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Environmental Technology Verification Report

Removal of Arsenic, Iron, Manganese, and Ammonia in Drinking Water

Nagaoka International Corporation CHEMILES NCL Series Water Treatment System

Prepared by

NSF International

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

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Prepared by:

NSF International
Ann Arbor, Michigan 48105

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Jeffrey Q. Adams, Project Officer
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Notice

The U.S. Environmental Protection Agency, through its Office of Research and Development, funded and managed, or partially funded and collaborated in, the research described herein. It has been subjected to the Agency's peer and administrative review and has been approved for publication. Any opinions expressed in this report are those of the author(s) and do not necessarily reflect the views of the Agency, therefore, no official endorsement should be inferred. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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Abbreviations and Acronyms

CAWET	California Waste Extraction Test
°C	Degree Celsius
C.U.	Color Units
°F	Degree Fahrenheit
DO	Dissolved Oxygen
DWS	Drinking Water Systems
EPA	Environmental Protection Agency
ETV	Environmental Technology Verification
ft^2	Square Feet or Square Foot
ft^3	Cubic Feet
FTO	Field Testing Organization
g	Gram
gfd	Gallons per Square Foot per Day
gpm	Gallon(s) Per Minute
gpd	Gallon(s) Per Day
hp	Horsepower
hr	Hour(s)
L	Liter
LCS	Laboratory Control Sample
m	Meter
MCL	Maximum Contaminant Level (USEPA standard)
mL	Milliliter
mg	Milligram
mg/L	Milligram per Liter
ND	Not Detected or Non-Detect
NIST	National Institute of Standards and Technology
NRMRL	National Risk Management Research Laboratory
NSF	NSF International
NTU	Nephelometric Turbidity Unit(s)
O&M	Operation and Maintenance
PLC/PC	Programmable Logic Controller/Personal Computer
psi	Pounds per Square Inch
PSTP	Product Specific Test Plan
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RSD	Relative Standard Deviation
SMCL	Secondary Maximum Contaminant Level
S.U.	Standard Units
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TSS	Total Suspended Solids
µg/L	Microgram(s) per Liter

Acknowledgements

The Field Testing Organization (FTO), CH2M Hill, was responsible for all field testing elements, including system operation, collection of samples, field data collection, and calibration and checks of instrumentation. NSF International was responsible for all laboratory sample analysis (except for backwash sludge analysis), data management, data interpretation, and preparation of this report. TriMatrix Laboratories was responsible for the backwash sludge analysis.

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NSF International wishes to thank the CH2M Hill Portland, Oregon office for functioning as the FTO for this verification project. NSF wishes to specifically thank the following CH2M Hill staff: Mr. Lee Odell, Mr. Matthew Steiner, and Ms. Brittany Hughes

NSF and CH2M Hill wish to thank Clark Public Utilities of Clark County, Washington, USA, for the use of the field testing site.

Chapter 1
Introduction

1.1 ETV Purpose and Program Operation

The U.S. Environmental Protection Agency (USEPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by 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; with stakeholder groups consisting of buyers, vendor organizations, and permitters; 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 testing, collecting and analyzing data and by 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.

The EPA has partnered with NSF International (NSF) under the ETV Drinking Water Systems (DWS) Center to verify the performance of drinking water systems that serve public drinking water supply systems. A goal of verification testing is to enhance and facilitate the acceptance of small drinking water treatment equipment by state drinking water regulatory officials and consulting engineers, while reducing the need for testing of equipment at each location where the equipment's use is contemplated. NSF meets this goal by working with manufacturers and NSF-qualified Field Testing Organizations (FTOs) to conduct verification testing under the approved protocols. It is important to note that verification of the equipment does not mean the equipment is "certified" by NSF or "accepted" by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations for those conditions tested by the FTO.

1.2 Testing Participants and Responsibilities

The ETV testing of the CHEMILES water treatment system was a cooperative effort among the following participants:

NSF International
CH2M Hill
Nagaoka International Corporation
Clark County (WA) Public Utilities
U.S. Environmental Protection Agency

The following is a brief description of all of the ETV participants and their roles and responsibilities.

1.2.1 NSF International

NSF is an independent, not-for-profit testing and certification organization dedicated to public health and safety and to the protection of the environment. Founded in 1946 and located in Ann Arbor, Michigan, NSF has been instrumental in the development of consensus standards for the protection of public health and the environment. NSF also provides testing and certification services to ensure that products bearing the NSF Name, Logo and/or Mark meet those standards. The EPA partnered with NSF to verify the performance of drinking water treatment systems through the EPA's ETV Program.

NSF prepared the Test/Quality Assurance Plan (TQAP) and authored the final report. The NSF Chemistry and Microbiology Laboratories analyzed all water samples except those analyzed in the field. NSF provided technical oversight of the verification test and conducted an audit of the field analytical and data gathering and recording procedures.

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Email: bartley@nsf.org

1.2.2 Field Testing Organization

CH2M Hill conducted the verification testing of the CHEMILES System. CH2M Hill operated the pilot unit, recorded operational parameter readings as necessary, collected and analyzed water samples for the parameters measured in the field, and collected and shipped to NSF the samples for laboratory analysis.

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CH2M Hill
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Portland, Oregon 97201
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Email: Lee.Odell@CH2M.com

1.2.3 Manufacturer

The treatment system was the CHEMILES NCL Series water treatment system manufactured by Nagaoka International Corporation (Nagaoka). The manufacturer was responsible for supplying a field-ready pilot testing system equipped with all necessary components, including treatment equipment, instrumentation and controls, and an operation and maintenance (O&M) manual.

The manufacturer was responsible for providing logistical and technical support, as needed, as well as technical assistance to the FTO during operation and monitoring of the equipment undergoing field verification testing.

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Nagaoka International Corporation
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Osaka, Japan 595-0055
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1.2.4 Analytical Laboratory

The NSF International Chemistry and Microbiology Laboratories in Ann Arbor, Michigan performed all water quality analyses.

Backwash toxicity analyses were performed by:

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5560 Corporate Exchange Court SE
Grand Rapids, Michigan 49512
Contact Person: Mr. Michael Movinski, Vice President, Sales and Marketing
Phone: 616-975-4500
Email: movinskim@trimatrixlabs.com

1.2.5 U.S. Environmental Protection Agency

The EPA, through its Office of Research and Development, has financially supported and collaborated with NSF under Cooperative Agreement No. R-82833301. This verification effort was supported by the DWS Center operating under the ETV Program. This document has been peer reviewed, reviewed by NSF and EPA, and recommended for public release.

1.3 Verification Testing Site

1.3.1 Site Description

The test site is the Clark Public Utilities Bridge Road Water Treatment Plant (also known as the Hayes Road Well), located near Woodland, Washington in Clark County, USA. The site is only about 200 feet away from the Lewis River, but it is not classified as ground water under the influence of surface water. The site has an 8-inch diameter well with a submersible pump rated at 50 gallons per minute (gpm). The plant is not continuously manned, and is only operated periodically, depending on the level in the finished water reservoir. The treatment plant includes manganese greensand filtration to remove iron, manganese, and arsenic. For the verification test, a separate 5 gpm pump was installed in the well casing to provide a dedicated supply to the pilot unit.

1.3.1.1 *Structural*

The water treatment plant is fully enclosed in a small building. The pilot unit was located outside, next to the building. The FTO used countertop space and a sink in the treatment plant building for onsite analytical activities.

1.3.1.2 *Handling of Filtrate and Residuals*

All treated water (filtrate) from the CHEMILES pilot unit was collected in a holding tank, and then discharged onto the ground on-site. Backwash wastewater from the pilot unit was stored in a separate holding tank, then flow to the water treatment plant's backwash holding tank. No solids were discharged onto the ground.

1.3.1.3 *Discharge Permits*

No discharge permits were required for the discharge of the filtrate. The State of Washington Department of Ecology does not require discharge permits for water treatment plants with on-site discharge.

1.3.2 Source/Feed Water Quality

Table 1-1 presents raw water quality for samples collected from the Bridge Road Water Treatment Plant well in 2005 and 2010. No arsenic speciation data was available, data was obtained as part of Task A: Raw Water Characterization.

Table 1-1. Historical Raw Water Quality Data

Parameter	Units	Date 10/21/2005	10/21/2010	02/25/2010 to 07/09/2010	10/17/2011 to 11/07/2011
Turbidity	NTU	—	0.5	—	—
Total Arsenic	µg/L	15	15	—	31-36
Ammonia	mg/L	—	—	—	0.30-0.32
Sulfate	mg/L	—	2.2	—	—
Fluoride	mg/L	—	<0.2	—	—
Silica	mg/L	26.3	26.3	—	—
Temperature	°C	—	—	9-12	—
pH	S.U.	—	—	5.9-6.6	6.4-6.6
Alkalinity	mg/L as $CaCO_3$	—	84	—	—
Hardness	mg/L as $CaCO_3$	—	66.3	—	—
Iron	mg/L	9.03	—	9.03-18.8	8.8-10.6
Manganese	mg/L	—	—	0.24-0.46	0.19-0.22
Total Dissolved Solids (TDS)	mg/L	—	242	—	—
Aluminum	µg/L	<50	—	—	—
Antimony	µg/L	<0.05	—	—	—
Barium	µg/L	<5.0	—	—	—
Beryllium	µg/L	<0.02	—	—	—
Cadmium	µg/L	<1	—	—	—
Calcium	mg/L	14.6	—	—	—
Chromium	µg/L	<1	—	—	—
Copper	µg/L	<10	—	—	—
Lead	µg/L	<1	—	—	—
Magnesium	mg/L	7.25	—	—	—
Manganese	µg/L	240	—	—	—
Mercury	µg/L	<0.5	—	—	—
Nickel	µg/L	<1	—	—	—
Potassium	mg/L	3.93	—	—	—
Selenium	µg/L	<5	—	—	—
Silver	µg/L	<1	—	—	—
Sodium	mg/L	43.1	—	—	—
Zinc	mg/L	0.04	—	—	—

Chapter 2 Equipment Capabilities and Description

2.1 General Description of Equipment

According to the manufacturer, the CHEMILES NCL Series system is a self-contained, system designed for treatment of groundwater with minimal and sometimes no use of chemicals. The system is a column design, intended for outdoor placement. The system does not include a chemical feed pump, but it does include a treated water pump and a backwash pump. The treatment column contains a sand filter medium, with a support gravel layer at the base. The system must be allowed to ripen for three to six months, to allow autotrophic bacteria to colonize the sand filter medium.

The CHEMILES NCL Series system comes equipped with a programmable logic controller (PLC) to control operation. The PLC allows the operator to monitor operation of the system, and to control the backwash frequency. Figure 2-1 is a photo of the system, and Figure 2-2 is a cross-section diagram of the treatment column.

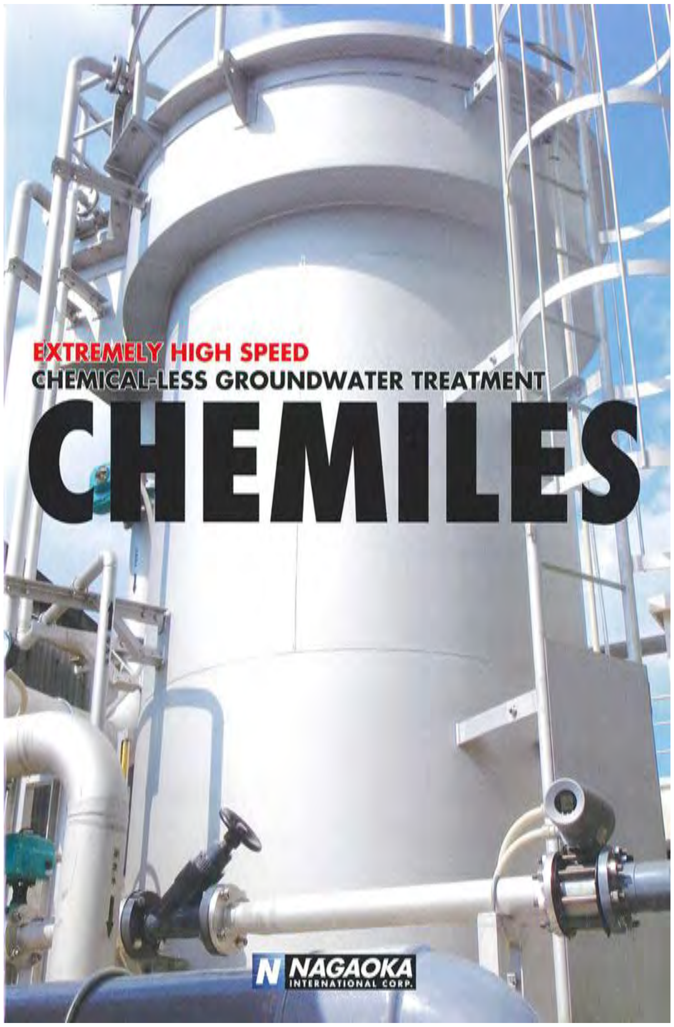
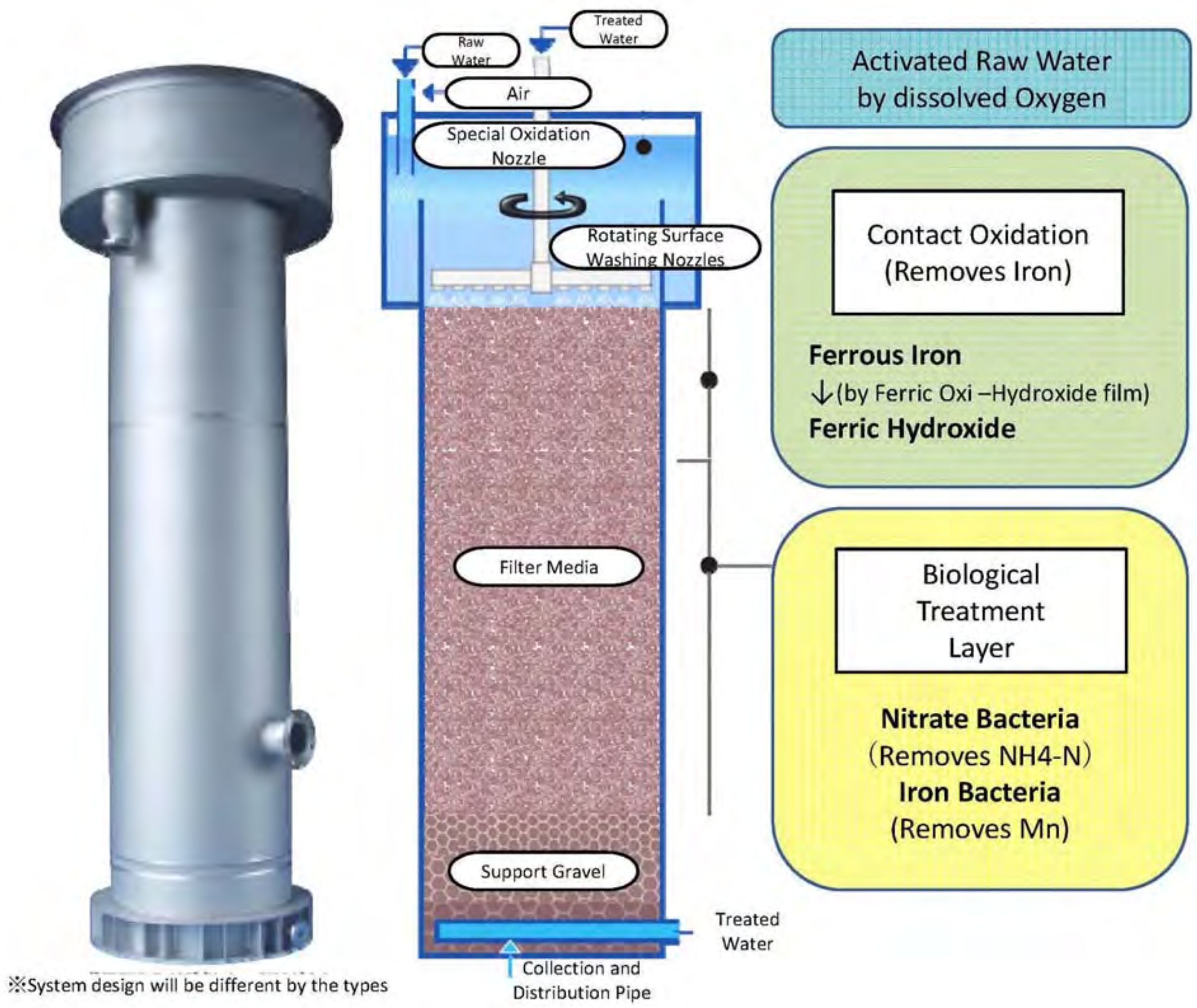


Figure 2-1. Photo of CHEMILES NCL Series Water Treatment System.



※System design will be different by the types

Figure 2-2. Cross-Sectional Diagram of CHEMILES NCL Series Column.

Raw water is introduced into the top of the column through a proprietary oxidation nozzle. The nozzle is Nagaoka International Corporation’s proprietary product, and is designed to induce air into the nozzle utilizing the “Venturi effect”, which reduces fluid pressure when the water flows through a constriction. Air is induced through a hole in the nozzle near the constriction, and causes the air and water to be mixed. Nagaoka designs their nozzles specifically for each application based on the raw water quality, flow and water pressure to maintain the desired dissolved oxygen concentration in the water.

The oxidation nozzle increases the dissolved oxygen (DO) level of the raw water, causing soluble ferrous iron to oxidize to insoluble ferric iron, and arsenic (III) to oxidize to arsenic (V). The sand filter media becomes coated with ferric oxi-hydroxide, which acts as a catalyst to oxidize and retain a remaining portion of the iron. The bacteria on the filter medium oxidize any remaining ferrous iron to ferric iron, and they also oxidize ammonia to nitrate, and soluble manganese to insoluble manganese dioxide. The ferric iron and manganese dioxide are retained by the filter medium.

There are two types of backwashes for the CHEMILES system – "P" backwashes and "W" backwashes. The P backwashes are partial backwashes, and W backwashes are whole-system backwashes. The P backwashes occur several times per day, while the W backwashes usually occur once per day or more infrequently. The P backwash just backwashes the upper filtration zone, where most of the arsenic and iron precipitate is retained. The P backwash utilizes Nagaoka's proprietary rotating surface washing nozzles to assist in the backwash process. This approach minimizes disturbances of the biological active lower treatment zone. During the filter ripening and initial test runs phase, Nagaoka sets the backwash frequency for this verification to be three times per day for P backwashes (every eight hours), and after every ninth P backwash for the W backwash. However, in the middle of the verification testing period, Nagaoka changed the W backwash frequency so that it occurred after every sixth P backwash. Each P backwash is designed to consume 66 gallons (gal) of treated water, and each W backwash is designed to use 92.5 gal. However, during the shakedown testing period, Nagaoka changed the backwash volumes to 48.16 gal for each P backwash, and 69.3 gal for each W backwash, based on the raw water quality of the test site.

2.2 Engineering and Scientific Concepts

It is well known that iron and arsenic can be removed from water by oxidation, coagulation and precipitation. In the presence of an oxidant such a chlorine or oxygen, iron oxidizes from soluble ferrous iron to relatively insoluble ferric iron, while arsenic oxidizes from the +3 valence state to the +5 valence state. It is also well known that removal of arsenic can be aided by adding iron (e.g. ferric chloride) as a coagulant. As (V) readily coagulates with iron, while As (III) must be first oxidized to As (V). The arsenic is then co-precipitated with the iron, and the precipitate can be retained by filtration media.

Ferrous iron can also be oxidized by autotrophic "iron bacteria", which use ferrous iron as an electron donor, thus oxidizing it to the ferric state.

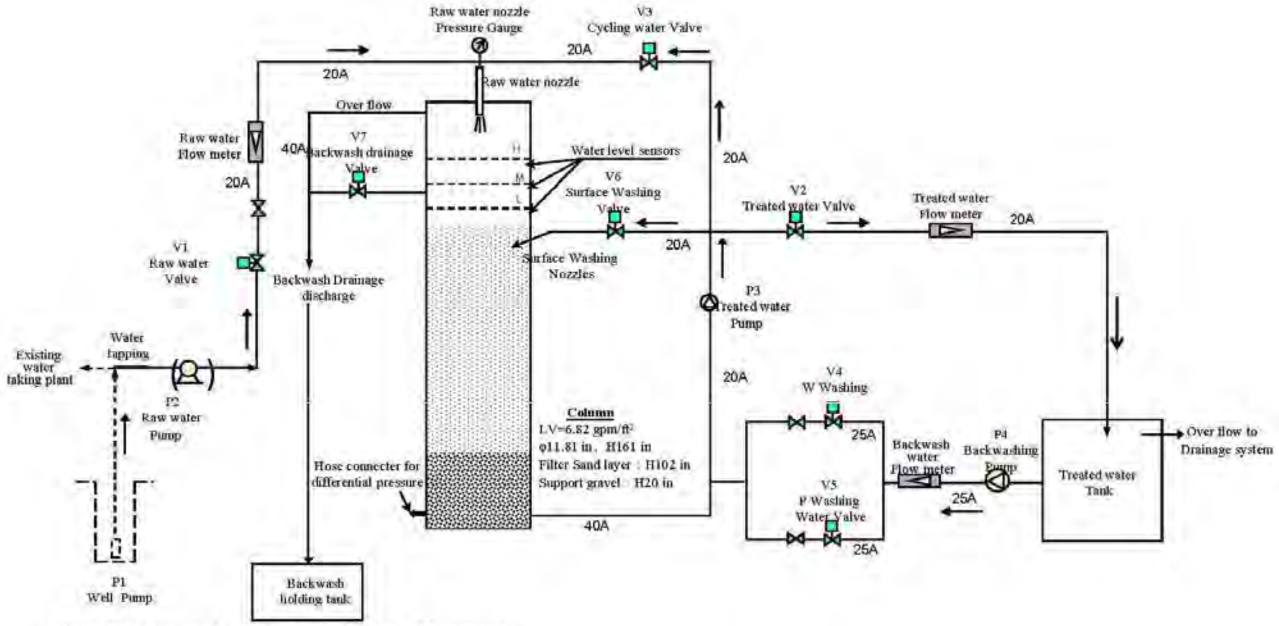
In the same manner, both ammonia and manganese can be oxidized by autotrophic bacteria. Ammonia present in water as ammonium (NH^{4+}) is oxidized first to nitrite, and then to nitrate. Soluble manganese (Mn^{2+}) is oxidized to manganese dioxide, which is insoluble, and is captured by the filtration media.

