6 | 6 | 10 | 6 | 12 |

To characterize the solids in the primary tank, total solids (TS), TSS, and volatile suspended solids (VSS) were measured in a sample collected on October 31, 2002. A sample was collected from the second compartment on November 6, 2002. These data, presented in Table 4-9, represent the solids/residue phase of the sample, excluding the liquid phase in the top of the sample column. An additional sample was collected from the first compartment on November 6, 2002. Before taking this second sample, the first compartment of the tank was thoroughly mixed using a large pump. This sample represents a mixed sample (solids and water) of the entire compartment contents, rather than being a single point grab sample.

**Table 4-9. TSS and VSS Results for the RetroFAST® 0.375 System Solids Samples**

| Date | Location | TS (mg/L) | TSS (mg/L) | VSS (mg/L) |
|---|---|---|---|---|
| 10/31/02 | Tank Compartment 1 Sludge sample | 4,100 | 3,100 | 2,200 |
| 11/06/02 | Tank Compartment 2 Sludge sample | 3,600 | 3,600 | 2,300 |
| 11/06/02 | Tank Compartment 1 Completely mixed contents | 4,900 | N/A | N/A |

N/A – not analyzed

The mass of solids present in the first compartment of the septic tank can be roughly estimated from these data. The concentration of TS is 4,900 mg/L in a total volume of 880 gallons. The estimated dry weight of solids, accumulated during the test, is approximately 36 pounds. The data also show that the VSS represented 71% of the TSS in the first compartment and 64% of the TSS in the second compartment.

## 4.4 Operations and Maintenance

Operation and maintenance performance of the RetroFAST® was monitored throughout the verification test and recorded in a field log. Data were collected on electric and chemical usage, noise, and odor. Observations were also recorded on the condition of the system, any changes in setup or operation (blower adjustments, cleaning, etc.), or any problems that required resolution. A complete set of field logs is included in Appendix F. There were no major mechanical component failures during the verification test.

### *4.4.1 Electric Use*

Electric use was monitored by a dedicated electric meter serving the RetroFAST® beginning in October 2001, and meter readings were recorded daily in the field log by MWTTP operators. A second electric meter was installed on March 5, 2002, because the first meter had shown no or very low power consumption on six days over a five-month period,, even though the blower had operated on these days as verified by the operators. Both meters were read daily through the end of the test period, and there was only one additional day, June 28, when meter readings were very low (0.4 kilowatts/day [kW/d]). Both meters gave similar results for the period of March through October 2002. Table 4-10 summarizes the electric use from startup through the end of the verification test. The complete set of daily electric readings is presented in a spreadsheet in Appendix E. The average electrical use was 2.1 kW/d, and power consumption was very consistent throughout the test.

**Table 4-10. Summary of RetroFAST® 0.375 System Electrical Usage**

| | Meter 1 kW/day | Meter 2 kW/day |
|---|---|---|
| Days | 364 | 232 |
| Average | 2.0 | 2.1 |
| Median | 2.1 | 2.1 |
| Maximum | 2.5 | 2.5 |
| Minimum | 0.0(1) | 0.0(1) |
| Std. Dev. | 0.38 | 0.24 |

(1) Measurement made during power failure stress test.

### *4.4.2 Chemical Use*

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

### *4.4.3 Noise*

A calibrated decibel meter was used to measure the noise levels associated with blower equipment twice during the verification period. Measurements were taken 1 meter from the unit and 1.5 meters above the ground, at 90º intervals in four directions around the blower housing. Table 4-11 shows the results of this test.

**Table 4-11. RetroFAST® 0.375 System Noise Measurements**

| Location | June 24, 2002 (decibels) | Sept. 18, 2002 (decibels) |
|---|---|---|
| East | 60 ± 2 for all | 61 |
| South | four locations | 64 |
| West | | 61 |
| North | | 58 |

Note: The June 24 readings are not specific for the location of the four measurements

### *4.4.4 Odor Observations*

Qualitative odor observations based on odor strength (intensity) and type (attribute) were made six times during the verification test. ). Intensity was stated as not discernable, barely detectable, moderate, or strong. Table 4-12 summarizes the results for the odor observations. As can be seen, no significant odors were found during any of the observation periods.

