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Environmental Technology Verification Report

Nutrient Reduction in Domestic Wastewater From Individual Residential Homes

F.R. Mahony & Associates, Inc. Amphidrome™ Model Single Family 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

TECHNOLOGY TYPE:	**BIOLOGICAL WASTEWATER TREATMENT – NITRIFICATION AND DENITRIFICATION FOR NITROGEN REDUCTION**
APPLICATION:	**REDUCTION OF NITROGEN IN DOMESTIC WASTEWATER FROM INDIVIDUAL RESIDENTIAL HOMES**
TECHNOLOGY NAME:	**AMPHIDROME™ MODEL SINGLE FAMILY SYSTEM**
COMPANY:	**F.R. MAHONY & ASSOCIATES, INC.**
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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 growth biological filter treatment system for nitrogen removal for residential applications. The Barnstable County (Massachusetts) Department of Health and the Environment (BCDHE) performed the verification testing. This verification statement provides a summary of the test results for the F.R. Mahony & Associates, Inc. (FRMA), Amphidrome™ Model Single Family System.

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

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

ABSTRACT

Verification testing of the Amphidrome™ Model Single Family System was conducted over a thirteen-month period at the Massachusetts Alternative Septic System Test Center (MASSTC) located at Otis Air National Guard Base in Bourne, Massachusetts. Sanitary sewerage from the base residential housing was used for the testing. An eight-week startup period preceded the verification test to provide time for the development of an acclimated biological growth in the Amphidrome™ System. The verification test included monthly sampling of the influent and effluent wastewater, and five test sequences designed to test the unit response to differing load conditions and power failure. The Amphidrome™ System proved capable of removing nitrogen from the wastewater. The influent total nitrogen (TN), as measured by TKN, averaged 37 mg/L with a median of 37 mg/L. The effluent TN (TKN plus nitrite/nitrate) concentration averaged 15 mg/L over the verification period, with a median concentration of 14 mg/L, with an average TKN concentration of 8.5 mg/L and a median concentration of 8.3 mg/L. The system operating conditions (pump and float settings, aeration cycles), are controlled by a programmable logic controller (PLC) and were adjusted four times during the first two months of the verification test, and after six months of test operation. In general, the mechanical equipment, pumps, level switches and alarms operated properly during the test, except for a discharge pump failure after nine months of operation, and the return pump slipping off its pedestal in June 2001. The Amphidrome™ System is sophisticated and requires a trained operator to monitor the system and ensure the pump cycle times, aeration periods, and backwash settings are set to the site specific conditions.

TECHNOLOGY DESCRIPTION

The following description of the F.R. Mahoney Amphidrome System was provided by the vendor and does not represent verified information.

The Amphidrome™ System consists of a submerged growth sequencing batch reactor used in conjunction with an anoxic/equalization tank (standard 2,000 gallon tank, but a 1,500 gallon two compartment septic tank for this test), and a clear well tank for wastewater treatment. The anoxic tank provides solid-liquid separation, and anoxic conditions for denitrification. The bioreactor consists of a deep bed sand filter, which alternates between aerobic and anoxic treatment. The reactor operates similar to a biological aerated filter, except that the reactor changes from aerobic to anoxic conditions during sequential cycling of the unit. Air, supplied by a blower, is introduced at the bottom of the filter by a distribution system that produces fine bubbles to enhance oxygen transfer. According to the vendor, the unique system design allows soluble organic removal, nitrification, and denitrification to occur in one reactor.

The cyclical action of the system is created by allowing a batch of wastewater to pass by gravity flow from the anoxic/equalization tank through the submerged sand filter (down flow mode) and into the clear well. The flow is then reversed using a pump to move water from the clear well up through the filter and into a return pipe, which carries the wastewater back to the anoxic tank. These cycles are repeated multiple times during a 24-hour period. The conditions in the filter change from aerobic to anoxic based on the timing of the aeration cycles, with a typical cycle being 3 to 5 minutes of aeration, followed by 15 minutes without aeration. The filter is backwashed using a combination of aeration and pumped water from the clear well. Treated wastewater is discharged once per day from the clear well by pumping to the receiving location. The Amphidrome™ System is supplied with a programmable logic controller (PLC), which controls the frequency and duration of pump operation, aeration cycles, backwash, and discharge, as well as all alarm functions and data collection.

VERIFICATION TESTING DESCRIPTION

Test Site

The MASSTC site is located at the Otis Air National Guard Base in Bourne, Massachusetts. The site uses domestic wastewater from the base residential housing, and sanitary wastewater from other military buildings in testing. A chamber located in the main interceptor sewer to the base wastewater treatment facility provides a location to obtain untreated wastewater that is pumped to the site dosing channel after passing through a one-inch bar screen. The channel is equipped with four recirculation pumps that are spaced along the channel length to ensure mixing and wastewater of similar quality in the channel. Wastewater is dosed to the test unit using a pump submerged in the dosing channel. A programmable logic controller (PLC) is used to control the pumps and the dosing sequence or cycle.

Methods and Procedures

The Amphidrome™ System was installed by a contractor in December 1999 as part of an earlier test program. The unit was installed in accordance with the installation instructions supplied by FRMA. In order to prepare for ETV testing, the entire system was emptied of wastewater and cleaned. Solids were removed from the septic tank and the clear well, all pumps, lines, and associated equipment were cleaned, and the sand filter was flushed repeatedly by recirculating clean water through the system. The entire system was then drained and remained off until the startup period. On January 15, 2001, the septic tank was filled with wastewater and the standard dosing sequence began. An eight-week startup period allowed the biological community to become established and the operating conditions to be monitored.

System monitoring during the startup period included visual observations, routine calibration of the dosing system, and collection of influent and effluent samples. Six sets of samples were collected for analysis over the startup period. Influent samples were analyzed for pH, alkalinity, temperature, BOD_5, TKN, NH_3, and TSS analyses. Effluent samples were analyzed for pH, alkalinity, temperature, $CBOD_5$, TKN, NH_3, TSS, dissolved oxygen, NO_2^- and NO_3^-.

Verification testing consisted of a thirteen-month period, with five stress test sequences simulating household conditions. The five stress sequences were performed at two-month intervals, and included washday, working parent, low load, power/equipment failure, and vacation conditions. Monitoring for nitrogen reduction was accomplished by measuring the nitrogen species (TKN, NH_3, NO_2, NO_3), while biochemical and carbonaceous oxygen demand (BOD_5/$CBOD_5$) and other basic parameters (pH, alkalinity, TSS, temperature) were monitored to provide information on overall system performance. Operational characteristics, such as electric use, residuals generation, maintenance tasks and labor, hardware durability, noise and odor production were also monitored.

The Amphidrome™ System was tested at the design capacity of 400 gallons per day (± 10 percent) for the entire thirteen-month test, except during the low load and vacation stress tests. The Amphidrome™ System was dosed 15 times per day with approximately 26.7 gallons of wastewater per dose. The unit received five morning doses, four mid-day doses, and six evening doses. Dosing volume was controlled by adjusting pump run time for each cycle, based on twice-weekly calibration of the dosing pump.

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

Samples were collected and preserved as appropriate, and transported to the laboratory. All analyses were performed according to "*Standard Methods for the Examination of Water And Wastewater*", 19th Edition, 1998. Washington, D.C. or other EPA approved 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 the analytical methods and QA/QC procedures are provided in the full Verification Report.

PERFORMANCE VERIFICATION

Overview

Evaluation of the Amphidrome System at MASSTC began on March 13, 2001, when the system pumps were activated and the wastewater dosing started. Verification testing continued for thirteen months until April 17, 2002. During the verification test, 53 sets of samples of the influent and effluent were collected to determine the system performance.

Startup

The unit started up with no difficulty. The installation instructions were easy to follow and installation proceeded without difficulty. FRMA representatives setup the PLC, which controlled all recirculation, aeration, backwash, and discharge times. No changes were made to the unit during the startup period and no special maintenance was required.

The Amphidrome™ System showed a reduction in $CBOD_5$ and TSS after the first week of operation, and continued to improve over the next seven weeks. At the end of the eight-week startup, effluent $CBOD_5$ was 5.0 mg/L and TSS was 4 mg/L. There was some TN reduction occurring, with effluent concentrations varying between 21 and 28 mg/L, compared to influent concentrations of 34 to 46 mg/L. However, it did not appear that the nitrifying organisms were firmly established in the system. Low wastewater temperature was considered the primary reason for the slow trend toward improved reduction in TN as the wastewater temperature was no higher than about 8 ^{o}C through March 13.

Verification Test Results

The verification protocol requires sampling during and following the major stress periods. This results in a large number of samples being clustered during five periods, with the remaining samples spread over the remaining months (monthly sampling). Both average (mean) and median results are presented, as the median values compared to average values can help in analyzing the impacts of the stress periods.

The TSS and BOD_5/$CBOD_5$ results for the verification test, including all stress test periods, are shown in Table 1. The influent wastewater had an average BOD_5 of 210 mg/L (median of 200 mg/L) and average TSS of 150 mg/L (median of 130 mg/L). The Amphidrome™ effluent had an average $CBOD_5$ of 4.9 mg/L, with a median $CBOD_5$ of 4.4 mg/L. The average effluent TSS was 5 mg/L and the median was 3 mg/L. During the thirteen-month test, effluent $CBOD_5$ concentrations typically ranged from 1 to 10 mg/L, except for two samples, and TSS ranged from 1 to 11 mg/L, except for 3 samples.

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
Average	210	4.9	97	150	5	96
Median	200	4.4	98	130	3	98
Maximum	370	20	>99	340	40	>99
Minimum	67	<2.0	90	61	1	64
Std. Dev.	73	3.5	1.5	67	7	6.0

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

The nitrogen results for the verification test, including all stress test periods, are shown in Table 2. The influent wastewater had an average TKN concentration of 37 mg/L (median of 37 mg/L) and an average ammonia nitrogen concentration of 23 mg/L (median of 23 mg/L). The average TN concentration in the influent was 37 mg/L (median of 37 mg/L), based on the assumption that the nitrite and nitrate concentrations in the influent were negligible. The Amphidrome™ System effluent had an average TKN concentration of 8.5 mg/L (median of 8.3 mg/L) and an average NH_3-N concentration of 7.0 mg/L (median of 6.1 mg/L). The nitrite concentration in the effluent averaged 0.27 mg/L, while effluent nitrate concentrations averaged 6.4 mg/L (median of 5.5 mg/L). Total nitrogen was determined by adding the daily concentrations of the TKN (organic plus ammonia nitrogen), nitrite, and nitrate. Average TN in the Amphidrome™ System effluent was 15 mg/L (median 14 mg/L) for the thirteen-month verification period. The System averaged a 59 percent reduction of TN for the entire test, with a median removal of 62 percent.

Table 2. Nitrogen Data Summary

	TKN (mg/L)		Ammonia (mg/L)		Total Nitrogen (mg/L)		Nitrate (mg/L)	Nitrite (mg/L)	Temperature (°C)
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Effluent	Effluent	Influent
Average	37	8.5	23	7.0	37	15	6.4	0.27	15
Median	37	8.3	23	6.1	37	14	5.5	0.25	14
Maximum	45	31	29	25	45	31	19	1.3	22
Minimum	24	1.0	18	0.4	24	10	<0.1	0.08	8.4
Std. Dev.	4.1	6.4	2.4	4.7	4.1	3.6	4.5	0.20	4.3

Note: The data in Table 2 are based on 53 samples, except for temperature, which is based on 42 samples.

Verification Test Discussion

Beginning in late March and early April, temperatures began to increase and the nitrifying population clearly became more firmly established, as indicated by the decrease in the effluent TKN and ammonia concentrations to 10 mg/L or less. Nitrate concentrations increased somewhat in this same period, but the data show that denitrification was also occurring. Organic concentration in the effluent was low, as measured by $CBOD_5$ concentrations of 4.0-5.0 mg/L. During May and June, the TN concentration in the effluent was in the range of 13 to 16 mg/L. The washday stress test in May 2001 showed no negative impact on nitrogen reduction.

In early July 2001, the data show that there was loss of the nitrifying population in the unit, with TKN and ammonia nitrogen levels in the effluent increasing to 31 and 25 mg/L, respectively. The nitrate levels dropped to less than 0.1 mg/L, which would be more typical of influent wastewater. On June 21, it was discovered that the return pump had slipped off its pedestal, disconnecting the return line and stopping the return flow through the sand filter to the anoxic tank. It is estimated that the wastewater was treated by only a single pass through the sand filter for about two weeks before the return pump problem was corrected and proper operation was restored. The lack of recycle flow apparently caused the loss of nitrification in the system.

The working parent stress test started on July 9 and continued until July 13, 2001. The Amphidrome System began to recover from the June upset with improved $CBOD_5$ and TSS performance, but the nitrification process was much slower in its recovery. Some removal of TKN, ammonia and TN occurred during the working parent stress test monitoring in mid-July, but at a lower performance level than during the previous two months. During the stress test, there was no sign that the stress test itself was having any additional impact on the system.

The monthly samples on August 1 and September 5 showed an improvement in the removal of TKN and ammonia, indicating that the nitrifying population was re-established. Nitrate levels in the effluent increased somewhat (from 3.3 to 7.9 mg/L) and TN in the effluent was in the 14 to 15 mg/L range.

The low load stress test began on September 17 and continued until October 8, 2002. During this stress period, the nitrification process became very efficient, dropping the TKN and ammonia levels in the effluent to less than 1 mg/L. Nitrate concentrations increased to 14 to 19 mg/L and TN was 14 to 20 mg/L. As the low load stress test ended, virtually all of the TN in the effluent was in the form of nitrate. Once the system returned to normal full flow conditions, the TKN and ammonia concentrations in the effluent rose slightly (from 1.2 to 4.8 mg/L), and nitrate concentrations decreased to 10 to 14 mg/L. Overall, the TN removal performance was steady at the end of the monitoring period with effluent concentrations of 10 to 14 mg/L, similar to the results obtained in May prior to the upset, except that the primary component of the TN concentration was nitrate. The vendor decreased the aeration time by ten percent to try to improve denitrification performance.

During the November 2001 to January 2002 period, including the power/equipment failure stress test in December, the Amphidrome System produced steady results, with TN in the effluent of 10 to 16 mg/L, a removal efficiency of 57 to 77 percent. TN in the effluent was composed of TKN and nitrate, similar to the two month period prior to the June upset condition. The power/equipment failure stress test, performed on December 3 did not have a major impact on the system.

The vacation stress test (no influent flow for eight days) was performed in February 2002. The effluent TKN and ammonia concentrations decreased in the samples taken immediately after flow was resumed to the system. The nitrate levels increased in a manner similar to the findings following the low load stress test. TN concentrations remained steady in the effluent ranging from 12 to 17 mg/L. By the end of the post stress test monitoring period, effluent concentrations consisted of TKN at 5.5 mg/L and nitrate at 6.8 mg/L. These data, supported by the results from the low load stress test, suggest that the Amphidrome™ System responded to decreases in flow by exhibiting improved nitrification and less denitrification. The TN performance, however, did not change much, with effluent concentrations remaining near the long-term average and median of 15 mg/L and 14 mg/L, respectively.

The Amphidrome System performance remained consistent for the duration of the verification test, with TKN and ammonia nitrogen effluent concentration consistently in the 7.6 to 9.5 mg/L range. The nitrate levels remained in the 3.0 to 4.8 mg/L range. The TN concentration in the effluent ranged from 11 to 15 mg/L.

The verification test provided a sufficiently long test period to collect data that included both a long run of steady performance by the Amphidrome™ System and a period of reduced nitrification and denitrification efficiencies. During the months of April through June, following startup, the TN removal was in the 45 to 71 percent range, with effluent concentrations typically in the 13 to 16 mg/L range. The June upset condition, caused by the problem with the return pump, dramatically impacted the nitrification process in early July. The system recovered from the upset by the end of July and continued to remove TN. During the last eight months of the verification test, the TN removal was in the 52 to 77 percent range. Effluent TN concentration ranged from 10 to 20 mg/L, with most concentrations in the 13 to 15 mg/L range. Data collected from the two low or no flow stress tests indicated that overall system performance for TN was not significantly impacted, but the effluent concentrations of TKN, ammonia and nitrate changed significantly during these lower flow periods.

Operation and Maintenance Results

Noise levels associated with mechanical equipment were measured once during the verification period using a calibrated decibel meter. Measurements were made one meter from the unit, and one and a half meters above the ground, at 90° intervals in four (4) directions. The average decibel level was 56.7, with a minimum of 54.3 and maximum of 60.0. The background level was 37.7 decibels.

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

Electric power use was monitored by a dedicated electric meter serving the Amphidrome™ System. The average electrical use was 4.1 kW/day. However, there was one two-week period of high electrical use in June 2001, when the return pump slipped off its pedestal, disconnecting the return line and pumping continuously for about two weeks.

During the verification test, one other mechanical problem occurred when the discharge pump failed. The high water alarm sounded and a service call was placed to FRMA. They responded within twenty-four hours and replaced the pump. Overall, the treatment unit appeared to be a durable design. The piping is PVC, which is appropriate for the applications. Pump and level switch life is always difficult to estimate, but the components used were made for wastewater applications. The PLC, which is critical to the operation of the system, functioned properly throughout the test. The system does not require or use any chemicals as part of normal operating conditions.

The Amphidrome™ System is a somewhat complex, PLC controlled wastewater treatment system, using a sophisticated operating cycle that must be setup and optimized to site specific and changing conditions. During the first two months of verification testing (April and May), the vendor adjusted the PLC on four occasions. The airflow was adjusted in early April and the backwash cycle was adjusted in mid-May. On May 24, the cycle times were adjusted to try to improve the performance, but were returned to the initial conditions on June 1. The anoxic cycle was adjusted on October 21, and the fixed airflow time was reduced by 10 percent on October 25, 2001 to try to improve denitrification. These adjustments were made to try to match the aerobic/anoxic cycles to the wastewater and system conditions. Based on these observations, it will be necessary for homeowners to have a qualified maintenance organization operate and maintain the system.

Quality Assurance/Quality Control

NSF International completed QA audits of the MASSTC and BCDHE laboratory during testing. NSF personnel completed a technical systems audit to assure the testing was in compliance with the test plan, a performance evaluation audit to assure that the measurement systems employed by MASSTC and the

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

Original signed by *Hugh W. McKinnon* *7/23/03*	*Original signed by* *Gordon E. Bellen* *7/23/03*
Hugh W. McKinnon Date	Gordon E. Bellen Date
Director	Vice President
National Risk Management Research Laboratory	Research
Office of Research and Development	NSF International
United States Environmental Protection Agency	

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:

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

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Prepared by

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

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May 2003

Notice

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

Foreword

The 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.

Hugh W. McKinnon, Director
National Risk Management Research Laboratory

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Glossary of Terms

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

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

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

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

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

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

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

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

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

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

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

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

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

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 USEPA to verify environmental technologies and to issue Verification Statements and Verification Reports.

