August 2001
NSF 01/27/EPADW395

Environmental Technology Verification Report

On-Site Water Purification and Inactivation of *E. coli* and MS-2 Virus in Raw Drinking Water

PentaPure H-3000-I Mobile Water Purification Station
PentaPure, Inc.

Prepared for

NSF International

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

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**MULTI-COMPONENT SYSTEM THAT INCLUDES AERATION/PRE-FILTRATION, DISINFECTION, AND POST-TREATMENT CARBON FILTRATION**
APPLICATION:	**WATER PURIFICATION AND MICROBIAL CONTAMINANT INACTIVATION IN DRINKING WATER**
TECHNOLOGY NAME:	**PENTAPURE H-3000-I**
COMPANY:	**PENTAPURE, INC.**
ADDRESS:	**150 MARIE AVENUE EAST WEST SAINT PAUL, MN 55118** PHONE: **(651) 450-4913** FAX: **(651) 450-5182**
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by substantially accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholders groups which consist of buyers, vendor organizations, 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 tests (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF) in cooperation with the EPA operates the Drinking Water Treatment Systems (DWTS) pilot, one of 12 technology areas under ETV. The DWTS pilot recently evaluated the performance of a stand-alone drinking water purification and disinfection system. This verification statement provides a summary of the test results for PentaPure's H-3000-I System. ARCADIS G & M, an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

The PentaPure H-3000 – I Water Purification Station is a complete on-site package treatment plant that treated an average flow rate of 45 gallons per minute (gpm). The verification test began on July 31, 2000 and ran, with several periods of downtime, until October 5, 2000. The cornerstone of PentaPure is the filtration unit that uses pentaiodide for microbial inactivation. The PentaPure H-300 consisted of a filtration component to remove solids in advance of a pentaiodide resin component for the inactivation of microorganisms. More operational difficulties were found with the filtration component than with the pentaiodide component which performed well throughout the study.

Average log removals of *Escherichia coli* with one pentaiodide resin tank in operation, and with two pentaiodide resin tanks in operation in parallel, were 6.9 and 6.3, respectively. For *MS-2* bacteriophage average log removal were 3.6 for one tank and 3.2 for the two-tank test. The difference in log removal results can be attributed to variability in influent and effluent microbe concentrations. The PentaPure unit was particularly effective in the removal of total coliforms with all treated water samples being below the detection limit of 20 CFU/100 mL.

Although the disinfected (semi-treated) water stream showed significant iodine concentrations, most of this iodine was removed again in the post disinfection carbon filters. The carbon filters were not as successful at removing iodide ions and the concentration of iodide ions in the treated water averaged 0.911 mg/L. Trace amounts of silver were detected in the treated water at an average level of 0.3 µg/L.

TECHNOLOGY DESCRIPTION

The PentaPure H-3000 – I Water Purification Station is a full on-site package treatment plant designed to treat an average flow rate of 50 gpm. The main components of the H-3000 – I that was provided for the test were: 1) diaphragm pump and coagulant dosage system, 2) Iron Curtain™ Pre-Filter System, 3) two Harmsco Hurricane™ centrifugal separators with 1 micron filter elements in parallel, 4) two fiberglass tanks in parallel with PentaPure® Formula 53 pentaiodide resin, supported on an underbedding of pea gravel, 5) two fiberglass tanks in parallel filled with coconut carbon and HyGene® brand Mark 4.3 silver-impregnated carbon. The key component of the station is the pentaiodide disinfection unit.

PentaPure disinfection resin is manufactured through a complex proprietary process. In short, polyiodide ions are bound to an anion exchange resin, creating a positively charged structure. According to the manufacturer, many waterborne pathogenic bacteria and viruses are associated with negatively charged particles. The filtering of particles through the disinfection resin prompts the release of iodine, which disinfects the water by deactivating microorganisms; when a contaminant comes into contact with the PentaPure resin bead, sufficient iodine is released to penetrate and kill associated microorganisms.

VERIFICATION TESTING DESCRIPTION

Test Site

The host site for this demonstration was the SJWD Water District Drinking Water Treatment Plant in Lyman, South Carolina, which draws water from the Middle Tyger River. The water is generally of good quality with a turbidity of less than 10 nephelometric turbidity units (NTU), hardness under 10 mg/l and TOC of approximately 2.5 mg/l. During storm events, the turbidity may rise significantly. Furthermore, the water is known to have coliforms with counts generally varying between 100 to 1,000 colony forming units (CFU) per 100 ml. Raw water was drawn at a rate of 50 gpm from a sump directly in contact with the Middle Tyger River.

US EPA ARCHIVE DOCUMENT

Methods and Procedures

The test was divided into three tasks: 1) equipment operation and disinfection production capabilities, 2) microbiological contaminant inactivation (challenge test), and 3) treated water quality.

Task 1 included the generation of data that describe the operation of the PentaPure H-3000 – I, including power consumption, potable water generation, the rate of water usage for backwashing, the rate of replacement of filter elements, the rate of coagulant usage and the required operations staff time. Also, a disinfection resin backwash sample was collected for analysis (including heavy metals) during the test period. Operation and maintenance issues were also evaluated during the testing period.

The objective of task 2 was to characterize the PentaPure H-3000 – I for its efficacy for inactivation of *Escherichia coli (E. coli)* bacterium and the Bacteriophage *MS-2* viral surrogate with two pentaiodide resin columns in operation in parallel, as well as with one pentaiodide resin column in operation. The task was split into bacterial and viral challenge sections. The initial part of Task 2 consisted of a tracer test with rhodamine dye to determine the hydraulic residence time.

The bacterial challenge tests were carried out using *E.coli*, *Migula* strain. The target concentration for *E. coli* in broth culture was 5 x 10^{10} colony forming units (CFU)/100 mL. During each challenge test, a peristaltic pump and autoclaved tubing was used to feed *E. coli* into the 50 gpm water stream leaving the prefiltration components of the H-3000-I and entering the pentaiodide resin beds, at a rate calculated to produce an *E. coli* concentration in the contact tanks of 1 x 10^6 cells/mL. Samples were collected at 5-minute intervals. These samples were submitted to Environmental Health Laboratories for *E. coli* enumeration by Standard Methods 9213 D *E. coli* membrane filtration procedure.

The viral challenge tests were carried out using the MS-2 bacteriophage. The target MS-2 concentration for the bacteriophage growth broth was 1 x 10^{11} plaque forming units (PFU)/mL. The samples were collected at 5-minute increments and submitted to BioVir Laboratories for phage enumeration by USEPA Method 1601 (modified for MS-2).

The objective of the third task was to assess the impact that treatment using the PentaPure H-3000 – I has on treated water quality. Samples were preserved, stored, shipped and analyzed in accordance with appropriate procedures and hold times, as specified by the analytical methods. Water quality parameters that were monitored during the test period include: pH, temperature, turbidity, hydrogen sulfide, alkalinity, total dissolved solids (TDS), ammonia nitrogen, total organic carbon (TOC), ultraviolet absorbance (UVA) at 254 nanometer (nm), true color, iron, manganese, bromide, chloride, sodium, silver, iodide, and iodine. In addition, total coliforms, and heterotrophic plate count (HPC) bacteria were enumerated five times per week. A metals scan as a one-time event was performed on the waste stream. Also, feed and treated total trihalomethane (TTHMs) and haloacetic acid (HAAs) sampling was conducted. Analytical samples were collected from various locations within the overall treatment system.

VERIFICATION OF PERFORMANCE

Operation and Maintenance

The PentaPure H-3000 - I system was initially installed on March 16 and 17, 2000. The system commenced verification testing two times. The first test run commenced in late April 2000 and was terminated on May 26, 2000 after it was determined that the pentaiodide resin beds had been prematurely fouled due to high turbidity levels caused by insufficient pretreatment. For the second test, the unit was modified with the addition of a coagulation unit. The second test began on July 31, 2000 and ran, with several periods of downtime, until October 5, 2000.

The cornerstone of PentaPure is the pentaiodide technology. The pentaiodide component operated well from an O&M standpoint and most operational difficulties were found in the pretreatment filtration system that consisted of non-PentaPure components. ARCADIS and site operations staff found the separate instructions provided by PentaPure adequate in addressing routine operation and maintenance issues pertaining to system components.

Consumables expended by the PentaPure H-3000 – I system during the 31 days of verification testing included electrical power, coagulant and Harmsco filter elements. Ten filter elements were used over the 31-day verification test. Initially, the coagulant dosing system was set up to deliver about 70 mL of solution per minute, but the coagulant delivery rate was lowered incrementally to about 40 mL/min toward the latter stages of the verification test interval. Optimization of coagulant dose will minimize the filter element replacement frequency and result in lower operating and maintenance costs. Operator staff time required for routine monitoring of the system was estimated at about 1 hour per day. Per gallon of treated water, the power consumption was approximately 1.31 Watthour.

Microbiological Contaminant Inactivation

ARCADIS performed both bacterial and viral challenge tests on the PentaPure H-3000-I to assess its disinfection capabilities. *E. coli* served as the bacterial challenge test microorganism and the *MS-2* bacteriophage was used as the viral challenge test microorganism. Bacterial and viral challenge test microorganisms were used to assess the disinfection capabilities of the PentaPure H-3000-I with both one and two pentaiodide resin tanks in operation. For all challenge testing, treated samples were collected at five minute intervals.

Prior to the inactivation tests, the hydrodynamic tracer test was conducted. Since the PentaPure H-3000 – I does not rely on a concentration-contact time (CT) relationship for facilitating microbial deactivation, the results of this tracer test were primarily to determine whether the proposed challenge testing sampling schedule was appropriate.

The average log removal of *E.coli* with one pentaiodide resin tank, and with two pentaiodide resin beds in operation was 6.9 and 6.3, respectively. The *MS-2* enumeration of the treated samples from the one-tank test ranged from 1.5×10^2 PFU/mL to 4.4×10^7 PFU/mL, whereas the average concentration of the feed water was 1.6×10^8 PFU/mL. The average of this range is 4.3×10^4 PFU/mL and resulted in a log removal of 3.6. Log removal for the two tank test was 3.2. Considerable variability in the *MS-2* concentrations in the disinfected water was seen in both the one and two pentaiodide resin tank viral challenge tests. The one pentaiodide resin tank test resulted in *MS-2* enumerations spanning seven orders of magnitude. The two pentaiodide resin tank test resulted in *MS-2* enumerations spanning six orders of magnitude.

Treated Water Quality

In the PentaPure H-3000-I system, the iodine concentration in the disinfected (before carbon filtration) water increased from 0.019 mg/L to 1.549 mg/L. However, nearly all of this iodine was removed again in the post disinfection carbon filters. The final iodine concentration in the treated water was 0.020 mg/L. The carbon filters were not as successful at removing iodide ions and the concentration the iodide ions in the treated water was 0.911 mg/L compared to an influent iodide concentration of 0.019 mg/L.

Turbidity of the raw river water was effectively reduced by the coagulation/filtration steps. Average raw water turbidity was 13.93 NTU with a maximum value of 78.3 NTU. Average pre-filtered (post-coagulation) turbidity was 1.19 NTU.

As part of daily routine analysis, total coliforms were monitored and heterotrophic plate counts (HPC) were conducted for raw and treated water. The PentaPure unit was particularly effective in the removal of total coliforms with all treated water samples being below the detection limit of 20 CFU/100 mL. Using the value of 20, the log removal rate for total coliforms was at least 1.6. The log removal rate for HPC organisms was 1.5.

The PentaPure H-3000-I performed well in removing aluminum and performance was fair for removal of manganese. All measured aluminum and manganese concentrations in the treated water were below 11 and 100 µg/L respectively. Also, iron was removed effectively by the unit, from an average of 1.5 mg/L in the raw water down to an average of 0.3 mg/L in treated water. Trace amounts of silver were detected in the treated water at an average level of 0.3 µg/L. In addition, single samples were taken to analyze metals concentration in the disinfection column backwash. Barium and copper were detected in the backwash stream at concentrations of 13 and 6.3 µg/L respectively as well as trace amounts of arsenic, chromium, nickel, thallium, and zinc.

Original Signed by
E. Timothy Oppelt *08/31/01*

E. Timothy Oppelt Date
Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Original Signed by
Gordon Bellen *09/05/01*

Gordon Bellen Date
Vice President
Federal Programs
NSF International

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

Availability of Supporting Documents
Copies of the *ETV Protocol for Equipment Verification Testing for Inactivation of Microbiological Contaminant* dated August 1999, the Verification Statement, and the Verification Report (NSF Report # 01/27/EPADW395) are available from the following sources:
(NOTE: Appendices are not included in the Verification Report. Appendices are available from NSF upon request.)

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

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On-Site Water Purification and Inactivation of *E. coli* and MS-2 Virus in Raw Drinking Water

PentaPure H-3000-I Mobile Water Purification Station
PentaPure, Inc.

Prepared for:

NSF International
Ann Arbor, Michigan 48105

Prepared by:

ARCADIS Geraghty and Miller, Inc.
4915 Prospectus Drive, Suite F
Durham, North Carolina 27713

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

Jeffrey Q. Adams, Project Officer
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Notice

The U.S. Environmental Protection Agency (EPA) through its Office of Research and Development has financially supported and collaborated with NSF International (NSF) under Cooperative Agreement No. CR 824815. This verification effort was supported by Drinking Water Treatment Systems Pilot operating under the Environmental Technology Verification (ETV) Program. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release.

Foreword

The following is the final report on an Environmental Technology Verification (ETV) test performed for the NSF International (NSF) and the United States Environmental Protection Agency (EPA) by ARCADIS Geraghty and Miller (ARCADIS), in cooperation with PentaPure, Inc. The test was conducted during August and September 2000 at SJWD Drinking Water Plant in Lyman, South Carolina.

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

EPA has partnered with NSF, an independent, not-for-profit testing and certification organization dedicated to public health, safety and protection of the environment, to verify performance of small drinking water systems that serve small communities under the Drinking Water Treatment Systems (DWTS) ETV Pilot Project. 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 will meet this goal by working with manufacturers and NSF-qualified Field Testing Organizations (FTO), in this case ARCADIS, to conduct verification testing under the approved protocols.

The ETV DWTS is being conducted by NSF with participation of manufacturers, under the sponsorship of the EPA Office of Research and Development, National Risk Management Research Laboratory (NRMRL), Water Supply and Water Resources Division, Cincinnati, Ohio. It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF or "accepted" by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations for those conditions tested by the FTO.

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Abbreviations and Acronyms

A	Ampères
AC	Alternating Current
ATCC	American Type Culture Collection
ARCADIS	ARCADIS G & M
CT	Concentration Time
CFU	Colony Forming Units
DBP	Disinfection By-Product
DC	Direct Current
DQA	Data Quality Audit
DQI	Data Quality Indicator
DWTS	Drinking Water Treatment System
ETV	Environmental Technology Verification
FOD	Field Operations Document
FRP	Fiberglass Reinforced Plastic
ft	Feet
FTO	Field Test Organization
gpm	Gallons Per Minute
HAAs	Haloacetic Acids
HPC	Heterotrophic Plate Count
HRT	Hydraulic Retention Time
Hz	Hertz
IC	Ion Chromatography
ICP	Inductively Coupled Plasma
kg	Kilogram
kWh	Kilowatt-Hour
L	Liter
lb	Pound
LCS	Laboratory Control Spike
LCSD	Laboratory Control Spike Duplicate
mg/l	Milligrams Per Liter
mL	Milliliter
MS/MSD	Matrix Spike/Matrix Spike Duplicate
NSF	NSF International, formerly known as the National Sanitation Foundation
NTU	Nephelometric Turbidity Units
OIT	Operator Interface Terminal
OSHA	Occupational Safety & Health Administration
pH	Minus Log Hydrogen Concentration
PEA	Performance Evaluation Audit
PE(S)	Performance Evaluation (Sample)
PFU	Plaque forming units
PLC	Programmable Logic Controller
ppm	Parts Per Million
psi	Pounds Per Square Inch
Pt/Co	Referring to the ratio of platinum to cobalt in a visual color standard
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance, Quality Control

RMP	Risk Management Plan
RMS	Root Mean Square
RSD	Relative Standard Deviation
SDS	Simulated Distribution System
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TSA	Technical System Audit
TTHMs	Total Trihalomethanes
U.S. EPA	United States Environmental Protection Agency
UVA	Ultraviolet Absorbance

ACKNOWLEDGMENTS

The Field Testing Organization, ARCADIS, was responsible for all elements in the testing sequence, including collection of samples, calibration and verification of instruments, data collection and analysis, data management, data interpretation and the preparation of this report.

ARCADIS Geraghty and Miller, Inc.
4915 Prospectus Drive, Suite F, Durham NC 27713
Contact Person: Michiel Doorn

The laboratories selected for microbiological analysis and non-microbiological analytical work for this verification project were:

Environmental Health Laboratories
110 S. Hill Street, South Bend, IN 46617
Contact Person: Paul Bowers

BioVir
685 Stone Road
Benicia, CA 94510

The laboratory used for the tracer test was:

Crawford and Associates, Inc.
1136 US 31W By-Pass
Bowling Green, KY 42101

The Manufacturer of the Equipment was:

PentaPure, Inc.
150 Marie Avenue East.
West Saint Paul, MN 55118
Contact Person: Mr. David Botts

ARCADIS wishes to thank the staff of the SJWD Drinking Water Purification Plant in Lyman, South Carolina and Mr. Doug Waldrop for all of the cooperation and practical advice they provided during the test.