2.3 Pilot Unit Specifications

The pilot unit was the CHEMILES NCL Series system with serial code CLT-300. The treatment column is grey PVC, and is 4.1 meters (m) high (161.41 inches (in)), with an internal diameter of 300 millimeters (mm) (11.81 in). The filtration media height for this system is 3.1 m (122 in). Table 2-1 gives the CLT-300 specifications. A schematic diagram of the system is provided as Figure 2-3, and a photo of the pilot unit at the test site is presented in Figure 2-4.

Table 2-1. CHEMILES CLT-300 Specifications

System Footprint	3 m x 3 m (118 in x 118 in)
System Height	4.5 m (177 in)
Filter Column Height	4.1 m (161.41 in)
Filter Column Internal Diameter	300 mm (11.81 in)
Filter Cross-Sectional Area	0.07 m^2 (0.75 square feet (ft^2))
Maximum Linear Velocity	400 meters per day (m/d) (6.82 gpm/ft^2)
Treatment Capacity	28.27 m^3/d (7,468 gallons per day (gpd))
Minimum Feed Pressure	2.0 bar (29 pounds per square inch (psi))
Feed pump Output	0.56 kW
Effluent Pump Output	0.56 kW
Backwash Pump Output	1.1 kW
Effluent Holding Tank Volume	0.5 m^3 (132 gal)
Partial ("P") Backwash Volume	0.25 m^3 (66 gal)
Whole ("W") Backwash Volume	0.35 m^3 (92.5 gal)



Note 1: Dotted Line area is out of Testing System Supplied from Nagaoka
Note 2: "( )": Would be used if necessarly

Figure 2-3. Schematic Diagram of the CHEMILES CLT-300 Pilot Unit.

Figure 2-4. Photo of CHEMILES CLT-300 Pilot Unit at Test Site.

2.4 Chemical Consumption and Production of Waste Material

2.4.1 Chemical Consumption

The CHEMILES system does not need any chemicals for water treatment. However, from March 27 to April 8 during the verification test, Nagaoka decided to raise the pH from 6.45 to 7.02 as measured in the field by the field testing organization, through the pumping of sodium hydroxide into the raw water stream. The goal was to evaluate whether manganese removal improved with a higher pH.

2.4.2 Waste Production and Physical and Chemical Nature of Wastes

Backwash wastewater containing the solids (iron, arsenic and manganese) was discharged to a backwash holding tank for sampling. The holding tank was then discharged to the Bridge Road Treatment Plant's backwash holding tank. The contents of the tank are periodically infiltrated into the ground infiltration pond next to the treatment plant. The treated water was also infiltrated into the ground at the same location.

2.5 Licensing Requirements

There are no special licensing requirements to operate the CHEMILES system during the ETV test since the treated water will be discharged to the ground.

2.6 Statement of Performance Objectives

The statement of performance objectives for the verification test was as follows:

The CHEMILES system is capable of reducing total arsenic, iron, and manganese in the source water to less than the EPA drinking water maximum contaminant levels (MCL). The CHEMILES system can also reduce ammonia in the source water by 75% or to less than 0.1 mg/L when the raw water contains a low level of ammonia.

2.7 Advantages of the CHEMILES System

According to Nagaoka, the main advantages of the CHEMILES system for removing iron, arsenic, manganese, and ammonia from water are as follows:

- The column design allows for a small footprint.
- The CHEMILES system does not require any chemicals for water treatment.
- Multiple contaminants can be removed by only one treatment column.
- The CHEMILES system is an extremely high speed treatment system.
- The system does not need to be installed inside a building.

2.8 Limitations of the CHEMILES System

Potential limitations of the CHEMILES system, with respect to source water quality are:

- Poor water quality in source water can cause high solids loadings to the filter, increasing backwash frequency and quantity of solids generated.
- A disposal location, such as a settling basin or a sanitary sewer system, is needed to handle the backwash waste generated on a daily basis.
- The raw water must be introduced directly into the system from the well. Nagaoka states that iron cannot be effectively removed if oxidized before introduction to the system.

Nagaoka has identified the water quality limitations listed in Table 2-2 for the CHEMILES system.

Table 2-2. CHEMILES Water Quality Limitations

Iron (total)	Not to exceed 40.0 mg/L
Manganese	Not to exceed 3.2 mg/L
Ammonia	Not to exceed 1.5 mg/L(1)
Arsenic (total)	Not to exceed 1.2 mg/L, or 1/30th of iron concentration
Total Alkalinity (as $CaCO_3$)	Not less than 60 mg/L
Sulfide (as H_2S)	Not to exceed 0.2 mg/L
pH	Between 6.5 and 8.0

(1) Treatment of higher concentrations possible by dilution-cycling treatment method.

Chapter 3
Methods and Procedures

3.1 Quantitative and Qualitative Evaluation Criteria

As defined in the ETV protocol, the objectives of the verification test are to evaluate equipment in the following areas:

- The actual results obtained by the equipment as operated under the conditions at the test site;
- The impacts on performance of any variations in feed water quality or process variation;
- The logistical, human, and other resources necessary to operate the equipment; and
- The reliability, ruggedness, ranges of usefulness, and ease of operation of the equipment.

To address these objectives, the verification test employed the quantitative and qualitative factors listed in Table 3-1 in evaluating the CHEMILES system performance.

Table 3-1. Quantitative and Qualitative Evaluation Criteria

Quantitative Factors	Qualitative Factors
• Feed water flow rate • Treated water quality • Length of operating cycle • Frequency of backwash cycles • Power consumption • Maintenance requirements • Required level of operator attention • Spatial requirements • Discharge requirements • Waste disposal	• Ease of operation • Safety • Susceptibility to environmental conditions • Impact of operator experience on successful operation

3.2 Key Water Quality Parameters

The key treated water quality parameters monitored for the CHEMILES verification test are listed in Table 3-2. Other parameters of interest that were measured are listed in Table 3-3. The parameters of interest were not expected to have an immediate impact on the treatment process, but are important parameters in drinking water supplies.

Table 3-2. Key Water Quality Parameters

Water Quality	Inorganic Parameters
• Temperature	• Arsenic (III)
• Alkalinity	• Arsenic (V)
• pH	• Total Iron
• Oxidation/Reduction Potential (ORP)	• Dissolved Iron
• Turbidity	• Ammonia
	• Nitrate/Nitrite
	• Manganese
	• Total Kjeldahl Nitrogen (TKN)

Table 3-3. Water Quality Parameters of Interest

Other Parameters
• Hardness
• True Color
• DO
• Total Organic Carbon (TOC)
• Total Suspended Solids (TSS)
• Volatile Suspended Solids (VSS)
• Color
• Dissolved Organic Carbon (DOC)
• Chloride
• Sulfate
• Sulfide
• Fluoride
• Heterotrophic Plate Count (HPC)
• Silica
• Sodium
• Potassium

3.3 Definition of Operational Parameters

The following are definitions used in this report and for designation of sampling locations:

Treated water is defined as the water produced by the CHEMILES treatment process.

Raw water is defined as the water introduced to the CHEMILES system. For this system, the raw water is equivalent to the feed water.

3.4 Operations and Maintenance

The manufacturer's operations and maintenance (O&M) documentation for a typical full-scale system were reviewed by the FTO, and the results of this review are included in the results and discussion section.

In addition, the following aspects of operability are addressed in this report:

- The fluctuation of flow rates and pressures through the unit such as how long feed pumps can hold to the feed rate;
- The presence of devices to aid the operator with flow control adjustment;
- How pressure in the system is measured and documented;
- The method for measuring the rate of flow of raw water; and
- The adequacy and ease of use of the control systems.

The test unit is a pilot unit that is representative of the full-scale system, which will allow observation of the design and operation of the system. The control system is also the same system used in commercial applications. Therefore, it was possible to evaluate the following operability issues directly during the verification test:

- Length of filter runs between backwash cycles;
- Change in pressure across the filtration media over time;
- Frequency and ease of backwash;
- Ease of operating the computer control system; and
- Availability of process data to the operator.

3.5 Field Operations Procedure

CH2M Hill, as the FTO, conducted the testing of the CHEMILES described in this report. The NSF Chemistry and Microbiology Laboratories performed the laboratory water quality analyses. CH2M Hill field personnel performed field analytical work, using field laboratory equipment and procedures.

The unit was operated 24 hours a day, seven days a week. The FTO visited the site once per day, Monday through Friday, throughout the entire verification testing period. The visit's purpose was for operational measurements, and sample collection when prescribed. Site visits also occurred over the weekends during the 320-hour daily sampling and monitoring periods. If any system operation alarm occurred, the details of the alarm and the occurrence time were shown on the PLC control panel monitor, and the FTO corrected the alarm condition.

3.6 Environmental Technology Verification Testing Plan

A TQAP was prepared for the CHEMILES NCL Series system verification test in accordance with the ETV EPA/NSF Protocol for Equipment Verification Testing for Arsenic Removal (September 2003). This protocol was used for the aspects of testing relating to removal of arsenic, iron, and manganese. There is no ETV Protocol for ammonia reduction, so best available professional judgment was used for the testing aspects related to this contaminant.

The TQAP divided the work into three main tasks (A, B, C) with Task C, the verification test itself, divided into six tasks. These tasks are:

Task A: Raw Water Characterization
Task B: Initial Test Runs
Task C: Verification Test

Task 1: Verification Testing Runs
Task 2: Raw and Treated Water Quality
Task 3: Operating Conditions and Performance
Task 4: Contaminant Removal
Task 5: Data Management
Task 6: Quality Assurance/Quality Control (QA/QC)

The TQAP, which included a Quality Assurance Project Plan (QAPP), specified procedures to be used to ensure the accurate documentation of both water quality and equipment performance.

An overview of each task is provided below with detailed information on testing procedures presented in later sections.

3.6.1 Task A: Raw Water Characterization

The objective of Task A was to obtain a chemical and physical characterization of the raw water at the beginning of the verification testing period.

3.6.2 Task B: Initial Test Runs

During Task B, Nagaoka and CH2M Hill operated the system to ripen the biological filter, and to evaluate equipment operation to determine the optimal operational settings needed to provide effective treatment of the raw water.

3.6.3 Task C: Verification Test Procedures

3.6.3.1 *Task 1: Verification Testing Runs*

The CHEMILES system verification testing period began on November 5, 2012, and finished on May 23, 2013. During this testing period, water quality measurements were made weekly, and from March 11 to March 24, and again from May 10 to May 23, there were two 320-hour (13 days plus 8 hours) daily sampling periods. However, the second 320-hour daily sampling period was for Manganese only. Within each 320-hour period there was one 48-hour intensive sampling period.

3.6.3.2 *Task 2: Raw Water and Treated Water Quality*

During verification testing, raw and treated water samples were collected and appropriate sample analyses were performed. The water quality analyses conducted for this verification are listed in Tables 3-2 and 3-3.

3.6.3.3 *Task 3: Operating Conditions and Performance*

During verification testing, operating conditions and performance of the water treatment equipment were documented. Equipment performance information includes data such as rate of filter head loss gain, duration of filter runs and volume of water filtered per run, and frequency and duration of backwashes. The operating conditions include plant flow rates and backwash frequency.

3.6.3.4 *Task 4: Contaminant Removal*

The objective of this task is to evaluate removal of iron, arsenic, manganese, and ammonia during verification testing by measuring these parameters in the raw and filtrate waters.

3.6.3.5 *Task 5: Data Management*

The objective of this task was to establish an effective field protocol for data management at the field operations site, and for data transmission between the FTO and NSF. Master field logs were prepared and field sheets for data collection were used to ensure all scheduled activities were performed. The logs were scanned and emailed to NSF on a weekly basis.

3.6.3.6 *Task 6: Quality Assurance/Quality Control (QA/QC)*

An important aspect of verification testing was the development of specific QA/QC procedures. The objective of this task was to assure accurate measurement of operational and water quality parameters during the verification test.

3.7 Task A: Raw Water Characterization

3.7.1 Site Background Information

One production well provides ground water for the Bridge Road Water Treatment Plant. The raw water is currently treated to remove iron, manganese, and arsenic. Section 1.3 provides a description of the treatment plant, and the historical water quality data are presented in Table 1-1.

3.7.2 Additional Analytical Data

On Day 3 of the verification test, the Week 1 grab samples of the raw water also served to confirm the historical data. The Week 1 analyses included arsenic speciation to determine the distribution of arsenic (III) and arsenic (V) in the raw water. Table 3-4 lists the parameters that were analyzed for this initial sample set. Information on sampling and analysis methods and procedures is provided in Sections 3.9.4 and 3.9.6.

Table 3-4. Water Quality Parameters for Raw Water Characterization

pH
Temperature
Turbidity
Alkalinity (total)
TDS
TSS
Hardness (total)
TOC
DOC
DO
True Color
Arsenic (total, plus speciation)
Chloride
VSS
Iron
Manganese
Nitrate
Nitrite
Ammonia
TKN
Sulfate
Fluoride
Silica
Sodium
Potassium
HPC
Sulfide

3.7.3 Evaluation Criteria

The historical water quality data were evaluated in the context of the Nagaoka statement of performance to confirm that the water source was appropriate for verification testing.

3.8 Task B: Initial Test Runs

3.8.1 Objectives

The primary objective of this task was to install and operate the pilot unit to ripen the filter media for biologically mediated oxidative treatment of manganese and ammonia. This task also served to check system integrity, and set the operational settings for optimal performance.

3.8.2 Work Plan

Nagaoka and CH2M Hill staff collaborated to install the equipment and ready the test system for operation. Once ready for operation, CH2M Hill operated the CHEMILES system periodically from October 2011 to November 2012. While operating, key water quality parameters were measured at least once per week to monitor system performance.

During and after cultivation of the biological treatment layer in the filtration media, startup and shakedown tests were conducted to determine the proper operating conditions for the verification test. The FTO and Nagaoka measured water quality parameters in the field, using test kits. Operational and water quality data collected during Task B are available upon request from the manufacturer.

3.8.3 Arsenic Loss Test

The arsenic loss test is required per the ETV protocol for arsenic removal by coagulation/co-precipitation, followed by filtration. This task is important for systems that add a coagulant, such as iron. The objective is to run the system without coagulant addition to see what amount of arsenic is removed, if any. The performance of the system without coagulant addition serves as a baseline against which to measure performance with coagulant. Since the CHEMILES system does not include coagulant addition, the arsenic loss test was not required for this verification, and thus was not conducted.

3.8.4 Analytical Schedule

While the system was in operation during Task B, the raw and treated water was measured weekly for iron, arsenic (total), manganese, ammonia, pH, DO, and temperature to monitor system performance.

3.8.5 Evaluation Criteria

The data obtained during Task B was evaluated by the FTO and Nagaoka to set the optimal pilot unit operational parameters for the verification test. When Nagaoka was satisfied that the pilot unit was performing suitably, CH2M Hill took full control of the system, and the verification test began.

3.9 Task C: Verification Test

3.9.1 Introduction

The TQAP called for the CHEMILES pilot unit to be operated for a minimum of six months, with weekly measurement of the key water quality parameters. During the verification test there was one required 320-hour (13 days plus 8 hours) daily sampling period, and within the 320-hour period there was a required 48-hour intensive sampling period. The verification test started on November 5, 2012, and was scheduled to end on May 1, 2013. The 320-hour daily sampling period occurred from March 11 to March 24, with the 48-hour intensive sampling period occurring March 18 through March 20. In April, Nagaoka requested an additional 320-hour daily sampling period be conducted in May for Manganese only because manganese removal had not stabilized and reached steady-state performance by the time of the March daily sampling period. Nagaoka also requested that the second week of additional testing in May be operated with the pH of the raw water raised to 7 to evaluate whether manganese removal improved with a higher pH. Forty-eight hour intensive sampling periods were performed each week of this additional testing period. The additional testing period began on May 10, 2013, and ended on May 23, 2013. The 48-hour intensive sampling periods were run May 14 through 16, and again May 21 through 23.

The test unit was operated continuously, 24 hours a day, seven days per week, unless operation had to be stopped for maintenance. Water quality data for the raw water, treated water, and backwash wastewater were collected in accordance with the schedule described in the following sections. All raw and treated water samples were grab samples collected from the sampling ports installed at the site. At Nagaoka's request, the FTO also sampled the aerated water for pH, temperature, ORP, and DO. These samples were collected from the top of the treatment column with a ladle. Backwash grab samples were collected from a backwash collection vessel also with a ladle.

3.9.2 Experimental Objectives

The objective of this task was to assess the ability of the CHEMILES system to demonstrate the treatment capability indicated in the Statement of Performance Objectives (Section 2.6). The verification test described herein was designed to collect and analyze contaminant reduction performance data, equipment operating performance data and characteristics, and other water quality information in order to achieve the objective. Statistical analyses (standard deviation and confidence intervals) were performed on all analytes with eight or more discrete samples collected over the verification period.

3.9.3 Task 1: Verification Testing Runs

3.9.3.1 *Introduction*

The verification test was designed to evaluate the CHEMILES system under optimal operating conditions, as determined by Task B, and to measure system performance over an extended operating period. The treated water produced during the verification was not used for public supply purposes, it was discharged on-site.

3.9.3.2 *Operating Schedule*

The CHEMILES system was operated continuously during the verification test, except for the scheduled backwashes or minor maintenance periods. The FTO field operators recorded daily measurements of the routine operating parameters listed in Table 3-5. Water quality sampling and analysis activities occurred as described in Section 3.9.4.

Table 3-5. On-site Equipment Operating Parameter Monitoring and Data Collection Schedule

Parameter	Monitoring Frequency	Monitoring Method
Treated water production	Check & record once per day.	Flow meter. (PLC)
Treated water flow rate	Check & record once per day.	Flow meter. (PLC)
Filter Head loss	Record initial clean bed total head loss at start of filter run. Check & record once per day. Record terminal head loss at end of filter run.	Water height change in sight column.
Backwash Flow Rate	Check & record when on site and backwash is occurring.	System backwash flow meter.
Total Backwash Volume and Duration	Check & record when on site and backwash is occurring.	Flow rate multiplied by length of cycle.
Operating Hours	Record once per day in log the total hours of operation since last site visit.	Based on PLC/PC and total volume meters, determine total hours.
Power Use	Determined at end of test.	Power use calculated based on equipment horsepower ratings.
Labor Hours	Determine labor hours required.	Record time on-site daily in logbooks.

To meet the goals of the verification testing for equipment employing precipitation and media filtration, the following conditions were met:

- Water treatment equipment operated continuously;
- Interruptions in filtration occurred only as needed for backwashing of the filters; with the exception of equipment failure or power interruption; and
- The duration of each filter run and the number of gallons of water produced per square foot of filter area were recorded in the operational results.

3.9.3.3 *Evaluation Criteria*

Field logs were used to record all of the information shown in Table 3-5. The hours of operation needed to meet the protocol requirements were documented. Backwash cycles and times were recorded. All data are summarized in this final report, including:

- Duration of each filter run;
- Average volume treated per run; and
- Volume produced per square foot of filter surface.

3.9.4 Task 2: Raw Water, Treated Water, and Backwash Wastewater Quality

3.9.4.1 *Introduction*

Water quality data were collected for the raw and treated water on a regular basis during the verification test, including two 320-hour daily sampling periods that included 48-hour intensive sampling periods. These data were the basis for determining performance of the system and documenting the water quality achieved.

3.9.4.2 *Work Plan*

Table 3-6 provides a list of the water quality parameters that were monitored during the verification test, along with the frequency of sampling for each parameter. The sampling plans for arsenic, iron, manganese, and ammonia are listed in Section 3.9.6. Nitrate and nitrite are also included in 3.9.6 with the target contaminants, since the treatment process oxidizes ammonia first to nitrite, then to nitrate.

The FTO field staff measured some water quality parameters on-site. The NSF Chemistry Laboratory measured the remaining water quality parameters. The methods used for measurement of the water quality parameters are identified in Table 3-7, which also identifies the party responsible for each parameter.

For the water quality parameters submitted to NSF, grab samples were collected in appropriate containers (containing necessary preservatives as applicable) prepared by NSF and shipped to CH2M Hill in coolers. The samples were shipped overnight on ice back to NSF. The NSF Chemistry Laboratory analyzed all samples in accordance with the appropriate procedures and holding times.

The backwash waste was analyzed per Table 3-6 during a backwash cycle to obtain information on the TSS concentration and pH of the backwash wastewater. Backwash samples were also measured for total arsenic, total iron, and manganese.

The ETV protocol calls for measuring the metals leached from any sludge produced from the system using the TCLP and California WET (CAWET) leaching analysis procedures. Arrangements were made to sample the sludge produced and to send the samples to an outside lab for these analyses. The CHEMILES system typically only produces sludge if the backwash waste is passed through a solids separator, or is sent to a settling basin to remove suspended solids prior to discharge. In other applications, the backwash would be discharged to a sewer system and would be treated at a wastewater treatment facility. Measuring the TSS, iron, arsenic, and manganese in the backwash waste provided the needed data to assess the quality of the backwash water and its acceptability to a wastewater treatment plant.