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

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

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

Abbreviations and Acronyms

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

Acknowledgments

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

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

1.0 Introduction

1.1 ETV Purpose and Program Operation

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

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

NSF International (NSF), in cooperation with the EPA, operates the Water Quality Protection Center (WQPC), one of six Centers in the ETV Program. Source Water Protection (SWP) is one of two technical areas addressed by the WQPC. The WQPC-SWP evaluated the performance of the Amphidrome™ Model Single Family System (Amphidrome™ System) for the reduction of nitrogen compounds (TKN, NH_3, NO_2, NO_3), present in residential wastewater. F.R. Mahony & Associates, Inc. (FRMA) sells the Amphidrome™ Model Single Family System to treat wastewater from single-family homes. Other models of the Amphidrome™ System are available for commercial businesses, and similar applications. The Amphidrome™ Reactor is designed to work in conjunction with a vendor provided anoxic/equalization tank and Clear Well, to provide nitrogen reduction in addition to the removal of organics and solids present in residential wastewater. The Amphidrome™ Reactor is based on a submerged growth bioreactor process, operating in a batch mode. This report provides the verification test results for the Amphidrome™ Model Single Family 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 Amphidrome™ System was a cooperative effort between the following participants:

- NSF International
- Massachusetts Alternative Septic System Test Center

- Barnstable County Department of Health and Environment Laboratory
- Groundwater Analytical, Inc.
- Scherger Associates
- F.R. Mahony & Associates, Inc.
- EPA

1.2.1 NSF International - Verification Organization (VO)

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

NSF's responsibilities as the Verification Organization included:

- Review and comment on the site specific VTP;
- Coordinate with peer-reviewers to review and comment on the VTP;
- Coordinate with the EPA Project Manager and the technology vendor to approve the VTP prior to the initiation of verification testing;
- Review the quality systems of all parties involved with the Testing Organization and, subsequently, qualify the companies making up the Testing Organization;
- Oversee the technology evaluation and associated laboratory testing;
- Carry out an on-site audit of test procedures;
- Oversee the development of a verification report and verification statement;
- Coordinate with EPA to approve the verification report and verification statement; and,
- Provide 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, Michigan 48105
(734) 769-8010

1.2.2 U.S. Environmental Protection Agency

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

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

The key EPA contact for this program is:

Mr. Ray Frederick, Project Officer, ETV Water Quality Protection Center
U.S. EPA, NRMRL
Urban Watershed Management Branch
2890 Woodbridge Ave. (MS-104)
Edison, NJ 08837-3679
(732)-321-6627
email: frederick.ray@epa.gov

1.2.3 Testing Organization

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

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

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

The responsibilities of the TO included:

- Prepare the site specific VTP;
- Conduct Verification Testing, according to the VTP;

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

The key personnel and contacts for the TO are:

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

Scherger Associates was responsible for:

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

The key contact at Scherger Associates is:

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

1.2.4 Technology Vendor

The nitrogen reduction technology evaluated was the Amphidrome™ System manufactured by F.R. Mahony & Associates, Inc. (FRMA). The vendor was responsible for supplying all of the equipment needed for the test program, and supporting the TO in ensuring that the equipment was properly installed and operated during the verification test. Specific responsibilities of the vendor include:

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

The key contact for FRMA is:

Mr. Keith Dobie
F.R. Mahony & Associates, Inc.
273 Weymouth Street
Rockland, MA 02370
(281) 982-9300
Email: keithdobie@frmahony.com

1.2.5 ETV Test Site

The Massachusetts Alternative Septic System Test Center (MASSTC) was the host site for the nitrogen reduction verification test. The MASSTC is located at Otis Air National Guard Base, Bourne, MA. The site was designed as a location to test septic treatment systems and related technologies. A full description of the technology verification test site is provided in Section 3.2 of this report. MASSTC provided the location to install the technology and all of the infrastructure support requirements to collect domestic wastewater, pump the wastewater to the system, operational support, and maintenance support for the test. Key items provided by the test site were:

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

1.2.6 Technology Panel

Representatives from the Technology Panel assisted the Verification Organization in reviewing and commenting on the Verification Test Plan. The Technology Panel consists of technical experts from the stakeholder group and other volunteer participants with specific knowledge of wastewater treatment processes. A list of current participants is available from NSF.

1.3 Background – Nutrient Reduction

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

The reduction of nutrients in domestic wastewater discharged through onsite treatment systems 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 have been demonstrated to be effective in removing nutrients in on-site domestic wastewater. The Amphidrome™ process is based on a submerged growth biological reactor operating in the batch mode. The Amphidrome™ process uses a submerged bioreactor with an attached microbial population for nitrification and denitrification. The process changes the bioreactor conditions between aerobic and anoxic by controlling the aeration period. The anoxic condition in the anoxic/equalization tank also promotes biological denitrification. A brief discussion of basic nitrification and denitrification processes is given below.

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

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

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

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

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

1. Organic loading: The efficiency of the nitrification process is affected by the organic loadings. Although the heterotrophic biomass is not essential for nitrifier attachment, the heterotrophs (organisms that use organic carbon for the formation of cell tissue) form biogrowth to which the nitrifiers adhere. The heterotrophic bacteria grow much faster than nitrifiers do at high BOD_5 concentrations. As a result, the nitrifiers can be over grown by heterotrophic bacteria, which can cause the nitrification process to cease. In order for nitrification to take place, the organic loadings for submerged growth sequencing batch reactors should be less than 1 kg/m^3/day.

2. Hydraulic loading: Wastewater is normally introduced at the top of the submerged growth filter systems and flows down through a medium. The total hydraulic flow to the submerged filter can be controlled to some extent by recirculation of the treated effluent. Both hydraulic and organic loadings are important parameters that must be considered. A benefit of recirculation in nitrifying reactors is the reduction of the influent BOD_5 concentration, which makes the nitrifiers more competitive.

3. pH: The nitrification process produces acid. The acid formation lowers the pH and can cause a reduction in the growth rate of the nitrifying bacteria. The optimum pH for *Nitrosomonas* and *Nitrobacter* is between 7.5 and 8.5. At a pH of 6.0 or less nitrification normally will stop. Approximately 5.9 pounds of alkalinity (as $CaCO_3$) are destroyed per pound of ammonia oxidized to nitrate.

4. Dissolved Oxygen (DO): The concentration of dissolved oxygen affects the rate of nitrifier growth and nitrification in biological waste treatment systems. The DO concentration at which nitrification is limited can be 0.5 to 2.5 mg/L in either suspended or attached growth systems under steady state conditions, depending on the degree of mass-transport or diffusional resistance and the solids retention time. The maximum nitrifying growth rate is reached at a DO concentration of 2 to 2.5 mg/L. However, it is not necessary to grow at the maximum growth rate to get effective nitrification if there is adequate contact time in the system. As a result, there is a broad range of DO values where DO becomes rate limiting. The intrinsic growth rate of *Nitrosomonas* is not limited at DO concentrations above 1.0 mg/L, but DO concentrations greater than 2.0 mg/L may be required in practice. Nitrification consumes large amounts of oxygen with 3.8 pounds of O_2 being used for every pound of ammonia oxidized.

1.3.2 Biological Denitrification

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

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

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

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

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

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

2. 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.

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

2.0 Technology Description and Operating Processes

2.1 Technology Description

The Amphidrome™ System consists of a submerged growth sequencing batch reactor used in conjunction with an anoxic/equalization tank, and a clear well tank for wastewater treatment. The anoxic tank provides solid - liquid separation, and anoxic conditions for denitrification. The bioreactor consists of a deep bed filter, which alternates between aerobic and anoxic treatment. The reactor operates similar to a biological aerated filter[(3)] (BAF) or re-circulating sand filter except that the reactor changes from aerobic to anoxic conditions during the sequential cycling of the unit. According to FRMA, the unique design allows for the removal of soluble organics, and for the nitrification and denitrification process to occur in one reactor. The cyclical action of the system is created by allowing a batch of wastewater to pass by gravity flow from the anoxic/equalization tank through the submerged granular biological filter and into the clear well. The flow is then reversed using a pump to move water from the clear well up through the filter and into a return pipe, which carries the wastewater back to the anoxic tank. These cycles are repeated multiple times, with the conditions changing from aerobic to anoxic within the biofilter. After several cycles, the wastewater is discharged from the clear well to the receiving leach field or other receiving environment.

In the submerged biofilter, organic material in the wastewater is degraded by microorganisms present on the media. Organic removal ($CBOD_5$) occurs as the wastewater passes through the media into the clear well. Nitrogen compounds, organic nitrogen and ammonia, are converted to nitrite and nitrate as the wastewater passes through the Amphidrome™ System's reactor under aerobic conditions. The treated effluent is recycled back through the biofilter (up flow mode) and returns to the anoxic tank. FRMA claims that denitrification occurs in the submerged biofilter unit, as the reactor changes from aerobic to anoxic conditions, based on programmable logic controller (PLC) control of the air injection system and pump cycle times. According to FRMA, both nitrifying and denitrifying organism are present in the Reactor. Denitrification also occurs in the anoxic tank, where nitrified wastewater, returned from the clear well (back through the submerged filter unit), mixes with incoming untreated wastewater.

2.2 Amphidrome™ System Process Description

2.2.1 Overview of the Amphidrome™ Process

The Amphidrome™ System is a somewhat complex and sophisticated system that uses PLC control of aeration and pump cycles to treat wastewater. There are numerous options within the PLC to adjust aeration duration and frequency, in addition to controlling return flow cycle times, frequency and duration of backwash, and discharge frequency and time of day. This section provides a simple overview of the process based on a "typical" setup for the system. Actual settings need to be determined based on site-specific conditions. A more detailed discussion of the process cycles and PLC options is presented in the next section and in Appendix A.

Figure 2-1 gives an overview of the normal cycles used in the Amphidrome™ System. There are normal forward, flow periods with aeration, normal forward, flow periods without aeration, and normal return flow periods with or without aeration. A typical sequence within a one-hour period is as follows:

1. Wastewater enters the anoxic tank from the residence and gravity flow moves the wastewater from the anoxic tank through the submerged filter in a downward mode. The water flows by gravity from the filter unit to the clear well. The aeration system is on (one of three 5 minute aeration periods in the hour), adding air (oxygen) to the system. This part of the cycle is called the CalOX™ cycle in Figure 2-1. During this time, the submerged filter is aerobic and nitrification is occurring, converting ammonia to nitrate. Organic removal is also occurring. Many solids in the anoxic tank effluent are trapped on the top of the sand filter.
2. Forward gravity flow continues after the aeration system shuts down. The submerged filter dissolved oxygen level decreases, as more wastewater flows downward through the unit. When the dissolved oxygen level becomes very low, denitrification begins to occur removing available nitrate in the wastewater. This cycle is shown in Figure 2-1 and is called the Denite® cycle.
3. After 15 minutes, the aeration system starts again and runs for 5 minutes, repeating the process described in number 1 above. As dissolved oxygen increases, the nitrification process increases, converting ammonia to nitrate. During cycles described in items 1, 2, and 3, treated wastewater is accumulating in the clear well.
4. After one hour, the return pump in the clear well is activated by the PLC. The accumulated water in the clear well is pumped upward through the filter, and enters the return line at the top of the filter. The return wastewater mixes with any incoming wastewater at the front of the anoxic tank. This cycle is shown in Figure 2-1 as the return CalOX™ cycle. The return pump shuts down when the low level switch in the clear well is activated. Thus, most of the wastewater in the clear well is recycled to the front of the system and flows again by gravity back through the filter system, receiving additional treatment.
5. The anoxic tank will have nitrate present from the clear well water (after nitrification in the filter unit, see step 1). Denitrification will occur in the anoxic tank.

The hourly cycle of forward gravity flow with/without aeration and the pumped return flow from the clear well to the anoxic tank, once per hour, is repeated for approximately 23 hours. At the end of the daily cycle, the treated wastewater in the clear well is pumped to the receiving location (leach field or other location). At this time, the system is ready to start another "batch" treatment of wastewater as it is received during the next day.

One additional cycle must occur periodically. The system will require backwashing to remove accumulated solids on the top of the sand filter and some of the solids attached to the submerged filter. Backwash normally occurs from once per day to once per week depending on the system needs. When the PLC activates the backwash cycle, the same pump that was used for the hourly return is used to pump clear well water up through the unit. Simultaneously, the process blower is activated which provides a vigorous aeration of the filter system. The combined effect of the up flow of water and the aeration is designed to dislodge the accumulate solids. Once a backwash is complete, the system returns to the normal hourly cycle described in items 1 through 5 above.

2.2.2 Detailed Process Amphidrome™ Process Description

The Amphidrome™ System is a submerged attached growth bioreactor process, designed around a deep-bed sand filter. FRMA states that it is specifically designed for the simultaneous removal of soluble organic matter, nitrogen, and suspended solids within a single reactor. Since it removes nitrogen, it is considered a biological nutrient removal (BNR) process. To achieve simultaneous oxidation of soluble material, nitrification, and denitrification in a single reactor, the process provides aerobic and anoxic environments for the two different populations of microorganisms. The treatment system utilizes two tanks and one submerged attached growth bioreactor, called the Amphidrome™ Reactor.

The first tank, the anoxic/equalization tank, receives raw wastewater from the home. The tank serves as a primary clarifier before the Amphidrome™ Reactor and is similar to a septic tank. FRMA describes the anoxic/equalization tank as having three zones, the equalization zone, the settling zone and the solids storage zone. The upper part of the tank receives the incoming raw wastewater and receives the return flow from the biofilter. The two flows mix in the tank and flow by gravity to the Amphidrome™ Reactor. Solids settle in the anoxic/equalization tank, moving through the settling zone to the bottom of the tank. Accumulated solids are stored in the bottom of the tank.

The Amphidrome™ Reactor consists of the following three items: under drain, support gravel, and filter media. The under drain, constructed of stainless steel, is located at the bottom of the reactor. It provides support for the media and even distribution of air and water into the reactor. The under drain has a manifold and laterals to distribute the air evenly over the entire filter bottom. Air is supplied by a single 1/3 hp blower supplied with the system. The design allows for both the air and water to be delivered simultaneously, or separately, via individual pathways to the bottom of the reactor. As the air flows up through the media, the bubbles are sheared by the gravel and sand, producing finer bubbles as they rise through the filter. On top of the under drain is 18" (five layers) of five different sizes of gravel (1 ½ × ¾ inch on the bottom, and progressively smaller to ½× ¼ inch at the top). Above the gravel is a bed of coarse, round silica sand media. The media functions as a filter, reducing suspended solids, and provides the surface area where attached growth biomass can be maintained.

During normal, gravity flow conditions, wastewater from the anoxic/equalization tank flows into the reactor, raising the water level (the biofilter is always submerged). The increased water level in the reactor pushes water from the underdrain through the pipe connected to the backwash/recirculation pump in the clear well. The water flows through the pump into the clear well chamber. A vent hole in the pipe within the clear well provides a vacuum break to prevent siphoning of water from the reactor into the clear well.

To achieve the two different environments (aerobic and anoxic) required for the simultaneous removal of soluble organics and nitrogen, aeration of the reactor is intermittent rather than continuous. Depending on the strength and the volume of the wastewater, a typical aeration scheme may be three to five minutes of air and ten to fifteen minutes without air. Concurrently, return cycles are scheduled every hour, regardless of the aeration sequence. During a return cycle, water from the clear well is pumped to the underdrain of the reactor, moves up through the filter, and overflows into an energy-dissipating TEE. A check valve in the influent line (located below the return/backwash line) prevents the flow from returning to the anoxic/equalization tank via that route. The energy-dissipating TEE is set at a fixed height above both the media and the influent line, and the flow is by gravity through the return/backwash line to the inlet end of the anoxic/equalization tank. FRMA indicates that the cyclical forward and reverse flow of the waste stream and the intermittent aeration of the filter achieve the required hydraulic retention time, and create the necessary aerobic and anoxic conditions to achieve the required level of treatment.

Figure 2-1 shows the Amphidrome™ System during each of the operating cycles and Figure 2-2 shows a process flow diagram for the system. Figures 2-3 through 2-5 show the three individual tanks used in the system. FRMA provides a Single Family Installation Instruction Manual, and an Operation and Maintenance Manual for the Amphidrome™ System. These manuals and general literature, providing additional details, are presented in Appendix A.

The Amphidrome™ System is controlled by a programmable logic controller (PLC). The PLC is programmed to operate the blower, all of the pump times/cycles, and respond to high and low level switches and alarms. For this verification test all programming of the PLC was performed by FRMA. The clear well of the system being tested had two pumps, a discharge pump and a return/backwash pump (for larger systems there can be four pumps, two discharge, one return, one backwash) installed to handle the various wastewater transfers.

The discharge pump is activated once per day (there is an option to discharge twice per day) to discharge treated wastewater from the system. This pump is started by the PLC timer and discharges wastewater until the pump is stopped by a middle level float in the clear well. There is also a high level float in the clear well, which activates the discharge pump for a short period (5 minutes) to prevent clear well overflow.

The second pump in the clear well is used to return wastewater from the clear well back through the filter (up flow mode) and into the anoxic tank. The PLC controls the number of return cycles by a timer and float system. Under normal operation, the PLC starts the return pump every hour, giving a return flow frequency of 24 times per day. The pump run time is set so that most of the water in the clear well is returned to the anoxic tank. The pump duration timer is started when the high float in the reactor is tripped, indicating that water has risen to the level of the gravity return line that carries the wastewater back to the anoxic tank. The return pump cycle, used in conjunction with the middle float in the clear well, is also used by the PLC to calculate the influent flow from the residence. The middle float in the clear well is used to stop the discharge pump (see discussion above), and thus can be used as an indicator of how much water has entered the system since the last discharge. When the return pump is started, the PLC monitors the time until the middle float drops, providing a basis for estimating the amount of influent volume received since the last discharge. This influent volume calculation is important as the PLC uses this estimate to adjust the aeration cycles for the reactor (see discussion below).

The return pump is also used as the backwash pump in small systems, such as the system used for the verification test. The PLC controls the timing and number of backwashes performed each day. When the PLC timer initiates a backwash cycle, the return pump is activated and the process blower is activated to aerate the filter media. Thus, the backwashing of the filter and removal of accumulated solids that could plug the bed is achieved by a combination of hydraulic flow in the up flow mode, supported by vigorous aeration from the process blower. Solids are carried upward with the wastewater to the return pipe at the top of the reactor, where they flow by gravity back to the anoxic tank.

FRMA stresses that to achieve the two different environments required for removal of organics and nitrogen, aeration of the reactor is intermittent and must be properly controlled. Control is achieved by four different means within the PLC. First, the length of six potential aeration periods may be adjusted; second, the process blower off time may be adjusted; third, the fixed aeration period may be adjusted; and finally, an aeration multiplier may be adjusted. The normal aeration setup used in the verification system was three to five minutes with aeration and ten to fifteen minutes without aeration. The first three controls are timer and cycle controls set in the PLC. The fourth control is based on the calculated flow in the system (using the return pump and middle float in the clear well described above), and mechanism is provided for the PLC to adjust aeration amounts based on the flow to the system. As described in the O&M Manual, it takes experience, review of data, and operating time to properly setup the system for a given application. FRMA monitored the verification test unit and made adjustments as needed. A complete description of the aeration PLC control is provided in the O&M Manual in Appendix A. The Installation Manual and O&M Manual in Appendix A also give a more detailed explanation of the operations and control of the treatment process.