Chapter 1
Introduction

1.1 ETV Purpose and Program Operation

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

ETV works in partnership with recognized standards and testing organizations; stakeholders groups which consist 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 (as appropriate) tests, collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International in cooperation with the EPA operates the DWTS pilot, one of 12 technology areas under ETV. The DWTS pilot evaluated the performance of PentaPure's H-3000-I system, which is a water purification and microbial contamination inactivation system for drinking water. The ETV test evaluated the PentaPure H-3000 – I Mobile Water Purification Station's ability to inactivate *Escherichia coli* and a viral surrogate, the MS-2 bacteriophage (*MS-2*), at a flow rate of 50 gallons per minute (gpm) through the full system (with two pentaiodide resin columns in parallel on-line) as well as with only one pentaiodide resin column on-line, treating a feed water source with a pH between 6 and 8, iron content less than 15 ppm, and manganese content less than 5 ppm.

1.2 Testing Participants and Responsibilities

The ETV testing of the PentaPure H-3000-I System was a cooperative effort between the following participants:

NSF International
ARCADIS Geraghty and Miller, Inc.
PentaPure, Inc.
SJWD Drinking Water Purification Plant
U.S. Environmental Protection Agency

The following is a brief description of each ETV participant and their roles and responsibilities.

1.2.1 NSF International

NSF is a not-for-profit testing and certification organization dedicated to public health safety and 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 the NSF to verify the performance of drinking water treatment systems through the EPA's ETV Program.

NSF provided technical oversight of the verification testing and conducted an audit of the field analytical and data gathering and recording procedures. NSF also provided review of the Field Operations Document (FOD) and this report.

Contact Information:

NSF International
789 N. Dixboro Rd.
Ann Arbor, MI 48105
Phone: (734) 769-8010 Fax: (734) 769-0109
Contact: Bruce Bartley, Project Manager
Email: bartley@nsf.org

1.2.2 Field Testing Organization

ARCADIS, an infrastructure and environmental engineering consulting firm, conducted the verification testing of the PentaPure H-3000-I System. ARCADIS is an NSF-qualified Field Testing Organization (FTO) for the ETV DWTS pilot project.

The FTO was responsible for conducting the verification testing for 30 calendar days. The FTO provided all needed logistical support, established a communications network, and scheduled and coordinated activities of all participants. The FTO was responsible for ensuring that the testing location and feed water conditions were such that the verification testing could meet its stated objectives. The FTO prepared the FOD, oversaw the pilot testing, managed, evaluated, interpreted and reported on the data generated by the testing, as well as evaluated and reported on the performance of the technology.

FTO employees conducted the on-site analyses and data recording during the testing. Oversight of the daily tests was provided by the FTO's Project Manager.

Contact Information:

ARCADIS G & M, Inc.
4915 Prospectus Drive, Suite F, Durham, NC 27713
Contact Person: Michiel Doorn
Phone: (919) 544-4535 Fax: (919) 544-5690
Email: mdoorn@arcadis-us.com

1.2.3 Manufacturer

The water purification station is manufactured by PentaPure, Inc. West Saint Paul, MN. The manufacturer was responsible for supplying a field-ready H-3000-I station equipped with all necessary components including treatment equipment, instrumentation and controls, as well as an operations and maintenance manual. The manufacturer was also responsible for providing logistical and technical support as needed as well as providing technical assistance to the FTO during operation and monitoring of the equipment undergoing field verification testing.

Contact Information:

PentaPure, Inc.
150 Marie Avenue East, West Saint Paul, MN 55118
Contact Person: Mr. David Botts
Phone: (651) 450-4913 Fax: (651) 450-5182
Email: dbotts@pentapure.com

1.2.4 Analytical Laboratories

Iodine, iodide, temperature, pH, TDS, turbidity, alkalinity, hydrogen sulfide analyses, as well as coliforms and HPC counts were conducted onsite in the laboratory of SJWD:

SJWD Water District
161 Groce Road, Lyman, South Carolina 29365
Contact Person: Mr. Doug Waldrop
Phone: (864) 949-2520

The SJWD onsite laboratory is certified by the state of South Carolina to perform selected drinking water analyses (Certificate No. 42012001).

Offsite chemical analyses and *E. coli* challenge testing enumerations were performed by:

Environmental Health Laboratories
110 Hill St., South Bend, Indiana 46617
Contact Person: Paul Bowers
Phone: (219) 233-4777 Fax: (219) 233-8207

EHL has been issued a certificate by the State of South Carolina to perform selected drinking water analyses (Certification No. 95005001).

MS-2 enumeration for the viral challenge testing was performed by:

BioVir Laboratories
685 Stone Road
Benicia, CA 94510
Phone: (800) 442-7342 Fax: (707) 747-1751

Analyses associated with the tracer test were performed by:

Crawford and Associates, Inc.
1136 US 31W By-Pass
Bowling Green, KY 42101

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. CR 824815. The Drinking Water Treatment Systems Pilot operating under the ETV Program supported this verification effort. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release.

1.3 Verification Testing Site

The host site for this demonstration was the SJWD Water District Drinking Water Treatment Plant in Lyman, South Carolina. The SJWD Water District Drinking Water Treatment Plant draws water from the Middle Tyger River. The Middle Tyger River is identified as watershed 03050107-040 and is located in Greenville and Spartanburg Counties. The watershed occupies 64,948 acres of the Piedmont region of South Carolina. Land use/land cover in the watershed includes: 9.02 percent urban land, 23.85 percent agricultural land, 0.77 percent scrub/shrub land, 1.08 percent barren land, 64.32 percent forested land, and 0.95 percent water. There are several ponds and lakes (ranging between 16-500 acres) in this watershed used for recreation, industrial, municipal and irrigation purposes. There are a total of 120.3 stream miles in the Middle Tyger River.

At the SJWD Drinking Water Treatment Plant, Middle Tyger River water is withdrawn into a flash mixer where caustic, alum and free chlorine are added. Next the water moves through 4-stage flocculators and into sedimentation basins. Following the sedimentation basins, the water being processed goes through dual media sand/anthracite filters into a clearwell where addition of caustic, phosphate, and occasionally free chlorine takes place. The clearwell effluent goes into a storage reservoir prior to being distributed to the public. The SJWD plant has a capacity of 6 million gallons per day (mgd).

1.3.1 Source Water

Water used for the verification testing at the SJWD plant was raw water drawn directly from the Middle Tyger River. Upstream of the plant is a reservoir that is used to regulate water levels in the river. During times of draught, the reservoir levels may fall significantly and in extreme cases the water may have high amounts of manganese and cadmium in it, which had been stored in the reservoir sediments. During storm events, the turbidity of the water can go up to several hundred nephelometric turbidity units (NTU). The maximum turbidity registered during the verification period was 78 NTU. Typically, the turbidity is around 10 NTU or lower. A summary of feed water quality measured during the verification testing period is presented in Table 1-1 below.

Table 1-1. Average Feed Water Quality During ETV Test Period

Analyte	Units	Average	St. Dev.	Sample size	Minimum	Maximum	95% C. Int. Minimum	95% C. Int. Maximum
pH		7.05	0.21	30	6.17	7.41	6.97	7.13
Temperature	C	23	2	29	18	27	22	24
Turbidity (grab)	NTU	13.93	17.25	31	4.86	78.3	7.86	20.00
Total Coliforms	#/100 mL	840	677	25	<20	3,100	556	1,098
HPC	#/mL	1,926	1,517	23	124	7,020	1,306	2,546
H_2S	µg/l	1.4	n/a	3	<0.1	4	n/a	n/a
Alkalinity	mg/l	21	7	6	15	33	15	26
TDS*	mg/l	64	n/a	1	n/a	n/a	n/a	n/a
TOC	mg/l	2.2	n/a	1	n/a	n/a	n/a	n/a
Aluminum	µg/l	660	675	3	79	1,400	0	1,423
Manganese	µg/l	118	13	5	101	130	107	129
Iron	mg/l	1.5	1.1	5	<0.1	2.8	0.5	2.5
Sodium	mg/l	1.7	n/a	1	n/a	n/a	n/a	n/a
Ammonia Nitrogen	mg/l	<0.3	n/a	4	<0.3	<0.3	n/a	n/a
UVA (UV 254)	1/cm	0.028	0.005	4	0.022	0.034	0.023	0.033
Chloride	mg/l	3.4	n/a	1	n/a	n/a	n/a	n/a
Bromide	µg/l	27	n/a	1	n/a	n/a	n/a	n/a
Iodine	mg/l	0.019	0.041	31	0	0.220	0.004	0.033
Iodide	mg/l	0.019	0.038	30	0.000	0.199	0.006	0.033

n/a = Not applicable because the sample size is two or less
* Two suspect, outlying raw water TDS values

Aquatic life uses are fully supported upstream based on the macroinvertebrate community, but may be threatened by a significantly increasing trend in turbidity, occurrences of zinc, and a very high concentration of cadmium measured in sediment. Aquatic life uses are fully supported midstream but may be threatened by a significantly decreasing trend in pH. Aquatic life uses are fully supported downstream based on physical, chemical and macroinvertebrate community data. Recreational uses are not supported at any site due to fecal coliform bacteria excursions and there is a significantly increasing trend in fecal coliform bacteria concentration.

1.3.2 Pilot Effluent Discharge

The effluent of the pilot treatment unit was disposed through a two-inch pipe to a nearby manhole that ultimately drained into the alum sludge holding pond of the SJWD plant. Because the effluent did not leave the jurisdiction of the SJWD plant, no discharge permit was required.

Chapter 2
Equipment Description and Operating Processes

The PentaPure H-3000 – I Water Purification Station is a complete on-site package treatment plant for drinking water. This unit is capable of treating an average flow rate of 50 gpm or 72,000 gallons per day, so it would be best suited for small developments, businesses, or small industrial sites. The system is built on four skids and includes all of the essential unit processes to render appropriate source waters potable (see Figure 2-1). Though PentaPure has independently utilized all of the technology associated with the unit processes featured in this system, the H-3000 – I Water Purification System represents their first system to combine the processes. The system has not been widely used to date. It is designed to be robust and portable, either by commercial conveyance or by means of a custom trailer system. The system requires a source of 230 and 110-volt power to operate. Each of the four skids weighs approximately 2,000 pounds. Consumables for this system are electricity, Hurricane™ filter elements, PentaPure® pentaiodide resin, granular activated carbon, coagulant (as/if required), and feed water for backwashing.

Figure 2-1. PentaPure H-3000 – I Water Purification Station at ETV-test site

To properly test the PentaPure® H-3000 – I Mobile Water Purification Station without interfering with the existing operations of the SJWD facility, a parallel treatment system was established for the purposes of this verification program. The system was fed by a pump that draws from an existing intake sump on the Middle Tyger River. This pump had a minimum capacity of 50 gpm at the total dynamic head required. After treatment by the H-3000 – I, the treated water was discharged to the SJWD alum sludge holding pond. Backwash and backflush water was also discharged to the alum sludge holding pond. Waste production from this system consists of a stream concentrated with the solid contaminants found in the feed water plus a one to eight part per million (ppm) iodine residual depending on water conditions. According to the manufacturer, the spent iodinated resin, spent Hurricane™ filter elements, and spent filter and carbon media are safe for landfill disposal.

The PentaPure H-3000 – I Mobile Water Purification Station that was provided for the test consisted of the following treatment train:

- 100' of 3" flexible suction hose with inlet strainer and check valve
- One (1) 5 hp pump
- Diaphragm pump and coagulant dosage system
- Iron Curtain™ Pre-Filter System consisting of one (1) 48" diameter by 72" tall aeration tank with remote control center and air compressor and three (3) 36" diameter by 72" tall fiberglass tanks plumbed in parallel and filled with multiple layers of Hellenbrand™ depth filtration media, each with 2" time clock controlled backwash valves (see Figure 2-2)
- Two (2) 20" Harmsco Hurricane™ centrifugal separators with 1 micron filter elements in parallel
- Two (2) 36" diameter by 72" tall fiberglass tanks plumbed in parallel and filled with 100 liters each of PentaPure® Formula 53 pentaiodide resin, supported on an underbedding of pea gravel, and each with 2" time clock controlled backwash valves
- Two (2) 36" diameter by 72" tall fiberglass tanks plumbed in parallel and filled with 8 cubic feet each of a blend of 12 x 30 acid washed coconut carbon and HyGene® brand Mark 4.3 silver impregnated carbon, supported on an underbedding of pea gravel, each with 2" time clock controlled backwash valves
- 100' – 3" flexible outlet tubing

In addition, there were two (2) 2" flow meters serving the waste and potable water lines; one (1) 50 gpm outlet flow controller; as well as four (4) pressure gauges to evaluate the head loss across the filtration components. Also, a small, valved tap was provided between the aeration/pre-filtration stage and the disinfection stage for challenge test organism introduction for the disinfection stage. Sample collection taps were provided to sample the combined feed to or combined effluent from in-parallel treatment units (see Figure 2-2). Sampling taps were located at:

- The feed water line (i.e., between the feed pump and the aeration/pre-filtration stage)

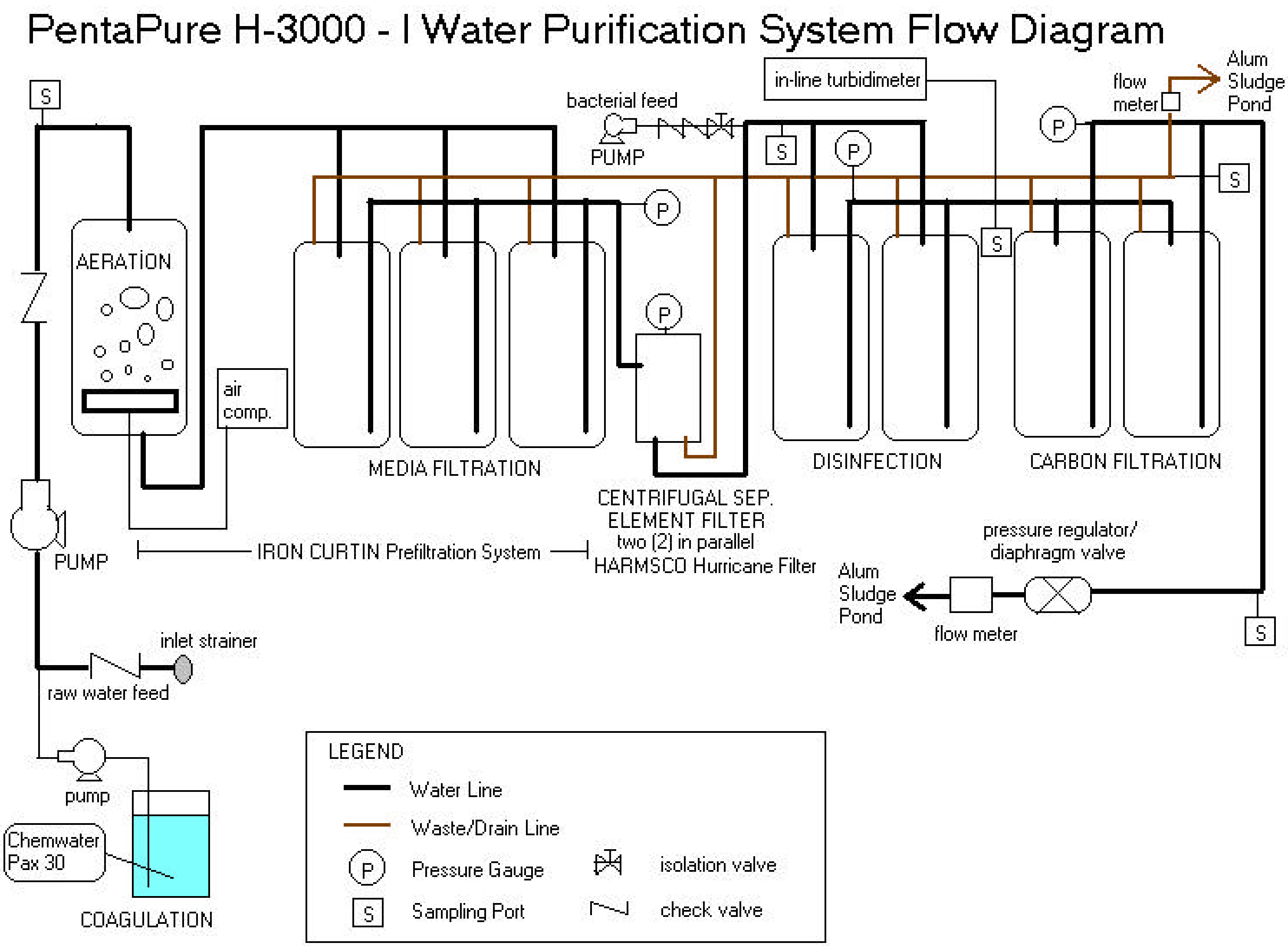

Figure 2-2. Flow Diagram PentaPure

- Between the aeration/pre-filtration stage and the disinfection stage of the system (to sample the oxidized/filtered water and the feed for the disinfection stage)
- At the discharge of the disinfection stage before the disinfected water proceeds on for further treatment in the adsorptive filtration stage
- After the adsorptive filtration stage for sampling the fully treated water
- On the common drain line from unit backwash and backflush pipes for sampling wastewater.