Table 3-6. Water Quality Sampling Schedule

Parameter	Sampling Frequency During 48-Hour Intensive Sampling Period	Sampling Frequency During 320-Hour Daily Sampling Period	Sampling Frequency During Remainder of Test	Test Streams to be Sampled
Temperature	0, 24, 48 hours	Daily	Weekly	Raw and Treated
pH	0, 24, 48 hours	Daily	Weekly	Raw and Treated
Alkalinity (total)	0, 24, 48 hours	Daily	Weekly	Raw and Treated
Turbidity	0, 24, 48 hours	Daily	Weekly	Raw and Treated
ORP	0, 24, 48 hours	Daily	Weekly	Raw and Treated
DO	0, 24, 48 hours	Daily	Weekly	Raw and Treated
TKN	0, 24, 48 hours	Daily	Weekly	Raw and Treated
Hardness (total)	Once	Weekly	Weekly	Raw and Treated
TSS	Once	Weekly	Weekly	Raw and Treated
TOC	Once	Weekly	Weekly	Raw and Treated
VSS	Once	Weekly	Monthly	Raw and Treated
True Color	Once	Weekly	Monthly	Raw and Treated
DOC	Once	Weekly	Monthly	Raw and Treated
Chloride	Once	Weekly	Monthly	Raw and Treated
Sulfate	Once	Weekly	Monthly	Raw and Treated
Sulfide	Once	Weekly	Monthly	Raw and Treated
Fluoride	Once	Weekly	Monthly	Raw and Treated
HPC	Once	Weekly	Monthly	Raw and Treated
Silica	Once	Weekly	Monthly	Raw and Treated
Sodium	Once	Weekly	Monthly	Raw and Treated
Potassium	Once	Weekly	Monthly	Raw and Treated
TSS(1)	Once	Weekly	Monthly	Backwash Water
pH(1)	Once	Weekly	Monthly	Backwash Water

(1) Samples were collected from the backwash holding tank immediately after completion of a backwash cycle~~d~~. The backwash collection vessel was thoroughly mixed immediately prior to sampling.

Table 3-7. Water Quality Analytical Methods, Sample Preservation, and Holding Times

Parameter	Analytical Method	Bottle Type	Preservation	Holding Time
Field Analyses				
pH	SM[(1)] 4500-H^+ B	Plastic	None	Analyze immediately
True Color	Hach 2120B	Glass	Cool to 2-6 ^{0}C	24 hours
Turbidity	EPA 180.1	Glass	None	Analyze immediately
Temperature	SM 2550	Plastic	None	Analyze immediately
ORP				
DO	SM 4500-O G	Glass	None	Analyze immediately
NSF Laboratory Analyses				
Alkalinity (total)	SM 2320B	Plastic	Cool to 2-6 ^{0}C	14 days
Hardness (total)	EPA 200.7	Plastic	HNO_3, Cool to 2-6 ^{0}C	6 months
TSS	SM 2540 D	Plastic	Cool to 2-6 ^{0}C	7 days
VSS	SM 2540 E	Plastic	Cool to 2-6 ^{0}C	7 days
TOC	SM 5310 C	Amber Glass	H_3PO_4, Cool to 2-6 ^{0}C	28 days
DOC	SM 5310 C	Amber Glass	H_3PO_4, Cool to 2-6 ^{0}C	28 days
Chloride	EPA 300.0	Glass	Cool to 2-6 ^{0}C	14 days
Sulfate	EPA 300.0	Glass	Cool to 2-6 ^{0}C	14 days
Sulfide	SM 4500-S^{2-}	Amber Glass	Cool to 2-6 ^{0}C	7 days
Fluoride	SM 4500-F C	Plastic	Cool to 2-6 ^{0}C	14 days
HPC	SM 9215 B	Sterile Plastic	Cool to 2-6 ^{0}C	30 hours
Silica	EPA 200.7	Plastic	HNO_3, Cool to 2-6 ^{0}C	6 months
Sodium	EPA 200.7	Plastic	HNO_3, Cool to 2-6 ^{0}C	6 months
Potassium	EPA 200.7	Plastic	HNO_3, Cool to 2-6 ^{0}C	6 months
TKN	EPA 351.2	Amber Glass	H_2SO_4, Cool to 2-6 °C	48 hours
Contract Lab Analyses				
EPA TCLP	EPA 1311	Plastic	Cool to 2-6 ^{0}C	6 months
California Wet Test	Special CA method and metals by SW846 6010 and 7470a	Plastic	Cool to 2-6 ^{0}C	6 months

(1) SM = Standard Method

3.9.4.3 *Analytical Schedule*

The sampling schedule in Table 3-6 is weighted toward the parameters that are critical to the treatment process. The parameters that were measured on a less frequent basis are general water quality parameters. Note that algae and UV_{254} are specified parameters in the ETV protocol for arsenic reduction, but they are not included here, as they are surface water related parameters and are generally not applicable to groundwater supplies. Aluminum is also specified, but it is not included, as it is not being used as a coagulant and is not a parameter of concern for the CHEMILES process.

3.9.4.4 *Water Quality Sample Collection*

Water quality data were collected following the schedule in Table 3-6. All raw and treated water samples were grab samples collected from sampling taps installed in the test system. The backwash samples were grab samples collected from a holding vessel immediately after completion of a backwash cycle. Prior to collecting the sample, each valve was flushed for at least five seconds to be sure fresh water was obtained from the process lines. Each sample was collected directly into a clean, large container. Aliquots of sample were then poured into the required containers for laboratory analysis or on-site analysis. The raw and treated water samples were both collected within a short period of time (less than one half hour when possible), so that both the raw and treated water results are representative of the current conditions at the sampling time.

Special sampling procedures were used for turbidity. The method for collecting grab samples consisted of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity

Temperature measurements were performed by collecting a sample into a clean container and immediately immersing the calibrated thermometer into the water.

The backwash samples were obtained from a backwash waste holding vessel, and were collected immediately after completion of a backwash cycle. The backwash waste was thoroughly mixed by mechanical agitation prior to sample collection. The samples were collected from the vessel with a ladle.

3.9.4.5 *Evaluation Criteria and Minimum Reporting Criteria*

Performance was evaluated in the context of the manufacturer's statement of performance objectives.

The water quality data and statistical analyses are presented in Chapter 4 in graphical and/or tabular format. The statistical analyses include mean, standard deviation, range, and 95% confidence interval.

3.9.5 Task 3: Operating Conditions and Treatment Equipment Performance

3.9.5.1 *Introduction*

The objectives of this task were to accurately and fully document the operating conditions during treatment and evaluate the equipment performance. Operating conditions, including flow rates, head loss gain over the course of filtration cycles, frequency and duration of filter backwash cycles, and any maintenance required. Electrical use was calculated from the horsepower ratings for the pumps and other equipment.

3.9.5.2 *Work Plan*

A description of the equipment and test system operating conditions are presented in Chapter 2. During verification testing, operating parameters were routinely monitored by the FTO. Table 3-5 presents a list of the operating parameters that were monitored to document the equipment performance during the verifications test.

3.9.5.3 *Schedule for Operating Parameter Data Collection*

Table 3-5 shows the list of operating parameters that were monitored during the verification test and the frequency of the observations.

3.9.5.4 *Evaluation Criteria*

The data developed from this task were used to present operating data on system flow rate, head loss (pressure drop) across the filter module, and frequency and duration of filter backwash cycles.

The results of operating and performance data were tabulated and included:

- Average volume of flow treated per day;
- Average treated water flow rate;
- Average run length and volume of water treated per filter run;
- Average pressure drop across the module;
- Average daily backwash wastewater production; and
- Typical suspended solids in the backwash.

3.9.6 Task 4: Contaminant Removal

3.9.6.1 *Introduction*

The effectiveness of the CHEMILES treatment process for removal of iron, arsenic, manganese, and ammonia were evaluated in this task. Assessment of treatment efficacy was made on the basis of removal of total arsenic, total iron, and manganese, and oxidation of ammonia to nitrate.

3.9.6.2 *Work Plan and Analytical Schedule*

Table 3-8 provides the sampling schedule for the contaminants, plus nitrate and nitrite that were monitored during the verification test.

Table 3-8. Contaminant Sampling Schedule

Parameter	48-Hour Intensive Sampling Period(1)	320-Hour Daily Sampling Period(1)	Remainder of Test	Test Streams to be Sampled
Arsenic (total)	0, 1, 3, and 6 hours after every backwash event	Daily	Weekly	Raw and Filtrate
Iron (total)		Daily	Weekly	Raw and Filtrate
Manganese		Daily	Weekly	Raw and Filtrate
Ammonia		Daily	Weekly	Raw and Filtrate
Nitrate/Nitrite(2)		Daily	Weekly	Raw and Filtrate
Arsenic (total)	Once	Weekly	Monthly	Backwash Water
Iron (total)	Once	Weekly	Monthly	Backwash Water
Manganese	Once	Weekly	Monthly	Backwash Water

(1) Only manganese was measured for the May 320-hour daily/48-hour intensive sampling period.
(2) To be measured with this schedule because the biological treatment process oxidizes ammonia to nitrite, then nitrate.

Raw water samples were collected from the raw water sample tap upstream of the CHEMILES system. Treated water samples were collected from the filtrate sample tap. Prior to collecting the sample, each valve was flushed for at least five seconds to be sure fresh water was obtained from the process lines. The sample was collected directly into a clean large container. Aliquots of sample were then poured into the required containers for laboratory analysis or on-site analysis. The raw and treated water samples were both collected within a short period of time (less than one half hour), so that data are representative of the current conditions.

Grab samples were collected in appropriate containers (containing necessary preservatives as applicable) prepared by NSF and shipped to CH2M Hill in coolers. The samples were shipped overnight on ice back to NSF. The NSF Chemistry Laboratory analyzed all samples in accordance with the appropriate procedures and holding times.

Table 3-9: Contaminant Analytical Methods

Parameter	Facility	Analytical Method	Bottle Type	Preservation	Holding Time
Arsenic (total)	Laboratory	EPA 200.8	Plastic	HNO_3, Cool to 2-6 ^{0}C	6 months
Iron (total)	Laboratory	EPA 200.7	Plastic	HNO_3, Cool to 2-6 ^{0}C	6 months
Manganese	Laboratory	EPA 200.8	Plastic	HNO_3, Cool to 2-6 ^{0}C	6 months
Ammonia	Laboratory	EPA 350.1	Amber Glass	H_2SO_4	28 days
Nitrate/Nitrite	Laboratory	EPA 300.0	Glass	Cool to 2-6 ^{0}C	48 hours

3.9.6.3 *Evaluation Criteria*

Performance evaluation was conducted in the context of the manufacturer's statement of performance objectives with respect to removal of iron, arsenic, manganese, and ammonia. The following information is presented in Chapter 4:

- The speciation of arsenic in the raw water;
- Graphs plotting raw and filtrate iron, arsenic, manganese, ammonia, nitrate, and nitrite over the six-month test period, as well as graphs for the 48-hour and 320-hour intensive sampling periods;
- Tables providing all sample results from the 48-hour and 320-hour sampling periods;
- Tables summarizing all measurements over the six-month test period, including mean, and standard deviation, range, and 95% confidence interval.

3.9.7 Task 5: Data Management

3.9.7.1 *Introduction*

The data management system used in the verification test included the use of computer spreadsheets and manual recording of operational parameters for the equipment on a daily or weekly basis. The FTO staff collected the information and entered it into logbooks and prepared field log sheets. All field activities were documented. Field documentation included field logbooks, photographs, field data sheets, and chain-of-custody forms. The procedures for logbook format and entries followed the procedures outlined below:

- Field notes were kept in a bound logbook;

- Pre-prepared log sheets were used to record all water treatment equipment operating data;
- Each log sheet was labeled with the project name and the verification day number;
- Completed pages were signed and dated by the individual responsible for the entries; and
- Errors were corrected by drawing a single line through the error. The line was initialed and dated.

Chain-of-custody forms accompanied all samples delivered to the analytical laboratory. Copies of field log sheets were reviewed during the QA/QC site inspection by NSF.

3.9.7.2 *Objectives*

The objectives of this task were to: 1) establish a viable structure for the recording and transmission of field testing data such that the FTO provided sufficient and reliable data for verification purposes, and 2) develop a statistical analysis of the data, as described in the document: *EPA/NSF ETV Protocol for Equipment Verification Testing for Arsenic Removal: Requirements For All Studies* and Chapter Three of the same document.

3.9.7.3 *Work Plan*

The FTO site operators recorded on-site data and calculations (e.g., calculating calibration flow rates using the bucket and stop watch and other similar routine calculations) by hand in field and laboratory logbooks. Daily measurements were recorded on specially prepared data log sheets as appropriate. The original logbooks were stored on-site, and copies were forwarded to NSF approximately once per week during the testing period. Operating logs also included descriptions of any problems or issues with the test system or analytical equipment.

A database for the project was set up in the form of custom-designed spreadsheets. The spreadsheets were capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the on-site laboratory logbooks and data log sheets was entered into the appropriate spreadsheet. Following data entry, the spreadsheet was checked against the handwritten data sheets, and any required corrections were made.

As samples were collected and sent to NSF for analysis, the samples were tracked by use of chain of custody sheets. Each sample bottle was labeled with an NSF Laboratory Information Management System (LIMS) label for tracking purposes.

3.9.8 Task 6: Quality Assurance/Quality Control

3.9.8.1 *Introduction*

The QA/QC of operation of the CHEMILES system and the measured water quality parameters were maintained during verification testing by following the QAPP developed as part of the TQAP. The QAPP included accuracy and precision objectives for the analytical work, discussion of the need to meet representativeness and completeness criteria, and calibration requirements for field meters and analytical equipment/methods.

3.9.8.2 *Experimental Objectives*

The objective of this task was to maintain strict QA/QC methods and procedures during verification testing. Maintenance of strict QA/QC procedures is crucial, so that if a question arises when analyzing or interpreting collected data, it will be possible to verify exact conditions at the time of testing.

3.9.8.3 *Work Plan*

Equipment flow rates were documented and recorded on a daily basis. A daily walkthrough during testing was established to verify that each piece of equipment or instrumentation was operating properly. Inline monitoring equipment, such as flow meters, etc., were checked to confirm they were operating properly.

The items listed below were performed in addition to any specified checks outlined in the analytical methods.

<u>Weekly QA/QC Verifications:</u>

- In-line flow meters (clean any fouling buildup as needed, and verify flow rate volumetrically, bucket and stop watch or tank fill time);
- In-line totalizer meter (clean any material buildup as needed and verify production rate volumetrically, monitor volume recorded over time based on calibrated flow rate); and
- Tubing/piping (verify good condition of all tubing and connections, replace as necessary).

<u>One-Time QA/QC Verifications:</u>

- Accuracy of pressure gauges was determined by using a dead weight pressure tester to check the calibration of the pressure gauges or was based on receiving a current (within the last six months) manufacturer’s calibration certification.

3.9.8.4 *Analytical Methods*

The analytical methods utilized in this verification test for monitoring of water quality are listed in Tables 3-7 and 3-10.

Sampling procedures are described in Sections 3.9.4.4 and 3.9.6.2.

The QAPP provided specific calibration procedures for the analytical methods performed on site and also a summary of the laboratory calibration requirements based on the analytical methods.

The NSF Chemistry Laboratory performed all water quality analyses using EPA or Standard Methods procedures as listed in Tables 3-7 and 3-10. All of the required calibration curves and quality control procedures were documented in accordance with the published methods and as described in the QAPP in the PSTP.

3.10 Operation and Maintenance

The FTO obtained the O&M manual (supplied in Appendix A) from Nagaoka to evaluate the instructions and procedures for their applicability during the verification test and for overall completeness. The results of the O&M manual review are reported in Chapter 4.

3.10.1 Maintenance

Evaluation during the verification test and review of the O&M manual included confirmation whether the manufacturer provided readily understood information on the recommended or required maintenance schedule for the following:

Operating equipment:

- pumps
- valves
- pressure gauges and
- flow meters.

Non-mechanical or non-electrical equipment:

- tanks
- piping and
- filter media.

3.10.2 Operation

Among the operating aspects that were evaluated are:

Media filtration:
- Control of filtration flow and rate;
- Observation and measurement of head loss across the media during the filter run;

Media backwashing:
- Programming automated frequency;
- Use of alternative water source;
- Proper backwash venting and disposal;
- Appropriate backwash rate;
- Monitoring during return of filter to service;

Monitoring and observing operation:
- flow rates; and
- Filter head loss.

The protocol recommends that a manufacturer should provide a troubleshooting guide – a simple checklist of what to do for a variety of problems including:

- No raw water (feed water) flow to plant;
- Inability to control rate of flow of water through equipment;
- Filter cannot be backwashed or backwash rate of flow cannot change;
- Automatic operation (if provided) not functioning;
- Filtered water turbidity too high;
- Filter head loss builds up excessively rapidly;
- Valve stuck or will not operate;
- Low feed pump pressure;
- Pump cavitation; and
- No electric power.

The O&M manual was reviewed for details and information provided on above lists and other operating conditions observed during the verification test.

3.10.3 Operability Evaluation

The following formed the basis of the review and evaluation for equipment operability during verification testing. These aspects of plant operation are reported to the extent practical in Chapter 4.

The factors considered included:

- Can automatic backwash be initiated by:
  - Reaching a set value for head loss?
  - Reaching a set turbidity level in the treated water?
  - Default minimum time?
- Is granular media pressure differential measurement provided?
- Is rate of flow of raw water measured?
- Is backwash rate of flow measured and variable?
- Is backwash duration (time) variable?

Other factors and questions included:

- Does the equipment have sensors or monitoring equipment that can detect an equipment malfunction, unsatisfactory filtrate water quality, or operating conditions that exceed allowable limits?
- If so, during such situations can the equipment be automatically shut down?
- Upon automatic shutdown, can notification be provided if the operator is not present on site?

Chapter 4
Results and Discussion

4.1 Introduction

The verification test program for the CHEMILES System began with equipment installation at the test site in October of 2011, and ended with the completion of the verification test on May 23, 2013. The test site is described in Section 1.3, and the CHEMILES CLT300 system is described in Chapter 2.

After installation and start up of the system, the FTO and Nagaoka operated the system to ripen the biological filter, and monitored system performance until October 2012. At that point, Nagaoka was satisfied with system performance for removal of arsenic, iron, and ammonia, but not for removal of manganese. Because of the six month testing schedule, and the fact that the ETV program was drawing to a close in October of 2013, NSF requested that the verification test be started for arsenic, iron, and ammonia reduction. Manganese reduction was to be evaluated later when system performance for this contaminant improved. Due to time constraints to start testing, the raw water samples collected for Week 1 of the test also served as the raw water characterization samples for Task A. The verification test started on November 5, 2012, and was scheduled to end on May 1, 2013. The manganese reduction evaluation period began on January 15. The 320-hour daily sampling period for all contaminants was from March 11 to March 24, with the 48-hour intensive sampling period occurring March 18 through March 20.

In April, Nagaoka requested an additional 320-hour daily sampling period be conducted in May for Manganese only. The second week of operation was with the pH of the raw water raised to 7 so as to evaluate whether manganese removal improved with a higher pH. Forty-eight hour intensive sampling periods were performed each week of this additional testing period. The additional testing period began on May 10, 2013, and ended on May 23, 2013. The 48-hour intensive sampling periods were run May 14 through 16, and again May 21 through 23.

This chapter presents a summary of the water quality and operating data collected during the verification test. All contaminant data (arsenic, iron, manganese, and ammonia) for the 320-hour daily sampling periods and the 48-hour intensive sampling periods are presented. Operating data are presented to describe the flow rates; volume of treated water produced, backwash volumes and frequency, pressure differential across the filter media, and related operating information. QA/QC information, as described by the QAPP in the PSTP for this verification test, is presented at the end of the chapter.

4.2 Equipment Installation, Start-up, and Shakedown

The pilot system was constructed by Nagaoka in Japan, and shipped to the test site. Nagaoka and CH2M Hill staff installed the equipment at the site in October 2011. As discussed in Section 1.3.1, a separate well pump was installed to supply water to the CHEMILES system. After system installation, the Washington State Department of Labor and Industries required replacement of some parts in the PLC control panel to meet the UL Standard 508 requirements. Due to these corrections, and the UL certification process for the PLC, the system was operated irregularly through April 2012. In addition, the treated water pump was not functioning properly, so it was removed from the unit and returned to the manufacturer. On September 15, 2012, Nagaoka staff visited the test site to replace the treated water pump, and from that time through the end of the verification test, the system was operated continuously. Nagaoka had estimated based on previous installations that the ripening process would take three to six months. However, for this water source, and due to the problems discussed above, ripening took much longer. As discussed above, in October 2012 Nagaoka agreed to begin the verification test for arsenic, iron, and ammonia reduction, and sampling started on November 7, 2012. Evaluation of manganese reduction began in January 2013 after the filter had more time to ripen.

4.3 Task A: Raw Water Characterization

Historical water quality data for the test site were supplied by Clark Public Utilities during the planning stage for this verification test. As shown in Table 1-1, total arsenic ranged from 15 to 36 µg/L, ammonia ranged from 0.30 to 0.32 mg/L, iron ranged from 8.8 to 18.8 mg/L, and manganese from 0.19 to 0.46 mg/L. As discussed in Section 4.1, the Week 1 raw water samples served also as the raw water characterization samples for this verification test. The chemical analyses for this task included total arsenic and arsenic speciation (arsenic [III] and [V]) for the water source.

The results of the initial raw water characterization test are presented in Table 4-1. The data confirmed that the raw water quality was similar to the historical water quality used to plan the verification test.

Results for pH, DO, and ORP are not included, because during NSF’s audit of the testing activities in early December, problems were found with these analyses that caused the preceding measurements to be discarded. See Section 4.4.3 for further discussion.

The levels of ammonia, iron, and manganese agree well with the historical water quality data. The total arsenic concentration was measured at 0.012 mg/L, and the arsenic (III) concentration was measured at 0.006 mg/L. So approximately 50% of the arsenic in the raw water was As (III) and the remaining 50% was As (V).

The TSS level of 11 mg/L was very high in this sample, compared to the rest of the samples for the verification test. All other TSS measurements were below the reporting limit of 2 mg/L, except for sample at 6 mg/L, and one at 4 mg/L.