Figure 2-1. Amphidrome™ Process Schematic

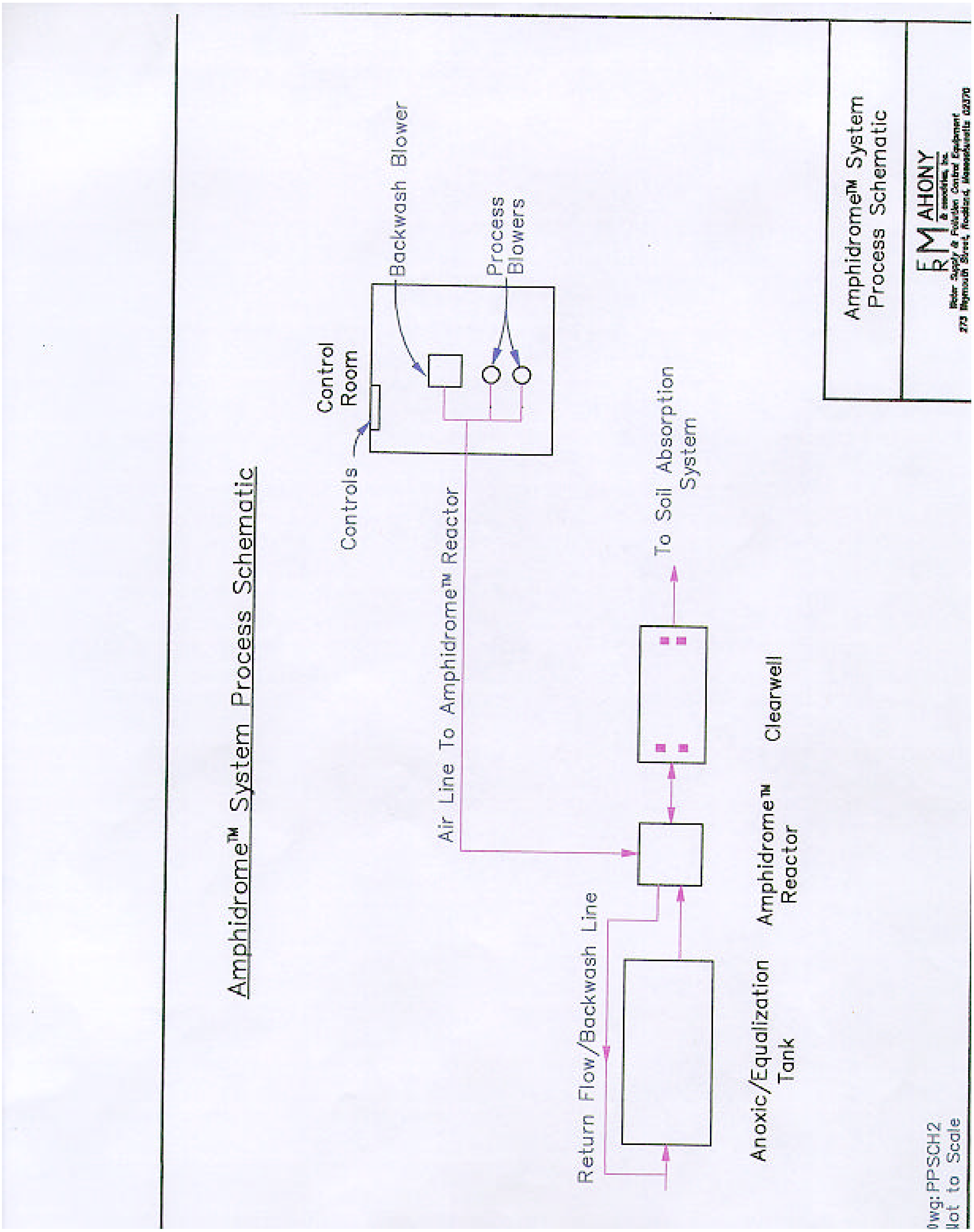


Figure 2-2. Amphidrome™ Process

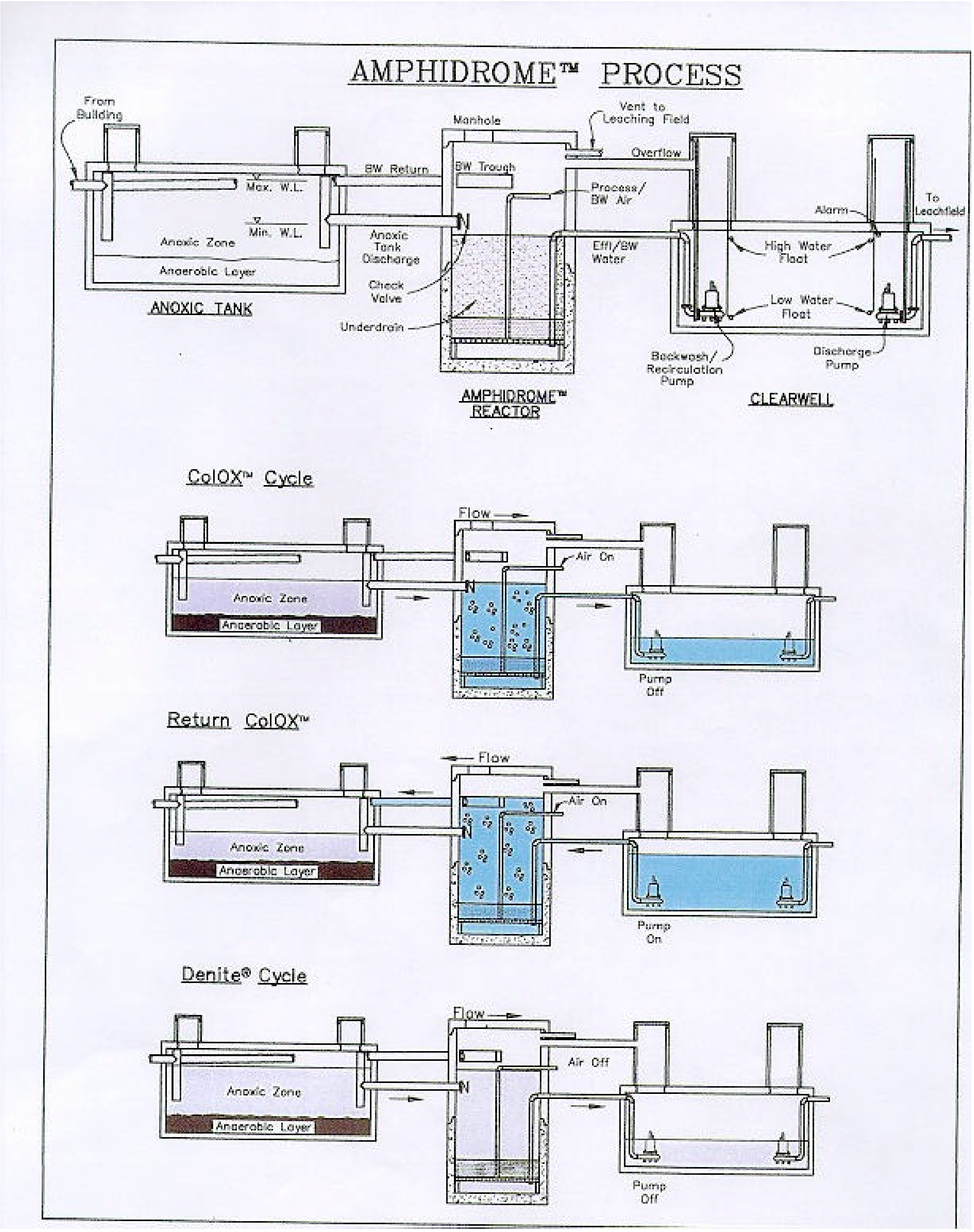
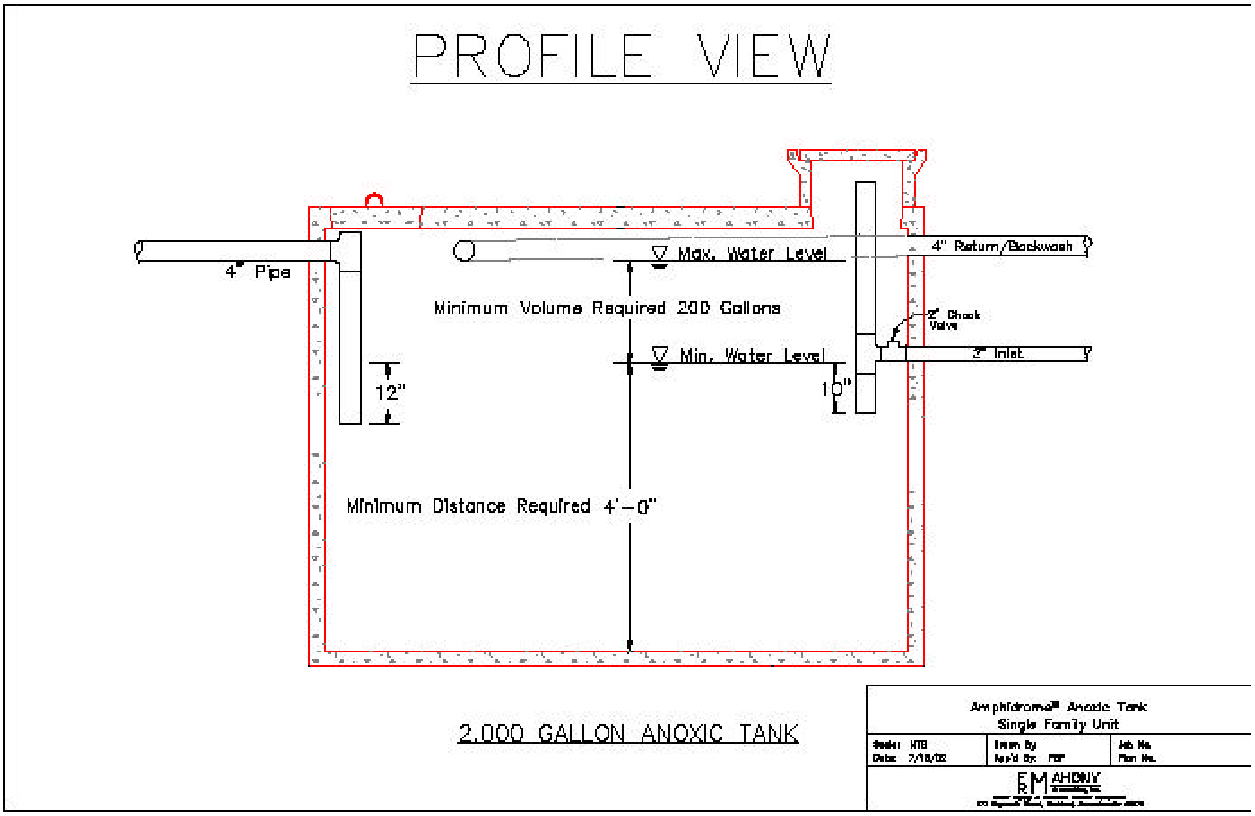


Figure 2-3. Amphidrome™ Anoxic Tank



NOTE: The Return/Backwash line extends to the inlet location, and enters the Anoxic Tank at the same location as the inlet wastewater.

Figure 2-4. Amphidrome™ Reactor

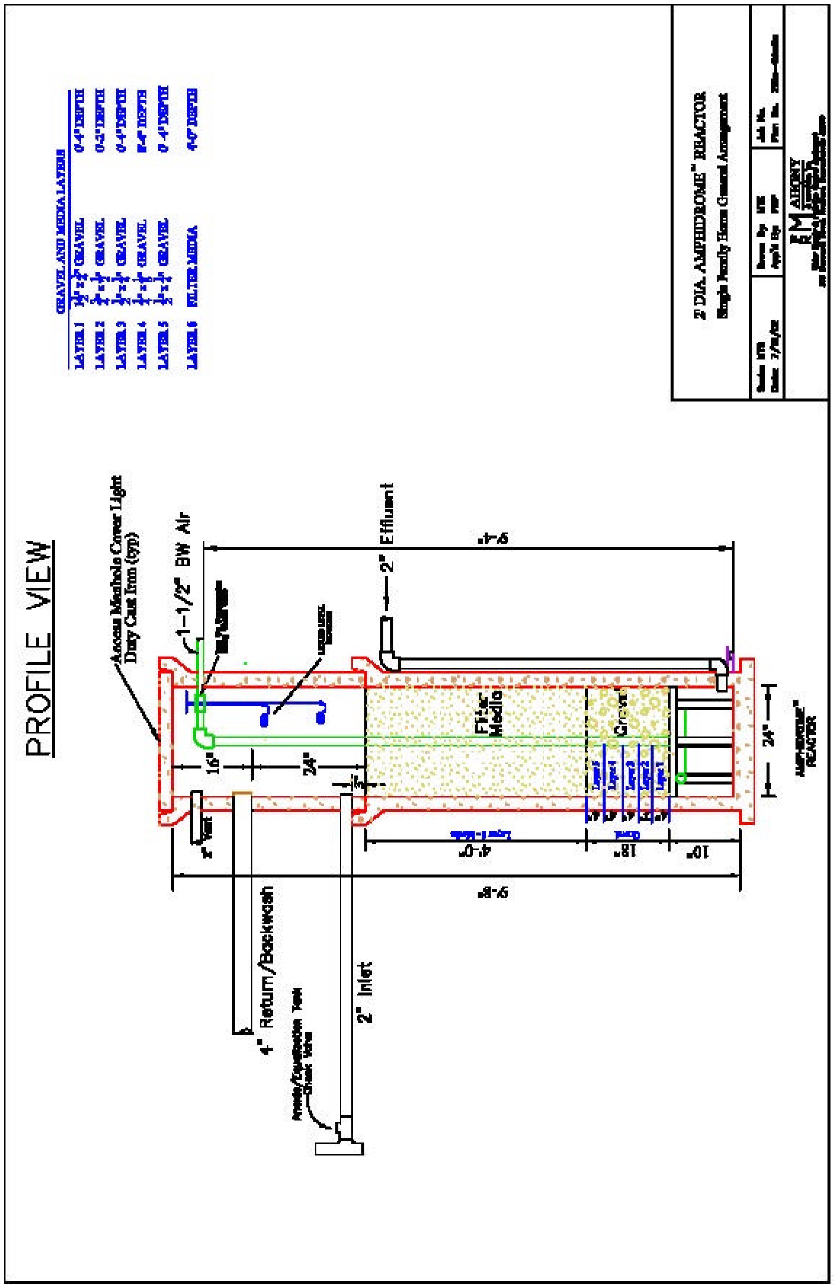
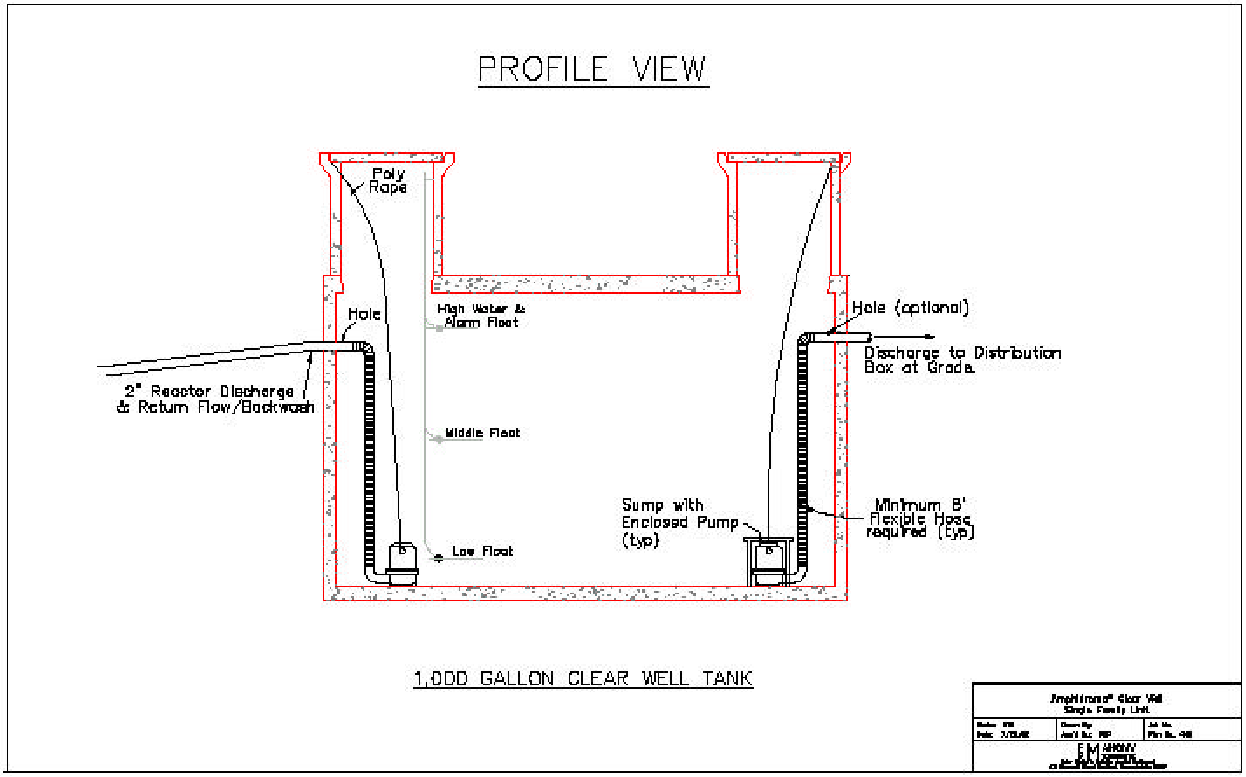


Figure 2-5. Amphidrome™ Clear Well



2.3 Equipment Specifications

The specifications for the Amphidrome™ Model Single Family System are summarized in Table 2-1. A full listing of the materials is shown in the Installation Manual in Appendix A. All of the piping used in the system is either Schedule 40 or 80 PVC pipe.

Table 2-1. Amphidrome™ System Specifications

Item	Quantity
Anoxic/Equalization Tank	1
Tank - 2000 gallon (1,500 gallon used in verification test)	
Anoxic Tank Cover	1
Tank Riser	1
Schedule 40 PVC TEE and Swing Check Valve Assembly	1
Energy dissipating TEE, 4 inch	1
PVC Schedule 40 pipe and fittings	
Amphidrome™ Reactor	1
Reactor Basin with cover (140 gallons)	
Underdrain system	1
Gravel - 18 inches	
Sand filter media – 4 feet (12.57 cu. ft.)	
Pipe mounted mini floats	2
Schedule 80 PVC pipe and fittings	
Clear Well	1
Tank - 1000 gallons (517 gallon tank used in verification test)	
Tank risers and covers	2
Discharge pump 1 ½hp	1
Return/backwash pump 1 ½hp	1
Process blower with pressure relief hp	1
Pipe mounted mini floats	3
Flexible hose and couplings for pumps	
Programmable Logic Controller (PLC)	1
Installation Manual	1
Operations and Maintenance Manual	1

2.4 Operation and Maintenance

FRMA provides a detailed Installation Manual, and an Operational and Maintenance Manual for the Amphidrome™ System. A copy of this information is presented in Appendix A. These manuals provide very important information on installation, startup, and operation of the system. The Amphidrome™ System uses a complex process, and it is important that the PLC settings for pump and aeration control are setup properly for a given application. FRMA requires that a FRMA representative be present to startup the unit after installation is complete.

The Installation Manual provides step-by-step procedures for installing the three tanks and the internal and external piping. Gravel and silica sand media installation procedures are described, as are the methods for checking the air distribution and flushing the system. During and following completion of installation, a representative of FRMA visits the site to inspect the system and initiate startup procedures. Startup procedures include inspection of the air pattern in the reactor and "Air Pattern Test" prior to installation of the media, and process startup, which includes verification of wiring connections, operation of the pumps, blower, and process controller (PLC).

The startup procedures include measuring the forward and reverse flow rates through the system, including the gravity flow from the anoxic tank through the Reactor to the clear well, and the pumped return and backwash flow rates. The PLC is preset to initiate return flow cycles every hour and backwash cycles once per day. The blower is typically set to operate for 3-5 minutes, followed by an off period of 10-15 minutes. Obtaining the proper aeration cycle is critical to the successful operation of the reactor. Once the unit is started, FRMA recommends that the unit be operated for a month and then inspected. At the first monthly visit, samples are collected for analyses and all equipment run times (pumps, blowers, etc.) are checked. FRMA recommends that samples be collected frequently during the first 30-90 days after startup. Bimonthly site visits and system checks are recommended after the initial monthly visit. The O&M Manual stresses that maintaining complete and accurate records of the system operating conditions, such as return pump run times, aeration run times, discharge pump run time, etc. are critical to operating the system and troubleshooting, if the needed treatment is not achieved. The PLC records the times for these operations as total time. Therefore, it is important for the service provider to record the times periodically during site visits so that averages can be reviewed and compared from one visit to the next. Meticulous records are the only way to determine if system operating conditions have changed or to evaluate the impact of changes made to the PLC settings.