2.1 Process Stages

The PentaPure H-3000 – I Mobile Water Purification Station incorporated four process stages (see Figure 2-2). These stages included:

- Coagulant dosage
- Aeration/pre-filtration stage to oxidize dissolved iron and manganese causing them to precipitate out of solution and be reduced along with suspended solids down to 1 micron in size
- Disinfection stage to deactivate pathogenic bacteria and viruses
- Adsorptive and absorptive filtration stage to reduce chemical, organic and taste and odor contamination.

The first process in the PentaPure H-3000 – I Mobile Water Purification Station consisted of coagulant dosage. A diaphragm pump was used to deliver a polyaluminum chloride coagulant, Chemwater PAX 30, to the raw water suction line, just before the pump, at a field-optimized rate sufficient for an approximately 20 ppm dosage. The coagulant and target dosage were selected based on jar testing, using the source water and glass fiber filtration, which showed a reduction in turbidity from approximately 10 NTU in the raw water to less than 0.5 NTU in the filtered water.

The PentaPure H-3000 – I Mobile Water Purification Station utilized a combination of aeration and multi-media depth filters (Hellenbrand™ Iron Curtain technology), consisting of engineered layers of various sized sand, gravel and garnet media to achieve a top-to-bottom, largest-to-smallest particle filtration media bed, to reduce dissolved and suspended iron, manganese and solids down to approximately 10 microns in size. The water then entered a combination centrifugal separator/pleated element filter (Harmsco Hurricane™ filter), which, for the verification test, had an absolute filtration capacity of 1 micron (various filter elements are available in a range of effective filtration sizes). This pre-treatment stage served to reduce suspended solids including protozoan cysts down to 1 micron in size.

From the pre-filtration stage, the water then flowed through a bed of PentaPure pentaiodide resin beads. PentaPure disinfection resin is manufactured through a complex proprietary process. In short, polyiodide ions are bound to an anion exchange resin, creating a positively charged structure. According to the manufacturer, this material is a solid phase disinfectant that operates as a demand-release material that deactivates bacteria and viruses through an electrostatic transfer of iodine into the organisms. It consists of 20–50 mesh of polystyrene, divinylbenzene, quaternary ammonium anion exchange resin beads which have been impregnated through a proprietary process with pentaiodide molecules. The manufacturer summarizes the process as follows: the filtering of particles through the disinfection resin prompts the release of iodine, which disinfects the water by deactivating microorganisms; when a contaminant comes into contact with the PentaPure resin bead, iodine is released to penetrate and kill associated microorganisms.

After the disinfection step, the water traveled through a bed, which consisted of a proprietary blend of 12 x 30-mesh acid washed activated carbon and 12 x 30 mesh silver-impregnated activated carbon. This material is intended to reduce chemical, organic, taste, and odor contaminants through both adsorption and absorption processes which occur on the surface or within the pore structure of the carbon. This proprietary blend also acts to absorb excess iodine produced by the disinfection stage through iodine absorption. According to the manufacturer, any iodides that are formed are bound within the pore structure of the carbon granules through a reduction oxidation reaction between the iodide and the silver, which forms a non-soluble silver-iodide compound.

Backflushing of the aeration tanks and backwashing of the sand filters, pentaiodide resin columns and carbon filters occurred periodically, based on operator-set timers. The timers (one per filter and aeration tank) opened a solenoid-actuated valve, which redirected a portion of the feed water countercurrent through the filter bed or aeration tank. The design backwash flow is 50 gpm per filter and the typical backwashing time is about 30 minutes. The PentaPure unit featured an outlet control valve to limit the flow of the treated water to no more than 50 gpm and all the automatic valves were interlocked, so that when one tank is backwashing, the output flow of treated water is shut off.

Chapter 3
Methods and Procedures

3.1 General Progress

The test was divided into three tasks, each of which is detailed below.

- Task 1 - Equipment operation and disinfection production capabilities
- Task 2 - Microbiological contaminant inactivation (challenge test)
- Task 3 - Treated water quality

In addition, operation and maintenance aspects were evaluated during the ETV test period.

3.1.1 Equipment Operation and Disinfection Production Capabilities (Task 1)

The objectives of Task 1 included the generation of data that describe the operation of the PentaPure H-3000 – I, which were then used to develop an economic assessment of operational costs during the reporting phase of the project. Task 1 involved the collection and recording of data for the entire 30-day verification interval (in reality, 31 days of such data were collected during the verification test of record).

The data generated by the operation of the PentaPure H-3000 – I included the rate of consumption of power, the rate of generation of potable water, the rate of water usage for backwashing, the rate of replacement of filter elements, the rate of coagulant usage and the required operations staff time. Additionally, the aggregate horsepower of the motors in the PentaPure H-3000 – I system was compiled to generate estimates of maximum power requirements. The potable water and wastewater flow rates were recorded twice per day. These recorded flow measurements were used to calculate the total number of gallons that the PentaPure H-3000 – I treated during the verification program. A disinfection resin backwash sample was collected for analysis (including heavy metals) during the test period.

A kilowatt-hour meter was used to measure the PentaPure H-3000 – I power consumption during the verification interval. Totalized power consumption was recorded daily. Water flow was determined by reading the effluent flow meter. Likewise, backwash and back flush water flow were measured using a flow meter. During the start-up and shakedown interval, SJWD personnel were trained in how to properly read the various instruments.

Total operational costs were estimated by adding the separate costs associated with operator labor, filter element replacement, coagulant usage, and power usage.

3.1.2 Operation and Maintenance

Operation and maintenance issues were also evaluated during the testing period. O&M issues were generally discussed with PentaPure, and the O&M manual was periodically consulted by the operators. The system tested generally operates automatically, with operator intervention required only for monitoring, maintenance and in case of malfunction. Comments and observations regarding O&M were recorded in the on-site field logbook and logging sheets (Appendix B) and are discussed in detail in Chapter 4.

In-line equipment is listed below. Please also refer to the process diagram in Figure 2-2.

1. Two-inch backwash/waste water flow meter
2. 50 gallon per minute flow controller
3. Five sample ports
4. Watt meter
5. Various pipe fittings and valves
6. In-line turbidimeter (Hach 1720D with AquaTrend interface)
7. PentaPure H-3000 – I treatment train, as described in Chapter 2.

Except for pipe and fittings, items 1 through 6 were items required only for verification testing and thus would not typically require maintenance during regular operation. ARCADIS inspected these items regularly and repaired/maintained them as necessary.

The Hach turbidimeter requires no operational actions once it has been installed, calibrated, and started up. ARCADIS personnel visually inspected the instrument regularly. Though the readings were steady and reasonable, the in-line turbidity measurements generally did not correspond well to the grab turbidity readings. This discrepancy was determined to be in part the result of air bubble entrainment in the samples which passed through the in-line turbidimeter. As such, grab sample measurements of turbidity should be considered more representative.

The PentaPure H-3000 – I and all of its parts typically operate automatically. Periodic maintenance is required to keep the components operating properly.

3.2 Task 2: Microbiological Contaminant Inactivation

The objective of this task was to characterize the PentaPure H-3000 – I for its efficacy for inactivation of *E. coli* bacterium and the Bacteriophage *MS-2* viral surrogate. The task was split into bacterial and viral challenge sections.

Between challenge tests, the disinfection stage of the equipment was sanitized by manually initiating a backwash cycle and then flushing the unit by running it for one hour with feed river water under regular disinfection operation. Regrowth of bacteria or bacteriophage in piping or hardware between challenge tests was not a problem since all tests were conducted in a single day.

3.2.1 Tracer Test

Tracer testing for the PentaPure pentaiodide resin bed was conducted on May 2, 2000. Forty-five (45) mL (which, at 1 mg/l strength, is approximately 45 µg) of the tracer, Rhodamine dye (an organic dye), was slug-dosed via syringe through the challenge test organism dosing port.

Disinfection chamber (resin bed) effluent samples were taken at periodic intervals over about 30 minutes after dosing. Note that the system was operated at the standard flow rate of 50 gpm with only one of the two disinfection beds valved to be in service. Ten (10) mL grab samples of the feed background, stock solution, and effluent were sent to Crawford and Associates (the tracer supplier) for analysis.

3.2.2 Bacterial Challenge Testing

The objective of this sub-task was to verify the PentaPure® H-3000 – I Mobile Water Purification Station's ability to kill *E. coli* at a flow rate of 50 gpm with two pentaiodide resin columns in operation in parallel, as well as with one pentaiodide resin column in operation, treating a feed water source with a pH between 6 and 8, iron content less than 15 ppm, and manganese content less than 5 ppm.

ARCADIS conducted the two bacterial challenge tests to permit the evaluation of the equipment at two separate pentaiodide resin retention times. Differing pentaiodide resin retention times were achieved by first running a bacterial challenge test under normal operating conditions with the 50 gpm water flow being split between two resin beds. Secondly, the 50 gpm flow was channeled through one resin bed thus reducing the contact time for disinfection in half.

The bacterial challenge tests were carried out using *Escherichia coli* (*E. coli*), *Migula* strain. *Migula* is described as a non-motile strain of *E. coli* with a primary application of testing disinfectants. Its American Type Culture Collection (ATCC) number is 26. The target concentration for *E. coli* in broth culture was 5 x 10^{10} cells/100 mL. Approximately 5 gallons of this cell suspension was shipped to the SJWD Water Treatment Plant on ice to arrive the day of the test. The broth was subsampled to create a trip control that remained on ice during the bacterial challenge-testing interval and was returned with the post-treatment samples.

During each challenge test, a peristaltic pump and autoclaved tubing was used to feed *E. coli* into the 50 gpm water stream, leaving the prefiltration components of the H-3000-I and entering the pentaiodide resin beds, at a rate calculated to produce an *E. coli* concentration in the contact tanks of 1 x 10^6 cells/mL. The pump flow rate was confirmed using a graduated cylinder and stopwatch. *E. coli* was fed to the disinfection stage continuously over the entire duration of each 50-minute challenge test. A total of three positive control samples and one duplicate positive control sample were collected at 5-minute intervals beginning at 10 minutes of elapsed time. A total of 5 treated samples and one duplicate, treated sample for *E. coli* enumeration were collected at 5-minute intervals beginning at 25 minutes and ending at 50 minutes. These samples were submitted to Environmental Health Laboratories for *E. coli* enumeration by Standard Method 9213 D, Standard Total Coliform Membrane Filter Procedure. *E. coli* was also quantified in the medium provided by EHL both before and after the test and in the raw river water before and after the test. Total coliform counts in the feed and treated water were monitored regularly, as required. The above test plan was applicable to both challenge tests (i.e., with one resin bed in service as well as with two resin beds in service). Log removals of *E. coli* were calculated per the following equation:

$$\text{log removal of bacteria} = \log_{10}\left[\frac{\left(CFU/_{100ml}\right)_{feedwater}}{\left(CFU/_{100ml}\right)_{effluent}}\right]$$

During the bacterial challenge tests, predisinfection control samples were collected from a ball valve sampling port after the Harmsco filters and an in-line mixer and before the pentaiodide resin tanks. Post disinfection samples were collected from a second ball valve sampling port located in the pentaiodide resin tank effluent piping. When collecting a sample, the ball valve was opened and the line was allowed to flush for 15 to 30 seconds prior to actual sample collection.

3.2.3 Viral Challenge Testing

The objective of this subtask was to assess the efficacy of the PentaPure® H-3000 – I Mobile Water Purification Station to kill *MS-2* bacteriophage (MS-2) at a flow rate of 50 gpm with two pentaiodide resin columns in operation in parallel and with one pentaiodide resin column in operation, treating a feed water source with a pH between 6 and 8, iron content less than 15 ppm, and manganese content less than 5 ppm.

As requested by PentaPure, ARCADIS conducted two viral challenge tests to permit the evaluation of the equipment at two separate pentaiodide resin retention times. Differing pentaiodide resin retention times were achieved by first running a viral challenge test under normal operating conditions with the 50 gpm water flow being split between two resin beds. Subsequently, the 50 gpm flow was channeled through one resin bed thus reducing the contact time for disinfection in half. The viral challenge tests were carried out using the MS-2 bacteriophage. The target MS-2 concentration for the bacteriophage growth broth was 1×10^{11} plaque forming units (PFU)/mL. Using a peristaltic pump, MS-2 was spiked into water that was leaving the prefiltration components of the H-3000-I and entering the pentaiodide resin beds to achieve a target viral particle density of 1×10^{7} PFU/mL. MS-2 was spiked for a total of 50 minutes per challenge test. Samples for MS-2 enumeration were collected at 5-minute increments beginning at 25 minutes and ending at 50 minutes. These samples were submitted to BioVir Laboratories for MS-2 enumeration by USEPA Method 1601 (modified for MS-2). MS-2 was also quantified in the medium provided by BioVir Laboratories both before (VB1 and VB2, Table 4-7) and after (VB3, and VB4, Table 4-7) the test and in the raw river water before and after the test. The above test sequence is applicable to both challenge tests (i.e., with one resin bed in service as well as with two resin beds in service).

Log removals of *MS-2* were calculated per the following equation:

$$\text{log removal of virus} = \log_{10}\left[\frac{\left(PFU/_{ml}\right)_{feedwater}}{\left(PFU/_{ml}\right)_{effluent}}\right]$$

During the viral challenge tests, predisinfection control samples were collected from a ball valve sampling port after the Harmsco filters and an in-line mixer and before the pentaiodide resin tanks. Post disinfection samples were collected from a second ball valve sampling port located in the pentaiodide resin tank effluent piping. When collecting a sample, the ball valve was opened and the line was allowed to flush for 15 to 30 seconds prior to actual sample collection.

3.3 Task 3: Treated Water Quality

The objective of this task was to assess the impact that treatment using the PentaPure H-3000 – I has on treated water quality. ARCADIS has prepared a summary of the types of treated water quality samples required during the verification program, the frequency with which individual analyses were performed, the analytical methodologies that were followed, and the reporting limits, holding times and sampling containers required. This information is summarized in Table 3-1 and was available to all personnel contributing to the verification program as a guide to sample collection.

Table 3-1 provides the identity of the laboratory that performed individual analytical tests. Samples for analyses that were performed at SJWD were transported to the on-site SJWD laboratory and properly stored according to the guidelines in Table 3-1 by SJWD personnel. ARCADIS personnel frequented the site to collect analytical samples intended for shipment to off-site laboratories.

Table 3-1. Sampling and Analysis Summary

Parameter	Sampling Frequency	Test Stream	Analytical Method	Analytical Laboratory	Reporting Limit	Hold Time	Container/ Preservative
pH	1/Day	Feed, Treated*, Waste (1/week)	SM 4500 H	SJWD	N/A	Immediately	Dedicated glass beaker
Temperature	1/Day	Feed, Treated, Waste (1/week)	SM 2550 B	SJWD	N/A	Immediately	NA
Turbidity (grab)	1/Day, Waste (1/week)	Feed, Pre-filtered water, Treated, Waste.	SM 2130 B	SJWD	0.1 NTU	48 hours	Dedicated glass beaker
Turbidity (continuous)	In-line	Disinfected water**	Hach 1720D	SJWD	0 – 100 NTU	NA	NA
Hydrogen Sulfide	1/Week	Feed	SM 4500-S2-A4c	SJWD	0.1 mg/L	Not specified	100-mL glass 4 drops zinc acetate
Alkalinity	1/Week	Feed, Treated, Waste	SM 2320 B	SJWD	10 mg/L	14 days	250-mL poly/4 °C
TDS	2/ Test	Feed, Treated, Waste	SM 2540 C	SJWD	5 mg/L	7 days	250-mL poly/4 °C
Total Coliform Bacteria	5/Week	Feed, Treated	SM 9221 B	SJWD	2 MPN/ 100 mL	30 hours	120-mL poly/4 °C 0.008% $Na_2S_2O_3$
HPC Bacteria	5/Week	Feed, Treated	SM 9215 B	SJWD	1000 CFU/L	8 hours	Sterile
Metals Scan	1/ Test	Waste	EPA 200.8	EHL Labs	Varies	Varies	250-mL poly/4 °C/HNO_3 < 2
Ammonia Nitrogen	1/Week	Feed, Treated	EPA 350.3	EHL Labs	0.3 mg/L	28 days	100-mL poly/4 °C pH<2 W/ H_2SO_4
TOC	1/ Test	Feed, Treated	SM 5310 C	EHL Labs	0.5 mg/L	28 days	Glass/4 °C
UVA	1/Week	Feed, Treated	SM 5910 B	EHL Labs	0.01/cm	Not to exceed 48 hrs	Glass/4 °C
True Color	1/Week	Feed, Treated	EPA 110.2	EHL Labs	5 PCU	48 hours	250-mL poly/4 °C
Iron	2/week	Feed, Treated	SM 3111 B	EHL Labs	20 µg/L	48 hours	250-mL poly/4 °C 2 mL HCl/100 mL
Manganese	2/week	Feed, Treated	EPA 200.8	EHL Labs	0.1 µg/L	6 months	120 plastic, HNO_3 < 2
Bromide	1/ Test	Feed, Treated	EPA 300.0	EHL Labs	0.2 mg/l	28 days	100-mL poly
Chloride	1/ Test	Feed, Treated	EPA 300.0	EHL Labs	1 mg/L	28 days	100-mL poly
Sodium	1/ Test	Feed, Treated	SM 3111 B	EHL Labs	0.2 mg/L	48 hours	Acid washed/4 C
Silver	2/week	Treated (after carbon filtration)	EPA 200.8	EHL Labs	0.2 µg/l	6 months	120 plastic, HNO_3 < 2
TTHMs	1/ Test	Feed, Treated	EPA 524.2	EHL Labs	Varies	14 days	3- 40 VOA vials
HAAs	1/ Test	Feed, Treated	EPA 552.1	EHL Labs	Varies	14 days	3- 40 VOA vials
Iodide	varies	Feed (1x/day), Disinfected (2x/day), Treated (2x/week), Waste (1x/week)	ASTM D3869 (Orion ISE)	SJWD	5 µg/l	24 hours	Acid washed/4 °C
Iodine	varies	Feed (1x/day), Disinfected (2x/day), Treated (2x/week), Waste (1x/week)	SM 4500 – I B	SJWD	10 µg/l	24 hours	Acid washed/4 °C
E. coli Enumeration	10/Bacterial Challenge Test	Background (1), Feed (2), Disinfected (6), process ctrl. (1)	SM 9213 D	EHL Labs	10/100 mL	24 hours	Autoclaved 1 liter glass ($Na_2S_2O_3$ added)
MS-2 Enumeration	10/Viral Challenge Test	Background (1), Feed (2), Disinfected (6), process ctrl. (1)	EPA 1601	BioVir	1 PFU/ml	24 hours	100 mL sterile plastic (provided by BioVir) ($Na_2S_2O_3$ added)

NA Not applicable.