Table 4-1. Raw Water Characterization Data – November 7, 2012

Parameter	Units	Result
Temperature	^{o}C	12.5
Turbidity	NTU	0.88
True Color	Color Units(CU)	4(1), 14(2)
Ammonia	mg/L N	0.34
Nitrate	mg/L N	<0.05
Nitrite	mg/L N	<0.02
TKN	mg/L N	<0.10
Total Arsenic	mg/L	0.012
Arsenic (3+)	mg/L	0.006
Iron	mg/L	11
Manganese	mg/L	0.22
Alkalinity	mg/L as $CaCO_3$	90
DOC	mg/L	0.9
Chloride	mg/L	27
Sulfate	mg/L	5.3
Potassium	mg/L	3.0
Magnesium	mg/L	6.7
Sodium	mg/L	25
TSS	mg/L	11(3)
VSS	mg/L	3
Hardness	mg/L as $CaCO_3$	58
TOC	mg/L	1.1
Fluoride	mg/L	0.1
Sulfide	mg/L	<0.01
TDS	mg/L	200
Silica	mg/L	58
HPC	CFU/mL	47

(1) True color measured for first time on November 29.

(2) True color also measured again on November 30.

(3) All other raw water TSS measurements for project were <2 mg/L, except for one sample with 6 mg/L , and a second sample with 4 mg/L

4.4 Task C: Verification Test

4.4.1 Operating Results

The CHEMILES system verification test started on November 5, 2012. The FTO operated the system based on the criteria established by Nagaoka during the filter ripening and shakedown testing period. The backwash frequency was set at every 8 hours for the partial backwash, and a full backwash after every 9th partial backwash. After the test started, Nagaoka requested that the full backwash frequency be changed to after every 6th partial backwash. The flow rate was set at 4.7 gpm.

Table 4-2 shows the daily operating data for the verification test. FTO staff visited the site daily, Monday through Friday, throughout the verification testing period to visually inspect system operation and record the water production, system flow rate, and to witness a backwash event.

The recorded treated water flow rates ranged from 4.41 gpm to 5.42 gpm, and averaged 4.87 gpm.

The system operated continuously, except for the backwashes. The P backwash cycle was 19 minutes and 40 seconds in length, while the W backwash cycle was 21 minutes and 40 seconds long. The backwash water flowed to waste for 9 minutes and 30 seconds during the P backwash, and 10 minutes and 30 seconds during the W backwash. Since the backwashes occurred every 8 hours, the system produced treated water for approximately 23 hours per day. The water production, normalized to a 24-hour day, averaged 6,527 gal, with a range of 3,121 to 6,698 gal. Excluding the one day with only 3,121 gal produced as an outlier, the minimum 24-h production was 5,367 gal. It is not known why only 3,121 gal were produced one day. The FTO did not note any operational issues, and the system flow rate recorded that morning was 4.78 gpm.

Filter head loss was monitored through a sight tube. For each backwash witnessed, the FTO staff recorded the head loss at the end of the filter run, and the head loss at the start of the next filter run. The ending head loss was often below the monitoring window on the sight tube, so only 47 actual ending head loss measurements were recorded over the 136 day test. For the 47 days where head loss recovery calculations are possible, the average recovery was 257 mm of water, with a rather wide range of 52 to 904 mm. The backwash flow rate was also recorded. The mean backwash flow was 5.19 gpm, with a range of 4.92 to 10.67 gpm.

Table 4-2. Summary Statistics for Operating Data

Parameter	Treated Flow Rate[1] (gpm)	Water Production per 24 hours (gal)	Feed Nozzle Pressure (psi)	Backwash Flow (gpm)	Head loss Recovery after Backwash (mm H_2O)
Count	137	135	136	130	47
Average	4.87	6,527	19	5.19	257
Minimum	4.41	5,637	18	4.92	52
Maximum	5.42	6,698	20	10.67	904
Std. Deviation	0.14	339.9	0.79	0.82	149
95% Confidence Interval	±0.2	±57.3	± 0.13	±0.14	±43

(1) Flow rate was the instantaneous reading each morning when the field staff checked the system.

4.4.2 Contaminant Reduction Results

This section presents the arsenic, iron, manganese, and ammonia reduction results for the raw and treated water. Also included with the ammonia results are the nitrate and nitrite results, since the system oxidizes ammonia to nitrate.

As the test progressed and the raw water results database was compiled, it became apparent that the water source had less stability than would be desired. As discussed in Section 1.3.1, the well was only about 200 feet from the Lewis River, and the groundwater level rises and lowers in conjunction with the river level due to water releases from the Merwin Dam upstream. A water plant operator informed the FTO that the groundwater level can rise as much as four feet when the river level rises. The rises in the water levels seem to be correlated with decreases in the levels of the contaminants in the raw water. For instance, on March 19, during the first 48-hour intensive sampling period, the raw water ammonia concentration dropped steadily from 0.63 mg/L as N at 12:20 PM on March 19 down to 0.25 mg/L as N at 9:20 AM on March 20. During this period, the U.S. Geological Survey stream gauge just downstream of the Merwin Dam on the Lewis River showed that the dam discharge approximately doubled from the morning to the evening of March 19. The dam discharge stayed high until the early morning of March 21.

4.4.2.1 *Ammonia*

The ammonia, nitrate, and nitrite weekly sampling summary statistics are presented in Table 4-3, and the March 320-hour daily sampling results and March 48-hour intensive sampling results are presented in Tables 4-4, and 4-5, respectively. The ammonia raw and treated water weekly sampling results and March 320-hour daily sampling results are plotted in Figure 4-1. The ammonia results for the March 320-hour daily sampling period only are plotted in Figure 4-2, while the March 48-hour intensive sampling results are plotted in Figure 4-3. Note that many of the nitrate and nitrite samples exceeded their 48-hour holding time prior to analysis. During the 320-hour daily sampling period, samples collected on a Friday were shipped out that day, but could not be delivered to NSF until the following Monday. And samples collected on a Saturday were not shipped to NSF until Monday, resulting in a Tuesday delivery. During the 48-hour sampling period, the samples collected March 18 at 5:20 PM through March 19 at 2:20 PM were delivered to NSF the morning of March 20. The italicized samples in Table 4-5 were not analyzed until March 22 due to an error with the automated analyzer the evening of March 20 that was not discovered until the morning of March 21.

As shown in Table 4-3, ammonia in the raw water for the weekly samples ranged from 0.07 to 0.71 mg/L as N, with a mean of 0.40 mg/L. Ammonia in the treated water ranged from 0.03 to 0.19 mg/L as N, with a mean of 0.05 mg/L. Nagaoka's target performance criterion for ammonia was 75% reduction. The 75% reduction performance level was achieved for all weekly raw/treated sample pairs, except three. The first pair was that for November 21, and in this instance 75% reduction was not achieved because the raw concentration was at the minimum of 0.07 mg/L measured for the entire test. The treated water level was less than the laboratory reporting limit of 0.03 mg/L, so the low percent reduction was simply a function of the low raw water concentration and the analytical method reporting limit. The other two sample pairs with less than 75% reduction corresponded to spikes in the raw water ammonia concentration on January 23 and March 12. There were three treated water samples that had greater than 0.1 mg/L of ammonia measured. Two were at 0.19 mg/L, occurring on January 23 and March 12 with the raw water ammonia spikes. The third was 0.11 mg/L on March 6. See Figure 4-1 for the ammonia spikes and corresponding treated water spikes. Since the CHEMILES System uses biologically mediated oxidation of ammonia for treatment, the system likely cannot respond rapidly to spikes in the raw water ammonia concentration, as were observed for this unique water source.

As discussed above, the raw water ammonia concentration dropped by approximately 50%, then rebounded during the March 320-hour daily sampling period, likely due to higher discharges from the upstream dam. See Table 4-4 and Figure 4-2 for the data. This occurrence was also captured in the 48-hour intensive sampling period from March 18 to 20. Despite these fluctuations in the raw water ammonia level, the CHEMILES system maintained 75% or greater reduction of ammonia for all of the 48-hour intensive sample pairs, and for all of the daily sampling pairs except for one – March 12 at 12:10 PM. The percent reduction for this sample pair was 71.2%.

As the CHEMILES System oxidized the ammonia and nitrate was produced, with a mean concentration of 0.44 mg/L as N, and a maximum concentration of 0.66 mg/L as N in the weekly treated water samples. Higher treated water levels were found during the March 48-hour intensive sampling period. These spikes correlated with backwashes of the filtration media. An examination of the data in Table 4-5 reveals that the treated water nitrate concentrations were highest immediately after a backwash event (zeros in the filtration time column). However, the highest measured concentration of 1.5 mg/L as N is well below the EPA MCL of 10 mg/L as N for nitrate. The nitrate levels dropped to the typical steady-state treatment levels in the samples collected an hour after the backwashes.

All weekly raw and treated water samples had nitrite below the laboratory reporting limit of 0.02 mg/L as N. During both the March daily sampling period and the March 48-hour intensive sampling period there were small spikes in the treated water nitrite level. As shown in Table 4-4, on March 15 the treated water nitrite level was measured at 0.04 mg/L as N. On March 19 during the 48-hour intensive sampling period there also was a small amount of nitrite detected in the treated water for multiple samples, reaching a maximum level of 0.07 mg/L as N. These levels are well below the EPA MCL of 1 mg/L as N for nitrite.

Table 4-3. Ammonia, Nitrate, and Nitrite Summary Data(1)

	Ammonia (mg/L N)		Nitrate (mg/L N)		Nitrite (mg/L N)	
Parameter	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**
Count	24	25	26	26	26	26
Mean	0.40	0.05	0.05	0.44	<0.02	<0.02
Minimum	0.07	0.03	<0.05	0.24	<0.02	<0.02
Maximum	0.71	0.19	0.14	0.66	<0.02	<0.02
Std. Deviation	0.17	0.05	0.02	0.13	NA	NA
95% Conf. Interval	±0.07	±0.02	±0.01	±0.05	NA	NA

(1) Concentrations reported as non-detect set equal to the detection limit for calculating statistics.

Table 4-4. Ammonia, Nitrate, and Nitrite Results from March 320-Hour Daily Sampling Period(1)

		Ammonia (mg/L N)		Nitrate (mg/L N)		Nitrite (mg/L N)	
Date	**Time**	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**
3/11/2013	11:36 AM	0.71	0.12	<0.05	0.39	<0.02	<0.02
3/12/2013	12:10 PM	0.66	0.19	<0.05	0.38	<0.02	<0.02
3/13/2013	-	0.67	0.16	<0.05	0.41	<0.02	<0.02
3/14/2013	10:38 AM	0.51	<0.03	<0.05	0.43	<0.02	<0.02
3/15/2013	10:41 AM	0.51	<0.03	*<0.05*(2)	*0.47*	*<0.02*	*0.04*
3/16/2013	9:00 AM	0.63	0.12	*<0.05*	*0.44*	*<0.02*	*<0.02*
3/17/2013	4:01 PM	0.63	0.11	<0.05	0.48	<0.02	<0.02
3/18/2013	2:30 PM	0.61	0.08	<0.05	0.42	<0.02	<0.02
3/19/2013	3:00 PM	0.53	0.07	<0.05	0.45	<0.02	<0.02
3/20/2013	2:45 PM	0.28	<0.03	<0.05	0.32	<0.02	<0.02
3/21/2013	12:10 PM	0.41	<0.03	<0.05	0.38	<0.02	<0.02
3/22/2013	11:57 AM	0.58	0.03	*<0.05*	*0.45*	*<0.02*	*<0.02*
3/23/2013	5:06 PM	0.58	0.04	*<0.05*	*0.50*	*<0.02*	*<0.02*
3/24/2013	3:38 PM	0.57	0.06	<0.05	0.48	<0.02	<0.02
Count		14	14	14	14	14	14
Mean		0.56	0.08	<0.05	0.43	<0.02	0.02
Minimum		0.28	0.03	<0.05	0.32	<0.02	0.02
Maximum		0.71	0.19	<0.05	0.50	<0.02	0.04
Std. Deviation		0.11	0.05	NA	0.05	NA	0.01
95% Conf. Interval		±0.06	±0.03	NA	0.03	NA	0.00

(1) Concentrations reported as non-detect set equal to the detection limit for calculating statistics.
(2) Results in italics are from samples where the 48-hour holding time was exceeded.

Table 4-5. Ammonia, Nitrate, and Nitrite Results from March 48-Hour Intensive Sampling Period(1)

		Filtration Run Time (hr)	Ammonia (mg/L N)		Nitrate (mg/L N)		Nitrite (mg/L N)	
Date	**Time**		**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**
3/18/2013	2:20 PM	3	0.61	0.08	<0.05	0.42	<0.02	<0.02
3/18/2013	5:20 PM	6	0.62	0.12	<0.05	0.40	<0.02	<0.02
3/18/2013	7:20 PM	0	0.55	<0.03	<0.05	1.5	<0.02	<0.02
3/18/2013	8:20 PM	1	0.63	0.096	*<0.05*(2)	*0.48*	*<0.02*	*<0.02*
3/18/2013	10:20 PM	3	0.62	0.09	*<0.05*	*0.45*	*<0.02*	*<0.02*
3/19/2013	1:20 AM	6	0.63	0.13	*<0.05*	*0.5*	*<0.02*	*0.07*
3/19/2013	3:20 AM	0	0.58	<0.03	*<0.05*	*1.3*	*<0.02*	*<0.02*
3/19/2013	4:20 AM	1	0.65	0.13	*<0.05*	*0.43*	*<0.02*	*0.04*
3/19/2013	6:20 AM	3	0.63	0.15	*<0.05*	*0.42*	*<0.02*	*0.03*
3/19/2013	9:20 AM	6	0.63	0.11	*<0.05*	*0.47*	*<0.02*	*0.07*
3/19/2013	11:20 AM	0	0.62	<0.03	*<0.05*	*1*	*<0.02*	*<0.02*
3/19/2013	12:20 PM	1	0.62	0.12	*<0.05*	*0.43*	*<0.02*	*0.03*
3/19/2013	2:20 PM	3	0.53	0.07	<0.05	0.45	<0.02	<0.02
3/19/2013	5:20 PM	6	0.47	<0.03	<0.05	0.42	<0.02	<0.02
3/19/2013	7:20 PM	0	0.44	<0.03	<0.05	0.75	<0.02	<0.02
3/19/2013	8:20 PM	1	0.39	<0.03	<0.05	0.43	<0.02	<0.02
3/19/2013	10:20 PM	3	0.37	<0.03	<0.05	0.47	<0.02	<0.02
3/20/2013	1:20 AM	6	0.35	<0.03	<0.05	0.36	<0.02	<0.02
3/20/2013	3:20 AM	0	0.34	<0.03	<0.05	0.84	<0.02	<0.02
3/20/2013	4:20 AM	1	0.33	<0.03	<0.05	0.32	<0.02	<0.02
3/20/2013	6:20 AM	3	0.29	<0.03	<0.05	0.39	<0.02	<0.02
3/20/2013	9:20 AM	6	0.25	<0.03	<0.05	0.34	<0.02	<0.02
3/20/2013	11:20 AM	0	0.27	<0.03	<0.05	0.76	<0.02	<0.02
3/20/2013	12:20 PM	1	0.30	<0.03	<0.05	0.34	<0.02	<0.02
3/20/2013	2:20 PM	3	0.28	<0.03	<0.05	0.32	<0.02	<0.02
Count			25	25	25	25	25	25
Mean			0.48	0.06	<0.05	0.56	<0.02	0.03
Minimum			0.25	0.03	<0.05	0.32	<0.02	0.02
Maximum			0.65	0.15	<0.05	1.50	<0.02	0.07
Std. Deviation			0.15	0.04	NA	0.31	NA	0.01
95% Conf. Interval			±0.06	±0.02	NA	±0.12	NA	±0.01

(1) Concentrations reported as non-detect set equal to the detection limit for calculating statistics.

(2) Results in italics are from samples where the 48-hour holding time was exceeded.

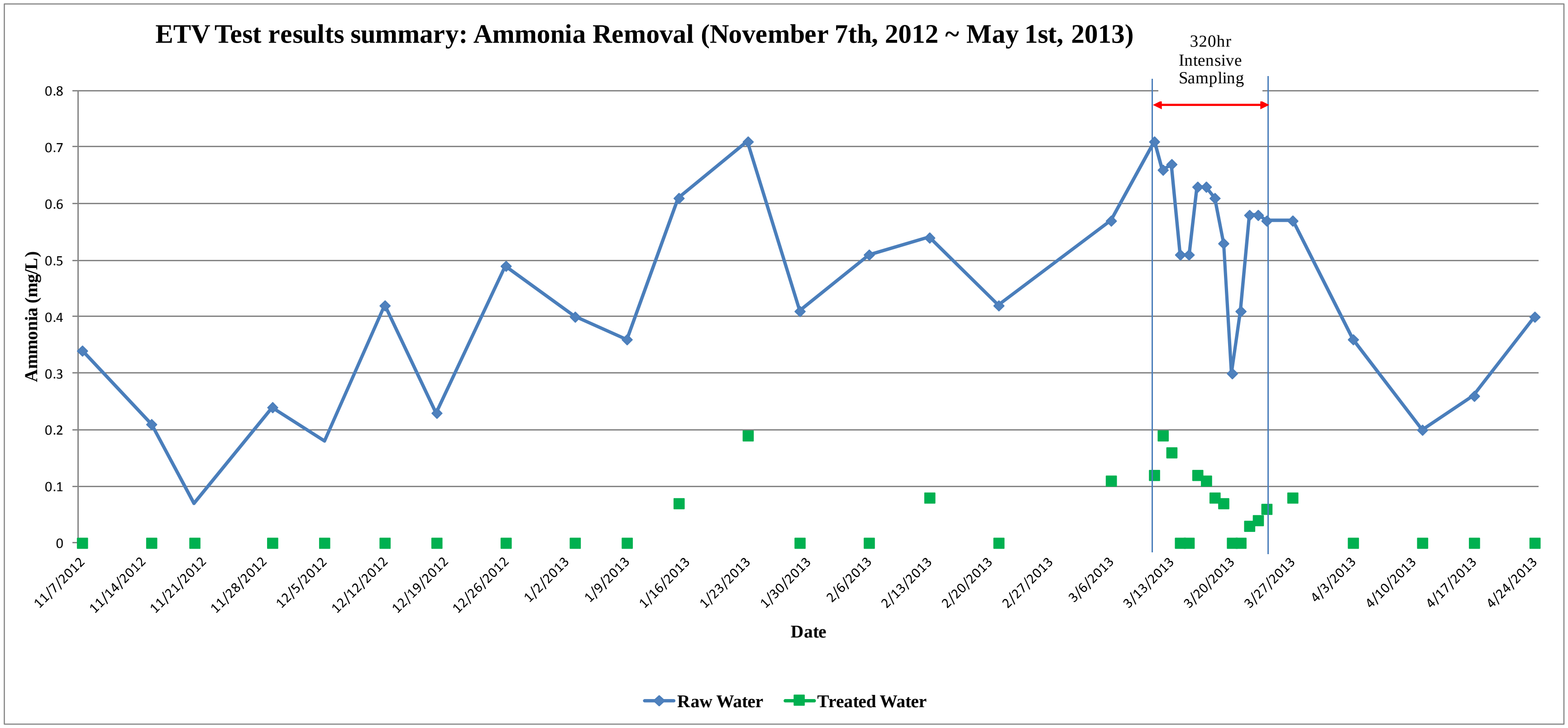


Figure 4-1. Verification Test Ammonia Results.

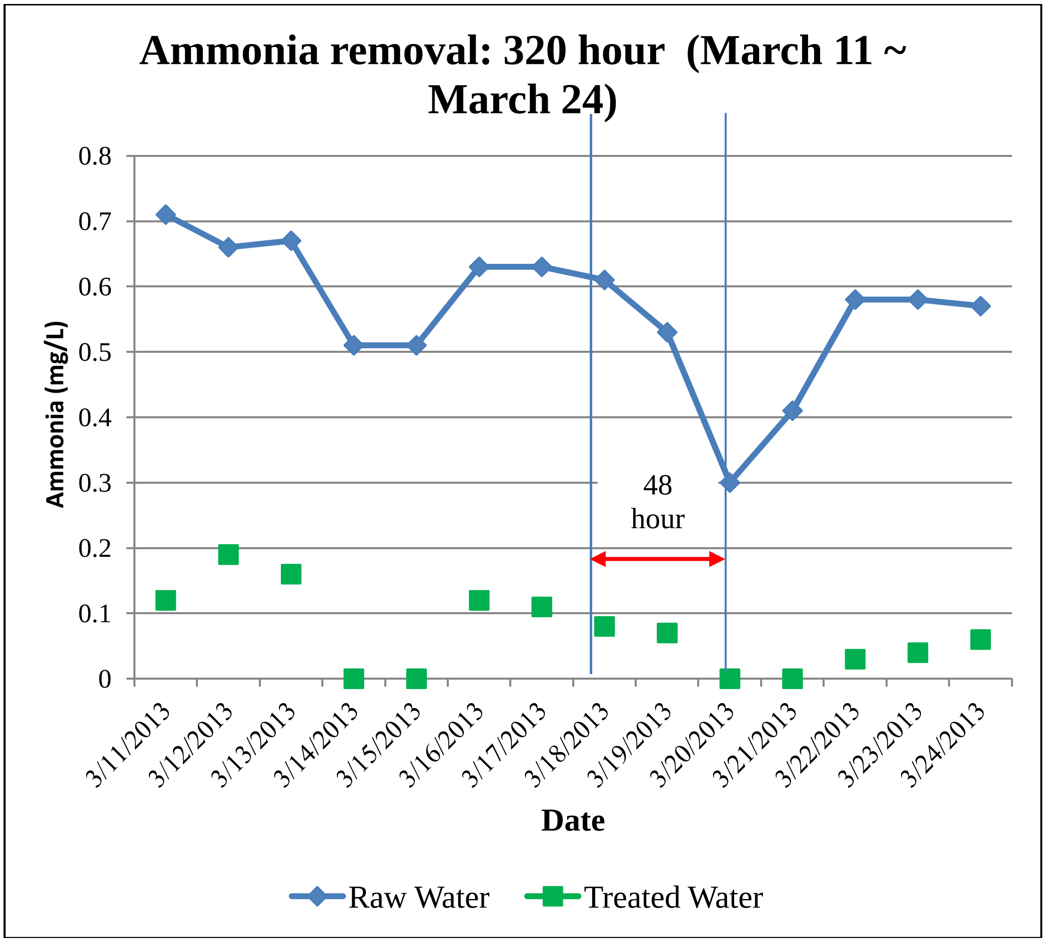


Figure 4-2. Daily Sampling Period Ammonia Results.