The entire Amphidrome™ System is PLC controlled, and therefore all changes to the system are made by changing PLC settings. The PLC can be adjusted using the operator interface system attached to the control panel, which allows the operator to make changes to aeration times, and pump start and stop times. There are four methods for controlling aeration cycles in the Reactor. These methods are described in detail in the O&M Manual. Both the return pump and discharge pump start and stop times can be adjusted with the operator interface. Typically, these settings are optimized during the startup period and are not changed, unless the system is not meeting discharge requirements. The PLC programming can be changed using a portable computer or a manufacturer's handheld programmer. Changes to the programming logic in the PLC are typically performed only by FRMA or under their supervision.

The FRMA recommended bimonthly system inspections, following the startup period, include checking the system visually (clarity of the effluent, any odor, color, or solids present, etc.) and performing analyses of the effluent using field test kits for ammonia and nitrate. The PLC records for pump and aeration run times are recorded by the service provider to provide a record of the system's operation since the last inspection. Pump operation, particularly return flow (up flow through the reactor) and backwash flow, is observed to ensure proper operation. The backwash cycle is activated to ensure both the pump and blower work properly. The aeration system is inspected and the bubble pattern above the media observed, as the bubble pattern should be evenly distributed over the media.

In addition to the O&M Manual, FRMA provided examples of inspection and maintenance check lists, operator logs, and preventive maintenance lists. A narrative description of all of the system components is also provided in the manual. There are several pages of troubleshooting guidelines that can help an operator evaluate equipment malfunctions and potential causes of poor quality effluent.

2.5 Vendor Claims

F.R. Mahony & Associates, Inc. claims the Amphidrome™ System is designed to consistently remove soluble organics, as measured by $CBOD_5$, total suspended solids (TSS), and nitrogen within a single reactor. FRMA states that if stringent total nitrogen limits (<10 mg/L) are required, a second smaller polishing reactor is required. The system installed for verification testing was not equipped with a second polishing reactor.

3.0 Methods and Test Procedures

3.1 Verification Test Plan and Procedures

A Verification Test Plan (VTP) was prepared and approved for the verification of the F.R. Mahony & Associates, Inc., Amphidrome™ System, and is included in Appendix B. The VTP, *Test Plan for The Massachusetts Alternative Septic System Test Center for the Verification Testing of the F.R. Mahony & Associates, Inc. Amphidrome™ Model Single Family Unit Nutrient Reduction Technology*(4), February 2001, detailed the procedures and analytical methods to be used to perform the verification test. The VTP was prepared in accordance with the SWP protocol, *Protocol for the Verification of Residential Wastewater Treatment Technologies for Nutrient Reduction*(1), November 2000. The VTP included tasks designed to verify the nitrogen reduction capability of the Amphidrome™ System and to obtain information on the operation and maintenance requirements of the Amphidrome™ System. There were two distinct phases of fieldwork to be accomplished as part of the VTP, startup of the unit, and a one-year verification test that included normal dosing and stress conditions. The Protocol requires twelve months of sampling, which was completed between March 2001 and April 2002.

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

3.2 MASSTC Test Site Description

The Massachusetts Alternative Septic System Test Center (MASSTC) was constructed at the Massachusetts Military Reservation, Otis Air National Guard Base, on Cape Cod, by the Buzzards Bay Project National Estuary Program (BBP), a unit of the Massachusetts Office of Coastal Zone Management, in collaboration with Massachusetts Department of Environmental Protection (DEP), Barnstable County Department of Health and the Environment (BCHED), and University of Massachusetts, Dartmouth's School of Marine Science and Technology (SMAST). Completed in 1999, the construction and operation of the facility was initially funded with a grant from EPA with subsequent funding received from the Massachusetts DEP, and EPA Region I. The facility is operated cooperatively by the BBP, DEP, BCHED and SMAST.

The site is designed to provide domestic wastewater for use in testing various types of residential wastewater treatment systems. The domestic wastewater source is the sanitary sewerage from the base residential housing and other military buildings. The sewer system for the base flows to an on-base wastewater treatment facility. An interceptor chamber, located in the main sewer line to the base wastewater treatment facility was constructed when the MASSTC was built, and provides a location to obtain untreated wastewater. The raw wastewater passes through a bar screen (grate) located ahead of the transfer pump. This bar screen has one inch spacing between the bars to remove large or stringy materials that could clog the pump or lines. The screened raw wastewater is pumped through an underground two-inch line to the dosing channel at the test site. The design of the interceptor chamber provides mixing of the wastewater just ahead of the transfer pump to ensure a well-mixed raw wastewater is obtained for the influent feed at the test site. Wastewater is pumped to the dosing channel at a rate of approximately 29 gallons per minute (gpm) on a continuous basis for 18 hours per day, yielding at total flow of approximately 31,000 gallons per day (gpd). Wastewater enters the dosing channel, an open concrete channel, sixty-five feet long by two feet wide and three feet deep, via two pipes midway in the channel. Approximately 4,000 to 6,000 gallons per day is withdrawn for test purposes in various treatment units. The excess wastewater flows by gravity to the base sanitary sewer and is treated at the base wastewater treatment plant. The dosing channel is equipped with four recirculation pumps. These pumps, spaced along the channel length, keep the wastewater in the channel constantly moving to ensure the suspension of solids, and to ensure that the wastewater is of similar quality at all locations along the channel.

Dosing of wastewater to the test units is accomplished by individual pumps submerged in-line along the dosing channel. The pumps are connected to the treatment technology being tested by underground PVC pipe. A custom designed, programmable logic controller (PLC) is used to control the pumps and the dosing sequence or cycle. Each technology feed pump can be controlled individually for multiple start and stop times, and for pump run time. For the Amphidrome™ System, the volumetric dosages were set to meet the dosing sequence described in the VTP.

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

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

Table 3-1. Historical MASSTC Wastewater Data

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

3.3 Installation and Startup Procedures

3.3.1 Introduction

FRMA provided installation instructions (included in Appendix A) for the Amphidrome™ System and was present at the site during the installation. The system delivered by FRMA consisted of a single compartment, 1,500 gallon anoxic/equalization tank, a complete Amphidrome™ Reactor, and a 517 gallon clear well tank with all associated pumps and float switches. This system was originally installed by a contractor in December 1999 as part of an earlier test program at MASSTC.

3.3.2 Objectives

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

- Install the Amphidrome™ System in accordance with vendor instructions;
- Start-up and test the Amphidrome™ System to ensure all processes were operating properly, the PLC and pumps were set for proper automatic operation, and any leaks that occurred during the installation were eliminated;
- Make any modifications needed to achieve operation; and,
- Record and document all installation and start-up conditions prior to beginning the verification test.

3.3.3 Installation and Startup Procedures

In order to prepare for start-up of the Amphidrome™ System for the ETV verification test, the entire system was emptied of wastewater and cleaned in November and December 2000. Solids were removed from the anoxic/equalization tank, and the clear well was drained and flushed. All pumps, lines, and associated equipment were cleaned. The filter media was repeatedly flushed to remove solids from the reactor. Clean water was recirculated in the unit in December to further clean the media and lines. The entire system was then drained and remained off until the beginning of the start-up period at which time the anoxic tank was filled with raw wastewater from the dosing channel, and the dosing sequence was started.

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

3.4 Verification Testing - Procedures

3.4.1 Introduction

The verification test procedures were designed to verify nitrogen reduction by the Amphidrome™ System. The verification test consisted of a thirteen-month test period, incorporating five stress periods of varying stress conditions simulating real household conditions. Monitoring for nitrogen reduction was accomplished by measurement of nitrogen species (TKN, NH_4, NO_2, NO_3). Carbonaceous biochemical oxygen demand ($CBOD_5$) and other basic parameters (pH, alkalinity, TSS, temperature) were monitored to provide information on overall treatment performance. Operational characteristics such as electric use, residuals generation, noise and odor were also monitored.

3.4.2 Objectives

The objectives of the verification test were to:

- Determine the nitrogen reduction performance of the Amphidrome™ System;
- Monitor removal of other oxygen-using contaminants (BOD_5, $CBOD_5$, TSS);
- Determine operation and maintenance characteristics of the technology; and,
- Assess chemical usage, energy usage, generation of byproducts or residuals, noise and odors.

3.4.3 System Operation- Flow Patterns and Loading Rates

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

3.4.3.1 <u>Influent Flow Pattern</u>

The influent flow dosed to Amphidrome™ System was controlled by the use of timed pump operation. The dosing pump was set to provide 15 doses of equal volume in accordance with the following schedule:

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

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

After each calibration test, the measured volume was compared to this target rate. If the volume was more than 10 percent above or below the target, the pump run time was increased or decreased to adjust the volume per dose back to the target volume. If the run time was changed, then a second calibration was performed to determine the total volume for the new timer setting. The QC requirement for the dosing volume was 100 ± 10 percent of the target flow (400 gallons per day) based on a thirty (30) day average, with the exception of periods of stress testing.

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

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

3.4.3.2 Stress Testing Procedures

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

Stress testing included the following simulations:

- Washday stress
- Working Parent stress
- Low Load stress
- Power/Equipment Failure stress
- Vacation stress

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

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

The low load stress simulation consisted of testing the unit at 50 percent of the target flow (200 gallons per day) loading for a period of 21 days. Approximately 35 percent of the total daily flow was dosed between 6 a.m. and 11 a.m., approximately 25 percent of the flow was dosed between 11 a.m. and 2 p.m., and approximately 40 percent of the flow was dosed between 5 p.m. and 8 p.m.

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

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

3.4.3.3 Sampling Locations, Approach, and Frequency

3.4.3.3.1 Influent Sampling Location

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

3.4.3.3.2 Amphidrome™ System Effluent Sampling Location

For the Amphidrome™ System effluent, the sampling site was located in the normal effluent pipe from the clear well. During installation and setup, a sampling point was constructed in the distribution box where the effluent from the two-inch force main from the system clear well discharged to the MASSTC sewer line. The sampling point was installed in the effluent pipe and was located so that it could be cleaned of any attached and settled solids. Cleaning of the sampling location, by brushing to remove any accumulated solids, was performed prior to each sampling period. This cleaning was performed to remove biomass that tended to grow in the effluent pipe sampling location during the weeks between sampling events. Cleaning would not be required in normal system, as the sampling location in the discharge pipe was installed for the verification test only and would not be present in a normal installation.

3.4.3.3.3 Sampling Procedures

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

Composite samples were collected using automated samplers at each sample collection point. The influent automated sampler was programmed to draw equal volumes of sample from the waste treatment stream at the same frequency and timing as influent wastewater doses. Samples taken in this manner were therefore flow proportional. The effluent sampler timing was set to correspond to the passage of a flow through the Amphidrome™ System discharge line. Since the Amphidrome™ System only discharged once per day, the sampler was set to collect multiple samples during the daily discharge cycle. The automatic samplers were calibrated before each use and the volume of sample collected was checked to ensure that the proper number of individual samples was collected in the composite container. A summary of the sampling matrix is presented in Table 3-2, and detailed sampling procedures are described in the MASSTC SOPs (Appendix C).

Table 3-2. Sampling Matrix

		Sample Location		
PARAMETER	**SAMPLE TYPE**	**INFLUENT**	**FINAL EFFLUENT**	**TESTING LOCATION**
BOD_5	24 Hour composite	√		Laboratory
$CBOD_5$	24 Hour composite		√	Laboratory
Suspended Solids	24 Hour composite	√	√	Laboratory
pH	Grab	√	√	Test Site
Temperature (°C)	Grab	√	√	Test Site
Alkalinity (as $CaCO_3$)	24 Hour composite	√	√	Laboratory
Dissolved Oxygen	Grab	√	√	Test Site
TKN (as N)	24 Hour composite	√	√	Laboratory
Ammonia (as N)	24 Hour composite	√	√	Laboratory
Total Nitrate(as N)	24 Hour composite		√	Laboratory
Total Nitrite (as N)	24 Hour composite		√	Laboratory

3.4.3.3.4 Sampling Frequency

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

Normal Monthly Frequency

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

Stress Test Frequency

Samples were collected on the day each stress simulation was initiated and when approximately 50 percent of each stress sequence was completed, except for the vacation and power/equipment failure stresses, when there was no flow to the system. Beginning twenty-four (24) hours after the completion of washday, working parent, low load, and vacation stress scenarios, samples were collected for six (6) consecutive days. Beginning forty-eight (48) hours after the completion of the power/equipment failure stress, samples were collected for five (5) consecutive days.

Final Week

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

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

3.4.3.3.5 Sample Handling and Transport

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

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

Table 3-3. Sampling Schedule for Amphidrome™ System

Month/Day	Sampling Event
Jan 23 and 31, 2001	Startup – 2 sampling events
February 14 and 28, 2001	Startup – 2 sampling events
March 7 and 13, 2001	Startup – 2 sampling events
March 21, 2001	Normal monthly sample
April 18, 2001	Normal monthly sample
May 8,10, and 13-18, 2001	Wash day stress - 8 samples
June 6, 2001	Normal monthly sample
July 3, 2001	Normal monthly sample
July 10, 13, and 15-20, 2001	Working parent stress – 8 samples
August 1, 2001	Normal monthly sample
September 5, 2001	Normal monthly sample
September 18, 27 and October 9-14, 2001	Low loading stress – 8 Samples
October 31, 2001	Normal monthly sample
November 28, 2001	Normal monthly sample
December 3, and 9-13, 2001	Power failure stress – 6 samples
December 28, 2001	Normal monthly sample
January 16, 2002	Normal monthly sample
February 4 and 14-19, 2002	Vacation stress – 7 samples
March 5-8, 2002 and March 11, 2002	Final week sampling – 5 samples
April 17, 2002	Additional monthly sample

3.4.3.4 Residuals Monitoring and Sampling

Solids in the influent wastewater settle in the primary (anoxic) tank and accumulate slowly over time. Byproducts or residuals generated within the reactor are also returned to the anoxic tank with the return and backwash water pumped from the clear well. Measurements of solids depth in the anoxic tank were made on February 4, 2002 and March 8, 2002, after thirteen and fourteen months of operation (including the startup period). The clear well was checked once for solids accumulation, on March 8, 2002.

A coring solids measurement tool (Core Pro) was used to estimate the depth of solids, liquid, and scum layers in the 1,500 gallon anoxic/equalization tank. The sampling device was a clear tube with a check valve on the bottom. The tube was pushed through the solids to the bottom of the tank, the valve closed and the entire sample column, water and solids, was removed from the tank. The column height was checked to ensure no sample has leaked from the device and the solids depth was determined by measuring the height of the solids in the clear tube, using a tape measure or ruler. This approach gives a direct measurement of depth of solids. The thickness of any scum layer present was also measured by ruler or tape. Three measurements of the solids depth and scum depth were made at each of the two access manholes.

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

3.4.4 Analytical Testing and Record Keeping

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

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

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

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

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

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

3.4.5 Operation and Maintenance Performance

Both quantitative and qualitative performance of the Amphidrome™ System was evaluated during the verification test. A field log was maintained that included all observations made during the startup of the system 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.

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

3.4.5.1 Electric Use

Electrical use was monitored by a dedicated electric meter serving the Amphidrome™ System. The meter reading was recorded twice weekly in the field log by BCDHE personnel. The meter manufacturer, model number, and any claimed accuracy for the meter was recorded in the field log. At the end of the testing period, the electric meter was returned to the manufacturer for calibration and the calibration data entered in the field log.

3.4.5.2 Chemical Use

Verification testing of the Amphidrome™ System did not require any process chemicals to achieve treatment.

3.4.5.3 Noise

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

3.4.5.4 Odors

Odor observations were made during the verification test, beginning in September 2001 and ending in March 2002. The observation was qualitative based on odor strength (intensity) and type (attribute). Intensity was stated as not discernable; barely detectable; moderate; or strong. Observations were made during periods of low wind velocity (<10 knots). The observer stood upright at a distance of three (3) feet from the treatment unit, at 90° intervals in four (4) directions. All observations were made by the same BCDHE employee.

3.4.5.5 Mechanical Components

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

3.4.5.6 Electrical/Instrumentation Components

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

4.0 Results and Discussion

4.1 Introduction

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

Evaluation of the Amphidrome™ System at MASSTC began on January 15, 2001. The system was filled with wastewater, the pumps were activated, and the initial dosing cycles started. The startup period continued until March 12, 2001. Six samples of the influent and effluent were collected during the startup period. Verification testing began on March 13, 2001 and continued for 13 months, until April 17, 2002. The extra month of dosing and sampling (thirteen months versus the planned twelve months) was added to the test to obtain data on the system response as the temperatures began to rise in the spring. During the verification test, 53 sets of influent and effluent samples were collected to determine the system performance.

4.2 Startup Test Period

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

4.2.1 Startup Flow Conditions

The flow conditions for the Amphidrome™ System were established at the target capacity of 400 gallons per day in accordance with the VTP. In early September, it was discovered that a MASSTC PLC problem resulted in the actual dosing rate being 14 doses per day, as the first dose in the morning was not occurring. Thus, for the startup period and approximately six months (March 13 to September 4) of the verification test, the unit received 14 doses per day, four (4) in the morning, four (4) mid day, and six (6) in the early evening. The average flow for the startup period was 367 gpd, which was within the ±10 percent (360-440 gpd) of the design flow on a monthly basis specified for the test. The volume of wastewater dosed to the system during the startup remained within the monthly average range of 360 to 440 gpd and only minor adjustments to the dosing pump run time were required. Table 4-1 shows a summary of the flow volumes during the startup period. The daily flow records are in Appendix F.

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

Date	Average		Actual Daily Volume
	Doses/day	Gallons/dose	(Gallons)
Jan 15 – 21	14	26.6	372
Jan 22 - 27	14	26.5	371
Jan 28 - 30	14	26.2	367
Jan 31 – Feb 3	14	26.1	365
Feb 4 - 13	14	26.0	364
Feb 14 – 17	14	26.8	375
Feb 18 - 20	14	25.8	361
Feb 21	14	31.0	434
Feb 22 - 23	14	25.7	360
Feb 24 – 25	14	19.0	266
Feb 26	14	28.0	392
Feb 27	14	27.5	385
Feb 28	14	29.0	406
Mar 1 – 3	14	26.5	371
Mar 4 – 6	14	27.0	378
Mar 7 – 10	14	26.3	368
Mar 11 –12	14	26.0	364

4.2.2 Startup Analytical Results

The results of the influent and effluent monitoring during the startup period are shown Tables 4-2 and 4-3. The first sets of samples were taken eighteen (18) days after the System was started. The initial data showed that the System reduced the $CBOD_5$ and TSS to 15 mg/L and 1 mg/L, respectively, and the Amphidrome™ System was removing some of the total nitrogen (34 mg/L in the influent, 21 mg/L in the effluent). Observations and additional sampling to determine the condition of the System continued for the next six weeks. The only adjustment made to the System during startup was to reset the clock on the PLC, which was off by a couple of hours. The treatment performance continued to improve through the end of the startup period.

At the end of the eight weeks allotted for the startup, when the verification test period began, the biological growth appeared to be fully established. The $CBOD_5$ of the effluent was 5.0 mg/L and TSS was 4 mg/L on the last sampling day before the start of the verification test. The System was removing some organic and ammonia nitrogen, with TKN of 20 mg/L and ammonia nitrogen of 19 mg/L in the effluent, compared to influent levels of 40 mg/L TKN and 25 mg/L ammonia. Denitrification was also starting to occur, as shown by the nitrate, nitrite, and total nitrogen concentrations in the effluent. On March 13, 2002, effluent nitrate and nitrite (combined) was 4.0 mg/L, and effluent Total Nitrogen was 24 mg/L, compared with influent Total Nitrogen of 40 mg/L (a removal of 40 percent). While there were clear signs that nitrification and denitrification were occurring, the processes did not appear to be firmly established. The pH in the effluent was lower than the influent which is expected when nitrification occurs. However, the overall alkalinity balance showed that less alkalinity was being removed/replaced than would be predicted in an established system. The startup began in the middle of winter and influent wastewater temperatures were low (7.1 to 8.2 ^oC) throughout the period. Low ambient air temperatures may have an effect, as ambient air is used to supply oxygen to the system and during backwash cycles. A low ambient temperature is most likely the principal cause of the slow startup for the nitrogen removal processes.