**Table 4-12. Odor Observations**

| Date | Number of Points Observed | Observation |
|---|---|---|
| 9/24/01 | 3 | No discernable odor |
| 11/21/01 | 3 | No discernable odor |
| 4/12/02 | 3 | No discernable odor |
| 03/06/02 | 3 | No discernable odor |
| 06/24/02 | 3 | No discernable odor |
| 09/18/02 | 3 | Barely detectable odor, musty |

### *4.4.5 Operation and Maintenance Observations*

The RetroFAST® system is relatively simple to operate and maintain. The only mechanical/electrical components are the blower, blower control panel, and the airlift system in the treatment unit. Vent openings on the blower housing should be checked for blockage, and a filter on the inlet to the blower needs inspection and periodic cleaning (interval will depend on site conditions). The airlift and media should be inspected for clogging and cleaned if necessary.

No maintenance or cleaning was required or performed during the verification test. On November 14, 2001 (after five months of operation), Bio-Microbics performed a system inspection in the presence of the test facility personnel, checking the blower housing vents, air filter, airlift system, and media. No cleaning was performed. The MWTTF operator noted in the field log that there was some evidence of minor clogging on the top of the media, but no cleaning was performed. Bio-Microbics has indicated that this was biological growth expected to be present. The blower setting was changed using the dip switches on the control panel from 30 minutes on/30 minutes off to continuous operation during this visit.

Two operational problems involving the blower occurred during the 16 months of operation. On August 16, 2001, during the startup period, the blower alarm indicated that the blower was off. The circuit breaker had tripped. The breaker was reset, and the blower started without difficulty. The system ran for 11 months with no shutdowns, until June 28, 2002, when the blower was found to be off. No apparent cause (tripped breaker, electrical interruption, clogged filters, etc.) was found for the blower shutdown. The blower was restarted, and it operated continuously until the end of the verification test.

Bio-Microbics provides a two-year warranty covering parts only. The Homeowners Manual (Appendix A) states that any component parts that fail within the warranty period should be returned to Bio-Microbics, which will replace them. The homeowner is responsible for any labor costs associated with replacement.

The Homeowners Manual also provides basic information on the operation of the system. The installation instructions for contractors cover the basic requirements for system installation and setup. A three-page troubleshooting guide gives some information on diagnosing system malfunctions, but there is no specific guidance given on what to do if problems cannot be solved by the owner. Bio-Microbics does provide a phone number for the Bio-Microbics office.

In the opinion of the MWTTP operators, the system was easy to operate and maintain. The vents and air filter are accessible and can be inspected/cleaned at ground level. The owner should be alert to unusual noises (or lack of sound from the blower), alarms, or any unusual odors coming from the system. If changes to the system are observed, the homeowner can consult the troubleshooting guide. The MWTTF operators believe that to help ensure proper performance of any advanced system, such as the RetroFAST® unit, homeowners should contract with a qualified service provider, who can monitor the system. Based on the observations during the verification test, annual inspection and cleaning may be adequate (no maintenance was required during the test), but semiannual maintenance checks would appear to be more appropriate to ensure system performance. It is estimated that semiannual maintenance checks could be performed in one hour by a qualified service provider. These maintenance activities should include inspecting and cleaning the air intake vents, air filter, and exhaust vents, and checking the airlift system and media condition. The blower and alarms (if included) should be checked for proper operation.

Both compartments of the septic tank should be checked for solids depth by a qualified service provider. If solids have built up in the primary (first) compartment of the septic tank or in the secondary compartment (where the unit is located), pumping of the system should be scheduled. The Homeowners Manual for the RetroFAST® 0.375 provides no guidance on the solids depth in the tank that would indicate that the tank should be pumped. The Bio-Microbics manual for their larger units (0.5 and larger) indicates that solids removal should occur if the solids depth reaches 20 inches in the first compartment or 14 inches in the secondary compartment. Based on the measurements in the two compartments of the tank used for the 16 months of operation during the verification test (Table 4-8), it is estimated that removal of solids could be required every 18 to 24 months. Actual pumping frequency will vary based on the size of the tank used in a given application and the nature of the wastewater.

The verification test (startup and testing) ran for a period of 16 months, which provided sufficient time to evaluate the overall performance of the unit. Based on observations during this test period, the equipment appeared to be properly constructed of appropriate materials for wastewater treatment applications. The verification did not run long enough to truly evaluate length of equipment life, but the basic components of the system appear durable and the overall system design and use of PVC components indicate that it should have a reasonable life expectancy. .