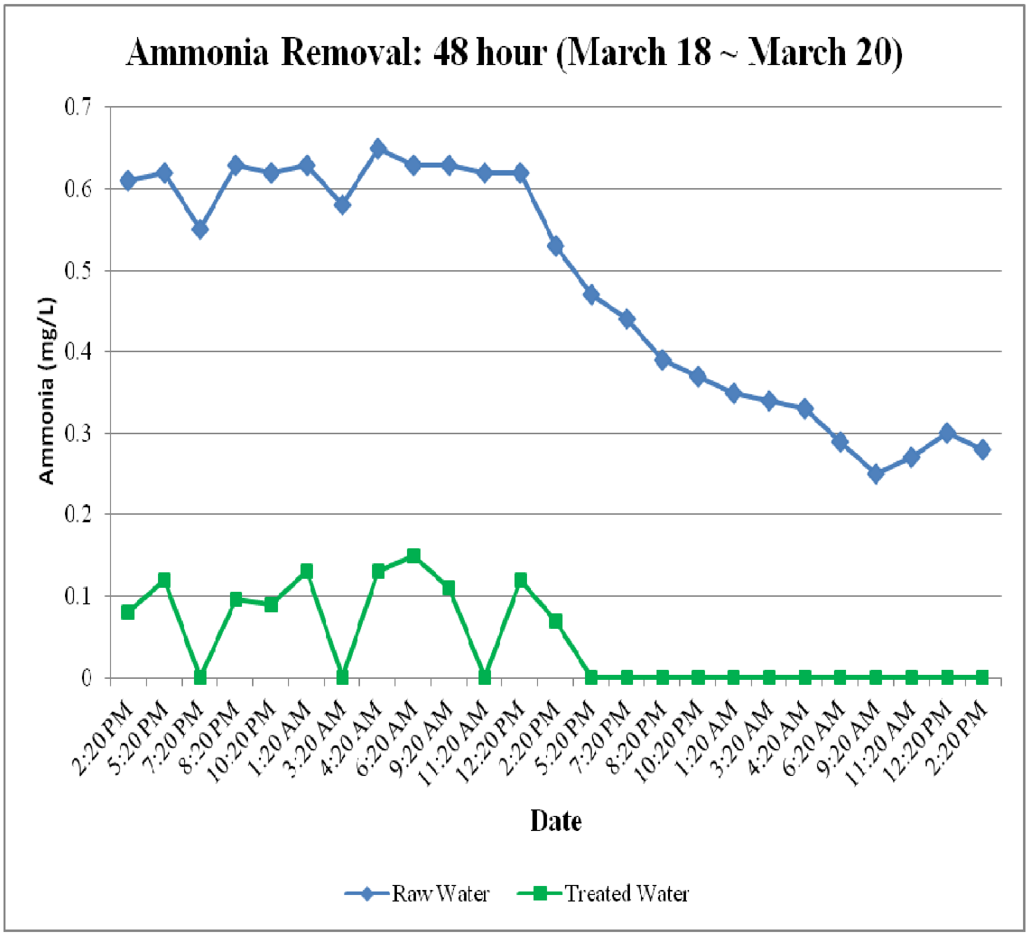


Figure 4-3. March 48-HourSampling Period Ammonia Results.

4.4.2.2 *Iron*

The raw and treated weekly sample summary statistics for iron are presented in Table 4-6, and the individual weekly sampling results, as well as the March daily sampling results, are plotted in Figure 4-4. The raw water iron concentrations varied widely during the test, just as the ammonia levels did, ranging from 2.0 to 15 mg/L, with a mean of 9.4 mg/L. All treated water iron measurements were below the EPA secondary MCL of 0.3 mg/L. The treated water iron concentrations ranged from 0.02 to 0.18 mg/L, with a mean of 0.05. On March 27, Nagaoka requested that the FTO raise the raw water pH with NaOH to try to improve the biologically mediated manganese treatment. At this time, the treated water iron level rose to 0.40 mg/L on March 27, and 0.62 mg/L on April 3. The pH adjustment was stopped on April 8, and the treated water iron level was measured at 0.03 mg/L on April 11. These two high treated water iron results are excluded from the weekly sample data set due to the change in the treatment condition. Nagaoka theorized that the NaOH reacted with a portion of iron in the raw water to produce colloidal $Fe(OH)_3$, which passed through the filtration media. See the vendor comments in Chapter 6 for further discussion. The results from the March daily sampling period are presented in Table 4-7, and these results are also graphically presented in Figure 4-5. The 48-hour intensive sampling results are presented in Table 4-8, and graphically in Figure 4-6. During the 48-hour sampling period, there were two treated water samples that had iron present above 0.3 mg/L – those from 11:20 AM and 3:20 AM. Both of these samples were collected right after a backwash (zeros in the filtration time column), and the samples collected an hour after both of these samples had iron at only 0.04 mg/L.

Table 4-6. Arsenic and Iron Weekly Sample Summary Data(1)

	Arsenic (mg/L)		Iron (mg/L)	
Parameter	**Raw**	**Treated**	**Raw**	**Treated**
Count	26	26	26	24
Mean	0.008	<0.002	9.4	0.05
Minimum	<0.002	<0.002	2.0	0.02
Maximum	0.014	<0.004	15	0. 18
Std. Deviation	0.003	NA	2.7	0. 05
95% Conf. Interval	±0.001	NA	±1.0	±0. 02

(1) Concentrations reported as non-detect set equal to the detection limit for calculating statistics.

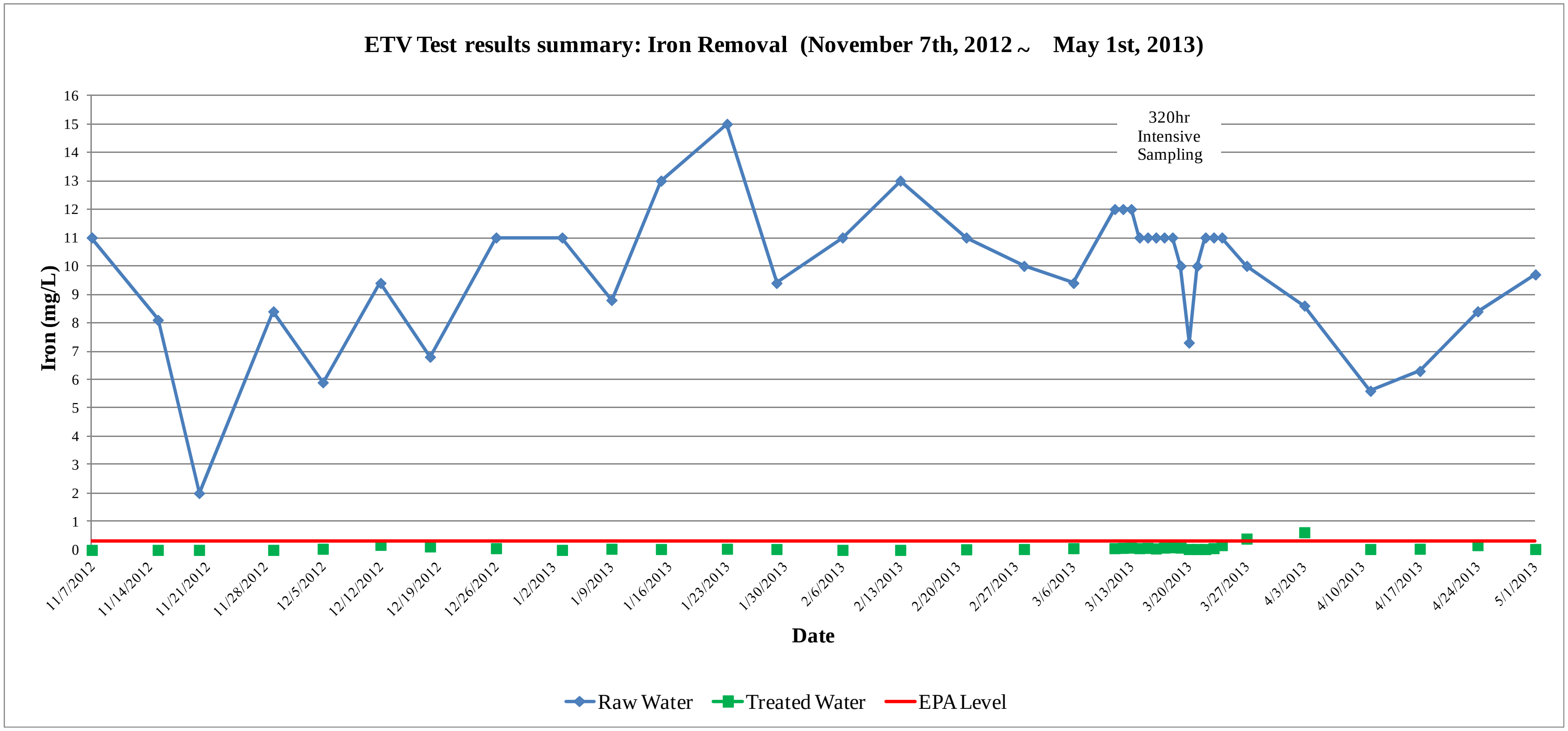


Figure 4-4. Iron Removal Results.

Table 4-7. Arsenic and Iron Results from March Daily Sampling Period

		Arsenic (mg/L)		Iron (mg/L)	
Date	**Time**	**Raw**	**Treated**	**Raw**	**Treated**
3/11/2013	11:36 AM	0.015	<0.002	12	0.06
3/12/2013	12:10 PM	0.014	<0.002	12	0.07
3/13/2013	-	0.014	<0.002	12	0.08
3/14/2013	10:38 AM	0.010	<0.002	11	0.06
3/15/2013	10:41 AM	0.011	<0.002	11	0.07
3/16/2013	9:00 AM	0.014	<0.002	11	0.05
3/17/2013	4:01 PM	0.014	<0.002	11	0.08
3/18/2013	2:30 PM	0.019	<0.002	11	0.09
3/19/2013	3:00 PM	0.013	<0.002	10	0.08
3/20/2013	2:45 PM	0.005	<0.002	7.2	0.06
3/21/2013	12:10 PM	0.008	<0.002	10	0.03
3/22/2013	11:57 AM	0.012	<0.002	11	0.03
3/23/2013	5:06 PM	0.013	<0.002	11	0.06
3/24/2013	3:38 PM	0.014	<0.002	11	0.17
Count		14	14	14	14
Mean		0.013	<0.002	11	0.07
Minimum		0.005	<0.002	7.2	0.03
Maximum		0.019	<0.002	12	0.17
Std. Deviation		0.003	NA	1.2	0.03
95% Conf. Interval		±0.002	NA	±0.63	±0.02

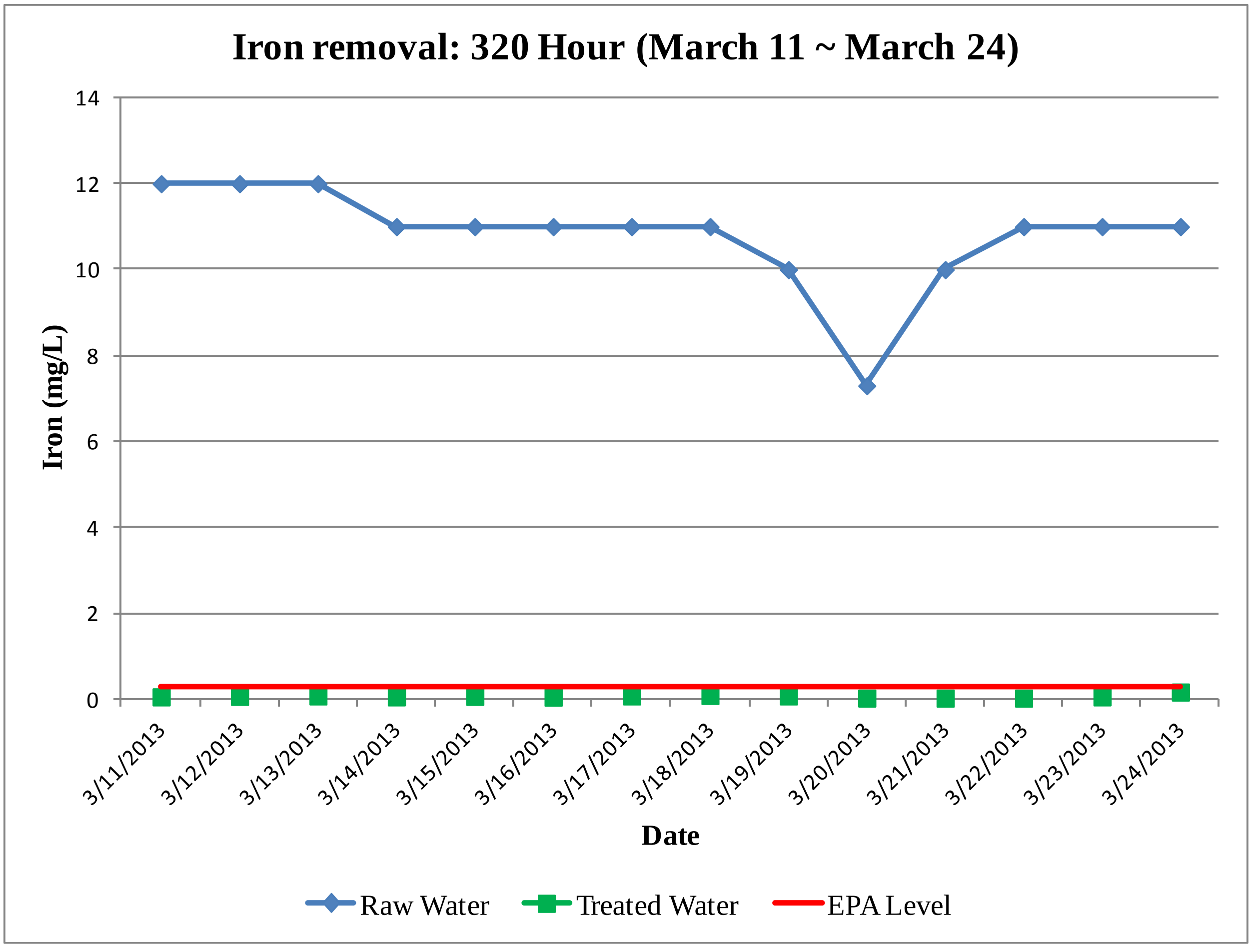


Figure 4-5. Iron Removal Results from March Daily Sampling Period.

Table 4-8. Arsenic and Iron Results from March 48-Hour Intensive Sampling Period

		Filtration Run Time (hrs)	Arsenic (mg/L)		Iron (mg/L)	
Date	**Time**		**Raw**	**Treated**	**Raw**	**Treated**
3/18/2013	2:20 PM	3	0.019	<0.002	11	0.09
3/18/2013	5:20 PM	6	0.020	<0.002	11	0.12
3/18/2013	7:20 PM	0	0.020	<0.002	12	0.29
3/18/2013	8:20 PM	1	0.020	<0.002	12	0.04
3/18/2013	10:20 PM	3	0.020	<0.002	12	0.06
3/19/2013	1:20 AM	6	0.020	<0.002	11	0.08
3/19/2013	3:20 AM	0	0.020	<0.002	13	0.29
3/19/2013	4:20 AM	1	0.020	<0.002	12	0.06
3/19/2013	6:20 AM	3	0.020	<0.002	11	0.06
3/19/2013	9:20 AM	6	0.020	<0.002	11	0.07
3/19/2013	11:20 AM	0	0.020	0.002	12	0.32
3/19/2013	12:20 PM	1	0.020	<0.002	12	0.04
3/19/2013	2:20 PM	3	0.013	<0.002	10	0.08
3/19/2013	5:20 PM	6	0.010	<0.002	9.4	0.05
3/19/2013	7:20 PM	0	0.008	<0.002	8.4	0.12
3/19/2013	8:20 PM	1	0.008	<0.002	8.4	0.03
3/19/2013	10:20 PM	3	0.008	<0.002	8.3	0.03
3/20/2013	1:20 AM	6	0.007	<0.002	8.2	0.04
3/20/2013	3:20 AM	0	0.008	<0.002	8.3	0.34
3/20/2013	4:20 AM	1	0.007	<0.002	8.0	0.04
3/20/2013	6:20 AM	3	0.007	<0.002	7.9	0.04
3/20/2013	9:20 AM	6	0.007	<0.002	7.8	0.03
3/20/2013	11:20 AM	0	0.006	<0.002	7.6	0.28
3/20/2013	12:20 PM	1	0.006	<0.002	7.3	0.03
3/20/2013	2:20 PM	3	0.005	<0.002	7.2	0.06
Count			25	25	25	25
Mean			0.014	<0.02	9.9	0.11
Minimum			0.005	<0.02	7.2	0.03
Maximum			0.020	0.02	13	0.34
Std. Deviation			0.006	NA	1.9	0.10
95% Conf. Interval			±0.003	NA	±0.74	±0.04

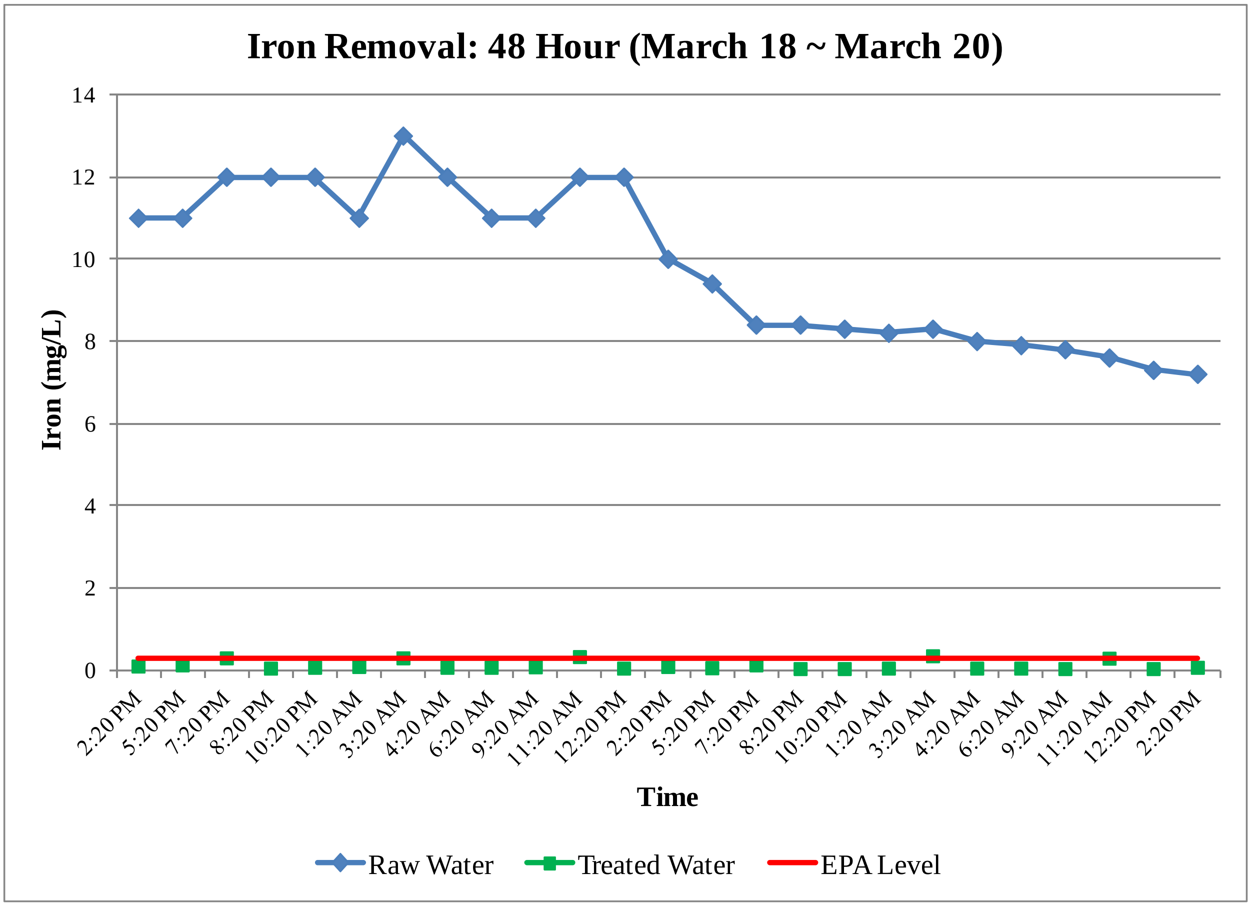


Figure 4-6. Iron Removal Results From March 48- Hour Intensive Sampling Period.

4.4.2.3 *Arsenic*

The arsenic weekly sample summary statistics are presented in Table 4-6 along with the iron and manganese data. The arsenic results for the 320-hour daily sampling period are reported in Table 4-7, and those for the 48-hour intensive sampling period are reported in Table 4-8. The weekly sampling results and the 320-hour daily sampling results are plotted together in Figure 4-7. The historical water quality data in Table 1-1 suggested that the arsenic concentration in the raw water ranged from 15 to 36 µg/L. However, this was not the case at any time during the verification test. The arsenic level reached as high as 0.020 mg/L during the March 48-hour intensive sampling period, but most of the time it was below the EPA MCL of 0.010 mg/L. The weekly samples statistical analysis shows a mean raw water arsenic concentration of 0.008 mg/L for the test, with a range of <0.002 to 0.014 mg/L. There were two weeks where the raw water arsenic level was below the laboratory reporting limit of 0.002 mg/L. Arsenic was below the reporting limit for all treated water samples, including all of those for the March 320-hour daily and 48-hour intensive sampling periods, except for one sample during the intensive sampling period with arsenic reported at 0.002 mg/L.