Table 4-2. Influent Wastewater Quality - Startup Period

Date	BOD_5 (mg/L)	TSS (mg/L)	Alkalinity (mg/L)	pH (S.U.)	Ammonia (mg/L)	TKN (mg/L)	TN (mg/L)	DO (mg/L)	Influent Temp. (^oC)
01/23/01	140	120	180	7.6	26	34	34	0.2	8.2
01/31/01	280	280	170	7.2	24	41	41	1.2	8.0
02/14/01	180	190	190	7.5	26	42	42	NS	NS
02/28/01	200	190	200	7.7	28	46	46	0.8	7.1
03/07/01	180	130	160	7.4	23	34	34	1.4	7.4
03/13/01	160	130	180	7.4	25	40	40	1.1	7.8

N/S – no sample

Table 4-3. Amphidrome™ System Effluent Quality during the Startup Period

Date	$CBOD_5$ (mg/L)	TSS (mg/L)	Alkalinity (mg/L)	pH (S.U.)	Ammonia (mg/L)	TKN (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	TN (mg/L)	DO (mg/L)	Discharge Temp (^oC)
01/23/01	15	1	150	7.7	17	20	0.80	<0.05	21	NS	NS
01/31/01	12	5	180	7.3	23	25	0.70	<0.05	26	7.5	NS
02/14/01	13	5	170	7.4	23	27	1.3	0.13	28	NS	NS
02/28/01	7.0	3	170	7.5	21	25	1.7	0.45	27	6.7	NS
03/07/01	3.6	6	160	7.4	20	24	2.2	0.84	27	NS	NS
03/13/01	4.9	4	150	7.2	19	20	2.4	1.6	24	NS	NS

N/S – no sample

4.2.3 Startup Operating Conditions

The Amphidrome™ System was started using the vendor's recommended settings. The PLC controlled all pump times, aeration cycles, and overall system operation. The return pump (which pumps treated wastewater from the clear well back through the media and into the anoxic tank) was setup to operate in normal mode, activating each hour, 24 hours per day. The aeration system was initially set to add air for seven and one half minutes and be off for fifteen minutes The discharge pump was set to discharge treated wastewater once per day. The backwash cycle was set to backwash the unit every once per week.

No changes were made to the System during the startup period. Regular observations showed that biological growth was being established and the effluent quality was visually improving.

FRMA staff visited the site periodically during startup to check on the system. There were no mechanical problems during the startup, and overall, the Amphidrome™ System started up with no difficulty.

4.3 Verification Test

In accordance with the startup period set forth in the VTP and the Protocol, the verification test was started officially on March 13, 2001. All results for the balance of the test were considered part of the verification test period. The data presented for the verification results do not include data from the startup period.

All Amphidrome™ System operating parameters (pumps, alarms, etc.) remained the same as during the initial startup period. During the second and third month of the verification test (April and May), a vendor representative adjusted the airflow cycle and the backwash cycle. On May 15 the backwash cycle was changed from once per week to 5 times per week, which remained the same for the duration of the test. On May 24, the timer for the return flow pump was changed from 30 seconds to 60 seconds, and the timer for the backwash pump was changed from 60 seconds to 90 seconds. These settings were adjusted to try to improve performance, but were changed back to the original settings on June 1. The fixed air run time was reduced by 10 percent in October 25, 2001 to 410 seconds per cycle to try to improve denitrification and was maintained for the remainder of the test.

4.3.1 Verification Test - Flow Conditions

The dosing sequence was performed every day from March 13 through September 3, 2001, except during the stress periods. Volume per dose and total daily volume varied only slightly during this period. In September, it was discovered that while the PLC was set to deliver 15 doses per day and showed 15 doses being delivered, only 14 doses were actually being pumped to the unit. The first dose each morning was being missed because of a timer issue with the start of wastewater flow at the test site. Beginning September 4, 2001, the problem was resolved and daily flow was dosed 15 times per day as specified in the VTP. The lower flow being dosed to the unit for the first six months was still within the specification that flow be ± 10 percent of the design flow on a monthly average basis (design flow 400 gpd). Table 4-4 shows the average monthly volumes for the verification period. As this data shows, the actual wastewater volume dosed to the Amphidrome™ was very close to the targeted volume of 400 gallons per day for the last seven months of the test.

Table 4-4. Amphidrome™ System Influent Volume Summary

	Target		Ave Monthly	
Mon/Year	**Gallon/dose**	**Doses/day**	**Gallon/dose**	**Gallon/day**
Mar-01	26.7	14	26.3	369
Apr-01	26.7	14	26.7	373
May-01	26.7	14	27.1	380
Jun-01	26.7	14	26.8	376
Jul-01	26.7	14	26.9	377
Aug-01	26.7	14	26.4	370
Sep-01	26.7	15(1)	26.8	403(2)
Oct-01	26.7	15	26.1	392(2)
Nov-01	26.7	15	25.2	379
Dec-01	26.7	15	26.7	400(3)
Jan-02	26.7	15	26.3	395
Feb-02	26.7	15	26.2	393(4)
Mar-02	26.7	15	26.2	393
Apr-02	26.7	15	26.3	394
Average			26.4	385
Maximum			27.1	403
Minimum			25.2	369
Std. Dev.			0.47	11.5

(1) The timer and PLC issue was fixed on September 4. Fifteen doses were delivered beginning on September 4, 2001.
(2) September/October – low load test run in September and October; average flow data for September and October does not include the low flow days. Only normal flow days are included. During the low load test, flow was set at 50 percent of normal flow. Actual average flow during the low load test (September 17 to October 7) was 200 gpd.
(3) December – 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.
(4) February 2002 – vacation test – 10-day test; no flow for 8 days, Only nine doses on first and last day; low or no flow days excluded from the calculation of monthly averages

4.3.2 BOD_5/$CBOD_5$ and Suspended Solids Results

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

The verification protocol requires sampling during and following the major stress periods. This results in a large number of samples being clustered during five periods, with the remaining samples spread over the remaining months (monthly sampling). Therefore, impacts of the stress test or an upset condition occurring during the concentrated sampling can have an impact on the calculation of average values. Both average and median results are presented in Table 4-5, as the median values compared to average values can help in analyzing these impacts.

The influent wastewater had an average (mean) BOD_5 of 210 mg/L and a median BOD_5 of 200 mg/L. The average influent TSS was 150 mg/L with a median concentration of 130 mg/L. The Amphidrome™ System effluent had an average $CBOD_5$ of 4.9 mg/L and a median $CBOD_5$ of 4.4 mg/L. The average effluent TSS concentration was 5 mg/L, with a median concentration of 3 mg/L. The Amphidrome™ System averaged 97 percent reduction of $BOD_5/CBOD_5$ with a median removal of 98 percent. TSS removal averaged 96 percent over the thirteen-month period, with a median removal of 98 percent. Except for two samples, the effluent $CBOD_5$ concentrations typically ranged from 1 to 10 mg/L, and, except for five samples, the effluent TSS ranged from 1 to 10 mg/L.

At the end of the startup period, the Amphidrome™ System was removing TSS and $CBOD_5$ at a high level of efficiency. The data suggests that an acclimated microbial population was present and the System was removing organics and suspended solids. The System came on line quickly and the data showed removal of $CBOD_5$ and TSS within a few days.

By the start of the first stress test in May 2001 (Washday stress), the System was producing effluent concentrations of 2.4 mg/L $CBOD_5$ and < 1 mg/L for TSS. After the washday stress test ended, the effluent $CBOD_5$ increased to 10 mg/L for one day (May 14). The effluent concentration dropped immediately to 1.0 mg/L on the next day (May 15), and remained low for the balance of the stress test monitoring period. This one elevated concentration corresponded to a period when the influent BOD_5 spiked to 340 mg/L. Overall, the washday stress did not appear to have an impact on the $CBOD_5$ and TSS performance. Post stress period monitoring showed steady performance through the end of May and June. Effluent $CBOD_5$ was less than 5 mg/L and TSS less than 6 mg/L (typically < 1 to 3 mg/L) during the two-month period.

The working parent stress test was started on July 9, 2001 and was completed on July 13, 2001. A July monthly sample taken the week before, on July 3, indicated a possible upset condition as $CBOD_5$ increased to 10 mg/L and TSS to 26 mg/L in the effluent. As will be discussed in the nitrogen section below, the nitrogen removal was clearly impacted by an upset condition in June 2001 (the recirculation pump slipped off the pedestal, as discussed further in the nitrogen discussion, Section 4.3.3.2). The impact on BOD_5 and TSS performance was short lived and removal of both $CBOD_5$ and TSS improved immediately. During and following the working parent stress test, the $CBOD_5$ and TSS effluent concentrations varied from 3 to 19 mg/L, with most results being less than 10 mg/L. The system was not as steady as during earlier and later periods, but overall treatment of $CBOD_5$ and TSS appeared acceptable. Conditions prior to working parent stress appeared to cause the instability on the system and not the actual stress test. System recovery may have been slightly slowed by the stress test, but the system did recover.

After the sampling on September 1, the system became very steady with respect to $CBOD_5$ and TSS removal. All results show effluent concentrations below 10 mg/L, and in the case of TSS all but one sample was less than 5 mg/L. The low load stress test was started on September 18 and had no apparent impact on $CBOD_5$ or TSS performance. The power/equipment failure stress test was initiated on December 3 and, again, removal continued to be steady. The last stress test, the vacation stress test was started on February 4 and the $CBOD_5$ and TSS results during this period, and through the end of the verification test, remained constant.

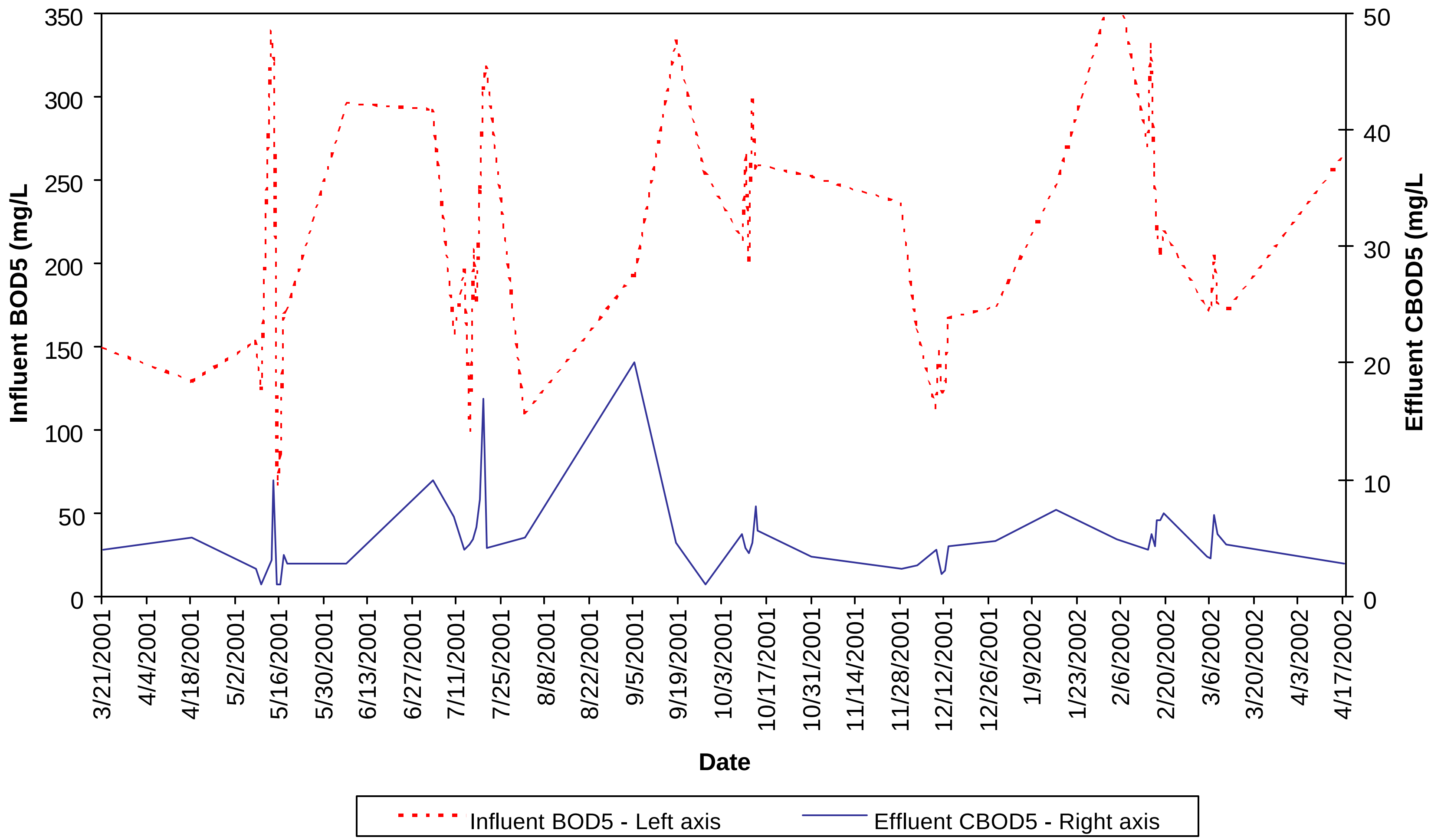

Figure 4-1. Amphidrome™ System BOD_5/$CBOD_5$ Results

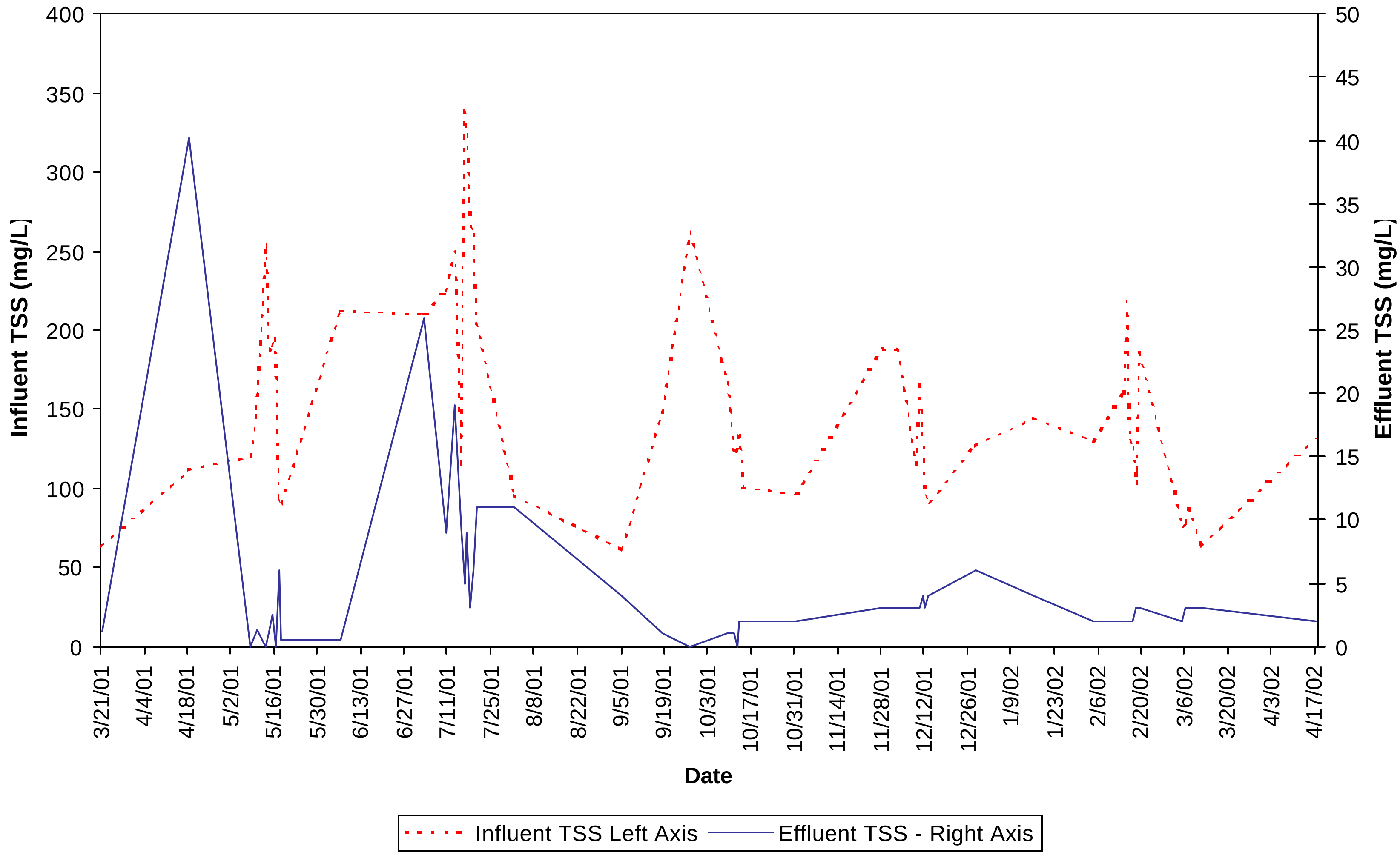

Figure 4-2. Amphidrome™ System Total Suspended Solids Results

Table 4-5. Amphidrome™ System BOD_5/$CBOD_5$ and TSS Results

	BOD_5	$CBOD_5$		TSS		
Date	Influent (mg/L)	Effluent (mg/L)	Removal (Percent)	Influent (mg/L)	Effluent (mg/L)	Removal (Percent)
03/21/01	150	3.9	97	63	1	98
04/18/01	130	4.6	96	110	40	64
05/08/01	150	2.4	98	120	<1	>99
05/10/01	120	<2.0	>98	150	1	99
05/13/01	340	3.1	99	250	<1	>99
05/14/01	320	10	97	190	1	99
05/15/01	67	<2.0	>97	190	3	99
05/16/01	86	<2.0	>98	200	<1	>99
05/17/01	170	3.6	98	92	6	93
05/18/01	170	2.9	98	90	<1	>99
06/06/01	300	2.8	99	210	<1	>99
07/03/01	290	10	97	210	26	88
07/10/01	160	6.8	96	220	9	96
07/13/01	200	4.1	98	250	19	92
07/15/01	99	4.4	96	120	9	92
07/16/01	210	4.9	98	340	5	99
07/17/01	180	6.0	97	320	9	97
07/18/01	240	8.4	97	260	3	99
07/19/01	300	17	94	260	6	98
07/20/01	320	4.2	99	200	11	95
08/01/01	110	5.0	95	96	11	89
09/05/01	190	20	90	61	4	93
09/18/01	330	4.6	99	150	1	99
09/27/01	250	<2.0	>99	260	<1	>99
10/09/01	210	5.3	98	170	1	99
10/10/01	260	4.2	98	150	1	99
10/11/01	200	3.7	98	120	1	99
10/12/01	300	4.6	98	120	<1	>99
10/13/01	260	7.7	97	130	2	99
10/14/01	260	5.6	98	100	2	98

Table 4-5. Amphidrome™ System BOD_5/$CBOD_5$ and TSS Results (continued)

	BOD_5	$CBOD_5$		TSS		
	Influent (mg/L)	Effluent (mg/L)	Removal (Percent)	Influent (mg/L)	Effluent (mg/L)	Removal (Percent)
10/31/01	250	3.4	99	96	2	98
11/28/01	240	2.4	99	190	3	98
12/03/01	160	2.7	98	190	3	98
12/09/01	110	4.1	96	120	3	97
12/10/01	150	3.2	98	170	3	98
12/11/01	120	2.0	98	140	4	97
12/12/01	130	2.3	98	95	3	97
12/13/01	170	4.3	97	91	4	96
12/28/01	170	4.7	97	130	6	95
01/16/02	250	7.5	97	140	4	97
02/04/02	370	4.9	99	130	2	98
02/14/02	270	4.0	99	160	2	99
02/15/02	330	5.3	98	220	2	99
02/16/02	250	4.3	98	130	2	98
02/17/02	220	6.6	97	130	2	98
02/18/02	210	6.6	97	100	3	97
02/19/02	220	7.1	97	190	3	98
03/05/02	170	3.4	98	76	2	97
03/06/02	180	3.3	98	78	3	96
03/07/02	200	7.0	97	87	3	97
03/08/02	180	5.4	97	81	3	96
03/11/02	170	4.4	97	63	3	95
04/17/02	260	2.9	99	130	2	98
No. Samples	53	53	53	53	53	53
Average	210	4.9	97	150	5	96
Median	200	4.4	98	130	3	98
Max	370	20	>99	340	40	>99
Min	67	<2	90	61	<1	64
Std. Dev.	73	3.5	1.5	67	7	5.5

Values below the detection limit are set to zero for concentration averages

4.3.3 Nitrogen Reduction Performance

4.3.3.1 Results

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

The influent wastewater had an average TKN concentration of 37 mg/L and an average ammonia nitrogen concentration of 23 mg/L, with median concentrations of 37 mg/L and 23 mg/L, respectively. Average TN concentration in the influent was 37 mg/L (median of 37 mg/L), based on the generally accepted assumption that the nitrite and nitrate concentration in the influent was negligible. The Amphidrome™ System effluent had an average TKN concentration of 8.5 mg/L, with a median of 8.3 mg/L. The average ammonia nitrogen concentration in the effluent was 7.0 mg/L, with a median concentration of 6.1 mg/L. The nitrite concentration in the effluent averaged 0.27 mg/L, with a median concentration 0.25 mg/L. Effluent nitrate concentrations averaged 6.4 mg/L over the thirteen-month test, with a median concentration of 5.5 mg/L. Total nitrogen was determined by adding the concentrations of the TKN (organic plus ammonia nitrogen), nitrite and nitrate, resulting in an average TN in the Amphidrome™ System effluent of 15 mg/L for the thirteen-month verification period, with a median concentration of 14 mg/L. The Amphidrome™ System averaged 59 percent reduction of TN for the verification test period, with a median removal of 62 percent.