## 4.5 Quality Assurance/ Quality Control

The VTP included a Quality Assurance Project Plan QAPP that identified critical measurements and established Data Quality Objectives (DQO). The verification test procedures and data collection followed the QAPP, and summary results are reported in this section. The laboratory reported QA/QC data with every set of sample results as part of the laboratory reports. Each report includes the results of blanks, laboratory duplicates, spikes, and other lab control sample results for the various analyses. These QA data are incorporated with the laboratory reports presented in Appendix C. Field duplicates were also collected by the TO and submitted for analyses. These results are presented in a spreadsheet in Appendix D.

### *4.5.1 Audits*

In April 2002, NSF conducted an audit of MWTTF and the CanTest Laboratory during the verification test. This audit found that the field and laboratory procedures were being followed as presented in the test plan. The audit was scheduled to coincide with a sampling period at the test site. This allowed the auditor to observe the actual sampling procedures and the preparation of samples for shipment to the laboratory by courier. At the laboratory where samples were being processed, the analyses were observed for several parameters.

The audit found that the procedures being used in the field and the laboratory were in accordance with the established QAPP. Legible field logs were being maintained. The laboratory had a firmly established QA/QC program, and observation of the analyses and a records review found that appropriate QC data was being performed with the analyses. All members of the testing team were reminded that an ETV requires that copies of all logs and raw data records be delivered to NSF at the end of the project.

### *4.5.2 Daily Flows*

One of the critical data quality objectives was to dose the system on a daily basis to within 10% of the design flow, or 375 gpd ± 10%, based on a monthly average of the daily flows. The dose volume was calibrated once per week and, if the volume changed by more than ten percent, the individual dosing time was adjusted in the test site SCADA. The objective was met for all months of the verification test period. The monthly averages were presented in Table 4-4, and the daily flows for all months are presented in spreadsheets in Appendix E. The field logs in Appendix F provide the once per week calibration data that is summarized in the spreadsheets.

### *4.5.3 Precision*

#### 4.5.3.1 Laboratory Duplicates

The analytical laboratory performed sample duplicates for all parameters at a frequency of at least one duplicate for every ten samples analyzed or one per batch if less than ten samples in a batch. The results of laboratory duplicates were reported with all data reports received from the laboratory. Table 4-13 shows the acceptance limits used by the laboratory.

The Relative Percent Difference (RPD) was calculated using the standard formula as follows:

$$RPD = [(C_1 - C_2) \div ((C_1 + C_2)/2)] \times 100\%$$

Where:

$C_1$ = Concentration of the compound or element in the sample
$C_2$ = Concentration of the compound or element in the duplicate

**Table 4-13. Laboratory Precision Limits**

| **Parameter** | **Acceptance Limits (RPD)** |
|---|---|
| TSS | 18 |
| Alkalinity | 10 |
| $BOD_5$/$CBOD_5$ | 15 |
| TKN | 20 |
| $NH_3$-N | 20 |
| $NO_2$ | 12 |
| $NO_2$ | 12 |

The laboratory precision for TKN, $NH_3$-N, $NO_2$, and $NO_3$ was excellent, with all results for the entire verification test being within the acceptance limits. Only one alkalinity duplicate and one $BOD_5$ duplicate were outside the limits, out of more than 100 sets of reported laboratory duplicates. On four occasions during the yearlong verification test, the TSS duplicates were outside of the established limits, but in each case, there were multiple duplicates in batch. As an example, the September 4, 2001, data reported ten duplicate results for TSS, with three being outside the QC limit. In each case, the majority of the duplicates were within acceptance limits, and the data were considered valid after review by the laboratory QA officer. NSF reviewed the QC data and agreed that the data were valid.

The laboratory precision for all parameters, as measured by the laboratory duplicates, was found to meet the QA objectives for the verification test.

4.5.3.2 Field Duplicates

Field duplicates were collected for influent and effluent samples to monitor the overall precision of the sample collection and laboratory analyses. The results for the field duplicates are presented in a spreadsheet in Appendix E. Summaries of the data are presented in Tables 4-14 and 4-15.