* Treated water = after disinfection and after carbon filtration step.

** Disinfected water = before carbon filtration.

As discussed in the experimental design sections, statistical uncertainty of the water quality parameters analyzed was evaluated through calculation of the 95% confidence interval around the sample mean. Confidence intervals were calculated for data collected for analytes that are critical to the verification program. In addition, 95% confidence intervals were also calculated for critical measurements that were performed at least daily, such as pH, iodine/iodide, temperature, turbidity, and total coliform and HPC enumerations. Where possible, confidence intervals were also calculated for alkalinity, ammonia nitrogen, UVA and true color data sets. For the broad range of water quality parameters, the consistency and precision of water quality data can be evaluated with use of the confidence interval. As the name implies, a confidence interval describes a population range in which any individual population measurement may exist with a specified percent confidence. Confidence intervals were calculated using Microsoft® Excel features. The theoretical formula employed for confidence interval calculation is:

$$\text{95\% confidence interval} = \overline{X} \pm t_{n-1,0.975}\left(S/\sqrt{n}\right) \qquad (2)$$

Where: $\overline{X}$ is the sample mean;

S is the sample standard deviation;

n is the number of independent measurements included in the data set;

t is the Student's t distribution value with n-1 degrees of freedom; and

α is the significance level, defined for 95% confidence as: 1 – 0.95 = 0.05

With input of the analytical results for pertinent water quality parameters into the 95% confidence interval equation, the output will appear as the sample mean value plus or minus the width of the confidence interval. The results off this statistical calculation may also be presented as a range of values falling within the 95% confidence interval. For example, the results of the confidence interval calculation may provide the following information: 520 +/- 38.4 mg/L, with a 95% confidence interval range described as (481.6, 558.4).

Chapter 4
Results and Discussion

4.1 General Progress

The PentaPure H-3000 - I system was initially installed on March 16 and 17, 2000. The system commenced verification testing two times. The first test run commenced in late April 2000 and was terminated on May 26, 2000 after it was determined that the pentaiodide resin beds had been prematurely fouled due to high turbidity levels caused by insufficient pretreatment. For the second test the unit was modified with the addition of a coagulation unit. The second test began on July 31, 2000 and ran, with several periods of downtime, until October 5, 2000. The second test run was the complete 30-day verification test, the results of which are highlighted in this report. A full timeline summarizing daily events pertaining to general O&M and system performance is provided as Table 4-1.

Table 4-1. Timeline of PentaPure System Verification Testing

Date	Test[1]	Day	Downtime (hr)	Remarks
3-16-00				PentaPure system set up on-site.
3-17-00				Electrician installs power.
4-19-00				Sample ports installed.
4-20-00				Leaks repaired. KWh meter installed.
4-21-00				System started up.
4-22-00				System shut down due to pressure drop across filter.
4-27-00				Filter replaced and system restarted. Turbidimeter installed.
4-28-00	A	1		
4-29-00	A	2	2.5	Zero pressure; filter replaced.
4-30-00	A	3	1.25	Low pressure; filter replaced.
5-1-00	A	4	9.25	Tried to wash clogged filters.
5-2-00	A	5	13	Filter clogged; system shut down. ARCADIS tracer test.
5-3-00				Additional filter housing installed. ARCADIS viral challenge test.
5-4-00	A	6	11	5 um filter installed in series with 1 um filter. ARCADIS bacterial challenge test.
5-5-00	A	7		
5-6-00	A	8		
5-7-00	A	9		Switched to two 5 um filters in parallel, per PentaPure
5-8-00	A	10		
5-9-00	A	11		
5-10-00	A	12		
5-11-00				System brought down for site modifications unrelated to ETV testing.
5-22-00	A	13		System started back up after site modifications unrelated to ETV testing.
5-23-00	A	14		
5-24-00	A	15		Changed both filters. No iodine residual; high bacterial counts.
5-25-00	A	16		No Iodine residual.
5-26-00	A	17		Test terminated due to suspected resin fouling.
7-24-00				New coagulation/direct filtration system setup; pretesting.
7-27-00				New chemical feed pump delivered.
7-28-00				New chemical feed pump installed/setup.
7-31-00	B	1		System restarted at 2:00 pm. Test B commenced.
8-1-00	B	2		
8-2-00	B	3		
8-3-00	B	4		
8-4-00	B	5		
8-5-00	B	6		
8-6-00				System shut down due to air leak and raw water line problem.

Table 4.1. Timeline of PentaPure System Verification Testing (continued)

8-7-00				Repairs made.
8-8-00	B	7		System restarted at 10 am. Filters replaced.
8-9-00	B	8		
8-10-00				System shut down due to raw water pump pressure relief valve venting.
8-15-00	B	9		PentaPure technician on-site. System restarted at 3:00 pm.
8-16-00				PentaPure technician on-site. AGM challenge testing.
8-17-00	B	10		AGM challenge testing.
8-18-00	B	11		Raw water pump pressure erratic/fluctuating.
8-19-00	B	12		Filters replaced.
8-20-00	B	13		
8-21-00	B	14		
8-22-00	B	15		
8-23-00				Pressure fluctuating; raw water pump feed line inspected; system shut down.
8-28-00				New inlet assembly installed; pump reprimed; system restarted.
8-29-00	B	16	2	Water line leak repaired. Filters replaced.
8-30-00	B	17		
8-31-00	B	18		
9-1-00	B	19		Cleaned suction line on coagulant feed system.
9-2-00	B	20	1	Air line to top of aeration chamber broken; repaired/restarted.
9-3-00	B	21		Replaced filters. Blew off air to restore normal pressures.
9-4-00	B	22		
9-5-00				Loss of system pressure and pump prime. System shut off, pending PP input.
9-11-00	B	23		Repaired raw pump lines and check valve, replaced coagulation pump tubing, restart system at 1 pm.
9-12-00	B	24		Timers reset.
9-13-00	B	25	1	Replace air recharge line.
9-14-00	B	26		
9-15-00	B	27		Replaced filters.
9-16-00	B	28		System restarted from unknown power outage.
9-17-00	B	29		
9-18-00	B	30		
9-19-00	B	31		
9-20-00				System continues to run normally, but without daily analyses.
9-21-00				System continues to run normally, but without daily analyses.
9-22-00				System continues to run normally, but without daily analyses.
9-23-00				System continues to run normally, but without daily analyses.
9-24-00				System continues to run normally, but without daily analyses.
9-25-00				Repair air recharge line. Off-site analytical samples collected.
9-26-00				Final off-site analytical samples collected. System shut down.
10-5-00				System restarted to take iodine column backwash samples and raw Al sample.
10-6-00				Logbook forwarded to ARCADIS.

[1] Test A refers to the aborted initial verification test. Test B refers to the full verification test conducted after adding a coagulation step and utilizing a new pentaiodide disinfection resin.

For the first aborted test, initial test runs were started on April 19, 2000 and the first verification test was started in earnest on April 28, 2000. During this first test period, the system had to be periodically shut down due to premature clogging of the one-micron filter elements. A tracer test was conducted by ARCADIS staff on May 2, 2000 and on May 3, 2000 a PentaPure technician installed an additional prefilter unit that could be operated in series or parallel with the original prefilter. After this modification, the system was setup with a 5-micron filter in series with a one-micron filter. This was changed on May 7, 2000 to operate using only two 5-micron filters in parallel with no one-micron filters utilized. As a result of this change, the frequency of filter replacement was greatly reduced.

On May 11, 2000, the system was shutdown due to unavoidable plant modifications occurring on-site that interfered with verification testing. The system was restarted on May 22, 2000 after site work was completed. Shortly thereafter, system operations staff noted a lack of iodine/iodide residual in disinfected effluent and very high bacterial plate counts. It was surmised that the problem with turbidity clogging the prefilters, and perhaps switching to the 5-micron prefilters (thus allowing very fine particles to pass through to the disinfection columns) caused a premature fouling of the iodinated resin beds (according to the manufacturer, typically, pentaiodide resin replacement is required at 6-18 month intervals), necessitating their replacement. After this time, it was decided to rework the pretreatment system to improve turbidity removal via a coagulation step and operation in a "direct filtration" mode, use an improved iodinated resin blend (called PentaPure Formula 53), and restart the verification testing from the beginning.

Changes to the system, which included switching out the resin and adding a chemical feed pump to directly dose coagulant into the raw water feed line at the inlet of the raw water pump, occurred in June and July 2000. A diaphragm pump was used to deliver a polyaluminum chloride coagulant, Chemwater PAX 30, to the raw water suction line, just before the pump, at a field-optimized rate sufficient for an approximately 20 ppm dosage. The coagulant and target doses were selected based on jar testing using the source water and glass fiber filtration, which showed a reduction in turbidity from approximately 10 NTU in the raw water to less than 0.5 NTU in the filtered water. The two Hurricane filters continued to be operated in parallel, now using 5-micron filter elements.

Initial testing for the second verification test run began July 24, 2000 and included primarily setting up and optimizing the chemical feed system. On July 31, 2000, the second verification test run started up. The new coagulation/direct filtration system proved to be effective and neither grossly premature filter clogging nor resin fouling were observed throughout the remainder of the test period. However, the system was shut down August 6-7, August 10-15, August 23-28, and September 5-11, 2000, because of problems associated with irregular system pressures and consequences resulting thereof. These events are described in detail below.

On August 6, 2000 during routine monitoring, an ARCADIS operator discovered zero pressure in the aeration tank and air leaking from the gauge fitting on the top of the tank. Later, the operator discovered the two-inch PVC raw water line from the raw water pump discharge port had blown out and evidently swung around and hit the air pressure gauge fitting, thus breaking it. When the problem was discovered, the feed pump was still running without water and was hot to the touch. The operator immediately turned the system off. Early morning monitoring data indicated that the prefilter pressures were relatively low, suggesting that these filters were clogged, thus causing a buildup of pressure at the pump. The high pressure (80-85 psi at raw water line) in conjunction with heat generation from the pump (running hard and not moving a lot of water for cooling) may have caused the PVC fitting adjacent to the cast iron pump housing to weaken, deform and break, which in turn broke the air fitting as discussed above. On August 7, the PVC raw water line was repaired along with the aeration tank fittings and the system was restarted on August 8, 2000 with daily backwashing of the media filters (rather than every third day as originally set up) to prevent clogging and possible pressure buildup resulting from coagulation/direct filtration step. Additionally, the pressure relief valve at the raw water pump was reset, as appropriate.

On August 10, 2000, an on-site operator discovered water blowing off of the pressure release valve on the raw water pump, again caused by an increase in system pressure. The system was restarted a few minutes later, but was shut down due to the problem recurring. On August 15, 2000, PentaPure staff arrived and modifications were made to the effluent flow restrictors to maintain flow at 50 gpm, after which the system was restarted. Before this adjustment was made, the average potable water flow rate through the system was about 40 gpm, while after adjustment, the average flow rate was about 46 gpm. Additionally, pressure gauges were installed on the raw water line and the media filter effluent line, the raw water pump pressure relief valve was again reset, and the backwash timers were reset.

On August 23, 2000, the system operator found pressures throughout the unit very low. The suction pipe and foot valve/strainer were removed from the raw water sump for inspection and it was discovered that the foot valve/strainer was badly damaged and clogged with sticks and other debris. The foot valve/strainer was cleaned manually and a repair was attempted; however, it was insufficient and the foot valve/strainer was lost within the sump during a subsequent attempt to reprime the pump. A new foot valve/strainer was sent to the site and installed on August 28. A new pump was also sent to the site, but after cleaning the impeller of the original pump of debris that passed the old, damaged inlet assembly, the original pump primed and developed good pressure.

System pressure and pump priming problems were noted again on September 5, 2000. It was concluded that this series of problems was related to the aeration tank backwash cycle and perhaps a faulty check valve between the aeration tank and the raw water pump that allowed the raw water pump to "see" the air pressure from the aeration tank, causing it to try to overcome extreme pressures, run hot, and eventually lose prime. In fact, on September 11, 2000, the check valve was replaced with a more dependable ball check valve, the system was restarted and operation appeared normal for the remainder of the verification test.

Another recurring problem during this verification test was that of the air compressor tubing cracking and breaking. This was determined to be an inappropriate application of the tubing, which appeared to have received ultraviolet light damage, causing brittleness.

The following O&M actions were taken while operating the PentaPure H-3000 – I during the verification test:

1. The filter elements on the Harmsco Hurricane™ centrifugal separators required periodic replacement; cleaning proved to be ineffective. The service interval for this component was based on the pressure drop across the separator (measured via pressure sensors upstream and downstream of the unit).
2. The disinfection (pentaiodide) and post-treatment (acid-washed and silver-impregnated activated carbon blend) media did not require replacement during the test period. The

original media was replaced with a different formulation (PentaPure Formula 53) after becoming prematurely fouled during the first, aborted verification test, discussed in Section 4, below. According to PentaPure the typical replacement interval for pentaiodide media is between 6 – 18 months, however, this was not verified during the ETV test.

3. Backflushing of the aeration tank and backwashing of the filter and resin beds was initiated automatically via timers provided with the system for this purpose. The design backwash flow was 50 gpm per filter and the typical backwashing time about 30 minutes. Only one filter was backwashed at any given time. Backflush and backwash water is collected in a common waste line which, for this installation, was directed into the SJWD alum sludge pond. The disinfection columns and activated carbon filters were set up to backwash every third day, while the other media filter units were set to backwash daily (initially set up to backwash every third day). Backflushing of the aeration tank occurred every four hours and consisted primarily of an exchange of removal of air (and some water) in the headspace and recharge with fresh air from the compressor.

4.1.1 Qualitative Operational and Maintenance Issues

The cornerstone of PentaPure is the pentaiodide technology. The pentaiodide filtration part of the system operated well from an O&M standpoint and most operational difficulties were found in the pretreatment system that consisted of non-PentaPure components. The configuration that was tested at SJWD was assembled to address the characteristics of the particular raw water found at SJWD and it was the first application by PentaPure, Inc. of these pretreatment units into the PentaPure system.

PentaPure provided printed installation and operation instructions for the separate components of the system. PentaPure was aware of the draft nature of the O&M documentation and intends to assemble a complete manual depending on the configuration of the system, in regard to pretreatment.

ARCADIS and site operations staff found the separate instructions adequate to address routine operation and maintenance issues pertaining to system components. For example, the O&M manual was used to assist in filter element cleaning and replacement as well as resetting of backwash timers. Additionally, PentaPure provided consistent field support during the aforementioned problems that were experienced during verification testing. The PentaPure H-3000 – I was installed and started up by a PentaPure technician. This technician provided operator training to ARCADIS and SJWD personnel.

Based on our experiences, including feedback from operations staff, ARCADIS recommends the following provisions with respect to Operation and Maintenance of the PentaPure H-3000 - I system:

- A system-specific O&M manual should be developed which includes the cut sheets, specifications and O&M documentation for system components, as well as information specific to operation of the system as a complete unit, including sections on troubleshooting, safety issues and monitoring for proper system performance. The O&M

manual should be well organized, such that an O&M issue with a given system component can be easily located by means of tabs, etc.