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

The pH of the influent was very consistent throughout the test, ranging from pH 7.2 to 7.6 with a median value of 7.4. The effluent from the Amphidrome™ System showed a decrease in pH, but in a similar range, consistently remaining in the pH 6.6 to 7.7 range and a median value of 7.1. The alkalinity of the influent averaged 180 mg/L as $CaCO_3$ with a maximum concentration of 230 mg/L and minimum of 160 mg/L. The effluent alkalinity was consistently lower than the influent (as expected when nitrification/denitrification is occurring), with an average concentration of 110 mg/L and a median concentration 110 mg/L. The effluent alkalinity varied based on the performance of the nitrification and denitrification process.

The Dissolved Oxygen in the influent wastewater was low, as would be expected. The average DO in the influent to the septic tank was 0.3 mg/L, and was less than 1.0 mg/L on all but two days. The Amphidrome™ System is designed to operate as an aerobic/anoxic system, with the blower on the System moving air through the media on a timed basis. During non-aeration periods, FRMA claims the bed goes anoxic to promote denitrification. The DO in the effluent from the Amphidrome™ System was normally in the range of 4 to 6 mg/L with a few days higher or lower (minimum was 2.3 mg/l, maximum was 9.6 mg/L). The average DO was 6.1 mg/L over the thirteen months of verification testing.

4.3.3.2 Discussion

As discussed in the startup section, at the end of the startup period (January 15 to March 12, 2001), the Amphidrome™ System effluent was showing some removal of total nitrogen (40 mg/L influent and 24 mg/L effluent). An acclimated microbial population was present for the treatment of $CBOD_5$, and both nitrifying and denitrifying organisms appeared to be present in the system, based on the removal of TKN and ammonia, and overall reduction of Total Nitrogen. Beginning in April and early May, the nitrification process became more firmly established, as can be seen by the lower ammonia and TKN concentrations in the effluent (10 mg/L or less). Denitrification also was occurring, as shown by the effluent Total Nitrogen concentrations, which dropped below 20 mg/L. Based on the assumption that all of the TKN removed is converted to nitrate, overall nitrate removal was in the range of 14-21 mg/L (March 21 – May 8 data).

Another measure of nitrification and denitrification can be made by the change in effluent alkalinity and pH. The theoretical relationship of alkalinity consumed to TN removed shows that 3.5 mg/L is consumed for each 1 mg/L of TN removed (7.1 mg alkalinity is consumed per 1 mg nitrogen converted to nitrate in the nitrification process, and 3.6 mg alkalinity is produced per mg TN removed by the denitrification process). The individual daily alkalinity data does not balance well with the actual TN data for this test, but on an entire verification test basis, the balance is close. The average measured TN removed was 22 mg/L, whereas the predicted TN removed is 20 mg/L using the alkalinity data. Even though the individual alkalinity mass balances do not accurately predict TN removal levels for this dataset, the information provides an indicator of system conditions. During the April and May period, as the TN removal improved, the alkalinity decreased as would be expected and the effluent pH was lower. By the start of the washday stress test on May 8, all of the data indicated that both nitrification and denitrification were occurring in the system.

The washday stress test was run from May 7 through 11, 2001. The system performance during and following the stress period remained steady indicating that the system was not impacted by the stress test. By the end of the monitoring period in May and during early June the performance was steady with TN concentration in the effluent in the 13 to 15 mg/L range, which represented removal efficiencies of 58 to 71 percent.

On July 3, a routine monthly sample was collected and the data clearly showed that some type of upset had occurred. The nitrification process was severely impacted as shown by influent and effluent ammonia levels of 24 mg/L and 25 mg/L, respectively. The nitrate levels dropped to less than 0.1 mg/L, which would be typical of influent wastewater, and indicating no nitrate was being produced by the nitrifying organisms. Further, the alkalinity of the influent and effluent were similar (effluent was actually slightly higher). The upset was caused by a lack of wastewater returning to the anoxic tank. The return pump was found to be running continuously on June 21 during an inspection by FRMA. The pump had slipped off the guide rails, fallen off its pedestal, and the recycle line had disconnected from the pump. The pump was operating, but only pumping water within the clear well. The float switch did not trigger the PLC to shutoff the pump. Therefore, from about June 6 (based electrical records) until June 21 when the problem was found, there was no recirculation of wastewater to the anoxic tank. During this time, wastewater from the anoxic tank was only receiving once through treatment in the biofilter. After flowing by gravity through the biofilter, the wastewater was collected in the clear well and discharged once per day from the system. The pump was resecured on the pedestal within the guide rails on June 21.

The working parent stress test started on July 9 and continued until July 13, 2001. The system began to recover from the upset with improved $CBOD_5$ and TSS performance, but the nitrification process was much slower in its recovery. Some removal of TKN, ammonia and TN was occurring during the working parent stress test monitoring in mid-July, but at a lower performance level than during the previous two months. During the stress test, there was no sign that the stress test itself was having any additional impact on the system.

The monthly samples on August 1 and September 5 showed improvement in the removal of TKN and ammonia, indicating that the nitrifying population was re-established. Nitrate levels in the effluent increased somewhat in this period (3.3 to 7.9 mg/L) and TN in the effluent was in the 14 to 15 mg/L range.

The low load stress test began on September 17 and continued until October 8, 2001. During this stress period, the nitrification process became very efficient, dropping the TKN and ammonia levels in the effluent to less than 1 mg/L. Nitrate concentrations increased to 14 to 19 mg/L and TN was 14 to 20 mg/L. As the low load stress test ended, virtually all of the TN in the effluent was in the form of nitrate. Once the system returned to normal full flow conditions, the TKN and ammonia concentrations in the effluent rose slightly (1.2 to 4.8 mg/L), and nitrate concentrations decreased to 10 to 14 mg/L. Overall, the TN removal performance was steady at the end of the monitoring period with concentrations in the effluent of 10 to 14 mg/L, similar to the results obtained in May prior to the upset.

The low load stress test had very little impact on the overall TN removal performance, but did change the balance between the TKN, ammonia and nitrate concentrations in the effluent. TKN and ammonia levels were very low and nitrate levels were elevated. This change may be due to the operational approach used by the Amphidrome™ System. The system provides periods of aeration followed by no aeration in combination with the recycle sequence. With the reduced flow during the low load stress test, the amount of aeration relative to the flow was higher, which may have resulted in the improved performance of the nitrifiers in removing TKN and ammonia. However, the denitrification process was not able to remove the additional nitrate, possibly due to additional oxygen being present. Thus, the effluent contained higher levels of nitrate, produced by the improved nitrification in the system. FRMA adjusted the aeration system by reducing the aeration by ten percent (aeration time set to 410 seconds) on October 25 to try to improve the denitrification performance. The reduced aeration time was maintained for the remainder of the test.

During the October 2001 to January 2002 period, including the power/equipment failure stress test in December, the system produced steady results, with TN in the effluent of 10 to 16 mg/L, a removal efficiency of 57 to 77 percent. The TN in the effluent was a mix of TKN and nitrate. After the low load stress test ended and flows returned to design levels, the nitrification and denitrification processes returned to the performance and balance levels found during the May and June 2001 period, prior to the upset condition in early July. The power/equipment failure stress test, performed on December 3 did not have a major impact on the system. The TKN and ammonia levels did increase somewhat compared the previous data point in November, but TN performance remained similar as the nitrate levels decreased somewhat during the post stress test monitoring period.

The vacation stress test was started on February 4 and continued until February 13. During this period, there was no wastewater dosed to the system, except on the first and last day of the stress test. The TKN and ammonia concentrations decreased in the effluent samples taken immediately after flow was resumed to the system. The nitrate levels increased in a manner similar to the findings following the low load stress test. TN concentrations remained steady in the effluent ranging from 12 to 17 mg/L. By the end of the post stress test monitoring period, the effluent concentrations had returned to a mix of TKN and nitrate, with TKN concentrations of 5.5 mg/L and nitrate of 6.8 mg/L. These data, supported by the results form the low load stress test, suggest that the Amphidrome™ System responded to decreases in flow by exhibiting improved nitrification and less denitrification. The TN performance, however, did not change, with effluent concentrations remaining in a tight range near the long-term average and median of 15 mg/L and 14 mg/L, respectively.

The system performance remained consistent for the duration of the verification test. The TKN and ammonia nitrogen effluent concentrations were consistently in the 7.6 to 9.5 mg/L range. The nitrate levels remained in the 3.0 to 4.8 mg/L range. The TN concentration in the effluent ranged from 11 to 15 mg/L. Alkalinity concentrations in the effluent were in the 100 to 120 mg/L range, as compared to influent alkalinity levels in the 160 to 190 mg/L range.

The verification test provided a sufficiently long test period to collect data that included both a long run of steady performance by the Amphidrome™ System and a period of reduced nitrification and denitrification efficiencies. During the months of April through June, following startup, the TN removal was in the 45 to 71 percent range, with effluent concentrations typically in the 13 to 16 mg/L range. The upset resulting from the dislocation of the return pump dramatically impacted the nitrification process in early July. Following the upset, the system recovered by the end of July and continued to remove substantial amounts of TN. During the last eight months of the verification test, the TN removal was in the 52 to 77 percent range. Effluent TN concentration ranged from 10 to 20 mg/L, with most concentrations in the 13 to 15 mg/L range. Data collected from the two low or no flow stress tests indicate that overall system performance for TN was not impacted. However, the concentrations of TKN/ammonia and nitrate changed during these lower flow periods. Nitrification was enhanced during low flow periods with a commensurate increase in nitrate concentrations in the effluent.