**Table 4-14. Duplicate Field Sample Summary – Nitrogen Compounds**

| Statistics | TKN Rep 1 (mg/L) | TKN Rep 2 (mg/L) | TKN RPD (%) | $NH_3$-N Rep 1 (mg/L) | $NH_3$-N Rep 2 (mg/L) | $NH_3$-N RPD (%) |
|---|---|---|---|---|---|---|
| Number | 26 | 26 | 26 | 26 | 26 | 26 |
| Mean | 23 | 23 | 9.2 | 17 | 16 | 8.0 |
| Median | 23 | 24 | 6.8 | 18 | 16 | 4.9 |
| Maximum | 52 | 49 | 87 | 35 | 31 | 55 |
| Minimum | 2.5 | 1.9 | 0.0 | 0.39 | 0.38 | 0.33 |
| Standard Deviation | 15 | 15 | 16 | 12 | 12 | 11 |
| **Statistics** | **$NO_2$ Rep 1 (mg/L)** | **$NO_2$ Rep 2 (mg/L)** | **$NO_2$ RPD (%)** | **$NO_3$ Rep 1 (mg/L)** | **$NO_3$ Rep 2 (mg/L)** | **$NO_3$ RPD (%)** |
| Number | 15 | 15 | 15 | 14 | 14 | 14 |
| Mean | 7.8 | 7.7 | 6.1 | 0.45 | 0.46 | 4.7 |
| Median | 6.1 | 6.2 | 1.6 | 0.46 | 0.47 | 1.6 |
| Maximum | 19 | 18 | 39 | 1.1 | 1.1 | 31 |
| Minimum | <0.05 | <0.05 | 0.0 | <0.002 | <0.002 | 0.0 |
| Standard Deviation | 6.33 | 6.20 | 11 | 0.26 | 0.26 | 8.1 |

Note: All influent $NO_2$ and $NO_3$ duplicates (11 sets for each parameter) were below detection limits yielding a RPD of zero and are not included in the above summary.

**Table 4-15. Duplicate Field Sample Summary – $BOD_5$/$CBOD_5$, TSS, Alkalinity**

| Statistics | $BOD_5$/$CBOD_5$ Rep 1 (mg/L) | $BOD_5$/$CBOD_5$ Rep 2 (mg/L) | $BOD_5$/$CBOD_5$ RPD (%) | TSS Rep 1 (mg/L) | TSS Rep 2 (mg/L) | TSS RPD (%) |
|---|---|---|---|---|---|---|
| Number | 26 | 26 | 26 | 26 | 26 | 26 |
| Mean | 72 | 69 | 26 | 97 | 95 | 16 |
| Median | 18 | 18 | 13 | 46 | 42 | 6.9 |
| Maximum | 195 | 198 | 110 | 325 | 353 | 114 |
| Minimum | 2.0 | 5.0 | 0.0 | 3 | 4 | 0.0 |
| Std. Dev. | 75 | 72 | 30 | 91 | 90 | 24 |

| Statistics | Alkalinity Rep 1 (mg/L as $CaCO_3$) | Alkalinity Rep 2 (mg/L as $CaCO_3$) | Alkalinity RPD (%) |
|---|---|---|---|
| Number | 26 | 26 | 26 |
| Mean | 110 | 110 | 2.4 |
| Median | 130 | 130 | 1.0 |
| Maximum | 170 | 270 | 15 |
| Minimum | 21 | 18 | 0 |
| Std. Dev. | 46 | 47 | 3.9 |

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, particularly for TSS and $BOD_5$. For this QA review, 30% RPD was selected as a target for the QA/QC review of field precision for nutrients and alkalinity, and 40% was the selected target for TSS and $BOD_5$.

The overall precision based on field duplicates for nitrogen compounds was excellent. Only one sample (out of 26, or 25 duplicates) for each of the nutrient analyses (TKN, $NH_3$-N, $NO_2$, and $NO_3$) exceeded 30% RPD. Alkalinity precision was also excellent with all replicates having a RPD of less than 15%.

The $CBOD_5$ and TSS data tended to have lower precision than the other analyses, which is expected in wastewater matrices, particularly in treated effluent that can be at low concentrations. The TSS results showed that four replicates out of 26 exceeded 40% RPD, but all four were effluent samples with low concentration (maximum of 18 mg/L). The low concentrations can exaggerate the relative percent difference calculation, as shown by one sample that had replicate TSS values of 4 and 7 mg/L, yielding a RPD of 55%. Eight of the 26 $BOD_5$/$CBOD_5$ field duplicates showed RPD above 40%; six of these eight replicates were on effluent samples. The low concentrations had an impact on the RPD calculations, as shown by the sample that had replicate $CBOD_5$ values of 2 and 7 mg/L, yielding a RPD of 110%. All of the field data are shown in a spreadsheet in Appendix E. While these data indicate that precision is lower at the lower concentrations, the information in overall data set demonstrates the ability of the treatment system to 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.