- If an in-line turbidimeter is to be installed, as it was for the verification test, provisions should be made by the system vendor to provide a degassing system to avoid the interference with bubbles entrained by the Iron Curtain aeration system causing higher than actual turbidity readings to be registered. We note that providing in-line turbidity measurement prior to the disinfection process (in order to assess pretreatment turbidity removal efficacy) may be a very worthwhile investment, as per the first, aborted test, it appears that excess turbidity can foul the disinfection resin media, necessitating its replacement.
- Extra caution should be exercised to ensure that all piping and components such as valves utilized in the system are appropriate for their given function and location. Since the system operates under relatively high pressure, this is particularly important as a safety issue. This item is noted in response to the deterioration of the air pump tubing (presumably due to UV light exposure) as well as the deformation and breakage of the pump discharge piping (presumably due to a malfunctioning check valve).

Provisions should be made to allow operations staff to know for sure whether a filter unit has backwashed properly, without them having to witness the backwash event.

4.1.2 Equipment Operation (Task 1)

Referring again to Table 4-1, the PentaPure system operated for 31 days with 41 hours of downtime recorded, for a total run time of 703 hours.

Potable water and wastewater flows were each measured with totalizing flow meters (see diagram in Figure 2.2). As indicated in Table 4-2 below, 1,902,000 gallons of potable water and 255,041 gallons of wastewater were generated, for a total water intake of 2,157,041 of raw river water. Since the test ran for approximately 703 hours, treated water was generated at a rate of about 65,000 gallons per day, while about 8,700 gallons per day of wastewater were generated. A typical disinfection resin bed backwash cycle was measured as generating approximately 1,500 gallons of wastewater. Disinfection bed backwash wastewater quality characteristics are presented in the sections below.

Table 4-2. Summary of Water and Waste Generation During Verification Period

	Potable Water Generated	Waste Water Generated	Total Water Used
Ending Totalizer Reading	3,010,900 gallons	352,421 gallons	N/A
Beginning Totalizer Reading	1,108,900 gallons	97,380 gallons	N/A
Total Volume	1,902,000 gallons	255,041 gallons	2,157,041 gallons

Consumables expended by the PentaPure H-3000 – I system during the 31 days of verification testing included electrical power, coagulant and Harmsco filter elements. Approximately 2,483 kWh of power were consumed over the verification test period, for an average power draw of about 3.5 kW. Per gallon of treated water, the power consumption was approximately 1.31 kWh per 1,000 gallons treated.

The nominal horsepower ratings of the motors used in this system, listed in Table 4-3 below, were totaled to estimate the maximum instantaneous power requirements of the system. As can be seen, the raw water feed pump is overwhelmingly the most power-intensive piece of equipment in the system. Disregarding the feed pump (which will likely be required for virtually any drinking water treatment system), the power consumption of the unit is almost negligible, as the air pump for the aeration tank has a nominal horsepower rating of only 1/6 horsepower and is used intermittently and the aggregate horsepower of all of the other motors (diaphragm metering pump and valve motors) is less than 0.2 hp. The maximum power draw based on the nameplate horsepower ratings of the motors in the system is about 4.0 kW. Note that this value assumes that the motors will be operating at their nameplate powers (typical runtime power draw is some fraction, say 85%, of nameplate power rating).

Table 4-3. Summary of PentaPure H-3000 – I System Component Power Requirements

Component	Nominal Power Draw (hp)	Power Draw (kW)
Raw Water Feed Pump	5.0	3.7
Aeration System Air Pump	0.17	0.1
Other Components	<0.2	0.2
Total	5.4	4.0

Harmsco Hurricane™ filter elements necessitated replacement at fairly frequent intervals based on pressure drop across the filters; however, the frequency of filter replacement was reduced as coagulant dosage was optimized/minimized (see paragraph below). While cleaning of the filter elements is possible, Harmsco literature recommends replacement when the pressure drop exceeds 25 psi over startup differential pressure or when filter is fouled with particles under 1 micron in size. Filter cleaning was attempted during the first, aborted phase of testing, but was ineffective. Ten filter elements were used over the 31-day verification test, at a cost of approximately $100 per filter element.

Coagulant solution was prepared by adding one gallon of Chemwater PAX 30 to 30 gallons of water. Twenty-six (26) 30-gallon batches were used over the course of the verification test interval to produce 1,902,000 gallons of potable water. Initially, the coagulant dosing system was set up to deliver about 70 mL of solution per minute, but the coagulant delivery rate was lowered incrementally to about 40 mL/min toward the latter stages of the verification test interval. This will be an aspect of the PentaPure H-3000 - I system that will need to be field-tested and optimized as it will be variable from site to site. Optimization of coagulant dose will minimize the filter element replacement frequency and result in lower operating and maintenance costs. A 55-gallon drum of PAX 30 cost $309, resulting in a coagulant cost of about 7.7 cents per 1,000 gallons of treated water.

Operator staff time required for routine monitoring of the system was estimated at about 1 hour per day. This estimate may be slightly high due to the necessity to monitor the system closely over the verification test period given the recurring problems that were eventually rectified toward the end of the period. Approximately 37 hours of operator time were spent in total addressing non-routine PentaPure operational problems during the verification period.

4.2 Hydrodynamic Tracer Test Results

Tracer testing for the PentaPure pentaiodide resin bed was conducted on May 2, 2000, per the methods and materials described in Section 3.2.1. Background concentrations of Rhodamine dye were measured at about 0.006 µg/l. Tracer recovery was approximately 50 µg, or about 110%. The data results are summarized in Table 4-4 and the raw data sheets are in Appendix C.

The results were plotted as standard C- and F-curves, as described in many chemical engineering and reactor analysis texts (Levenspiel, 1972) and shown as Figure 4-1. The F-curve shows the cumulative percentage of tracer recovered from the effluent versus time after slug-dosing the tracer. The actual hydraulic retention time was calculated as the area above the curve, per Equation 1 below (DiGiano, Weber, 1996).

TABLE 4-4. PentaPure Tracer Test Data

Time (minutes)	Corrected Conc.* (µg/l)	F (%)
0	0	0%
1	0.073	27%
2	0.06	50%
3	0.04	65%
4	0.029	76%
5	0.02	83%
6	0.013	88%
7	0.01	92%
8	0.007	94%
9	0.004	96%
10	0.003	98%
12	0.001	98%
14	0.001	99%
16	0	99%
18	0	99%
20	0.001	100%
23	0	100%
26	0	100%
29	0	100%
32	0	100%
Undiluted Dye	974	N/A
Trip Blank	ND	N/A

* Corrected Concentration is the measured concentration minus the background concentration.

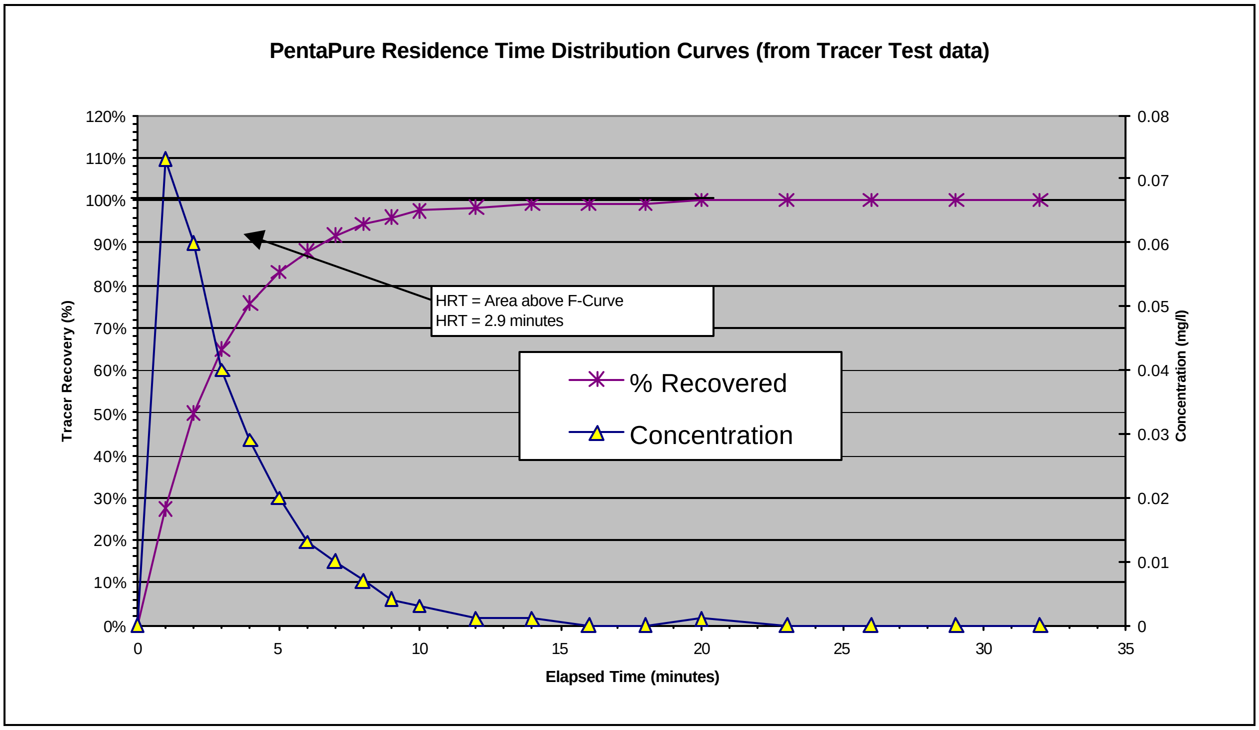

Figure 4-1. C-Curve and F-Curve for PentaPure ETV Tracer Test

$$HRT = t_m = \int_0^\infty t \cdot dF(t) \qquad (1)$$

The F-curve was plotted on grid paper with a relatively fine grid resolution and the number of grid squares above the curve (up to 100 percent recovery) was manually counted (see Figure 4-2). The hydraulic residence time (HRT) was then calculated per Equation 2.

$$HRT = 290\,squares \times \frac{0.02F}{grid} \times \frac{0.5\min.}{grid} = 2.9\min. \qquad (2)$$

Assuming a 50% porosity of each resin bed and knowing that the volume occupied by each disinfection bed is no more than half of the total cylinder volume, the liquid volume in each cylindrical tank is between 238 gallons (for a cylinder half-full of media) and 317 gallons (for an empty cylinder). The flow rate through the disinfection cylinder was 50 gpm. Thus, an "ideal" plug flow reactor would yield an HRT of 4 to 6 minutes with one cylinder in operation. The estimated actual HRT of 2.9 minutes thus indicates, as expected for a packed bed system, non-ideal plug flow conditions, but reasonable performance. Since the PentaPure H-3000 – I does not rely on a concentration-contact time (CT) relationship for facilitating microbial deactivation, the results of this tracer test were primarily to determine whether the proposed challenge testing sampling schedule was appropriate. While tracer testing was conducted prior to the first, aborted verification test interval, it was decided, per review and approval by NSF International, that these tracer test results could also be applied to the replacement resin and second, complete verification testing interval.

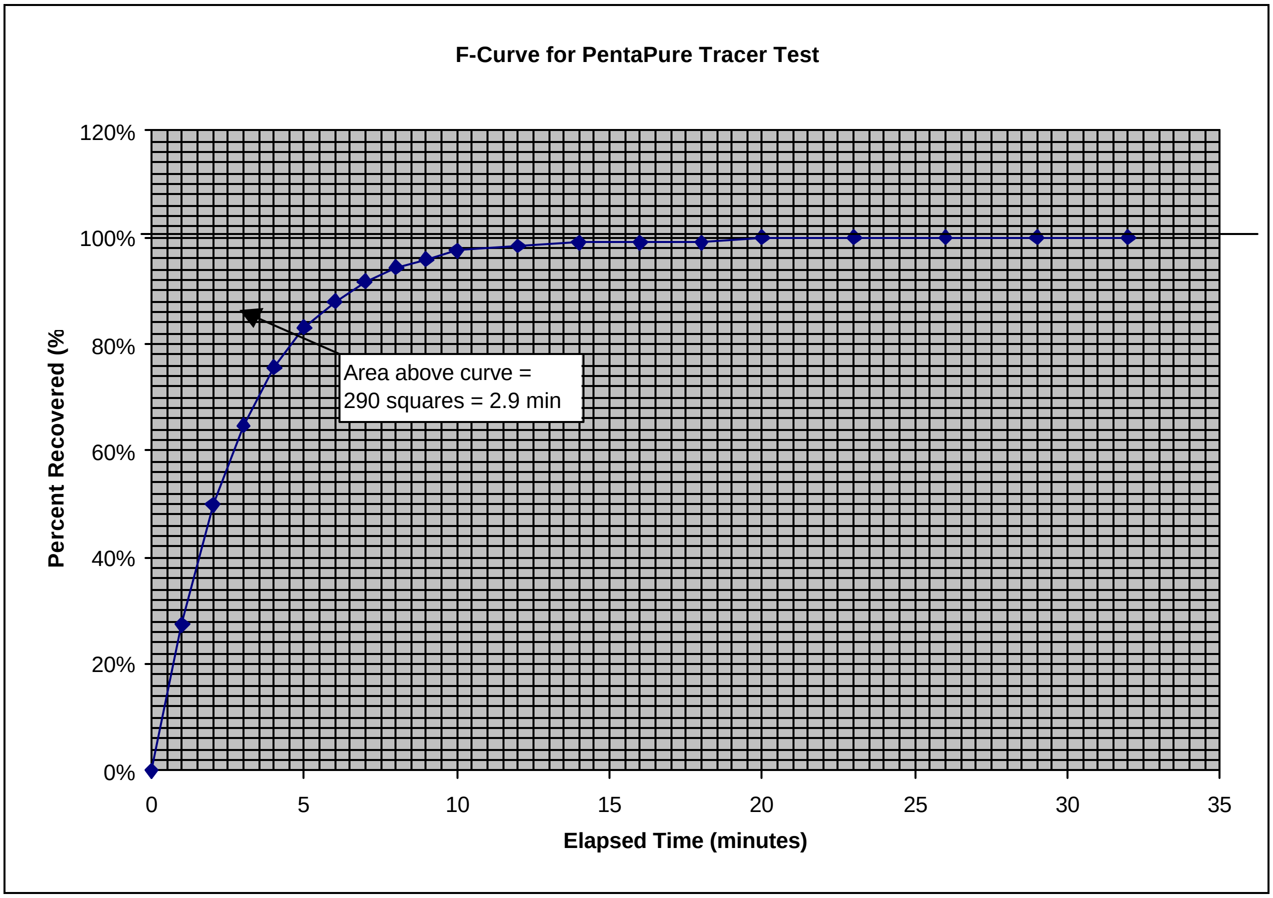

Figure 4-2. F-Curve for PentaPure ETV Tracer Test HRT Calculation

4.3 Microbiological Contaminant Inactivation (Task 2)

ARCADIS performed both bacterial and viral challenge tests on the PentaPure H-3000-I to assess its disinfection capabilities. *Escherichia coli* served as the bacterial challenge test microorganism and the MS-2 coliphage was used as the viral challenge test microorganism. Bacterial and viral challenge test microorganisms were used to assess the disinfection capabilities of the PentaPure H-3000-I with both one and two pentaiodide resin beds in line. Specific challenge tests with a varied number of pentaiodide resin beds in line served to vary the time that the microorganisms were exposed to the disinfection media. The challenge testing was conducted on August 17, 2000. The field notes on the challenge testing are included in Appendix C.

Prior to both the bacterial and viral challenge tests, iodine and iodide were quantified in the disinfected water prior to carbon tank entry. Table 4-5 contains the results of these analyses.

Although a classical CT value cannot be calculated for the PentaPure H-3000-I, this data is useful for comparison to post-disinfection iodine and iodide concentrations during the rest of the verification interval.

Table 4-5. Iodine and Iodide Concentrations in Raw, Disinfected and Treated Water Samples Prior to Bacterial and Viral Challenge Testing

Stream Sampled	Iodine (mg/L)	Iodide (mg/L)
Raw Water – Viral Test	0.000	0.000
Disinfected Water – Viral Test	1.802	2.125
Treated Water – Viral Test	0.005	0.413
Raw Water – Bacterial Test	NP	NP
Disinfected Water – Bacterial Test	1.968	2.461
Treated Water – Bacterial Test	0.003	0.441

NP = not performed

The results of the bacterial challenge tests are found in Table 4-6. The results of the viral challenge tests are found in Table 4-7. The target concentration for *E. coli* in the broth culture was 5.0 x 10^{10} CFUs/100 mL. Magellan Laboratories, who supplied the *E. coli,* quantified it in the whole broth at 1.1 x 10^{11} CFUs/100 mL. The difference in the delivered broth concentration and the target is considered to be a positive outcome because a higher *E. coli* log removal can be demonstrated as a result. Approximately five gallons of this cell suspension was shipped to the SJWD Water Treatment Plant on ice for challenge testing. The target concentration for MS-2 was 1 x 10^{11} plaque forming units/mL (PFU/mL). BioVir quantified MS-2 at 1 x 10^{14} PFU/mL in the growth broth. The difference in the delivered broth concentration and the target is considered to be a positive outcome because a higher MS-2 log removal can be demonstrated as a result. Two 1-liter containers of viral growth broth were shipped to the SJWD Water Treatment Plant on ice for challenge testing. A smaller volume of growth broth was required for MS-2 challenge testing than for *E. coli* challenge testing because a much higher microorganism density can be achieved with viral cultures.