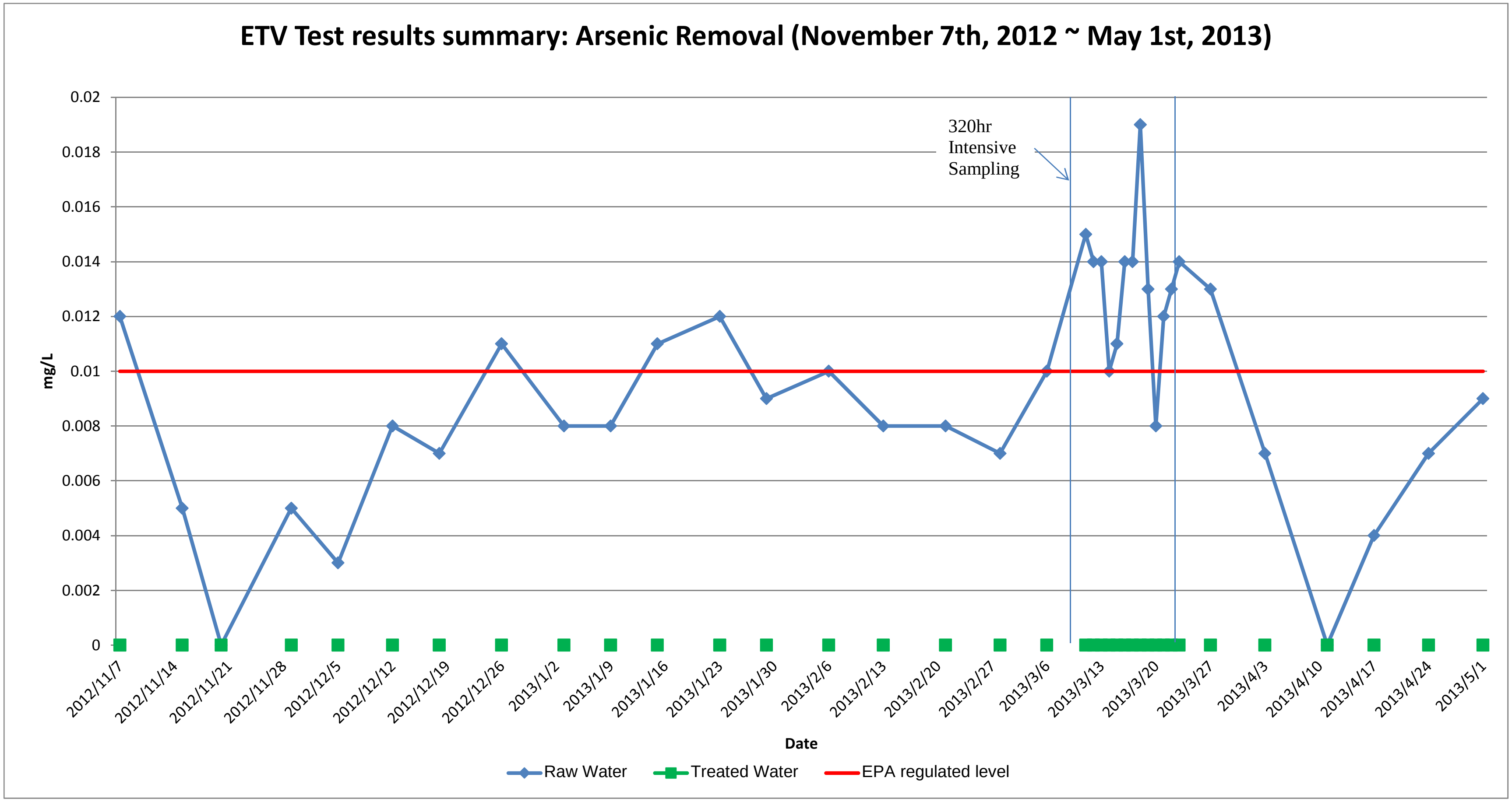


Figure 4-7. Arsenic Removal Results For Weekly Samples and March 320-Hour Daily Samples.

4.4.2.4 *Manganese*

The monitoring period for manganese removal was delayed until January 2013 to allow more time for the manganese oxidizing bacteria to cultivate on the filtration media. As discussed previously, the verification testing period was extended into May of 2013 to allow for second 320-hour daily sampling and 48-hour intensive sampling periods focusing only on manganese reduction. The results of the weekly manganese samples from January 15 to May 22 are presented in Table 4-9. These results, as well as the March 320-hour daily sampling results, are presented graphically in Figure 4-8. The weekly sample raw water manganese levels ranged from 0.13 to 0.32 mg/L, with a mean of 0.21 mg/L. The treated water levels ranged from 0.02 to 0.28 mg/L, with a mean of 0.11 mg/L. Of the fifteen treated water weekly manganese sample results, only two samples were below the EPA secondary MCL of 0.05 mg/L. These were the samples from April 3 and April 11. April 3 was during the pH adjustment period discussed above in Section 4.4.2.2, while the April 11 sample was collected three days after pH adjustment was stopped on April 8. No other official verification testing samples were collected during this first pH adjustment period; Nagaoka only had the FTO measuring manganese reduction in the field to monitor performance. Adjustment of pH was also included in the May extended testing period, as described below.

The results for the May 320-hour daily sampling period for manganese only are presented in Table 4-10, and are plotted in Figure 4-9. During the first week, from May 10 to May 16, the pH of the raw water was not raised. From May 17 to May 23, the mean feed water pH after NaOH addition was 7.03, with a range of 6.85 to 7.28. From May 10 to May 16, the raw water manganese concentration ranged from 0.09 to 0.19 mg/L, with a mean of 0.14 mg/L. For the second week, from May 17 to May 23, the raw water manganese concentration was higher, ranging from 0.21 to 0.32 mg/L, with a mean of 0.25 mg/L. Likewise, the treated water manganese concentrations were lower the first week than the second week. From May 10 to May 16 the treated water manganese ranged from 0.03 to 0.07 mg/L, with a mean of 0.04 mg/L. From May 18 to May 23, the treated water manganese ranged from 0.02 to 0.12 mg/L, with a mean of 0.06 mg/L. For this second week, the two lowest manganese measurements were on the 22nd and 23rd, at 0.02 and 0.04 mg/L, respectively. This indicates that perhaps pH adjustment takes a few days to affect the treated water levels.

The manganese results for the two May 48-hour intensive sampling periods are provided in Table 4-10, and graphically in Figures 4-10 and 4-11. An examination of the second data set for the May 21 to May 23 period more clearly shows the effect of the raw water pH adjustment. From 2:20 PM on May 21 to 6:20 AM on May 22, the treated water manganese level remained fairly constant between 0.10 and 0.13 mg/L. But then it dropped to 0.04 mg/L three hours later at the May 22 9:20 AM sampling point, and it remained low at a mean concentration of 0.05 mg/L (data not shown) and a maximum of 0.07 mg/L through the end of the intensive sampling period at 2:20 PM on May 23.

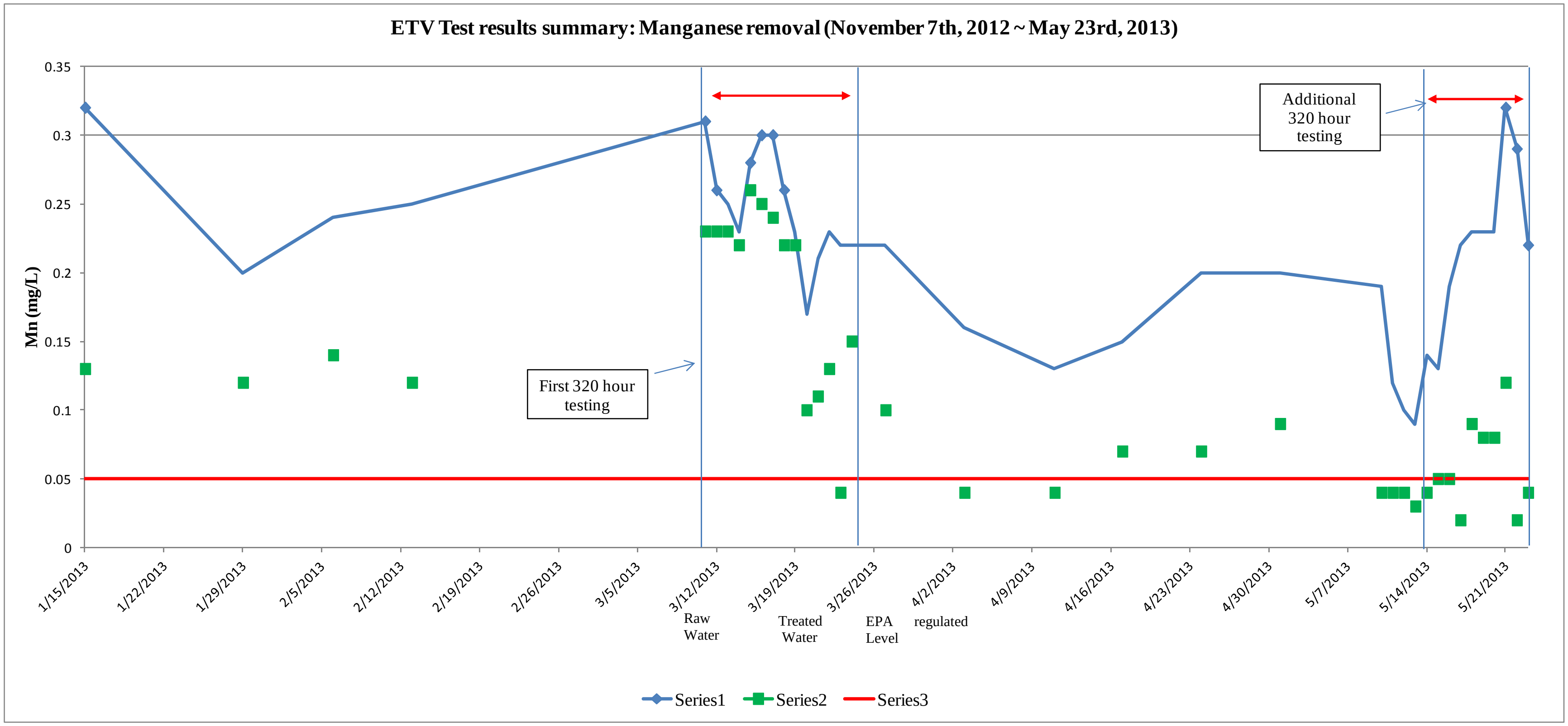


Figure 4-8. Manganese Removal Results.

Table 4-9. Manganese Results from May Daily Sampling Period

Without pH adjustment				With pH Adjustment			
		Manganese (mg/L)				Manganese (mg/L)	
Date	**Time**	**Raw**	**Treated**	**Date**	**Time**	**Raw**	**Treated**
5/10/2013	12:20 PM	0.19	0.04	5/17/2013	12:40 PM	0.22	0.02
5/11/2013	10:00 AM	0.12	0.04	5/18/2013	9:45 AM	0.23	0.09
5/12/2013	10:00 AM	0.10	0.04	5/19/2013	1:15 PM	0.23	0.08
5/13/2013	12:30 PM	0.09	0.03	5/20/2013	12:45 PM	0.23	0.08
5/14/2013	3:10 PM	0.14	0.04	5/21/2013	2:36 PM	0.32	0.12
5/15/2013	2:40 PM	0.14	0.04	5/22/2013	2:48 PM	0.29	0.02
5/16/2013	2:20 PM	0.19	0.07	5/23/2013	2:20 AM	0.21	0.04
Count		7	7	Count		7	7
Mean		0.14	0.04	Mean		0.25	0.06
Minimum		0.09	0.03	Minimum		0.21	0.02
Maximum		0.19	0.07	Maximum		0.32	0.12

Table 4-10. Manganese Results from May 48-Hour Intensive Sampling Periods

		Manganese (mg/L)					Manganese (mg/L)	
Date	**Time**	**Raw**	**Treated**		**Date**	**Time**	**Raw**	**Treated**
5/14/2013	2:20 PM	0.14	0.04		5/21/2013	2:20 PM	0.32	0.12
5/14/2013	5:20 PM	0.16	0.04		5/21/2013	5:20 PM	0.27	0.13
5/14/2013	7:20 PM	0.18	0.03		5/21/2013	7:20 PM	0.30	0.10
5/14/2013	8:20 PM	0.16	0.04		5/21/2013	8:20 PM	0.28	0.10
5/14/2013	10:20 PM	0.14	0.05		5/21/2013	10:20 PM	0.31	0.12
5/15/2013	1:20 AM	0.14	0.05		5/22/2013	1:20 AM	0.29	0.12
5/15/2013	3:20 AM	0.14	0.04		5/22/2013	3:20 AM	0.27	0.10
5/15/2013	4:20 AM	0.14	0.04		5/22/2013	4:20 AM	0.27	0.10
5/15/2013	6:20 AM	0.15	0.05		5/22/2013	6:20 AM	0.29	0.10
5/15/2013	9:20 AM	0.14	0.05		5/22/2013	9:20 AM	0.31	0.04
5/15/2013	11:20 AM	0.13	0.04		5/22/2013	11:20 AM	0.33	0.06
5/15/2013	12:20 PM	0.13	0.05		5/22/2013	12:20 PM	0.31	0.06
5/15/2013	2:20 PM	0.14	0.04		5/22/2013	2:20 PM	0.29	0.02
5/15/2013	5:20 PM	0.15	0.04		5/22/2013	5:20 PM	0.24	0.03
5/15/2013	7:20 PM	0.18	0.04		5/22/2013	7:20 PM	0.24	0.05
5/15/2013	8:20 PM	0.18	0.04		5/22/2013	8:20 PM	0.23	0.04
5/15/2013	10:20 PM	0.19	0.05		5/22/2013	10:20 PM	0.23	0.05
5/16/2013	1:20 AM	0.20	0.06		5/23/2013	1:20 AM	0.22	0.06
5/16/2013	3:20 AM	0.18	0.04		5/23/2013	3:20 AM	0.20	0.07
5/16/2013	4:20 AM	0.18	0.04		5/23/2013	4:20 AM	0.19	0.05
5/16/2013	6:20 AM	0.20	0.06		5/23/2013	6:20 AM	0.17	0.05
5/16/2013	9:20 AM	0.17	0.06		5/23/2013	9:20 AM	0.17	0.05
5/16/2013	11:20 AM	0.19	0.05		5/23/2013	11:20 AM	0.22	0.04
5/16/2013	12:20 PM	0.17	0.06		5/23/2013	12:20 PM	0.22	0.04
5/16/2013	2:20 PM	0.19	0.07		5/23/2013	2:20 PM	0.21	0.04
Count		25	25		Count		25	25
Mean		0.16	0.05		Mean		0.26	0.07
Minimum		0.13	0.03		Minimum		0.17	0.02
Maximum		0.20	0.07		Maximum		0.33	0.13
Std. Deviation		0.02	0.01		Std. Deviation		0.05	0.03
95% Conf. Interval		±0.01	±0.004		95% Conf. Interval		±0.02	±0.01

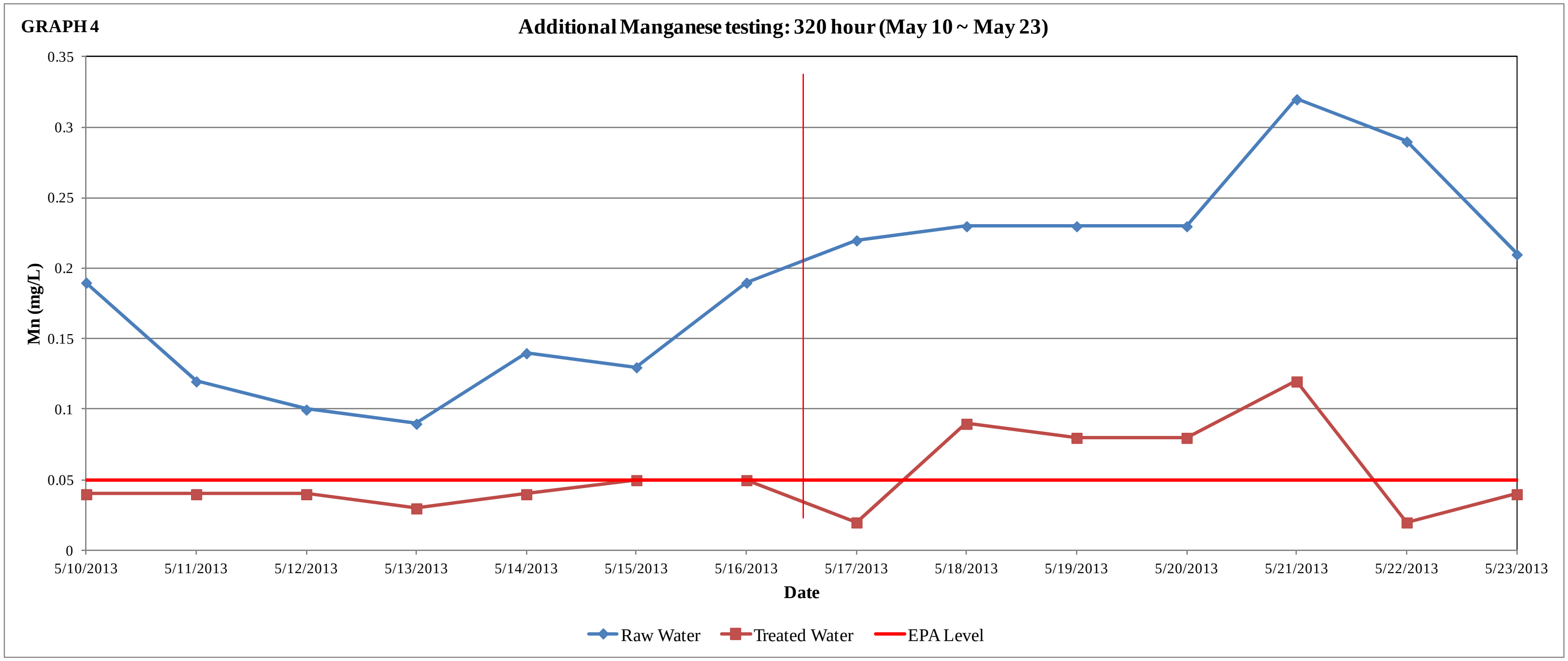


Figure 4-9. Manganese Removal Results from May Daily Sampling Period.

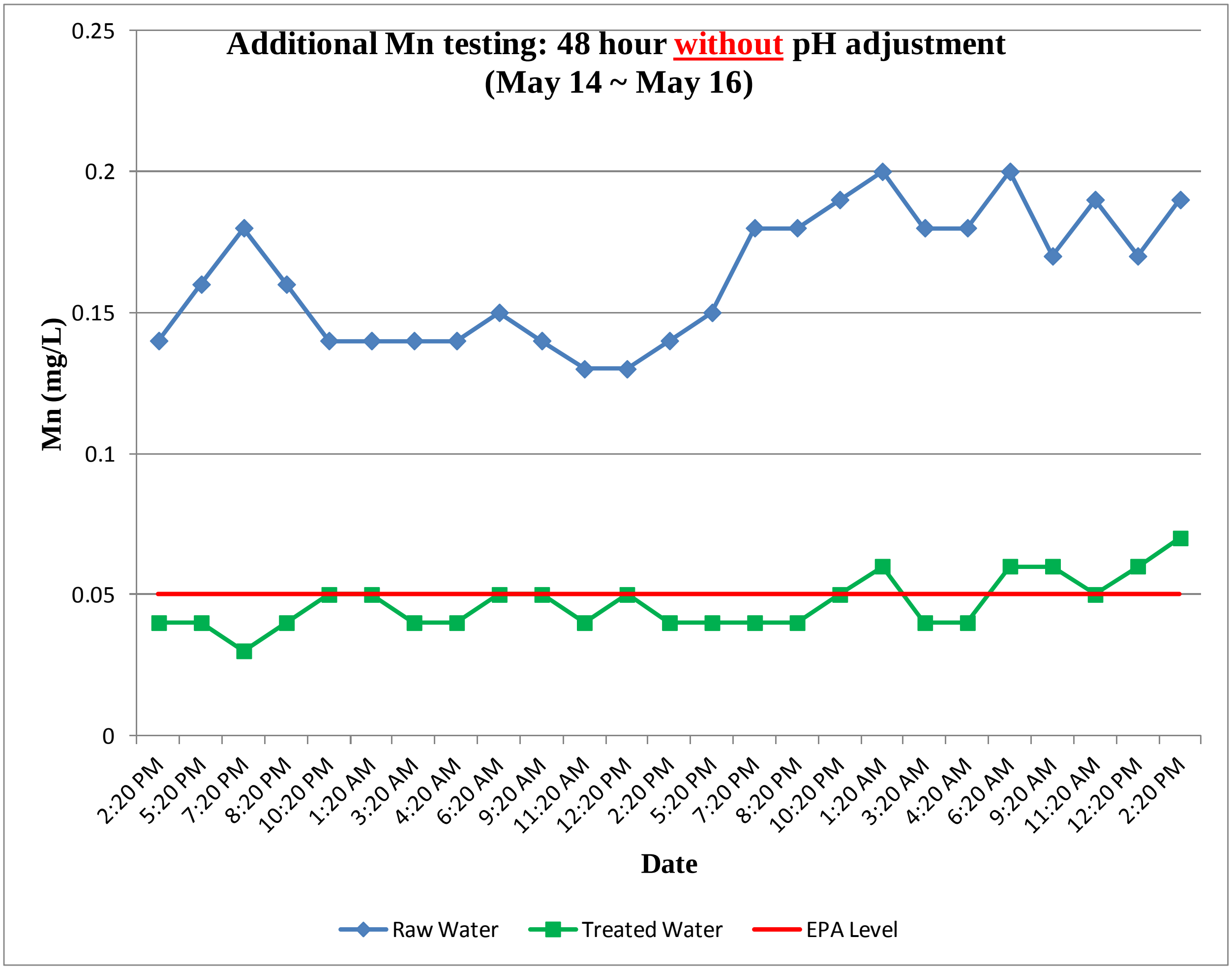


Figure 4-10. Manganese Removal Results From May 14-16 48-Hour Intensive Sampling Period Without pH Adjustment.