#### *4.5.4 Accuracy*

Method accuracy was determined and monitored using a combination of matrix spikes, laboratory control samples (known concentration in blank water), and proper equipment calibration and traceability depending on the analytical method. Recovery of the spiked analytes was calculated and monitored during the verification test. The laboratory used the control samples and recovery limits shown in Table 4-16 and reported the data with each set of analytical results.

The equations used to calculate the recoveries for spiked samples and laboratory control samples are as follows:

Matrix Spike Samples:

$$\text{Percent Recovery} = (Cr - C_o)/C_f \times 100\%$$

Where:
$C_r$ = Total amount detected in spiked sample
$C_o$ = Amount detected in un-spiked sample
$C_f$ = Spike amount added to sample.

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Lab Control Sample:

$$\text{Percent Recovery} = (C_m / C_{known}) \times 100\%$$

Where:

$C_m$ = measured concentration in the spike control sample
$C_{known}$ = known concentration

**Table 4-16. Laboratory Control Limits for Accuracy**

| Parameter | Method Blank | Calibration Curve Check | Lab Control Sample | Matrix Spike | Recovery Limits (%) |
|---|---|---|---|---|---|
| TSS | X | N/A | X | N/A | 80-120 |
| Alkalinity | X | N/A | X | N/A | 85-115 |
| $BOD_5$/$CBOD_5$ | X | N/A | X(1) | N/A | N/A |
| TKN | X | X | X | X | 66-124 |
| $NH_3$-N | X | X | X | X | 80-120 |
| $NO_2$ | X | X | X | X | 86-112 |
| $NO_3$ | X | X | X | N/A | 90-110 |

(1) Seed Control Sample
X Denotes sample collected
N/A Not applicable

Based on review of the data reports, all of the accuracy limits were met in all analytical batches for TSS, Alkalinity, $BOD_5$/$CBOD_5$, $NH_3$-N, $NO_2$, and $NO_3$. Five sample batches for TKN (out of more than 100 batches; more than 120 samples of influent and effluent) had matrix spike recoveries higher than the upper control limit. These data were reviewed, and all other QC parameters (calibration curve, continuing calibration curve checks, control samples, etc.) were found to be within acceptance limits. Based on this review, the laboratory QA officer accepted these data as valid. Overall, the accuracy data for all parameters was found to be excellent and met the quality objectives.

The balance used for TSS analysis was calibrated routinely with weights that were National Institute of Standards and Technology (NIST) traceable. Calibration records were maintained by the laboratory and inspected during the on-site audit. 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 NIST-traceable thermometer. The DO meter was calibrated daily using ambient air and temperature readings in accordance with the standard operating procedure (SOP). The noise meter was calibrated prior to use. All of these traceable calibrations were performed to ensure the accuracy of measurements.

### *4.5.5 Representativeness*

The field procedures were designed to ensure that representative samples were collected of both influent and effluent wastewater. The composite sampling equipment was checked 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 field duplicate samples. However, review of the overall data set for influent and effluent samples did not show specific sampling bias for either TSS or $BOD_5$/$CBOD_5$. These data indicated that while individual sample variability may occur, the data were representative of the concentrations in the wastewater.

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

### *4.5.6 Completeness*

The test plan 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 once a week, as specified. The flow records were 100% complete. Electric meter records were maintained in the field logbook. Electric meter readings were performed daily and summarized in a spreadsheet. The electric monitoring was not started until late October 2001, so only eleven months of power usage data were collected compared to the goal of twelve months of data. Completeness was 92% for the power measurements, which met the QA objective of 83%.

All monthly samples and all stress test samples were collected in accordance with the schedule. Therefore, sample collection was 100% complete, exceeding the goal of 83% for both types of collections.

A goal of 90% was set for the completeness of analytical results from the laboratory. All scheduled analyses for delivered samples were completed and found to be useable data; therefore, laboratory data are 100% complete.

# Appendices

A Bio-Microbics - Homeowners Manual
B Verification Test Plan
C Lab Data and QA/QC Data
D Field Operations and Lab Logbooks
E Spreadsheets with calculation and data summary
F Laboratory Raw Data

Appendices are not included in the Verification Report. Appendices are available from NSF upon request.

# Glossary

**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 startup 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 (QAPP) –** a written document that describes the implementation of quality assurance and quality control (QA/QC) 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** (SOP) **–** 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** (TO) – an independent organization qualified by the Verification Organization (VO) 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** (VTP) – 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 VTP includes detailed instructions for sample and data collection, sample handling and preservation, and QA/QC requirements relevant to the particular test site.

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