The bacterial growth broth was subsampled at the beginning and end of the period of time required to complete both the one pentaiodide resin tank test and the two pentaiodide resin tank test to create two trip controls that remained on ice during the respective testing intervals and were shipped to the analytical laboratories with the challenge test samples. The analytical results for these two bacterial trip controls can be found in Table 4-6 identified as BB1 and BB2. The viral growth broth was sampled at the beginning and end of each viral challenge test resulting in four viral trip controls. The results for these viral trip controls can be found in Table 4-7 identified as VB1, VB2, VB3, and VB4 respectively. All values for trip controls compare favorably with the concentrations provided by Magellan Laboratories and BioVir for the broths confirming that both viral and bacterial microorganisms remained viable during the challenge test interval.

Prior to commencement of both challenge tests, the raw water flow rate for the PentaPure H-3000-I was verified using the in-line totalizer. The raw water flow rate was determined at the beginning of the day on August 17 to be 50.2 gpm. Challenge test microorganisms were pumped into an injection port located after the Harmsco filters and before an in-line mixer that was installed in the Schedule 80 PVC pipe leading to the pentaiodide resin tanks. The MS-2 viral growth broth was injected at 19 mL/minute. The *E. coli* growth broth was injected at 180 mL/minute.

Table 4-6. PentaPure H-3000-I Bacterial Challenge Test Results

ARCADIS Sample I.D.	EHL Laboratory Sample I.D.	Sample Description	Collection Date	*E. coli* Concentration (CFU/100 mL)
		Results with One Iodine Resin Tank		
BB1	524614-6	*E. coli* spiking broth prior to challenge tests	8/17/00	8.5×10^{10} [a]
BB2	524617-9	*E. coli* spiking broth after the challenge tests	8/17/00	6.5×10^{10} [a]
BRWPRE	524622	*E. coli* background in raw water prior to challenge tests	8/17/00	1
BRWPOST	524623-4	*E. coli* background in raw water after the challenge tests	8/17/00	545 [b]
B1TPRE1	524628	Positive Control @ 10 min after test initiation	8/17/00	2.4×10^7
B1TPRE2A	524631	Duplicate Pos. Control @ 15 min after test initiation	8/17/00	1.7×10^7
B1TPRE2B	524634	Duplicate Pos. Control @ 15 min after test initiation	8/17/00	2.0×10^7
B1THRT	524637	Allowed to sit for one HRT prior to sodium thiosulfate addn.	8/17/00	2.7×10^7
B1T25	524651-2	Treated Sample @ 25 minutes	8/17/00	7.5 [b]
B1T30	524654-5	Treated Sample @ 30 minutes	8/17/00	2.5 [b]
B1T35A	524657-8	Duplicate Treated Sample @ 35 minutes	8/17/00	3.5 [b]
B1T35B	524660-1	Duplicate Treated Sample @ 35 minutes	8/17/00	1.5 [b]
B1T40	NA	Treated Sample @ 40 minutes	8/17/00	Broken in Transit
B1T45	524664-5	Treated Sample @ 45 minutes	8/17/00	2.5 [b]
B1T50	524668	Treated Sample @ 50 minutes	8/17/00	1
		Results with Two Iodine Resin Tanks		
B2TPRE1	524640	Positive Control @ 10 min after test initiation.	8/17/00	1.8×10^7
B2TPRE2A	524643	Duplicate Pos. Control @ 15 min after test initiation	8/17/00	1.5×10^7
B2TPRE2B	524646	Duplicate Pos. Control @ 15 min after test initiation	8/17/00	1.4×10^7
B2THRT	524649	Allowed to sit for one HRT prior to sodium thiosulfate addn.	8/17/00	2.0×10^7
B2T25	524671	Treated Sample @ 25 minutes	8/17/00	1
B2T30	524672-4	Treated Sample @ 30 minutes	8/17/00	30 [c]
B2T35A	524676-7	Duplicate Treated Sample @ 35 minutes	8/17/00	2.5 [b]
B2T35B	524679-80	Duplicate Treated Sample @ 35 minutes	8/17/00	2 [b]
B2T40	524683	Treated Sample @ 40 minutes	8/17/00	1
B2T45	524684-6	Treated Sample @ 45 minutes	8/17/00	123 [c]
B2T50	524687-8	Treated Sample @ 50 minutes	8/17/00	135 [b]

[a] concentration generated using SM9215 B
[b] result is the average of two reportable dilutions
[c] result is the average of three reportable dilutions

Table 4-7. PentaPure H-3000-I Viral Challenge Test Results

ARCADIS Sample I.D.	BioVir Laboratory Sample I.D.	Sample Description	Collection Date	MS-2 Concentration (PFU/mL)
		Results with One Iodine Resin Tank		
VB1	B001006A	MS-2 spiking broth prior to one tank challenge test	8/17/00	1.6×10^{13}
VB2	B001006B	MS-2 spiking broth after one tank challenge test	8/17/00	9.6×10^{12}
VB3	B001006Z	MS-2 spiking broth prior to two tank challenge test	8/17/00	2.2×10^{13}
VB4	B001006AA	MS-2 spiking broth after two tank challenge test	8/17/00	5.3×10^{11}
VRWPRE	B001006C	MS-2 background in raw water prior to challenge test	8/17/00	1
VRWPOST	B001006D	MS-2 background in raw water after the challenge test	8/17/00	1.1×10^{2}
V1TPRE1	B001006E	Positive Control @ 10 min after test initiation	8/17/00	1.3×10^{9}
V1TPRE2A	B001006F	Duplicate Pos. Control @ 15 min after test initiation	8/17/00	2.0×10^{8}
V1TPRE2B	NA	Duplicate Pos. Control @ 15 min after test initiation	8/17/00	Broken in Transit
V1THRT	B001006G	Allowed to sit for one HRT prior to sodium thiosulfate addn.	8/17/00	1.5×10^{7}
V1T25	B001006H	Treated Sample @ 25 minutes	8/17/00	8.3×10^{4}
V1T30	B001006I	Treated Sample @ 30 minutes	8/17/00	3.7×10^{6}
V1T35A	B001006J	Duplicate Treated Sample @ 35 minutes	8/17/00	4.4×10^{7}
V1T35B	B001006K	Duplicate Treated Sample @ 35 minutes	8/17/00	2.0×10^{3} [a]
V1T40	B001006L	Treated Sample @ 40 minutes	8/17/00	1.5×10^{2}
V1T45	B001006M	Treated Sample @ 45 minutes	8/17/00	1.5×10^{3}
V1T50	B001006N	Treated Sample @ 50 minutes	8/17/00	4.6×10^{4} [a]
		Results with Two Iodine Resin Tanks		
V2TPRE1	B001006O	Positive Control @ 10 min after test initiation.	8/17/00	5.0×10^{5}
V2TPRE2A	B001006P	Duplicate Pos. Control @ 15 min after test initiation	8/17/00	9.3×10^{5}
V2TPRE2B	B001006Y	Duplicate Pos. Control @ 15 min after test initiation	8/17/00	7.0×10^{6}
V2THRT	B001006Q	Allowed to sit for one HRT prior to sodium thiosulfate addn.	8/17/00	3.5×10^{6}
V2T25	B001006R	Treated Sample @ 25 minutes	8/17/00	5.8×10^{3}
V2T30	B001006S	Treated Sample @ 30 minutes	8/17/00	6.8×10^{3}
V2T35A	B001006T	Duplicate Treated Sample @ 35 minutes	8/17/00	1.4×10^{7}
V2T35B	B001006U	Duplicate Treated Sample @ 35 minutes	8/17/00	1.4
V2T40	B001006V	Treated Sample @ 40 minutes	8/17/00	9.1
V2T45	B001006W	Treated Sample @ 45 minutes	8/17/00	9.1×10^{2}
V2T50	B001006X	Treated Sample @ 50 minutes	8/17/00	3.2×10^{2}

[a] leaked in transit

The raw river water was sampled at the beginning and completion of the each challenge test to establish the background concentration of native *E. coli* and MS-2. The analytical results for these samples identified as BRWPRE and BRWPOST are in Table 4-6 for *E. coli* and VRWPRE and VRWPOST in Table 4-7 for MS-2. BRWPRE was below the detection limit (< 10 CFU/100 mL) and the analysis performed on BRWPOST by EHL resulted in 545 CFU/100 mL. VRWPRE contained 1 PFU/mL and VRWPOST contained 110 PFU/mL.

Two separate positive control samples were collected prior to entry into the pentaiodide resin tank(s) to establish the bacterial/viral concentration in the water prior to disinfection. One of these positive control samples was collected in duplicate (see Tables 4-6 and 4-7). These positive control samples were spaced approximately 5 minutes apart. The bacterial positive control samples are identified in Table 4-6 as B1TPRE1, B1TPRE2A/B1TPRE2B and B2TPRE1, B2TPRE2A/B2TPRE2B. The viral positive control samples are identified in Table 4-7 as V1TPRE1, V1TPRE2A/V1TPRE2B and V2TPRE1, V2TPRE2A/V2TPRE2B. In addition, a bacterial and viral control sample was collected and allowed to sit quiescent for the HRT of each pentaiodide resin tank configuration prior to the addition of sodium thiosulfate. The results of a tracer test on the PentaPure system revealed a 2-tank HRT of 5.8 minutes. The HRT for 1-tank tests was considered to be 2.9 minutes. These quiescent positive control samples are identified in Table 4-6 as B1THRT/B2THRT and in Table 4-7 as V1THRT/V2THRT. For all practical considerations, these samples can also be considered positive controls. Both the positive control samples and the quiescent positive control samples should be considered microorganism-spiked, pentaiodide resin tank influent samples. The water into which microorganisms were spiked to create these positive control samples had been processed through coagulant injection, aeration, media filters, and Harmsco Hurricane filters prior to microorganism injection.

ARCADIS would also like to note that certain bacterial and viral samples received damage in shipment to the two analytical laboratories. The bacterial sample B1T40 for the one pentaiodide resin tank challenge test was broken in transit and thus no results are available for this sample. Additionally, the one pentaiodide resin tank viral sample identified as V1TPRE2A leaked completely from the sample vessel during shipment. Consequently, no results are available from this sample. Two other viral samples from the one pentaiodide resin tank challenge test leaked but still contained a partial sample volume upon reaching BioVir. In the case of both of these samples, the plastic sample bottles were distorted in shape leading to an improper seal at the closure. BioVir was instructed to process these samples (V1T35B and V1T50) and the results are included in the report. ARCADIS feels this approach is justified based on the nature of the sample vessel leakage that would allow sample to leak out but discourage contaminants from leaking into the individual sample vessel. Lastly, due to weather related problems, Fed Ex was unable to deliver the MS-2 samples to BioVir until August 19, 2000 (two days in transit). Using the high MS-2 recovery rates established through MS-2 enumeration of the viral trip controls identified in Table 4-7 as VB1 and VB2, ARCADIS does not believe that the viability of the MS-2 phage was substantially affected by the extended shipping interval.

For all challenge testing, treated samples were collected at 25 minutes, 30 minutes, 35 minutes (in duplicate), 40 minutes, 45 minutes, and 50 minutes. All pre-treatment samples collected can be distinguished by the ARCADIS sample identification "_ _ _ PRE_ _". All samples collected after disinfection can be distinguished by the presence of the respective number of elapsed minutes since test initiation.

Bacterial Challenge Test Results for One Pentaiodide Resin Tank

The *E. coli* enumeration of the positive control samples for the one pentaiodide resin tank test ranged from 1.7×10^7 CFUs/100 mL to 2.7×10^7 CFUs/100 mL with an average of 2.2×10^7 CFUs/100 mL. The 95 percent confidence interval bounding positive control enumeration is 1.8×10^7 CFUs/100 mL to 2.6×10^7 CFUs/100 mL with three degrees of freedom. Figure 4-3 is a graphic portrayal of the positive control sample enumerations. Figure 4-4 shows the mean of the positive control enumerations. Additionally, the statistically calculated 95 percent confidence interval is displayed on Figure 4-4.

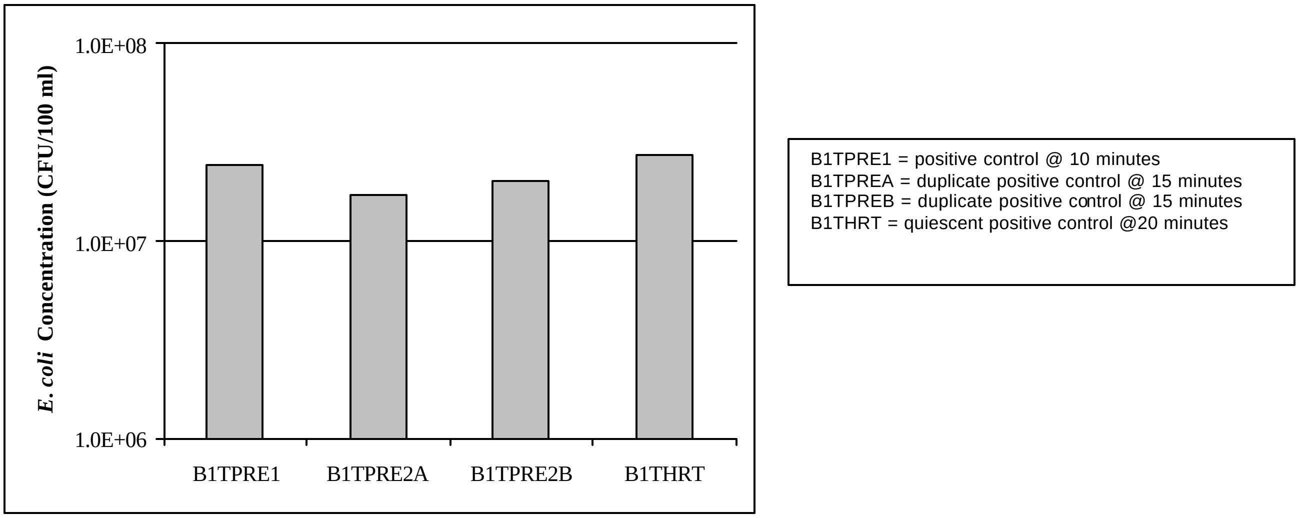

Figure 4-3. Positive Control Results for Bacterial Challenge Test with One Pentaiodide Resin Tank

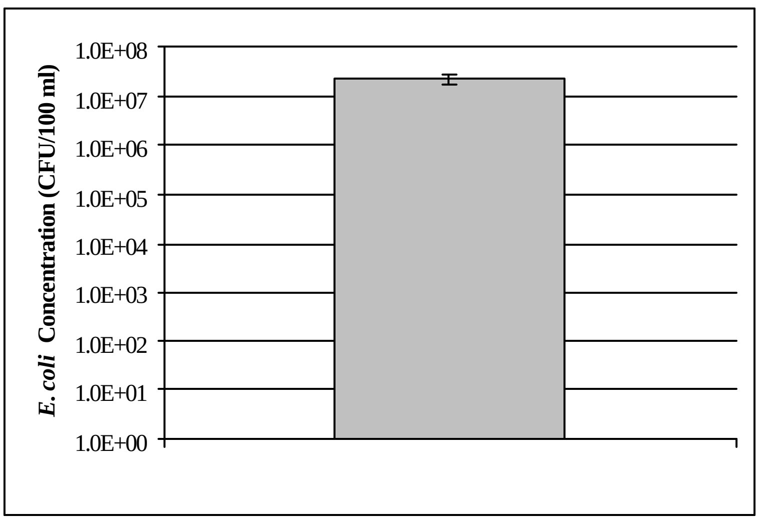

Figure 4-4. Mean Positive Control Concentration for Bacterial Challenge Test with One Pentaiodide Resin Tank

ARCADIS statistically analyzed the *E. coli* concentration results for the treated, one pentaiodide resin tank challenge test to evaluate the log reduction. The *E. coli* concentration in treated samples ranged from 1 CFU/100mL to 7.5 CFU/100 mL. The average of this range is 2.5 CFU/100 mL. The 95 percent confidence interval bounding positive control enumeration is 1.4 CFUs/100 mL to 4.4 CFUs/100 mL with five degrees of freedom. Figure 4-5 is a graphic portrayal of the treated sample enumerations for the one pentaiodide tank challenge test. Figure 4-4 shows the mean of the positive control enumerations. Additionally, the statistically calculated 95 percent confidence interval is displayed on Figure 4-6.