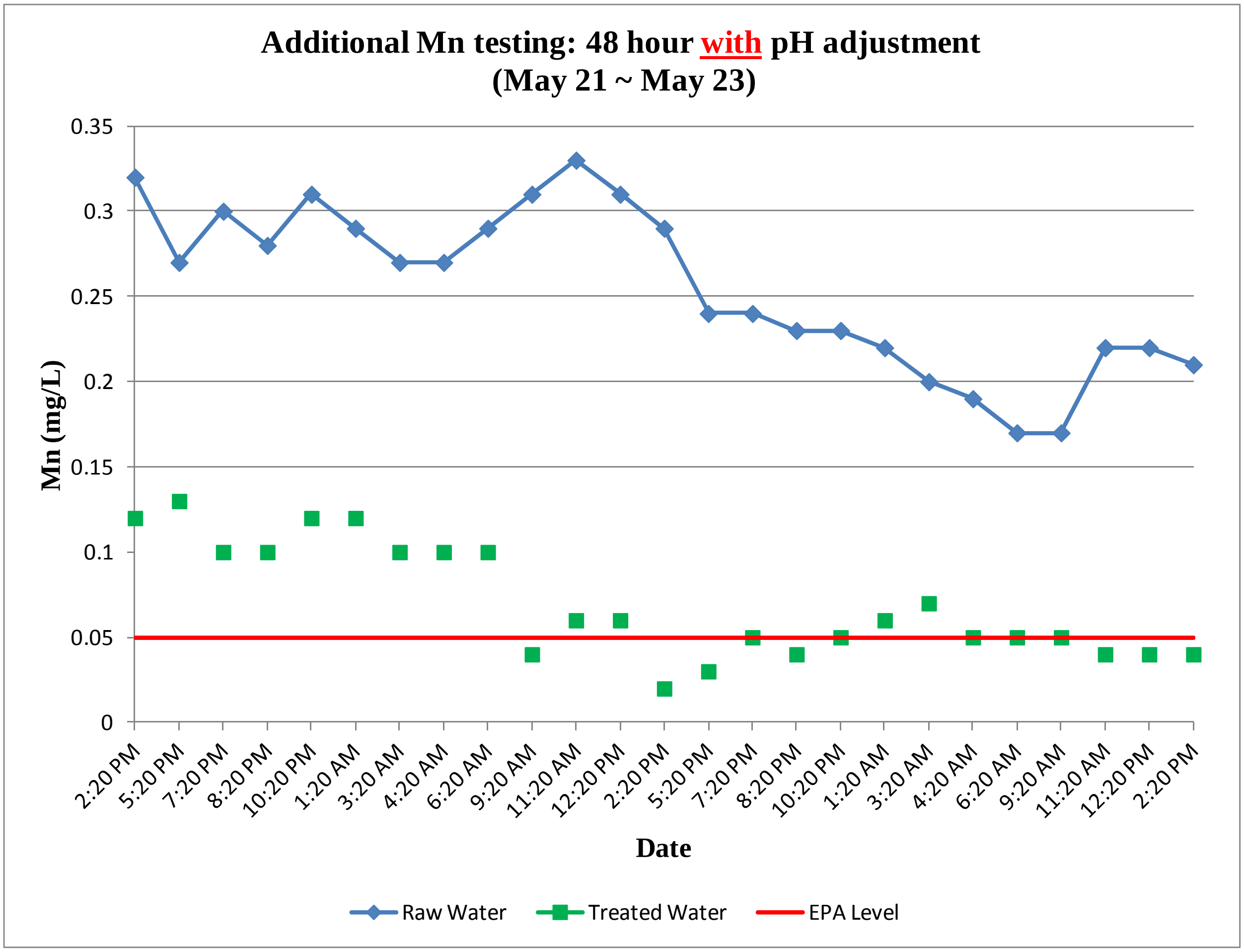


Figure 4-11. Manganese Removal Results From May 21-23 48-Hour Intensive Sampling Period With pH Adjustment.

4.4.3 Raw and Treated Water Quality Results

The water quality sampling schedule was presented in Table 3-6. The water quality parameters were measured in both the raw water and treated water streams. Temperature, pH, ORP, and DO were also measured in samples collected from the top of the treatment column, immediately downstream of the aeration nozzle. The summary statistics for the weekly on-site water quality measurements are provided in Table 4-11, and the summary statistics for the weekly laboratory measurements are provided in Table 4-12. Table 4-13 provides the on-site measurement results for the March 320-hour daily sampling period, while Table 4-14 provides the results for the May 320-hour daily sampling period. The May data are split up by week, with individual summary statistics for each week, because of the NaOH addition for pH adjustment the second week. And note that for the May data, the split caused the sample counts to be below eight, so the standard deviation and 95% confidence intervals are not calculated. The ETV protocols call for these parameters to be reported only when the sample size is eight or more.

All pH measurements prior to December 12, 2012 were excluded from the weekly samples dataset due to calibration of the pH meter using expired buffer solutions. The aerated water and treated water pH measurements from March 27 and April 3 were also excluded from the weekly samples dataset because of the previously discussed pH adjustment with NaOH injection. The raw water results from these two days are included because the NaOH injection was downstream of the raw water sampling port. The pH of the raw water averaged 6.39 over the verification testing period, with a minimum of 6.17 and a maximum of 6.57. Aeration of the raw water for treatment raised the pH to a mean of 6.68, with a range of 6.55 to 6.80. The pH of the treated water was slightly lower, with a mean of 6.46 and a range of 6.36 to 6.54. The raw water temperature was steady throughout the verification test, ranging from 11.9 to 14.2 °C.

The DO measurements prior to December 12 were also excluded because of a bad membrane on the DO probe. The DO of the raw water ranged from 2.97 to 4.16 mg/L, with a mean of 3.49 mg/L. Aeration of the water raised the DO level to an average of 9.77 mg/L (range 7.61 to 11.31). Passage of the water through the media column consumed oxygen, as would be expected for a biological treatment process. The DO of the treated water averaged 6.51 mg/L (range 3.62 to 8.85).

The ORP measurements prior to January 15 were excluded because the measurement procedure was not standardized. The FTO found that the ORP continued to drift at a good pace while measurements were attempted, even after waiting up to ten minutes for it to stabilize. Prior to January 15, the official measurement was made after waiting varying times. From January 15 onward, the procedure was standardized such that the measurement was always recorded after waiting for three minutes. Also, a portion of the ORP measurements are missing from the March 320-hour daily sampling dataset in Table 4-13 due to the ORP probe being broken. The ORP of the raw water ranged from -65 to 87 mV, with a mean of 2 mV. Aeration increased the ORP to a mean of 17 mV, with a range of -36 to 106 mV. Treatment of the water through the CHEMILES further increased the ORP to the range of 94 to 435 mV, with a mean of 213 mV, even though the treatment process consumed a portion of the dissolved oxygen in the water.

The turbidity of the raw water was low, at 0.09 to 0.88 NTU, with a mean of 0.33 NTU. The treatment process raised the turbidity somewhat, to a range of 0.17 to 3.23 NTU (mean of 0.80).

The HPC results from the November and December monthly samples were excluded from the dataset because the samples were collected from sampling tubes that were contaminated with biofilm. For the remaining samples collected during the verification test, the tubing was removed, and the samples were collected directly from the sampling valves. While the valves still likely contained some biofilm, this was the only option available for collecting the HPC samples. The HPC samples were always collected last, to allow as much flushing as possible prior to sample collection.

The treatment process did not seem to affect any of the laboratory measurement parameters, except for the HPC count. But these data are questionable because all treated water HPC counts were below 10 CFU/mL, except for one count of 149. For most raw/treated sample pairs, the raw water count was 1, or <1 CFU/mL, so the treatment process did add a small amount of HPC to the water but not to a degree warranting any concern about hitting the EPA MCL of 500 CFU/mL.

Table 4-11. Weekly Summary Data for On-Site Measurements(1)

	pH			Temperature (°C)			ORP (mV)			DO (mg/L)			Turbidity (NTU)		True Color (CU)	
Parameter	**Raw**	**Aerated**	**Treated**	**Raw**	**Aerated**	**Treated**	**Raw**	**Aerated**	**Treated**	**Raw**	**Aerated**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**
Count	27	19	23	33	30	33	21	17	21	28	24	28	33	33	11	11
Mean	6.39	6.68	6.46	12.7	12.6	12.9	2	17	203	3.49	9.77	6.51	0.33	0.77	12	7
Minimum	6.17	6.55	6.36	11.9	11.7	11.9	-65	-36	55	2.97	7.61	3.62	0.09	0.17	0	0
Maximum	6.57	6.80	6.54	14.2	14.5	14.5	87	106	435	4.16	11.31	8.85	0.88	3.23	17	15
Std. Deviation	0.09	0.07	0.06	0.50	0.70	0.62	45	43	101	0.31	0.74	1.38	0.20	0.61	5	6
95% Conf. Interval	±0.03	±0.03	±0.02	±0.17	±0.25	±0.21	±19	±20	±43	±0.12	±0.29	±0.51	±0.07	±0.21	±3	±4

(1) Concentrations reported as non-detect set equal to the detection limit for calculating statistics.

Table 4-12. Weekly Summary Data for Laboratory Measurements(1)

	Alkalinity (mg/L)		DOC (mg/L)		Chloride (mg/L)		Sulfate (mg/L)		Potassium (mg/L)		Magnesium (mg/L)		Sodium (mg/L)		TSS (mg/L)	
Parameter	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**
Count	14	14	10	10	10	9	28	27	10	10	27	27	10	10	27	27
Mean	87	79	1.3	1.1	49	57	4.0	4.1	3.9	3.8	7.6	7.7	35	39	3	<2
Minimum	70	61	0.6	0.6	21	21	0.9	1.0	3.0	3.0	6.0	6.0	20	20	<2	<2
Maximum	100	120	1.8	1.7	80	160	8.6	8.7	5.0	4.7	9.5	10	53	70	11	<2
Std. Deviation	11	17	0.43	0.38	21	44	2.1	2.1	0.74	0.61	0.87	1.0	12	16	1.9	NA
95% Conf. Interval	±5.6	±8.9	±0.27	±0.23	±13	±29	±0.77	±0.78	±0.46	±0.38	±0.33	±0.38	7.2	9.8	0.71	NA

	VSS (mg/L)		Hardness (mg/L $CaCO_3$)		TOC (mg/L)		Fluoride (mg/L)		Sulfide (mg/L)		HPC (CFU/mL)		Silica (mg/L)	
Parameter	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**
Count	10	10	27	25	28	28	10	10	10	10	8	8	10	10
Mean	2	<2	68.4	68.6	1.4	1.0	0.1	0.1	0.02	<0.01	3	24	55	52
Minimum	<2	<2	56.0	54.0	0.5	0.1	<0.1	<0.1	<0.01	<0.01	<1	2	50	45
Maximum	3	<2	90.0	88.0	2.1	1.7	0.1	0.1	0.03	<0.01	20	149	61	57
Std. Deviation	0.3	NA	8.24	8.69	0.4	0.3	NA	NA	0.01	NA	7	51	4.1	3.8
95% Conf. Interval	±0.2	NA	±3.11	±3.41	±0.2	±0.1	NA	NA	±0.004	NA	±5	±35	±2.6	±2.3

(1) Concentrations reported as non-detect set equal to the detection limit for calculating statistics.

Table 4-13. On-Site Water Quality Measurements for March 320-hour Daily Sampling Period

		pH			Temperature (°C)			ORP (mV)			DO (mg/L)			Turbidity (NTU)	
Date	**Time**	**Raw**	**Aerated**	**Treated**	**Raw**	**Aerated**	**Treated**	**Raw**	**Aerated**	**Treated**	**Raw**	**Aerated**	**Treated**	**Raw**	**Treated**
3/11/2013	11:36 AM	6.44	NM(1)	6.44	12.8	NM	13.0	-1	NM	417	3.27	NM	4.22	0.19	1.46
3/12/2013	12:10 PM	6.47	6.67	6.41	13.1	13.2	13.4	-46	-33	121	3.10	8.97	3.62	0.15	1.25
3/13/2013	NR(2)	6.38	NM	6.38	13.1	NM	13.4	-1	NM	118	3.50	NM	4.02	0.45	1.09
3/14/2013	10:38 AM	6.40	6.61	6.38	12.8	13.1	13.4	-19	6	90	3.17	8.40	4.23	0.54	0.89
3/15/2013	10:41 AM	6.39	6.59	6.37	13.1	13.3	13.7	0	27	101	3.30	8.75	4.16	0.35	1.44
3/16/2013	9:00 AM	6.45	6.65	6.51	12.3	12.4	12.3	-28	0	76	3.39	8.36	3.59	0.69	1.91
3/17/2013	4:01 PM	6.47	6.58	6.36	12.5	12.6	13.4	NM	NM	NM	3.74	8.62	4.33	0.38	0.31
3/18/2013	2:30 PM	6.50	6.65	6.42	13.0	12.7	12.9	NM	NM	NM	3.92	8.69	3.84	0.35	1.05
3/19/2013	3:00 PM	6.49	6.66	6.50	12.9	13.0	13.2	NM	NM	NM	3.84	8.82	4.37	0.38	0.84
3/20/2013	2:45 PM	6.39	6.51	6.43	12.1	12.0	12.2	NM	NM	NM	4.44	8.36	5.51	0.20	1.24
3/21/2013	12:10 PM	6.45	6.62	6.43	11.9	11.4	12.3	NM	NM	NM	4.39	9.51	5.29	0.49	1.67
3/22/2013	11:57 AM	6.48	6.67	6.43	12.5	12.4	12.6	NM	NM	NM	3.64	8.86	3.82	0.30	0.52
3/23/2013	5:06 PM	6.39	NM	6.34	12.3	NM	12.8	NM	NM	NM	3.19	NM	3.57	0.75	0.69
3/24/2013	3:38 PM	6.43	NM	6.42	12.8	NM	13.2	NM	NM	NM	3.37	NM	4.67	0.28	0.76
Count		14	10	14	14	10	14	6	4	6	14	10	14	14	14
Mean		6.44	6.62	6.42	12.7	12.6	13.0	-16	0	154	3.59	8.73	4.23	0.39	1.08
Minimum		6.38	6.51	6.34	11.9	11.4	12.2	-46	-33	76	3.10	8.36	3.57	0.15	0.31
Maximum		6.50	6.67	6.51	13.1	13.3	13.7	0	27	417	4.44	9.51	5.51	0.75	1.91
Std. Deviation		0.04	0.05	0.05	0.39	0.59	0.48	NM(3)	NC	NC	0.43	0.35	0.59	0.18	0.45
95% Conf. Interval		±0.02	±0.03	±0.03	±0.21	±0.37	±0.25	NC	NC	NC	±0.23	±0.22	±0.31	±0.09	±0.24

(1) NM = not measured
(2) NR = not recorded
(3) NM = not measured, probe broken from 3/17 through 3/24
(4) NC = not calculated due to sample count

Table 4-14. On-Site Water Quality Measurements for May 320-hour Daily Sampling Period

		pH			Temperature (°C)			ORP (mV)			DO (mg/L)			Turbidity (NTU)	
Date	**Time**	**Raw**	**Aerated**	**Treated**	**Raw**	**Aerated**	**Treated**	**Raw**	**Aerated**	**Treated**	**Raw**	**Aerated**	**Treated**	**Raw**	**Treated**
5/10/2013	12:20 PM	6.31	6.64	6.45	14	14.5	14.4	31	43	165	2.59	8.98	7.70	0.35	0.23
5/11/2013	10:00 AM	6.18	NM	6.37	13.7	NM	14.2	113	NM	205	2.86	NM	7.95	0.34	0.22
5/12/2013	10:00 AM	6.11	NM	6.38	14	NM	14.4	53	NM	330	2.79	NM	7.80	0.21	0.24
5/13/2013	12:30 PM	6.16	NM	6.43	13.7	NM	14.4	68	NM	254	2.86	NM	8.10	0.25	0.29
5/14/2013	3:10 PM	6.29	6.62	6.43	14.1	15.3	13.9	141	131	239	3.07	9.30	7.91	0.18	0.24
5/15/2013	2:40 PM	6.32	6.69	6.53	14.2	13.6	14.2	87	103	314	3.45	9.18	7.75	0.25	0.33
5/16/2013	2:20 PM	6.32	6.63	6.42	13.9	14.2	14.7	91	83	481	2.81	9.25	6.04	0.41	0.45
Count		7	4	7	7	4	7	7	4	7	7	4	7	7	7
Mean		6.24	6.65	6.43	13.9	14.4	14.3	83	90	284	2.92	9.18	7.61	0.28	0.29
Minimum		6.11	6.62	6.37	13.7	13.6	13.9	31	43	165	2.59	8.98	6.04	0.18	0.22
Maximum		6.32	6.69	6.53	14.2	15.3	14.7	141	131	481	3.45	9.30	8.10	0.41	0.45
5/17/2013	12:40 PM	6.47	7.28	7.01	14.5	14.4	14.3	-227	-178	2	4.08	8.20	6.52	0.44	2.40
5/18/2013	9:45 AM	6.51	7.07	6.97	13.9	13.3	14.2	-117	-92	27	3.21	8.75	8.15	0.15	8.31
5/19/2013	1:15 PM	6.53	7.03	6.81	13.9	13.9	14.6	-117	-105	98	3.71	8.71	6.06	0.44	0.57
5/20/2013	12:45 PM	6.52	7.01	6.83	13.6	14.2	13.7	145	-196	-77	3.28	8.85	6.16	0.19	0.36
5/21/2013	2:36 PM	6.48	6.92	6.73	13.6	13.4	13.8	-86	-77	32	2.98	8.93	5.84	0.3	0.46
5/22/2013	2:48 PM	6.57	7.06	7.48	12.6	12.5	12.7	-1	9	55	3.82	10.34	6.79	0.14	0.61
5/23/2013	2:20 AM	6.36	6.85	6.95	12.8	12.9	12.9	-65	-18	55	3.87	10.24	7.84	0.32	0.59
Count		7	7	7	7	7	7	7	7	7	7	7	7	7	7
Mean		6.49	7.03	6.97	13.6	13.5	13.7	-69	-94	27	3.56	9.15	6.77	0.28	1.90
Minimum		6.36	6.85	6.73	12.6	12.5	12.7	-227	-196	-77	2.98	8.20	5.84	0.14	0.36
Maximum		6.57	7.28	7.48	14.5	14.4	14.6	145	9	98	4.08	10.34	8.15	0.44	8.31

(1) NM = not measured

4.4.4 Backwash Frequency and Wastewater Quality

As described in Sections 2.1 and 4.4.1, the CHEMILES System backwash cycle was set to occur automatically every eight hours. Most of the backwashes were the partial backwash described in 2.1; the whole backwash only occurred after every 6th partial backwash. The backwash waste was discharged into a collection vessel from which the backwash samples were drawn. This vessel was used only for collection of the backwash waste for the scheduled sampling events. The non-sampled backwash waste was collected into a different vessel, from which the waste was slowly discharged onto the ground. During the NSF QA audit on December 5, a backwash event was observed, and it was noted that the backwash waste volume on that day was greater than the 50 gallon capacity of the vessel by about five gallons. However, the FTO noted that for the next backwash sampling event on January 3, the entire backwash volume was captured by the 50 gallon vessel. To ensure that all of the backwash waste was collected prior to sampling, the FTO began using a 65-gallon collection vessel for the remaining backwash sample collection events.

The backwash waste was sampled and analyzed following the schedules in Tables 3-6 and 3-8. Immediately following a backwash event, samples were collected from the backwash collection vessel with a ladle. Table 4-12 shows the results for total arsenic, total iron, manganese, TSS, and pH. The backwash waste was enriched in arsenic, iron, manganese, and TSS, as would be expected, given the removal of contaminants as measured in the treated water. The CHEMILES System produced an average daily volume of 6,527 gal, and generated an average backwash volume of 150 gpd. Thus, on a mass balance basis, the theoretical concentration of contaminants in the backwash would be projected to be approximately 42 times higher in the backwash, based on complete removal of contaminants from the media into the backwash waste. However, comparison of the mean raw water concentrations in Table 4-6 to the backwash results in Table 4-15 reveals increases of only about 7X for arsenic, 13X for iron, and 4X for manganese. Analysis of the filter media by Nagaoka after the test ended revealed that the filter media particle sizes had increased, indicating the backwashes did not fully remove the accumulated contaminants from the filter media particles.

Table 4-15. Backwash Water – Water Quality Results

Date	Total Arsenic (mg/L)	Total Iron (mg/L)	Manganese (mg/L)	TSS (mg/L)	pH
12/05/12	0.057	220	0.28	410	NR[1]
01/03/13	NM	NM	NM	NM	6.53
02/13/13	0.012	32	0.48	100	6.49
03/06/13	0.045	73	NM	160	6.31
03/12/13	0.041	82	0.71	170	6.47
04/03/13	0.160	290	2.4	540	6.86
05/01/13	0.025	54	0.27	120	6.39
Count	6	6	5	6	6
Average	0.057	125	0.83	250	6.51
Minimum	0.012	32	0.27	100	6.31
Maximum	0.160	290	2.4	540	6.86

(1) Not reportable due to improper calibration of pH meter

(2) NM = not measured

Local disposal requirements determine whether water is acceptable for discharge to a sanitary sewer system or another discharge location, or if it requires further treatment prior to discharge. The suspended solids present in the backwash waste can be expected to contain most of the arsenic, iron, and manganese because the basis of the technology is to precipitate and filter out the contaminants. If solid separation were required before the backwash waste could be discharged, the solids would need to be sent to a landfill for disposal. A sample of the backwash was collected and analyzed following the EPA TCLP and the CAWET requirements. The backwash solids were not considered a hazardous waste based on the arsenic concentrations, which were below the 5 mg/L limit under the Resource Conservation and Recovery Act (RCRA). Table 4-16 presents the results of the TCLP and CAWET analyses.