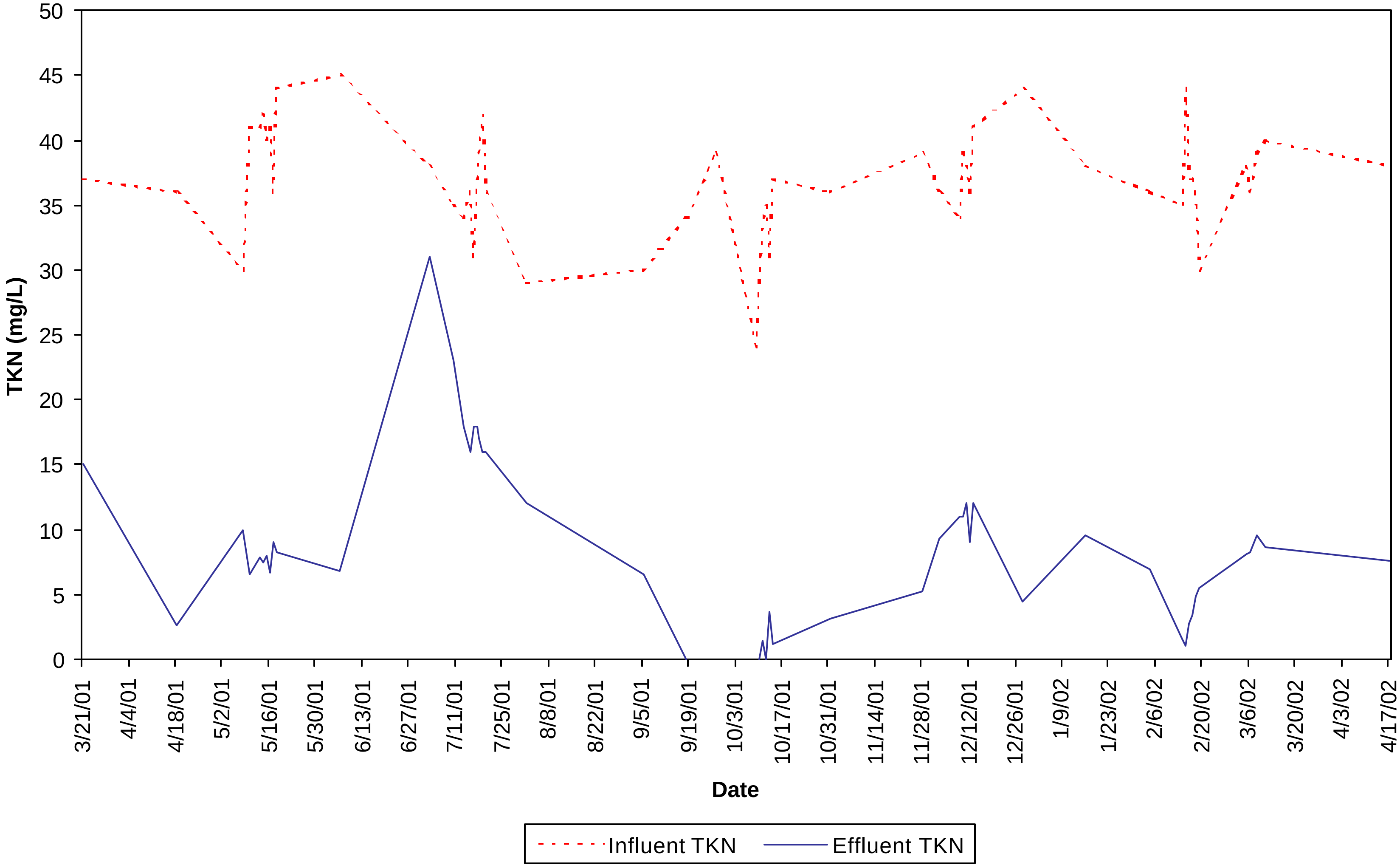

Figure 4-3. Amphidrome™ System Total Kjeldahl Nitrogen Results

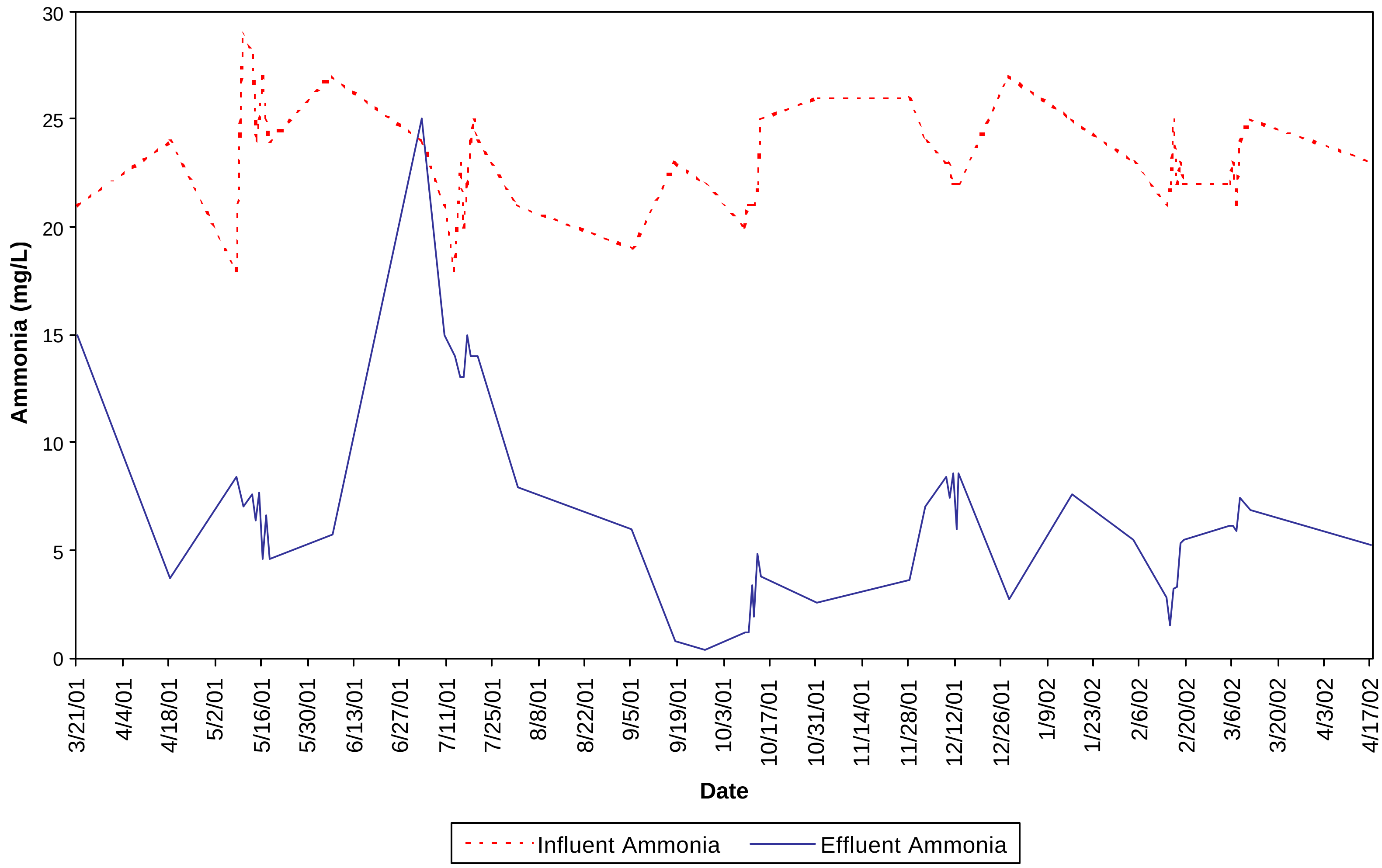

Figure 4-4. Amphidrome™ System Ammonia Nitrogen Results

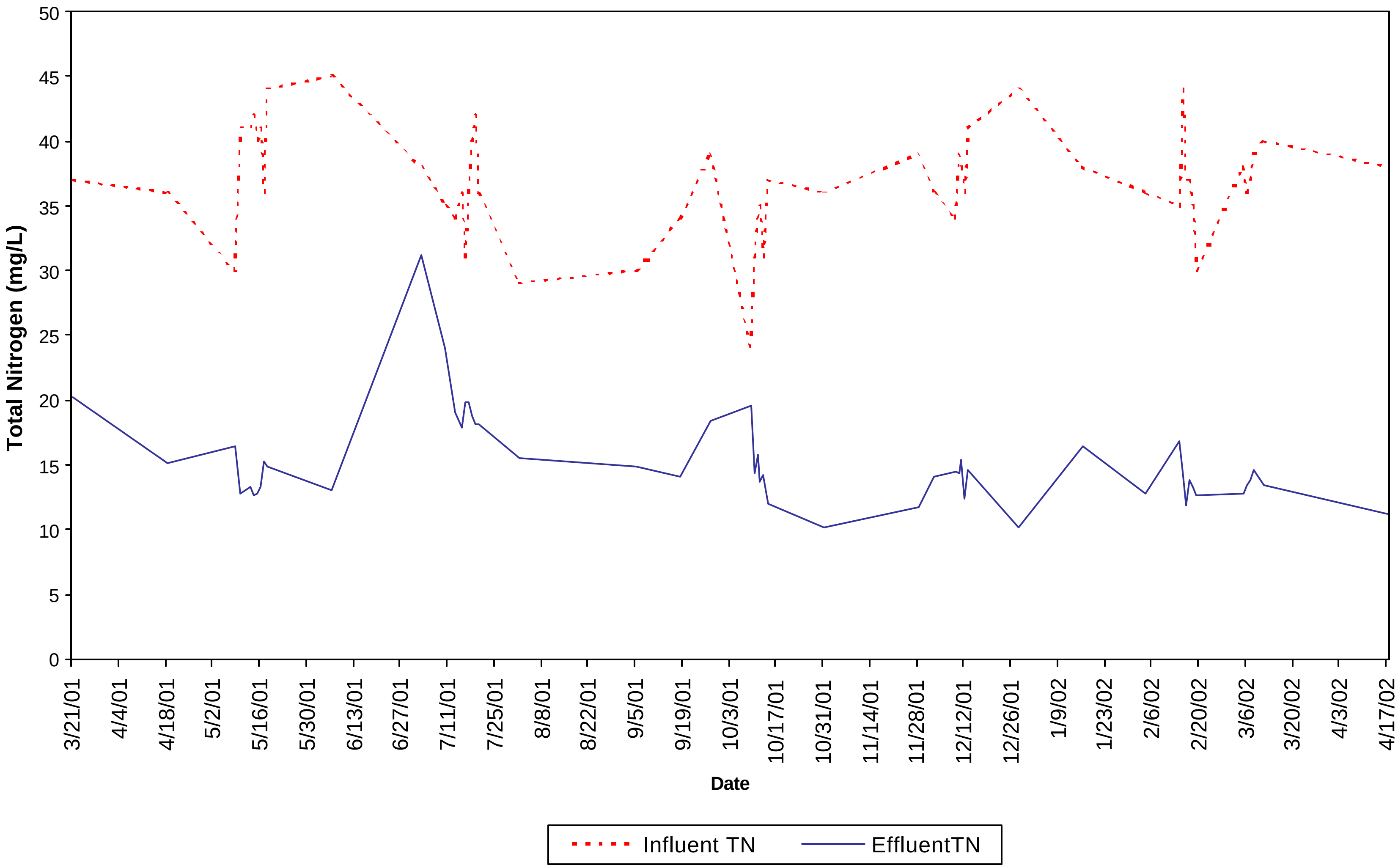

Figure 4-5. Amphidrome™ System Total Nitrogen Results

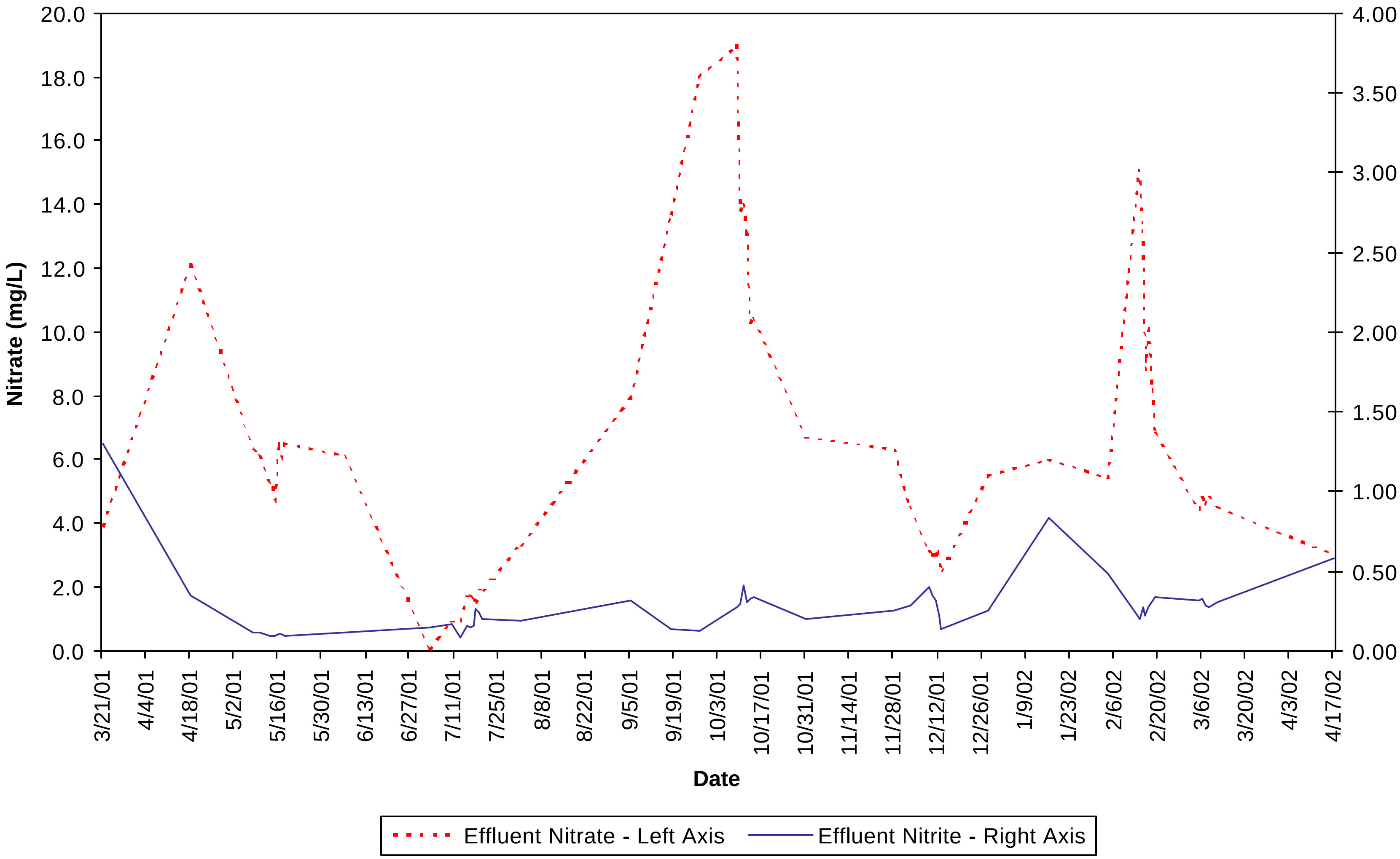

Figure 4-6. Amphidrome™ System Nitrite and Nitrate Effluent Concentrations

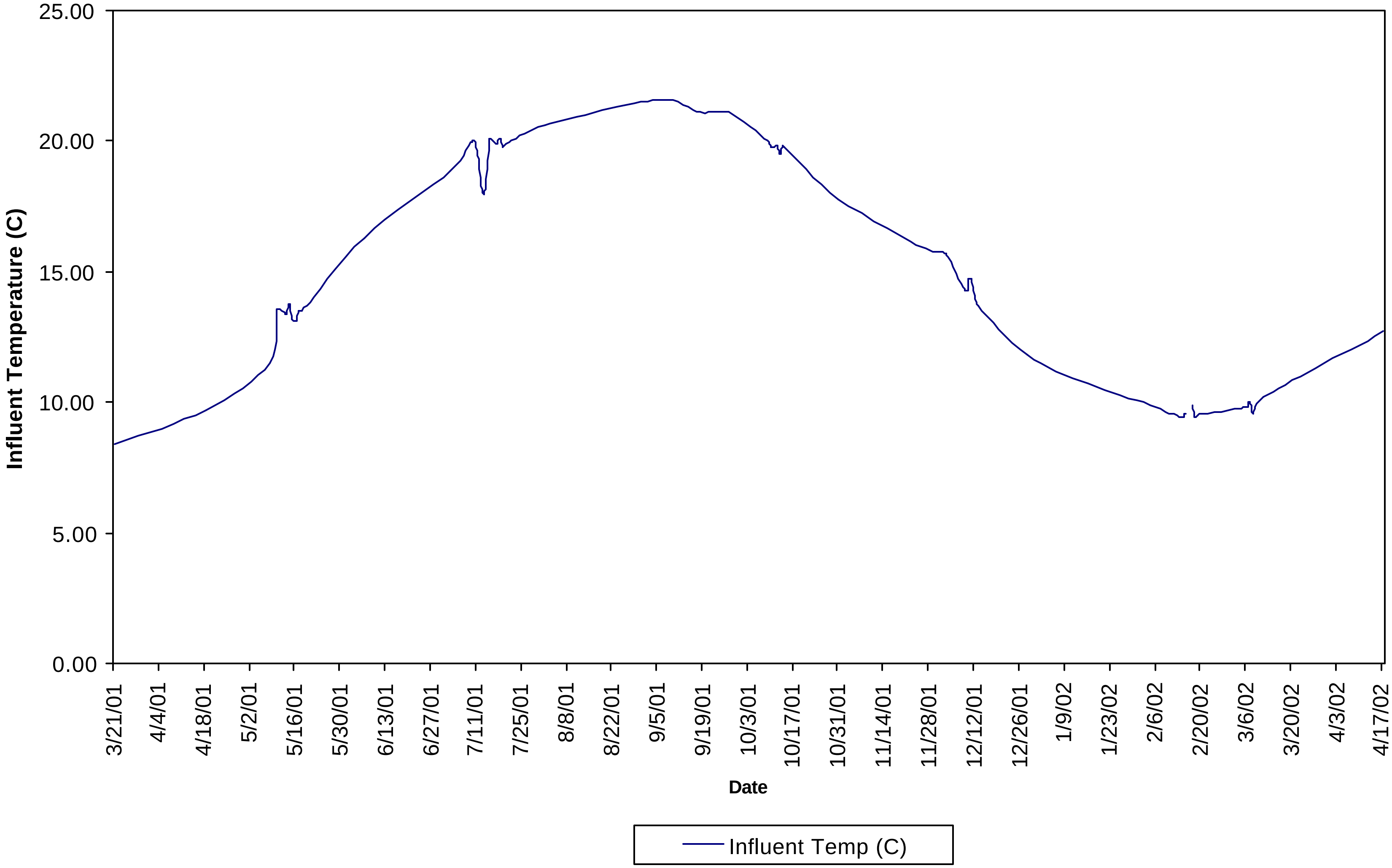

Figure 4-7. Amphidrome™ System Influent Temperature

Table 4-6. Amphidrome™ System Influent and Effluent Nitrogen Data

Date	TKN (mg/L)		Ammonia Nitrogen (mg/L)		Total Nitrogen (mg/L)		Nitrate-Nitrogen (mg/L)	Nitrite-Nitrogen (mg/L)	Temperature (^oC)
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Effluent	Effluent	Influent
03/21/01	37	15	21	15	37	20	3.9	1.3	8.4
04/18/01	36	2.7	24	3.7	36	15	12	0.35	9.7
05/08/01	30	10	18	8.4	30	16	6.3	0.11	12
05/10/01	41	6.5	29	7.0	41	13	6.1	0.11	14
05/13/01	41	7.9	28	7.6	41	13	5.3	0.09	13
05/14/01	42	7.5	24	6.4	42	13	5.1	0.09	14
05/15/01	40	8.0	25	7.7	40	13	4.7	0.09	13
05/16/01	41	6.7	27	4.6	41	13	6.5	0.10	13
05/17/01	36	9.1	25	6.6	36	15	6.0	0.10	14
05/18/01	44	8.3	24	4.6	44	15	6.5	0.09	14
06/06/01	45	6.8	27	5.7	45	13	6.1	0.11	16
07/03/01	38	31	24	25	38	31	<0.10	0.15	19
07/10/01	35	23	21	15	35	24	0.90	0.17	20
07/13/01	34	18	18	14	34	19	0.90	0.08	18
07/15/01	36	16	23	13	36	18	1.7	0.16	20
07/16/01	31	18	20	13	31	20	1.7	0.15	20
07/17/01	36	18	22	15	36	20	1.6	0.16	20
07/18/01	40	17	24	14	40	19	1.5	0.26	20
07/19/01	42	16	25	14	42	18	1.9	0.24	20
07/20/01	36	16	24	14	36	18	1.9	0.20	20
08/01/01	29	12	21	7.9	29	15	3.3	0.19	21
09/05/01	30	6.6	19	6.0	30	15	7.9	0.32	22
09/18/01	34	<0.5	23	0.8	34	14	14	0.14	21
09/27/01	39	<0.5	22	0.4	39	18	18	0.12	21
10/09/01	24	<0.5	20	1.2	24	20	19	0.27	20
10/10/01	30	<0.5	21	1.2	30	14	14	0.29	20
10/11/01	34	1.4	21	3.4	34	16	14	0.41	20
10/12/01	35	<0.5	21	1.9	35	14	13	0.30	20
10/13/01	31	3.6	22	4.8	31	14	10	0.33	20
10/14/01	37	1.2	25	3.8	37	12	10	0.34	20

Table 4-6. Amphidrome™ System Influent and Effluent Nitrogen Data (continued)

Date	TKN (mg/L)		Ammonia Nitrogen (mg/L)		Total Nitrogen (mg/L)		Nitrate-Nitrogen (mg/L)	Nitrite-Nitrogen (mg/L)	Temperature (°C)
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Effluent	Effluent	Influent
10/31/01	36	3.2	26	2.6	36	10	6.7	0.20	18
11/28/01	39	5.2	26	3.6	39	12	6.3	0.25	16
12/03/01	36	9.3	24	7.0	36	14	4.5	0.28	16
12/09/01	34	11	23	8.4	34	15	3.1	0.40	14
12/10/01	39	11	23	7.4	39	14	3.0	0.35	15
12/11/01	38	12	22	8.6	38	15	3.0	0.32	15
12/12/01	36	9.0	22	6.0	36	12	3.1	0.22	14
12/13/01	41	12	22	8.6	41	15	2.5	0.14	14
12/28/01	44	4.4	27	2.7	44	10	5.5	0.25	12
01/16/02	38	9.6	25	7.6	38	16	6.0	0.83	11
02/04/02	36	6.9	23	5.5	36	13	5.4	0.48	9.9
02/14/02	35	1.5	21	2.8	35	17	15	0.20	9.4
02/15/02	44	1.0	22	1.5	44	14	13	0.27	9.6
02/16/02	37	2.8	25	3.2	37	12	8.8	0.22	NR
02/17/02	37	3.4	22	3.3	37	14	10	0.27	9.9
02/18/02	35	4.8	23	5.3	35	13	8.2	0.30	9.4
02/19/02	39	5.5	22	5.5	39	13	6.8	0.34	9.5
03/05/02	38	8.1	22	6.1	38	13	4.4	0.32	9.8
03/06/02	36	8.3	23	6.1	36	13	4.8	0.33	9.8
03/07/02	37	8.9	21	5.9	37	14	4.6	0.28	10
03/08/02	39	9.5	24	7.4	39	15	4.8	0.27	9.6
03/11/02	40	8.6	25	6.9	40	13	4.5	0.30	10
04/17/02	38	7.6	23	5.2	38	11	3.0	0.58	13
No. Samples	53	53	53	53	53	53	53	53	52
Average	37	8.5	23	7.0	37	15	6.4	0.27	15
Median	37	8.3	23	6.1	37	14	5.5	0.25	14
Maximum	45	31	29	25	45	31	19	1.3	22
Minimum	24	1.0	18	0.4	24	10	<0.1	0.08	8.4
Std. Dev.	4.1	6.4	2.4	4.7	4.1	3.6	4.5	0.20	4.3

Values below the detection limit set equal to zero (0) for statistical calculations
N/R – not reported

Table 4-7. Amphidrome™ System Alkalinity, pH, and Dissolved Oxygen Results

Date	Alkalinity (mg/L as $CaCO_3$)		Dissolved Oxygen (mg/L)		pH (S.U.)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
03/21/01	200	110	0.4	NR	7.6	7.0
04/18/01	190	56	1.9	NR	7.6	6.8
05/08/01	160	120	NR	NR	7.3	6.9
05/10/01	190	98	0.6	NR	7.4	7.0
05/13/01	180	130	0.4	NR	7.5	7.0
05/14/01	170	130	0.7	NR	7.5	7.4
05/15/01	180	140	0.5	NR	7.4	7.0
05/16/01	180	120	0.4	NR	7.4	7.2
05/17/01	180	110	0.3	NR	7.5	7.1
05/18/01	190	98	0.3	NR	7.6	7.3
06/06/01	180	110	0.4	NR	7.6	7.4
07/03/01	190	210	0.4	6.2	7.3	7.2
07/10/01	180	190	0.8	NR	7.5	7.1
07/13/01	170	180	0.7	NR	7.5	7.5
07/15/01	190	170	0.1	NR	7.6	7.3
07/16/01	200	180	0.1	NR	7.6	7.5
07/17/01	180	180	0.1	NR	7.4	7.1
07/18/01	190	160	0.2	NR	7.2	7.3
07/19/01	200	160	0.2	NR	7.2	7.1
07/20/01	190	150	0.1	NR	7.4	7.2
08/01/01	170	140	0.3	2.3	7.5	7.3
09/05/01	170	110	0.3	4.5	7.3	7.0
09/18/01	180	74	0.3	6.1	7.4	7.0
09/27/01	190	54	0.1	6.3	7.3	6.9
10/09/01	170	66	0.2	5.4	7.5	7.1
10/10/01	180	66	<0.1	5.3	7.4	7.5
10/11/01	190	80	<0.1	5.3	7.3	6.9
10/12/01	180	72	0.1	6.4	7.2	6.8
10/13/01	180	94	0.1	5.5	7.4	7.0
10/14/01	190	88	<0.1	4.9	7.4	6.9

Table 4-7. Amphidrome™ System Alkalinity, pH, and Dissolved Oxygen Results (continued)

Date	Alkalinity (mg/L as $CaCO_3$)		Dissolved Oxygen (mg/L)		pH (S.U.)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
10/31/01	200	70	0.3	3.8	7.4	6.6
11/28/01	190	98	0.2	5.0	7.4	6.9
12/03/01	170	120	0.1	9.5	7.3	7.4
12/09/01	180	130	0.2	4.3	7.5	7.1
12/10/01	190	140	0.1	4.6	7.5	7.4
12/11/01	180	130	0.1	4.6	7.4	7.0
12/12/01	180	110	0.4	9.6	7.4	7.3
12/13/01	190	130	0.4	NR	7.6	7.1
12/28/01	230	92	0.3	5.8	7.5	7.2
01/16/02	190	100	0.2	7.3	7.6	7.7
02/04/02	180	98	0.2	NR	7.4	7.2
02/14/02	170	58	0.2	8.9	7.5	7.1
02/15/02	200	76	0.2	8.4	7.3	7.0
02/16/02	190	98	0.2	8.0	7.4	7.0
02/17/02	180	98	0.2	7.9	7.5	7.2
02/18/02	170	100	0.1	5.6	7.5	7.4
02/19/02	180	110	0.4	7.5	7.4	7.3
03/05/02	160	110	0.5	5.9	7.4	6.9
03/06/02	170	100	0.6	7.8	7.4	6.8
03/07/02	180	100	0.2	5.6	7.4	6.7
03/08/02	180	110	0.5	4.8	7.4	6.9
03/11/02	190	100	1.1	5.6	7.5	6.8
04/17/02	190	120	0.1	5.9	7.4	6.9
No. Samples	53	53	52	32	53	53
Average	180	110	0.3	6.1	N/A	N/A
Median	180	110	0.2	5.7	7.4	7.1
Maximum	230	210	1.9	9.6	7.6	7.7
Minimum	160	54	0.0	2.3	7.2	6.6
Std. Dev.	11	36	0.3	1.7	N/A	N/A

N/A – not applicable
N/R – not reported

4.3.4 Residuals Results

During the treatment of wastewater in the Amphidrome™ System, solids accumulate in the anoxic tank. Inert solids are removed in the anoxic tank just as in a septic tank. Biological solids accumulate from influent wastewater solids, the recycling of solids trapped on the sand media or solids generated during treatment in the Amphidrome™ System. Eventually, a buildup of solids will reduce the capacity of the anoxic tank and the solids will need to be removed.