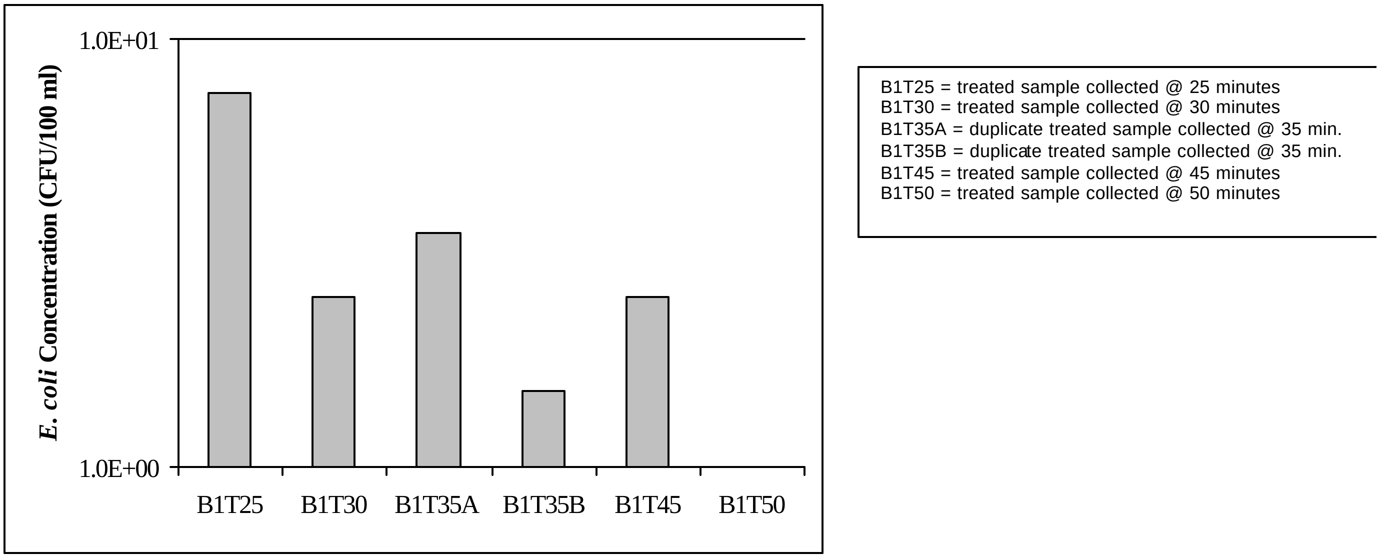

Figure 4-5. Treated Sample Results for Bacterial Challenge Test with One Pentaiodide Resin Tank

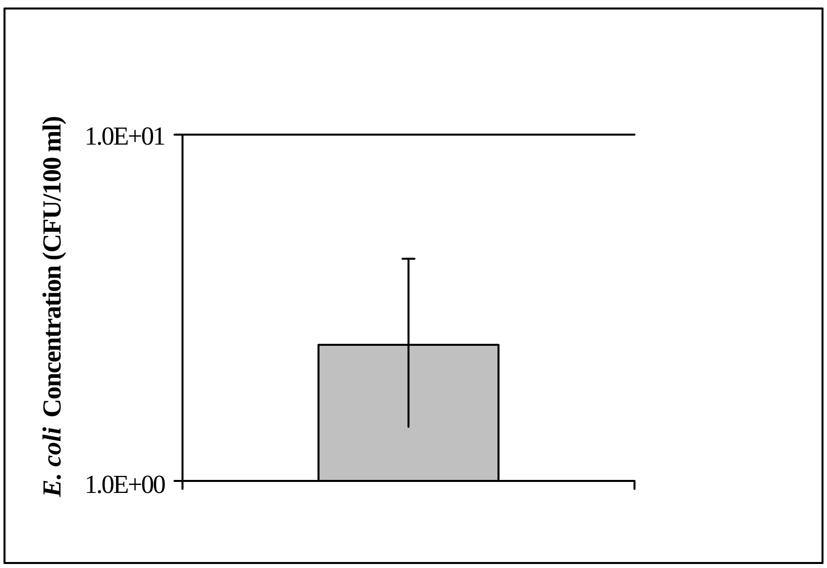

Figure 4-6. Mean Treated Sample Concentration for Bacterial Challenge Test with One Pentaiodide Resin Tank

Enumerations for the four positive control samples demonstrate that *E. coli* was recovered at a log-average concentration of 2.2 x 10^7 CFU/100 mL. Enumerations for the six treated samples indicate an average of 2.5 CFU/100 mL. Using these figures, the log removal of *E. coli* is calculated below.

$$\text{log removal of } E.\ coli = \log_{10}\left[\frac{(CFU/100mL)_{feedwater}}{(CFU/100mL)_{effluent}}\right]$$

$$\text{log removal of } \textit{E. coli} = \log_{10}\left[\frac{2.2x10^{7}\, CFU/100mL}{2.5x10^{0}\, CFU/100mL}\right]$$

log removal of *E. coli* = 6.9

<u>Bacterial Challenge Test Results for Two Pentaiodide Resin Tanks</u>

The *E. coli* enumeration of the positive control samples for the two pentaiodide resin tank test ranged from 1.4 x 10^7 CFUs/100 mL to 2.0 x 10^7 CFUs/100 mL with an average of 1.7 x 10^7 CFUs/100 mL. The 95 percent confidence interval bounding positive control enumeration is 1.4 x 10^7 CFUs/100 mL to 1.9 x 10^7 CFUs/100 mL with three degrees of freedom. Figure 4-7 is a graphic portrayal of the positive control sample enumerations. Figure 4-8 shows the mean of the positive control enumerations. Additionally, the statistically calculated 95 percent confidence interval is displayed on Figure 4-8.

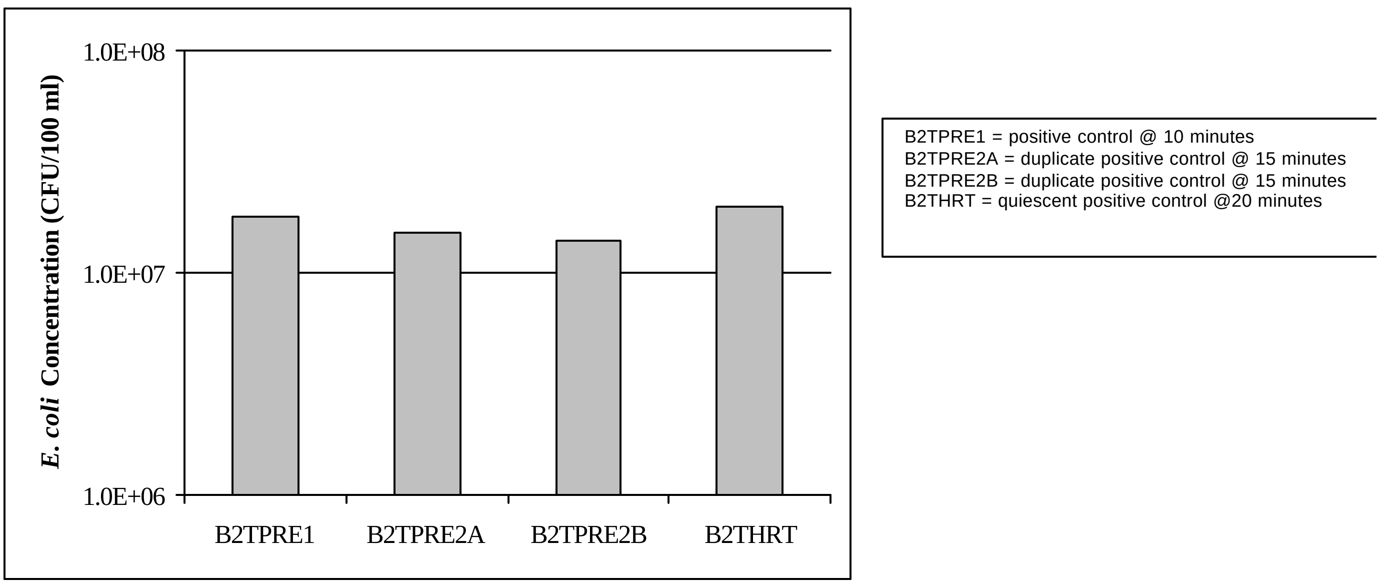

Figure 4-7. Positive Control Results for Bacterial Challenge Test with Two Pentaiodide Resin Tanks

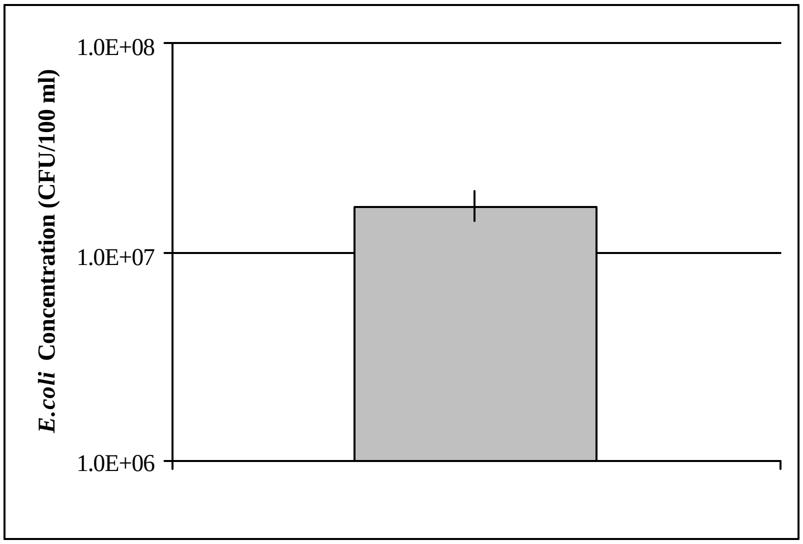

Figure 4-8. Mean Positive Control Concentration for Bacterial Challenge Test with Two Pentaiodide Resin Tanks

ARCADIS also statistically analyzed the *E. coli* concentration results for the treated, two pentaiodide resin tank challenge test to evaluate the log reduction. The individual results for *E. coli* enumeration of the effluent samples collected from Contact Tank 2 ranged from 1 CFU/100 mL to 250 CFU/100 mL. The average of this range is 8.2 CFU/100 mL. The 95 percent confidence interval bounding positive control enumeration is 1.6 CFUs/100 mL to 42 CFUs/100 mL with six degrees of freedom. Figure 4-9 is a graphic portrayal of the treated sample enumerations for the two pentaiodide tank challenge test. Figure 4-10 shows the mean of the positive control enumerations. Additionally, the statistically calculated 95 percent confidence interval is displayed on Figure 4-10.

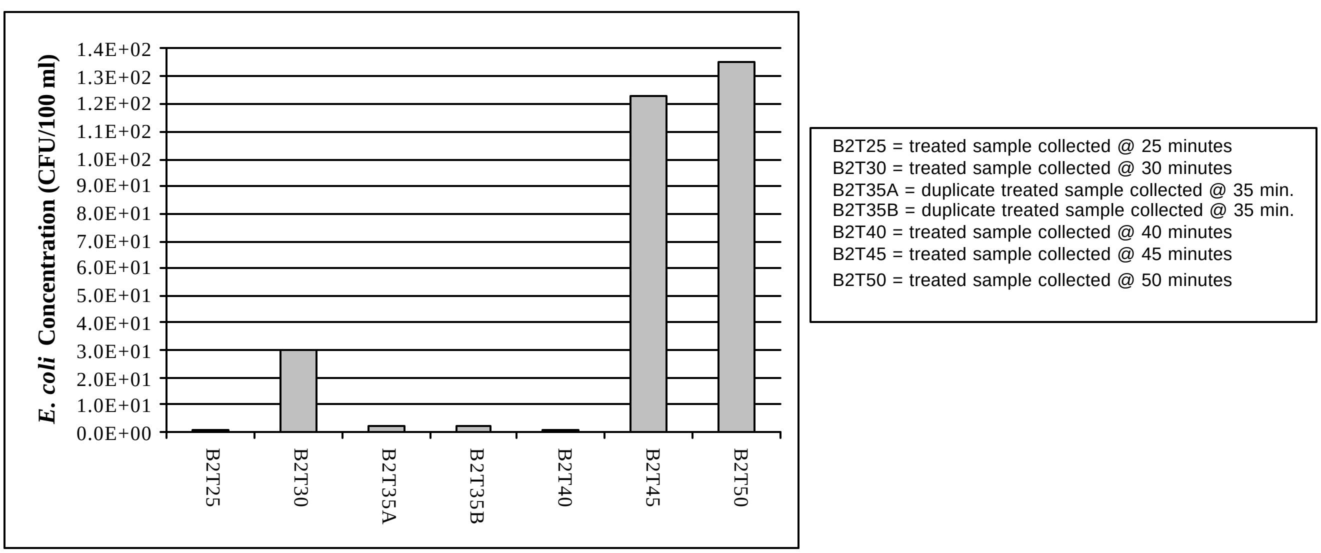

Figure 4-9. Treated Sample Results for Bacterial Challenge Test with Two Pentaiodide Resin Tanks

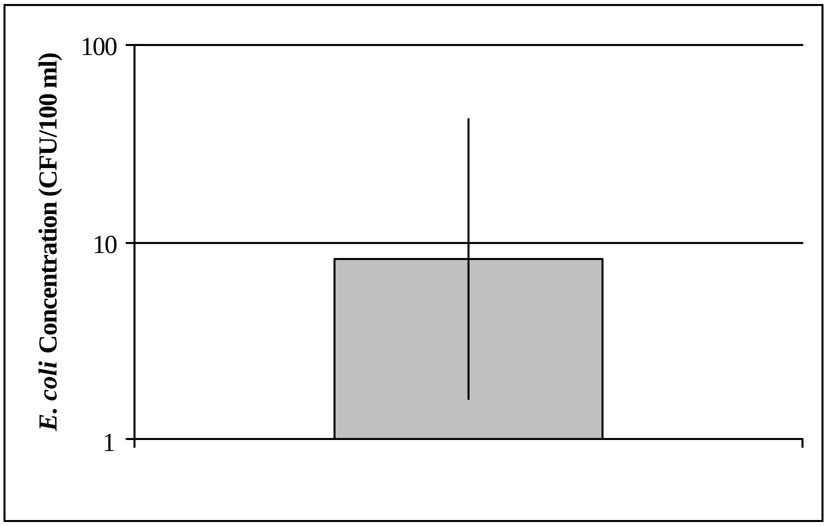

Figure 4-10. Mean Treated Sample Concentration for Bacterial Challenge Test with Two Pentaiodide Resin Tanks

Enumerations for the four positive control samples demonstrate that *E. coli* was recovered at an average concentration of 1.7 x 10^7 CFU/100 mL. Enumeration of the six treated samples indicates an average of 8.2 CFU/100 mL. Using these figures, the log removal of *E. coli* is calculated below.

$$\text{log removal of } E.\ coli = \log_{10}\left[\frac{(CFU/100mL)_{feedwater}}{(CFU/100mL)_{effluent}}\right]$$

$$\text{log removal of } E.\ coli = \log_{10}\left[\frac{1.7x10^{7}\,CFU/100mL}{8.2x10^{0}\,CFU/100mL}\right]$$

log removal of *E. coli* = 6.3

Viral Challenge Test Results for One Pentaiodide Resin Tank

The MS-2 enumeration of positive control samples for the one pentaiodide resin tank test ranged from 1.5 x 10^7 PFU/mL to 1.3 x 10^9 PFU/mL with an average of 1.6 x 10^8 PFU/mL. The 95 percent confidence interval bounding positive control enumeration is 1.2 x 10^7 PFU/mL to 2.0 x 10^9 PFU/mL with two degrees of freedom. Figure 4-11 is a graphic portrayal of the positive control sample enumerations. Figure 4-12 shows the mean of the positive control enumerations. Additionally, the statistically calculated 95 percent confidence interval is displayed on Figure 4-12.