Table 4-16. Backwash Solids – TCLP and CAWET Analyses

Parameter	Units	TCLP	CAWET
Arsenic	mg/L	<0.50	1.6
Barium	mg/L	<0.35	0.37
Cadmium	mg/L	<0.050	<0.050
Chromium	mg/L	<0.25	<0.050
Copper	mg/L	<0.050	<0.25
Lead	mg/L	<0.25	<0.25
Mercury	mg/L	<0.00020	<0.0030
Nickel	mg/L	<0.050	<0.050
Selenium	mg/L	<0.20	<0.50
Silver	mg/L	<0.050	<0.010
Zinc	mg/L	<0.25	0.95

4.5 FTO System Operability Review

4.5.1 Introduction

In general the pilot treatment plant was very easy to operate and maintain. The unit was completely automated and required only minimal maintenance. Initially, the unit required some process modifications, but once they were adjusted, very little adjustment was required. Below are some detailed descriptions of operations and maintenance issues.

The quality of the equipment provided, including piping, valves and controls was excellent and held up quite well throughout the test period. There was relatively easy access to the piping, controls and pilot filter. Even though the pilot filter was quite tall, an enclosed structure with ladder steps and access platforms was provided.

4.5.2 Pilot Treatment System Controls

The pilot system is controlled by a PLC. The PLC monitored flow in the system, operated pumps and valves and conducted backwashing. The PLC was standard commercial equipment available in Japan and the US, and equipment manuals were provided in English. The O&M manual provided by Nagaoka accurately described the PLC set points and, the FTO staff was able to change the set-points when requested by Nagaoka.

4.5.3 Electrical Equipment

When the pilot system arrived, it did not have an Underwriter's Laboratory (UL) sticker on the panel, since the panel was constructed in Japan. Nagaoka hired a local electrical inspector to inspect the equipment and a UL listing was achieved after some modification to the conduits. This is not likely to be an issue in the future, since Nagaoka is now familiar with UL listing requirements in the U.S.

4.5.4 O&M Manual

The O&M Manual provided by Nagaoka accurately described the treatment system and explained how to operate the pilot plant. There were a few instances in the O&M manual where English translations could be improved for clarity, but our staff had no difficulty in understanding the manual and the instructions included within it.

4.5.5 Monitoring

Pilot plant monitoring was done through a combination of data recording and sample collection. Data recording was a mix of items recorded by the PLC and field recording. Field recording was required of flow rates and head loss in the filter. The PLC monitored some flow rates, and backwash statistics (number of backwashes, time since last backwashing). The pilot system could be improved by adding a differential pressure recording device across the filter and incorporating all of the flow data into the PLC. A data logger would also be useful to allow evaluation of data on a more frequent basis.

The Nagaoka CHEMILES system uses a finished water pump with a VFD to control the filter rate of the system. This finished water pumping system provides a nice way to adjust or maintain a filter loading rate, however it creates a vacuum on the bottom of the filter when the pump is operating under some conditions. This vacuum makes traditional means of measuring head loss across a filter difficult by either a traditional differential pressure meter or by piezometric readings. Further, the filter vacuum is a function of how fast the pump is running and therefore is not useful in determining when a backwash should be initiated based on head loss. There are differential pressure-meters than can measure positive and negative pressure and including one on this system would provide useful head loss information.

Sample collection provisions were provided for raw and finished water. In the pilot test, to collect the aerated raw water sample, the sample collector had to access the top of the filter and collect a water sample with a scoop; however the full scale systems have a permanent sample line which makes sample collection easier. The aerated water sample is a key point for assessing the influent dissolved oxygen content.

4.5.6 Operations

Operation of the pilot plant was very easy. Since the pilot plant was highly automated, only monitoring and some infrequent maintenance were required to operate the treatment plant. Infrequent maintenance included cleaning the aeration nozzles. Nagaoka provided a spare aeration nozzle with the pilot unit, and to clean the aeration nozzle, CH2M HILL replaced the original nozzle with the replacement nozzle and soaked the original one in a dilute acid solution to remove the precipitated iron. Over the testing period, the aeration nozzle only required replacement and cleaning one time.

Nagaoka provided excellent customer support for operations and recommended some operational modifications based on the data collected. The suggested modifications were implemented and improved performance of the unit.

4.6 Power Consumption

The CHEMILES Systems uses three pumps for operation: a raw water pump, a treated water pump, and a backwash pump. The horsepower ratings and operational details of these pumps are provided in Table 4-16. Based on an estimated pump efficiency of 90%, these three pumps consume approximately 29.5 kW/day. The electrical consumption of the PLC and online meters was not included in this power consumption analysis.

Table 4-17. CHEMILES System Pumps and Operation per Day

		Time during each 8 Hour Cycle (hrs)				During 24 Hour Span (hrs)
Pump	Horsepower Rating (hp)	Filtrating	Backwash	Water Cycling	Total	Total
Raw Water	0.75	7.667			7.667	23
Treated Water	0.75	7.667		0.167	7.833	23.5
Backwash	1.5		0.167		0.167	0.5

4.7 Quality Assurance/Quality Control

As described in Section 3.9.8, Task 6 was implementation of a structured QA/QC program as part of this verification to ensure the quality of the data being collected. A QAPP was developed as part of the PSTP and followed by the field staff and laboratory during the testing period. Careful adherence to the established procedures ensured that the data presented in this report are sound, defensible, and representative of the equipment performance.

4.7.1 Documentation

FTO site operators recorded on-site data and calculations (e.g., calculating calibration flow rates using the bucket and stop watch, and other similar routine calculations) in a field logbook and prepared field log sheets. Daily measurements were recorded on specially prepared data log sheets. The original logbook was stored on site, and copies were forwarded to the project coordinator at NSF offices once per week during the verification test. The operating logbook included calibration records for the field equipment used for on-site analyses.

Data from the field log sheets and NSF Laboratory data reports were entered into Excel spreadsheets. These spreadsheets were used to conduct the statistical analyses. The data in the spreadsheets were proofread by the initial data entry person. NSF staff then checked at least 10% of the data entered into the spreadsheets to confirm that the information was correct.

Samples delivered to the NSF Laboratory for analyses were tracked using chain-of-custody forms. Each sample bottle was labeled with a bar code for tracking in the NSF LIMS system. The NSF laboratory reported the analytical results using the NSF LIMS system reports. These laboratory data were entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

4.7.2 Quality Audits

The NSF QA department conducted an on-site audit on December 05, 2012 to review the field procedures, including the collection of operating data and performance of on-site analytical methods. The PSTP requirements and QAPP were used as the basis for the audit. The NSF QA auditor prepared an audit report. All deficiencies were corrected, and a second site visit was conducted by NSF on December 17 and 18 to follow up on the audit issues. The audit findings that impacted the test data are discussed elsewhere in this report.

4.7.3 Data Quality Indicators

The data quality indictors established for the ETV project and described in the QAPP included:

- Representativeness
- Accuracy
- Precision
- Completeness

4.7.3.1 *Representativeness*

Representativeness refers to the degree to which the data accurately and precisely represent the frequency distribution of a variable in a population. In this verification testing, representativeness was assured by executing consistent sample collection procedures in accordance with established approved procedures, and following specific sample preservation, packaging, and delivery procedures. Approved analytical methods were used to provide results that represent the accurate and precise measurements of drinking water. For equipment operating data, representativeness entailed collecting and documenting a sufficient quantity of data during operation to be able to detect a change in operations.

Because manganese removal had not stabilized and reached steady-state performance by the time of the March daily sampling period, the March Manganese data did not represent the true Manganese removal performance of the system. Additional verification testing was performed in May and those data were representative for Manganese removal evaluation. The March data are presented below for reference.

Table 4-18. Manganese Weekly Sample Summary Data(1)

	Manganese (mg/L)	
Parameter	**Raw**	**Treated**
Count	17	15
Mean	0.21	0.11
Minimum	0.13	0.02
Maximum	0.32	0.28
Std. Deviation	0.06	0.08
95% Conf. Interval	±0.03	±0.04

(1) Concentrations reported as non-detect set equal to the detection limit for calculating statistics.

Table 4-19. Manganese Results from March Daily Sampling Period

		Manganese (mg/L)	
Date	**Time**	**Raw**	**Treated**
3/11/2013	11:36 AM	0.31	0.23
3/12/2013	12:10 PM	0.26	0.23
3/13/2013	-	0.25	0.23
3/14/2013	10:38 AM	0.23	0.22
3/15/2013	10:41 AM	0.28	0.26
3/16/2013	9:00 AM	0.30	0.25
3/17/2013	4:01 PM	0.30	0.24
3/18/2013	2:30 PM	0.26	0.22
3/19/2013	3:00 PM	0.23	0.22
3/20/2013	2:45 PM	0.16	0.11
3/21/2013	12:10 PM	0.21	0.11
3/22/2013	11:57 AM	0.23	0.13
3/23/2013	5:06 PM	0.22	0.04
3/24/2013	3:38 PM	0.22	0.15
Count		14	14
Mean		0.25	0.19
Minimum		0.16	0.04
Maximum		0.31	0.26
Std. Deviation		0.04	0.07
95% Conf. Interval		±0.02	±0.04

Table 4-20. Manganese Results from March 48-Hour Intensive Sampling Period

		Filtration Run Time (hrs)	Manganese (mg/L)	
Date	Time		Raw	Treated
3/18/2013	2:20 PM	3	0.26	0.22
3/18/2013	5:20 PM	6	0.26	0.22
3/18/2013	7:20 PM	0	0.27	0.20
3/18/2013	8:20 PM	1	0.26	0.20
3/18/2013	10:20 PM	3	0.26	0.22
3/19/2013	1:20 AM	6	0.26	0.22
3/19/2013	3:20 AM	0	0.27	0.21
3/19/2013	4:20 AM	1	0.27	0.23
3/19/2013	6:20 AM	3	0.26	0.24
3/19/2013	9:20 AM	6	0.26	0.23
3/19/2013	11:20 AM	0	0.26	0.21
3/19/2013	12:20 PM	1	0.26	0.22
3/19/2013	2:20 PM	3	0.23	0.22
3/19/2013	5:20 PM	6	0.21	0.15
3/19/2013	7:20 PM	0	0.21	0.13
3/19/2013	8:20 PM	1	0.19	0.15
3/19/2013	10:20 PM	3	0.19	0.14
3/20/2013	1:20 AM	6	0.19	0.13
3/20/2013	3:20 AM	0	0.19	0.11
3/20/2013	4:20 AM	1	0.18	0.12
3/20/2013	6:20 AM	3	0.18	0.12
3/20/2013	9:20 AM	6	0.18	0.11
3/20/2013	11:20 AM	0	0.17	0.09
3/20/2013	12:20 PM	1	0.17	0.10
3/20/2013	2:20 PM	3	0.16	0.11
Count			25	25
Mean			0.22	0.17
Minimum			0.16	0.09
Maximum			0.27	0.24
Std. Deviation			0.04	0.05
95% Conf. Interval			±0.02	±0.02

4.7.3.2 *Accuracy*

*4.7.3.2.1. **On-Site Equipment Accuracy and Calibration***

The accuracy of on-site analytical equipment and flow meters was regularly calibrated or checked for accuracy according to Table 4-21. The calibration records were recorded on the field data sheets. All calibrations and calibration checks were performed at the required frequency. All calibrations and calibration checks were within the specified QC objectives.

Table 4-21. Field Instrument Calibration Schedule

Instrument	Calibration Method	Frequency	Acceptable Accuracy
Flow Meters	Volumetric "bucket & stop watch"	Weekly	± 10%
Portable Turbidimeter	Secondary turbidity standards Primary turbidity standards	Daily Weekly	N/A
Portable pH/ISE Meter with Combination pH/ Temperature Electrode	Three-point calibration using 4.0, 7.0 and 10.0 buffers	Daily	± 5%
DO Meter	Based on known air saturation concentrations of DO at the measured air temperature	Daily	N/A
Thermometer (National Institute of Standards and Technology [NIST]-traceable)	Calibration against a NIST–traceable thermometer within the previous 12 months from the expected end date of the test.	None	± 5%
Spectrophotometer (true color)	Chlorine check standard	Daily	± 25%
ORP Meter	Per manufacturer's instructions	Daily	

N/A = Not Applicable.

4.7.3.2.2. Laboratory Analyses

Accuracy for the laboratory analyses was quantified as the percent recovery of a parameter in a sample to which a known quantity of that parameter was added. The following equation was used to calculate accuracy:

$$\text{Accuracy} = \text{Percent Recovery} = 100 \times [(X_{\text{known}} - X_{\text{measured}}) \div X_{\text{known}}]$$

where X_{known} = known concentration of measured parameter
X_{measured} = measured concentration of parameter

Accuracy also incorporates calibration procedures and use of certified standards to ensure the calibration curves and references for analysis are near the "true value." Accuracy of analytical readings is measured through the use of spiked samples and lab control samples. The percent recovery is calculated as a measure of the accuracy.

The QAPP and the NSF Chemistry Laboratory QA/QC requirements established the frequency of spike sample analyses at 10% of the samples analyzed. Laboratory control samples (LCS) are also run at a frequency of 10%. The recovery limits specified for the parameters in this verification were 70-130% for laboratory-fortified samples and 85-115% for LCS. These recovery limits for the QC sample analyses associated with samples from this test were not reviewed for this verification. The QC sample results are reviewed by the appropriate NSF Laboratory staff as part of laboratory QA/QC requirements.

4.7.3.3 *Precision*

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. Analytical precision is a measure of how far an individual measurement may be from the mean of replicate measurements. Precision of duplicate analyses was measured by use of the following equation to calculate RPD:

$$RPD = \left| \frac{S_1 - S_2}{S_1 + S_2} \right| \times 200$$

where:

S_1 = sample analysis result; and

S_2 = sample duplicate analysis result.

Acceptable analytical precision for the verification test was set at an RPD of 30%.

Field duplicates were collected to incorporate both sampling and analytical variation to measure overall precision against this objective. The precision goal, as measured by RPD, for the field measurements was ±30%. The NSF Laboratory's precision requirements varied depending on the method, but were generally around 20%.

4.7.3.3.1. ***Field Duplicates***

The field duplicate results and RPD calculations are provided in Table 4-18. All duplicate measurements have an RPD of 30% or less, except for the raw water turbidity replicate pairs on February 28 and April 11, and the treated water turbidity pair on April 11. It is not known why the turbidity appeared to be unstable on April 11. No observations were recorded indicating any operational issues with the treatment equipment.

Table 4-22. Precision Data – Field Duplicates for Field Parameters

pH (S.U.)

Date	**Raw Water**			**Treated Water**		
	Rep 1	Rep 2	%RPD	Rep 1	Rep 2	%RPD
01/23/13	6.48	6.48	0	6.49	6.51	0.31
02/13/13	6.40	6.42	0.31	6.36	6.37	0.16
02/28/13	6.37	6.38	0.16	6.38	6.38	0
04/11/13	6.18	6.17	0.16	6.43	6.44	0.16

Turbidity (NTU)

Date	**Raw Water**			**Treated Water**		
	Rep 1	Rep 2	%RPD	Rep 1	Rep 2	%RPD
01/23/13	0.34	0.28	19	0.77	0.79	2.6
02/13/13	0.24	0.19	23	0.61	0.60	1.7
02/28/13	0.32	0.45	34	0.72	0.77	6.7
04/11/13	0.28	0.18	43	0.17	0.46	92

Temperature (°C)

Date	**Raw Water**			**Treated Water**		
	Rep 1	Rep 2	%RPD	Rep 1	Rep 2	%RPD
01/23/13	12.1	12.0	0.83	12.3	12.3	0
02/13/13	12.7	12.7	0	12.6	12.6	0
02/28/13	12.7	12.7	0	12.9	12.9	0
04/11/13	12.8	12.8	0	13.3	13.3	0

ORP (mV)

Date	**Raw Water**			**Treated Water**		
	Rep 1	Rep 2	%RPD	Rep 1	Rep 2	%RPD
01/23/13	-13	-16	21	153	118	26
02/13/13	-57	-45	24	240	238	0.84
02/28/13	13	16	21	136	120	13
04/11/13	83	78	6.2	309	317	2.6

DO (mg/L)

Date	**Raw Water**			**Treated Water**		
	Rep 1	Rep 2	%RPD	Rep 1	Rep 2	%RPD
01/23/13	3.45	3.86	11	5.89	6.09	3.3
02/13/13	3.44	3.39	1.5	5.82	5.72	1.7
02/28/13	3.99	3.69	7.8	5.84	5.94	1.7
04/11/13	3.27	2.97	9.6	8.85	8.75	1.1

4.7.3.3.2. Laboratory Analytical Duplicates

The NSF Chemistry Laboratory precision was monitored during the verifications test in accordance with QAPP and the NSF quality assurance program. Laboratory duplicates were analyzed at 10% frequency of samples analyzed. All duplicate sample analyses met the NSF Chemistry Laboratory's RPD

4.7.3.4 *Method Blanks*

The NSF Laboratory included method blanks as part of the standard analysis procedures. Method blanks were analyzed in accordance with the approved methods. No data were flagged as having been affected by method blank results.

4.7.3.5 *Completeness*

Completeness refers to the amount of valid, acceptable data collected from a measurement process compared to the amount expected to be obtained. Completeness was calculated using the following:

$$\%C = (V/T) \times 100$$

where: %C = percent completeness
V = number of measurements judged valid
T = total number of measurements

. Table 4-19 provides the completeness objectives for performance parameters and/or methods based on the sample frequency.

Table 4-23. Completeness Objectives

Number of Samples Per Parameter and/or Method	Percent Completeness
0-10	80%
11-50	90%
>50	95%

For the purpose of evaluating the completeness requirements, only data up through the originally scheduled end date of May 1 were evaluated. The completeness calculations are provided in Table 4-20 for those parameters with less than 100% completeness.

Table 4-24. Completeness Results

Parameter	Number of Scheduled Samples	Number of Reported Samples	Percent Completeness	Completeness Requirement Met?	Comment
Backwash Monitoring	123	116	95%	Yes	No backwash was monitored on 7 of 123 days.
Ammonia – Raw Water	60	58	97%	Yes	
Ammonia – Treated Water	60	59	98%	Yes	
Manganese – Treated Water	60	59	98%	Yes	
Iron – Treated Water	60	58	97%	Yes	Treated water results from pH adjustment period discarded. See Section 4.4.2.2.
Hardness – Treated Water	26	23	88%	No	
Hardness – Raw Water Samples	26	25	96%	Yes	
Sulfate – Treated Water	26	25	96%	Yes	
Magnesium – Raw and Treated Water	26	25	96%	Yes	
TSS – Raw and Treated Water	26	25	96%	Yes	
HPC – Raw and Treated Water	8	6	75%	No	Contaminated samples as previously discussed
TKN – Raw and Treated Water	38	36	95%	Yes	
Nitrate – Raw and Treated Water	60	47	78%	No	Some samples analyzed past allowable holding time, as discussed in Section 4.4.2.1.
Nitrite – Raw and Treated Water	60	47	78%	No	Some samples analyzed past allowable holding time, as discussed in Section 4.4.2.1.
pH – Raw Water	38	32	84%	No	pH measurements discarded from data set, as discussed in Section 4.4.3.
pH – Treated Water	38	30	79%	No	pH measurements discarded from data set, as discussed in Section 4.4.3.
pH – Backwash Waste	7	6	86%	Yes	
ORP – Raw and Treated Water	38	20	53%	No	ORP measurements discarded from data set, as discussed in Section 4.4.3, and ORP probe broke.
DO – Raw and Treated Water	38	33	87%	No	DO measurements discarded from data set, as discussed in Section 4.4.3.

Chapter 5
References

Standard Methods for the Examination of Water and Wastewater, 20th edition, APHA, AWWA, and WEF, Washington D.C. 1999.

U.S. EPA Drinking Water Methods for Chemical Parameters. EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

Chapter 6
Vendor Comments

I believe this report significantly contributes to the understating of an effective groundwater treatment technology and we are proud that our Chemiles is the first and the only Japanese drinking water treatment technology that conducted EPA's ETV testing.

The Chemiles is designed for simultaneously removing Iron, Arsenic, Manganese, and Ammonia in only one treatment column. In addition, the treatment process does not require any chemical injection; therefore it sharply reduces operation cost and eliminates the need of chemical storage and injection facilities. Filtration and backwash processes are automatically controlled and that makes it easier for operation and maintenance works.

As seen in the report, the Chemiles was effective for reduction of Iron, Arsenic to less than EPA secondary MCL level, and Ammonia to less than desired level of 0.1 mg/L. The reduction of Manganese to below EPA secondary MCL level took longer time than we expected. It was caused by the low pH of the site's raw water pH, which ~~was at~~ averaged 6.39, lower than our desired pH level of 6.5 to 8.0. And as stated in Section 4.2, the continuous operation of the system was affected by the UL Standard certification process, as well as repair and replacement of the treated water pump. During that time the system was randomly stopped and restarted and that caused the ripening period for Manganese-removal-effective bacteria to take longer ~~time~~ than our experiences.

However, with the data of the addition May 320-hour testing period, we could say that low pH of groundwater will require more time for Manganese ripening process but the system could reduce Manganese to below EPA secondary MCL without a need of pH adjustment.

pH adjustment could reduce Manganese even more below EPA secondary MCL level. However, if the groundwater contained DO, which is not common for deep well, (the groundwater used in this ETV Test contained 3.49 mg/L DO), part of Fe^{2+} was oxidized to Fe^{3+} before coming to the system. When a pH increasing reagent is injected into such groundwater, $Fe(OH)_3$ will be formed and it might cause leakage through the filter media. Therefore we suggest that the pH adjustment should ~~only~~ be an optional operation method only if raw water pH is too low, below 6.0.

Raw water qualities are different case by case and site by site. Based on raw water quality, Nagaoka can design and select optimum operating conditions of CHEMILES system in order to ensure that treated water qualities meet with requirements of the customer as well as with EPA's regulated level for drinking water.

I wish to express my sincerest thanks to all who made this ETV Test Project possible, including CH2M Hill, NSF, USEPA, Clark Public Utilities, and IPS Service. Your continued support over a long time project implementation helped us overcome many difficulties and make this ETV Test successful.

We hope our Chemiles system will contribute to an environmentally-friendly and economical solution for drinking water treatment.

Very sincerely,
Katsuhiko Yamada

Appendix A – Operation and Maintenance Manual

Provided upon request.