The approximate quantity of the residuals accumulated in the system was estimated by measuring the depth of solids in the anoxic tank. Measurement of solids depth was difficult in the anoxic tank, as access to the unit is limited to access openings in the top of the unit. Solids depth was estimated at three locations from each of the two openings using a Core Pro solids-measuring device. 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 in February 2002 after 13 months of operation (including startup), and again in March 2002 after approximately fourteen months of operation. The results are presented in Table 4-8.

Table 4-8. Solids Depth Measurement

	Anoxic Tank Solids/Scum Depth in Inches			
Access Opening Location	East	Middle	West	Average
February 4, 2002-Anoxic Tank Influent End	18	20	27	22
February 4, 2002-Anoxic Tank Effluent End	19	16	31	22
February 4, 2002 Scum Depth on Influent End	0	0	0	0
February 4, 2002 Scum Depth on Effluent End	0	0	0	0
March 8, 2002-Anoxic Tank Influent End	15	22	28	22
March 8, 2002-Anoxic Tank Effluent End	32	13	14	20
March 8, 2002 Scum Depth on Influent End	0	0	0	0
March 8, 2002 Scum Depth on Effluent End	0	0	0	0
March 8, 2002-Clear Well	0	0	0	0

In order to characterize the solids in the anoxic tank, total suspended solids and volatile suspended solids were measured in samples collected in March 2002. These data are presented in Table 4-9. These concentrations represent the solids concentration in the total sample collected, which included the solids and the water present in the sample tube. Based on an average of twenty one inches of solids present in the tube and an additional 38 inches of water, the concentration needs to be multiplied by a factor of 2.8 (the ratio of total tank depth to solids depth) to estimate the actual solids concentration in the settled solids layer.

Table 4-9. TSS and VSS Results for the Amphidrome™ System Solids Samples

Date	Location	TSS (mg/L)	VSS (mg/L)
3/8/02	Anoxic Tank	10,000	1,900

The mass of solids present in the septic tank can be estimated from these data. The average concentration of solids in the anoxic tank, 10,000 mg/L, multiplied by the tank total volume of 1500 gallons shows that the solids accumulated during the test was approximately 130 pounds. The percent solids in the settled solids layer can be estimated using the average solids depth of 21 inches and the total water column height of 60 inches. Multiplying the "dilution" ratio of 60/21 times the concentration solids (10,000 mg/L) shows that the actual solids layer had a concentration of approximately 2.8 % or 28,000 mg/L. The total mass can be estimated using the average depth of solids and the tank dimensions. The anoxic tank holds a volume of approximately 31 gallons per inch of depth. Therefore, the solids volume, based on an average 21 inches depth (March 2002), was about 654 gallons. Based on a solids concentration of 28,000 mg/L (estimated concentration in the settled solids layer), the weight of dry solids accumulated was approximately 150 pounds. The volatile solids represented 19 percent of the solids in the tank, which is lower than would be expected.

4.4 Operations and Maintenance

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

4.4.1 Electric Use

Electric use was monitored by a dedicated electric meter serving the Amphidrome™ System. The meter reading was recorded biweekly in the field log by BCDHE personnel. Table 4-10 shows a summary of the electrical use from startup through the end of the verification test. The complete set of electrical readings is presented in a spreadsheet in Appendix F. The basic system tested used one pump for discharge and one pump to recycle the clear well water back through media. A blower was used to add air to the system. There was one period in June 2001 when the electrical use went up to 24 to 32 kW/day for a twelve-day period (see spreadsheet in Appendix F). The increased electrical use resulted from the return pump running continuously from June 6 until June 21, 2001, as previously described.

Table 4-10. Summary of Amphidrome™ Electrical Usage

	kW/day (1)	kW/day (2)
Number of Readings	190	183
Average	4.1	3.20
Median	3.3	3.33
Maximum	32	9.00
Minimum	0.0	0.00
Std. Dev.	4.7	1.39

(1) Includes all data

(2) Excludes period June 6-22 when pump ran continuously

4.4.2 Chemical Use

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

4.4.3 Noise

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

Table 4-11. Amphidrome™ Noise Measurements

Location	First Reading (decibels)	Second Reading (decibels)	Average
Background	37.5	38.0	37.7
Amphidrome™			
East	56.2	56.4	56.3
South	55.1	54.3	54.7
West	59.1	60.0	59.5
North	56.4	56.2	56.3
All Locations			56.7

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

4.4.4 Odor Observations

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

4.4.5 Operation and Maintenance Observations

The Amphidrome™ System is a sequencing batch reactor that uses gravel and sand for the media in the biofilter section, based on the principals of a submerged growth filter operating under both aerobic and anoxic conditions. The system is comprised of an anoxic/equalization tank, the filter housing holding the media, a blower and distribution plate system for air injection (Amphidrome Reactor™), and a clear well. The entire system is run by a PLC that controls the pumps and blower, monitors the level switches, and makes some adjustments based on flows sensed by level changes and pump times in the clear well.

The installation, operation, and maintenance requirements for the system are described in detail in two documents, the Single Family Installation Instructions, and the Operation & Maintenance Manual (Appendix A). The Amphidrome™ System, as tested, had two pumps, five level/float switches, a back check valve, and one blower. The system is dependent on controlling the oxygen conditions in the submerged biofilter (through blower time control), on recycle of treated wastewater to the anoxic tank, and on pump timer cycles for discharge and backwash. All of these processes, controlled by the PLC, appear to be dependent on specific site conditions. In the opinion of the MASSTC operating staff, the system is sophisticated, complex, and needs to be setup and maintained by experienced operators, who can make necessary adjustments to the system. Homeowner involvement in operation and maintenance of the system would be limited. A service contract with an authorized service provider would be necessary to properly maintain this complex system.

According to the vendor's O&M Manual, the PLC does not allow operator access to the main program logic, but the operator does have a large degree of flexibility in adjusting the system by accessing the memory registers of the PLC. Adjusting the memory registers allows the operator to optimize the system by adjusting pump cycles, run times, blower on-off cycles, etc. However, in order to take advantage of this flexibility, FRMA states; ". . . a thorough understanding of both the Amphidrome™ System and the biological processes involved is required." During the verification test, the MASSTC operators observed the unit, which did not require any regular cleaning or maintenance, but did not change or adjust the PLC. All PLC adjustments were performed by FRMA trained representatives.

During the first two months of verification testing (April and May), FRMA adjusted the PLC on four occasions. The airflow was adjusted in early April and the backwash cycle was adjusted in mid-May. On May 24, the cycle times were adjusted to try to improve the performance, but were returned to the initial conditions on June 1. On October 21, the anoxic cycle was adjusted, and on October 25, 2001, the fixed airflow time was reduced by 10 percent to try to improve denitrification. These adjustments were made to try to match the aerobic/anoxic cycles to the wastewater and system conditions.

In addition to PLC changes, the internal clock required adjustment to daylight savings time in April and October. The clock also was "off" by a couple of hours on two occasions which seemed to correspond to times when the power was off to the unit. FRMA adjusted the clock during the site visits to check on other parts of the system.

During the test, two mechanical problems occurred, one when the recirculation pump slipped off the pedestal (June 2001), and one when the discharge pump failed. On June 21, 2001, an FRMA representative arrived at the site and found that the recirculation pump had slipped off the pedestal and the recirculation line disconnected. The pump was running continuously and no water was being returned to the anoxic tank, so the float switch was not activated to trigger the PLC to shutdown the pump. The pump was reset within the guide rails and the piping reconnected. Communications from FRMA indicate that they have recognized this problem in the small systems (the guide rail design was adapted from larger systems that use pumps designed for use with guide rail systems), and that they no longer use the guide rails in their small scale systems, but now use hard pipe connections to stabilize the pump.

In November 2001, the high water alarm sounded, indicating that water levels were above the normal operating range in the clear well. MASSTC operators attempted to manually activate the discharge cycle, but no discharge occurred. The emergency number provided by FRMA was called and a response was received within a couple of hours. Based on the observations of the MASSTC operators, FRMA instructed that the flow be discontinued to the unit. FRMA arrived on site within 24 hours and replaced the pump in the clear well resolving the problem.

In the opinion of the test site operators, there is very little maintenance or adjustment that the average homeowner can or should perform. The System, as mentioned above, does have a PLC control and relatively sophisticated operating cycle. Therefore, it will be necessary for homeowners to have a qualified maintenance organization operate and maintain the System.

FRMA recommends bimonthly inspections once the startup period ends and the system is operating properly. These inspections include checking the system visually (noting clarity of the effluent, any odor, color, or solids present, etc.), and performing analyses of the effluent using field test kits for ammonia and nitrate. The PLC records for pump and aeration run times are recorded to provide a record of the system's operation since the last inspection. Pump operation, particularly recycle flow (up flow through the reactor) and backwash flow, is observed to ensure proper operation. The backwash cycle is activated to ensure both the pumps and blowers are working properly, and the aeration system is inspected and the bubble pattern above the media observed. The bubble pattern should be evenly distributed over the media.

The anoxic tank should be checked for solids depth and, if solids have built up in the tank, pumping of the tank should be scheduled. The troubleshooting checklist in the Operation and Maintenance Manual indicates that solids removal should be scheduled when the solids are within two feet of the outlet from the anoxic tank. Since the outlet in the standard anoxic tank is set for a water depth of four feet, pumping of solids would typically be performed when solids depth is about two feet. General guidance for standard residential septic tank systems is to pump solids every 3 to 5 years. The more frequent pumping of solids from the anoxic tank is to be expected based on the additional solids load generated by the reactor system. The regular maintenance checks should include measurement of solids level in the anoxic tank.

Based on fifteen months of observation, it is estimated that regular maintenance checks, requiring approximately two hours by a person knowledgeable of the system, is appropriate to ensure the system is in good operating condition (after initial startup and optimization of the unit, which may take several site visits). The skill level needed is the equivalent of a Class II Massachusetts treatment plant operator.

FRMA provides examples of inspection and maintenance check lists, operator logs, and preventive maintenance Lists in their Operation and Maintenance Manual (Appendix A). A narrative description of all of the system components is also provided in the Manual. There are several pages of troubleshooting guidelines that can help an operator evaluate equipment malfunctions and potential causes of poor quality effluent.

The verification test ran for a period of fifteen months (with startup), which provided sufficient time to evaluate the overall performance of the system. However, a much longer period (several years) would be needed to evaluate the life cycle for the equipment, pumps, floats, filter and distribution assembly, etc. The basic components of the system appear durable and should perform acceptably under typical home wastewater conditions.

No particular special design considerations are necessary relative to siting of the system. The Amphidrome™ System is mostly underground, except for the blower unit. While the blower makes only limited noise, consideration for blower placement may be desired, as mentioned in the FRMA manuals.

The Installation, and Operation and Maintenance Manual (Appendix A) provided by FRMA are comprehensive and provide information for installation, startup, operation, and servicing of the Amphidrome™ System. The manual includes information on the theory of biological treatment and descriptions of observations that can be made to visually check the condition of the system. FRMA indicates that visual color and turbidity inspections, along with observations of suspended solids and odor in the effluent, can give an indication of possible upset conditions. FRMA also recommends the use of field test kit(s) to monitor the effluent quality for ammonia and nitrate, and regular sample collection and analysis for parameters such as BOD_5, TSS, TKN, NH_3, and NO_3.

4.5 Quality Assurance/ Quality Control

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

4.5.1 Audits

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

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

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

4.5.2 Daily Flows

One of the critical data quality objectives was to dose the system on a daily basis to within 10 percent of the design flow. For the Amphidrome™ System, the design flow was 400 gpd. The QC objective was to dose the system at 400 gpd plus or minus 10 percent, based on a monthly average of the daily flows. The dose volume was calibrated twice per week and if the volume changed by more than ten percent the dosing pump run time was adjusted in the test site PLC. The objective was met for all 13 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 spreadsheet format in Appendix F. The field logs in Appendix G provide the twice per week calibration data that is summarized in the spreadsheets.

4.5.3 Precision

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

The precision for nitrogen compounds was generally excellent, particularly given the low levels of ammonia, TKN, and nitrate in some of the effluent samples. A few sample results were outside the target window of either 10 percent RPD (nitrite, nitrate) or 20 percent RPD (TKN, NH_3), but in most cases, the results were for samples that were very low in concentration. As an example, one set of data for TKN showed replicate one as 0.9 mg/L and replicate two as 0.5 mg/L with a detection limit of 0.5 mg/L. The calculated RPD for this sample is 57 percent. Even though the relative percent difference (RPD) is high, the data is reasonable given the low concentration found in the samples.

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

Table 4-12. Duplicate Field Sample Summary – Nitrogen Compounds

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

Table 4-13. Duplicate Field Sample Summary – CBOD, BOD, Alkalinity, TSS

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

Table 4-14. Duplicate Field Sample Summary – pH, Dissolved Oxygen

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

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

The laboratories performed lab duplicates on a frequency of at least one per batch or 10 percent of samples. The laboratory precision data is summarized in Tables 4-16 and 4-17. The various nitrogen analyses showed excellent precision, as did the alkalinity results. Nitrite results showed that no samples (60 total) exceeded the target of 10 percent RPD. Nitrate results showed 14 out 211 values exceeded the 10 percent RPD target, but only 1 result out 211 exceeded a 20 percent difference. Only one ammonia duplicate out of 53 was outside the ± 20 percent RPD objective for field duplicates, and only 4 out of 59 TKN replicates exceeded ± 20 percent. The laboratory duplicates included ETV samples and other samples that were part of the GAI batch runs.

The $CBOD_5$ and TSS precision was generally within the target objective of 20 percent RPD, except when the concentrations were low. As discussed earlier, when effluent samples were below 10 mg/L the calculated percent differences were higher, as would be expected. The $CBOD_5$ and BOD_5 analyses used very similar procedures, and were performed together under the same conditions in the laboratory. The BOD_5 data showed much higher precision (average of 8 percent) than the $CBOD_5$ (average 15 percent) primarily due to the higher concentrations of

BOD_5 (influent wastewater samples). In summary, 18 out of 57 results exceeded the $CBOD_5$ target of 20 percent RPD, but none of the samples over 10 mg/L exceeded the target (0 out of 17); BOD_5 results showed 7 out of 64 results were above the target; and 8 out of 44 TSS samples showed RPD above 20 percent. On-site audits and review of procedures and calibrations indicated that good laboratory practice was being followed. There were no systematic errors identified that would account for the difference. The data for all analyses was judged acceptable and useable for evaluating the treatment efficiency.

Table 4-15. Laboratory Precision Data – Nitrogen Compounds

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

Table 4-16. Laboratory Precision Data – $CBOD_5$, BOD_5, Alkalinity, TSS

	$CBOD_5$ (mg/L)			BOD_5 (mg/L)		
Statistics	Rep 1	Rep 2	RPD	Rep 1	Rep2	RPD
Number	57	57	57	64	64	64
Average	18	18	15	160	160	7.7
Median	5.9	6.7	7.6	170	170	4.4
Maximum	100	100	73	500	530	32
Minimum	<2.0	2.0	0.0	<2.0	<2.0	0.0
Std. Dev.	24	24	15	120	120	8.1

	TSS (mg/L)			Alkalinity (mg/L as $CaCO_3$)		
Statistics	Rep 1	Rep 2	RPD	Rep 1	Rep2	RPD
Number	44	44	44	48	48	48
Average	72	73	13	83	84	6.1
Median	52	54	5	80	80	1.8
Maximum	290	310	130	190	190	40
Minimum	1	4	0	2	2	0
Std. Dev.	73	72	24	58	59	12

4.5.4 Accuracy

Method accuracy was determined and monitored using a combination of matrix spikes and lab control samples (known concentration in blank water) depending on the method. Recovery of the spiked analytes was calculated and monitored during the verification test. Accuracy was in control throughout the verification test. All TKN and ammonia recoveries for lab control samples were within the accuracy window of 80 to 120 percent. Matrix spike samples for TKN and ammonia, in real world samples not necessarily ETV samples, were generally within the window of 70 to 130 percent recovery. One matrix spike sample out of 50 was low for ammonia and 4 samples gave low recoveries for TKN. Each data set was examined and each data set was judged valid and useable. All recoveries for all spiked samples for alkalinity, BOD_5, nitrite, and nitrate were within the established windows. Only 1 result out of 51 spiked samples was outside the recovery target for $CBOD_5$. Tables 4-18 and 4-19 show a summary of the recovery data. All quality control data is presented in Appendix D.

Table 4-17. Accuracy Results – Nitrogen Analyses

Statistics	TKN (% Recovery)		Ammonia (% Recovery)	
	Matrix Spike	Lab Control Sample	Matrix Spike	Lab Control Sample
Number	54	59	50	57
Average	95	100	99	107
Median	96	99	100	107
Maximum	137	114	112	120
Minimum	62	86	51	91
Std. Dev.	16	6.2	9.3	7.2
Statistics	**Nitrite (% Recovery)**		**Nitrate (% Recovery)**	
	Matrix Spike	Lab Control Sample	Matrix Spike	Lab Control Sample
Number	50	54	24	119
Average	104	99	98	99
Median	104	99	97	98
Maximum	123	120	113	116
Minimum	80	82	85	81
Std. Dev.	10	9.7	8.4	8.0

Table 4-18. Accuracy Results – CBOD, BOD, Alkalinity

Statistics	$CBOD_5$ (% Recovery) Lab Control Sample	BOD_5 (% Recovery) Lab Control Sample	Alkalinity (% Recovery Lab Control Sample
Number	51	54	61
Average	100	101	100
Median	101	101	100
Maximum	106	109	113
Minimum	77	84	93
Std. Dev.	5	4	3

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

4.5.5 Representativeness

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

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

4.5.6 Completeness

The VTP set a series of goals for completeness. During the startup and verification test, flow data was collected for each day and the dosing pump flow rate was calibrated twice a week as specified. The flow records are 100 percent complete. Electric meter records were maintained in the field log book. Electric meter readings were performed twice a week and summarized in a spreadsheet. All electric meter readings were taken and were 100 percent complete.

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

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

The only analytical work that was not 100 percent complete was effluent temperature and dissolved oxygen measurements made in the field. Some measurements were not taken as the Amphidrome™ System only discharged once per day. In the first months of the test, the discharge was missed and the composite sample was used for these measurements. This data was not valid and was not reported. Procedures were changed and most of the measurements were obtained in the last months of the verification test. These two field parameters were not critical parameters in the data objectives and were being collected to provide basic water quality information.

5.0 References

5.1 Cited References

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5.2 Additional Background References

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

Appendix A

FRMA Literature and
Homeowners Installation Manual
Operation & Maintenance Manual

Appendix B

Verification Test Plan

Appendix C

MASSTC Field SOP's

Appendix D

Lab Data and QA/QC Data

Appendix E

Field Lab Log Book

Appendix F

Spreadsheets with Calculation and Data Summary

Appendix G

Field Operations Logs