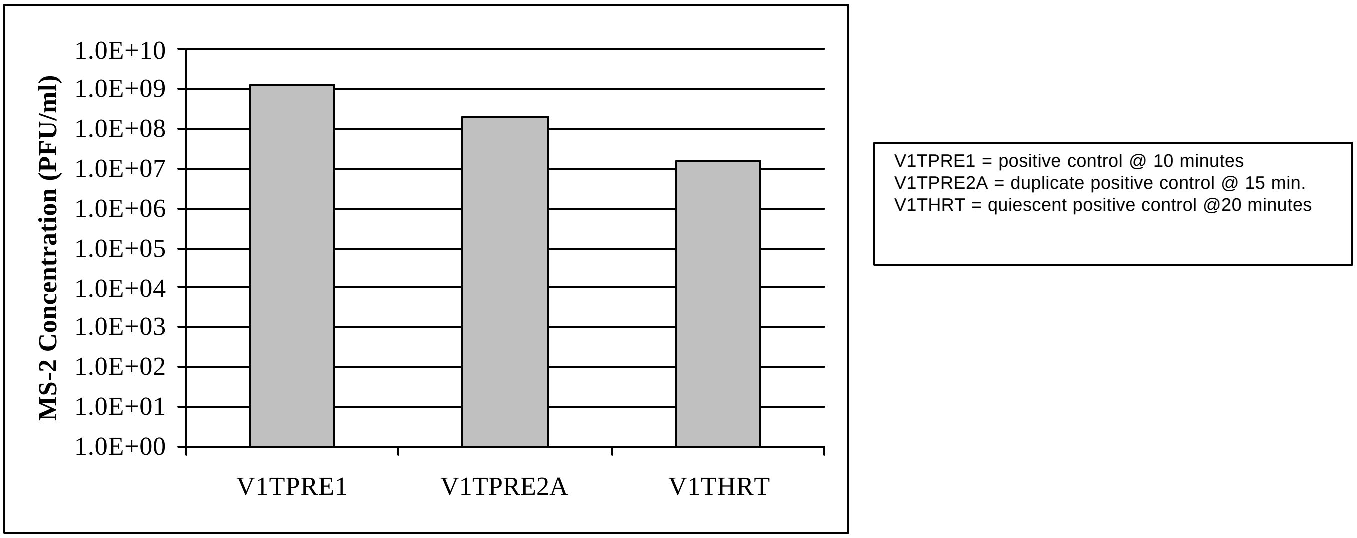

Figure 4-11. Positive Control Results for Viral Challenge Test with One Pentaiodide Resin Tank

ARCADIS statistically analyzed the MS-2 concentration results for the treated, one pentaiodide resin tank challenge test to evaluate the efficacy in MS-2 disinfection. The MS-2 enumeration of the treated samples ranged from 1.5 x 10^2 PFU/mL to 4.4 x 10^7 PFU/mL. The average of this range is 4.3 x 10^4 PFU/mL. The 95 percent confidence interval bounding positive control enumeration is 1.6 x 10^3 PFU/mL to 1.2 x 10^6 PFU/mL with six degrees of freedom. Figure 4-13 is a graphic portrayal of the treated sample enumerations for the one pentaiodide tank challenge test. Figure 4-14 shows the mean of the positive control enumerations. Additionally, the statistically calculated 95 percent confidence interval is displayed on Figure 4-14.

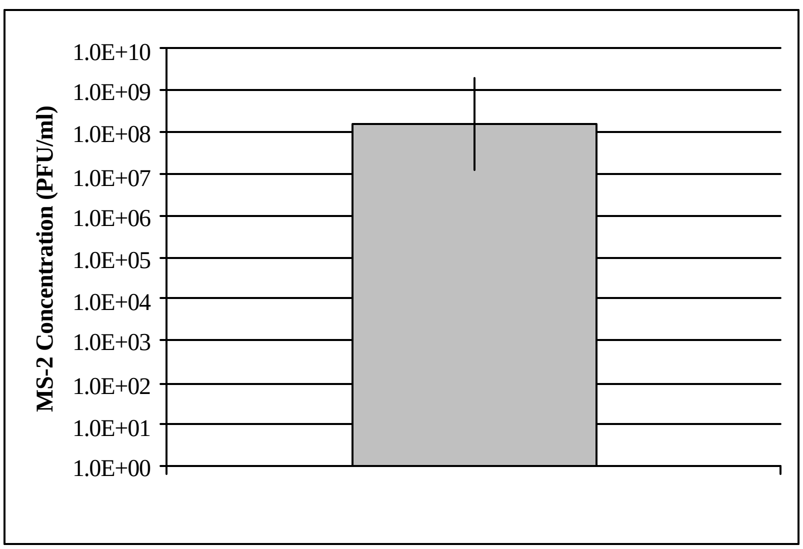

Figure 4-12. Mean Positive Control Concentration for Viral Challenge Test with One Pentaiodide Resin Tank

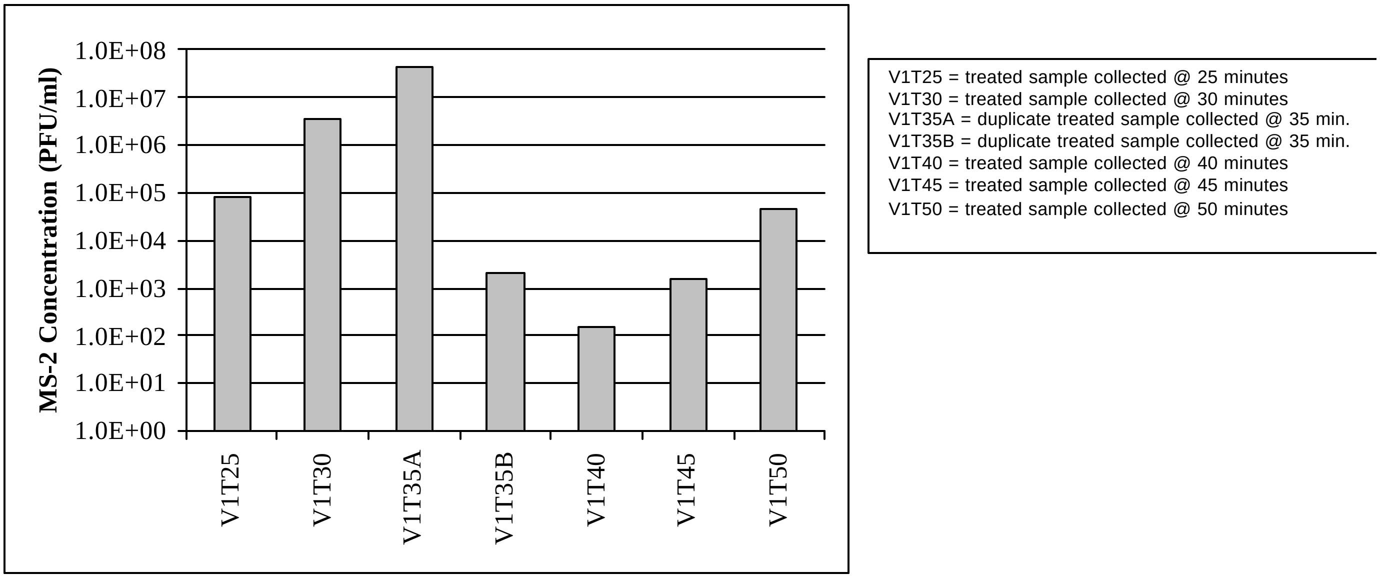

Figure 4-13. Treated Sample Results for Viral Challenge Test with One Pentaiodide Resin Tank

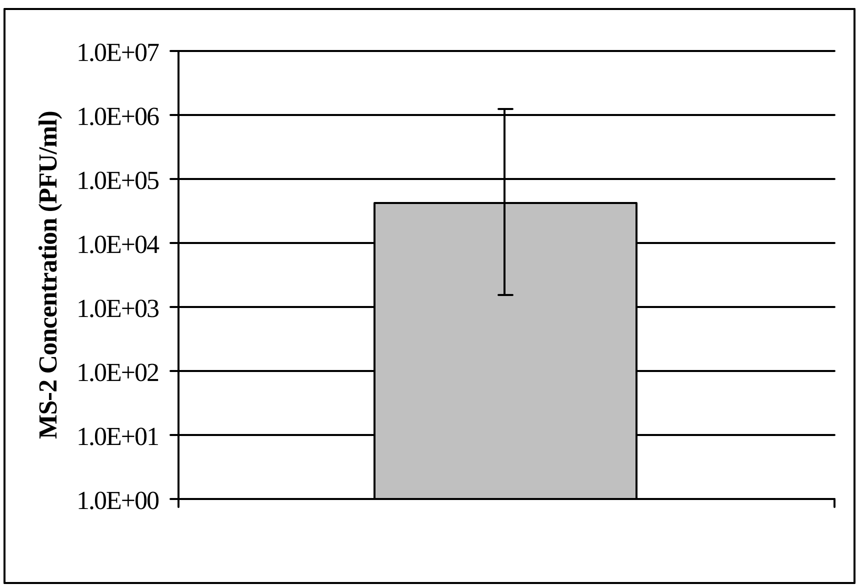

Figure 4-14. Mean Treated Sample Concentration for Viral Challenge Test with One Pentaiodide Resin Tank

Enumerations for the three positive control samples demonstrate that MS-2 was recovered at a log-average concentration of 1.6×10^8 PFU/mL. Enumeration of the seven treated samples reveals an average of 4.3×10^4 PFU/mL. Using these figures, the log removal of MS-2 is calculated below.

$$\text{log removal of MS-2} = \log_{10}\left[\frac{\left(PFU/ml\right)_{feedwater}}{\left(PFU/ml\right)_{effluent}}\right]$$

log removal of MS-2 = $\log_{10}\left[\frac{1.6x10^{8}PFU/ml}{4.3x10^{4}PFU/ml}\right]$

log removal of MS-2 = 3.6

Viral Challenge Test Results for Two Pentaiodide Resin Tanks

The MS-2 enumeration of the positive control samples for the two pentaiodide resin tank test ranged from 5.0 x 10^5 PFU/mL to 7.0 x 10^6 PFU/mL with an average of 1.8 x 10^6 PFU/mL. The 95 percent confidence interval bounding positive control enumeration is 5.6 x 10^5 PFU/mL to 6.0 x 10^6 PFU/mL with three degrees of freedom. Figure 4-15 is a graphic portrayal of the positive control sample enumerations. Figure 4-16 shows the mean of the positive control enumerations. Additionally, the statistically calculated 95 percent confidence interval is displayed on Figure 4-16.

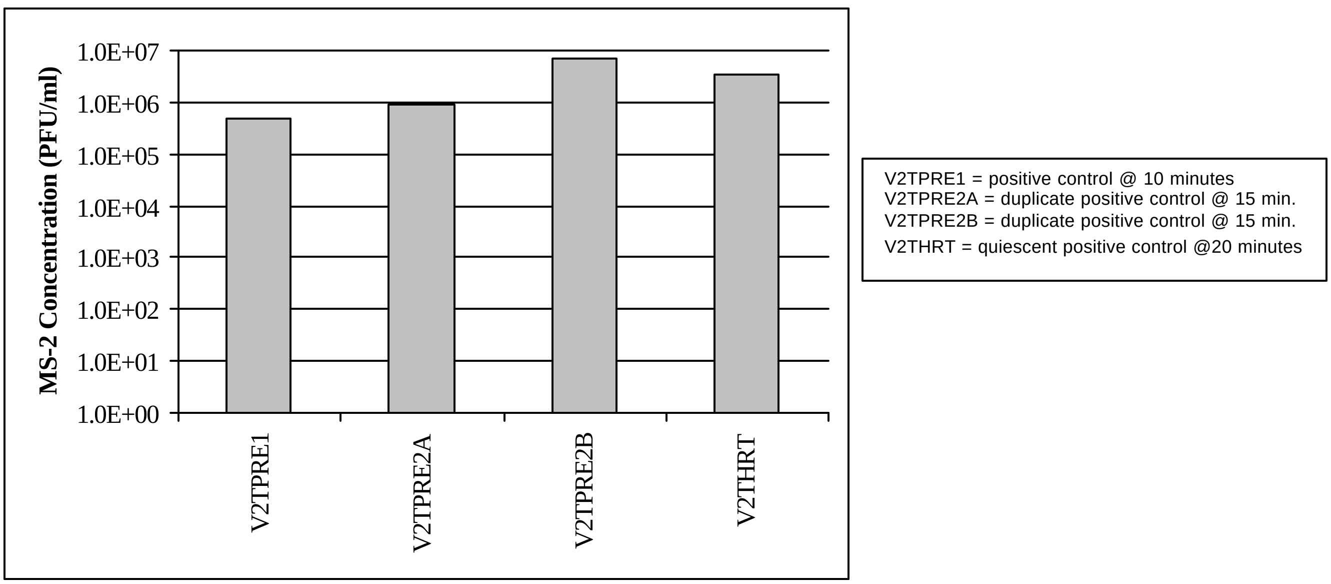

Figure 4-15. Positive Control Results for Viral Challenge Test with Two Pentaiodide Resin Tanks

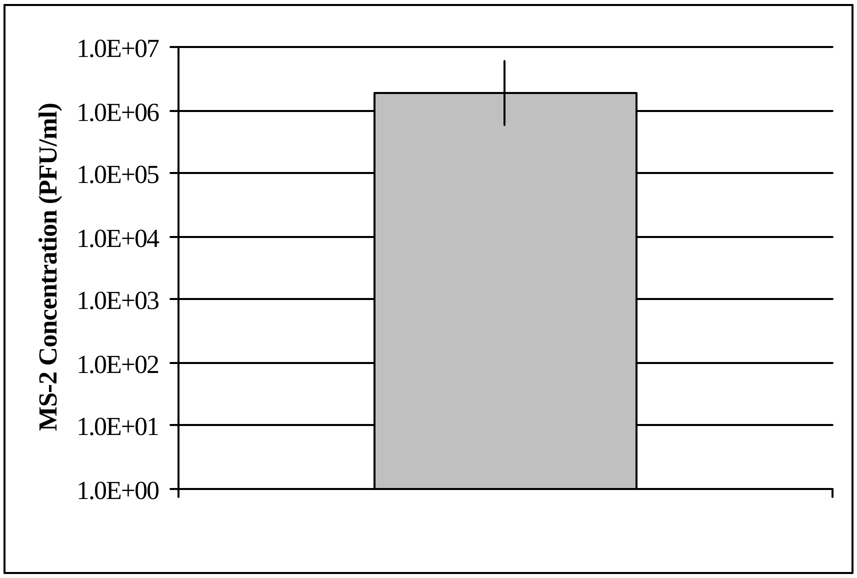

Figure 4-16. Mean Positive Control Concentration for Viral Challenge Test with Two Pentaiodide Resin Tanks

ARCADIS also statistically analyzed the MS-2 concentration results for the treated, two pentaiodide resin tank challenge test to evaluate the MS-2 disinfection efficiency. The MS-2 enumeration of the treated samples ranged from 1.4 PFU/mL to 1.4 x 10^7 PFU/mL. The average of this range is 1.1 x 10^3 PFU/mL. The 95 percent confidence interval bounding positive control enumeration is 23 PFU/mL to 5.4 x 10^4 PFU/mL with five degrees of freedom. Figure 4-17 is a graphic portrayal of the treated sample enumerations for the two pentaiodide tank challenge test. Figure 4-18 shows the mean of the positive control enumerations. Additionally, the statistically calculated 95 percent confidence interval is displayed on Figure 4-18.

Enumerations for the four positive control samples demonstrate that MS-2 was recovered at a log-average concentration of 1.8 x 10^6 PFU/mL. Enumeration of the six treated samples provides an average of 1.1 x 10^3 PFU/mL. The log removal of MS-2 is calculated below.

$$\text{log removal of MS-2} = \log_{10}\left[\frac{\left(PFU/ml\right)_{feedwater}}{\left(PFU/ml\right)_{effluent}}\right]$$

$$\text{log removal of MS-2} = \log_{10}\left[\frac{1.8x10^6 PFU/ml}{1.1x10^3 PFU/ml}\right]$$

log removal of MS-2= 3.2

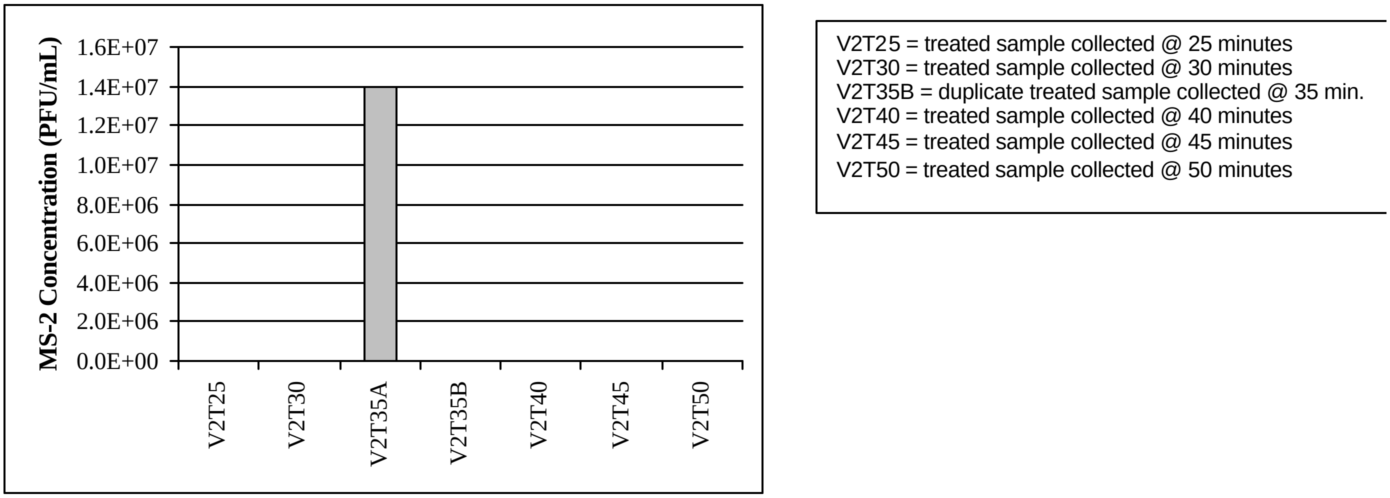

Figure 4-17. Treated Sample Results for Viral Challenge Test with Two Pentaiodide Resin Tanks

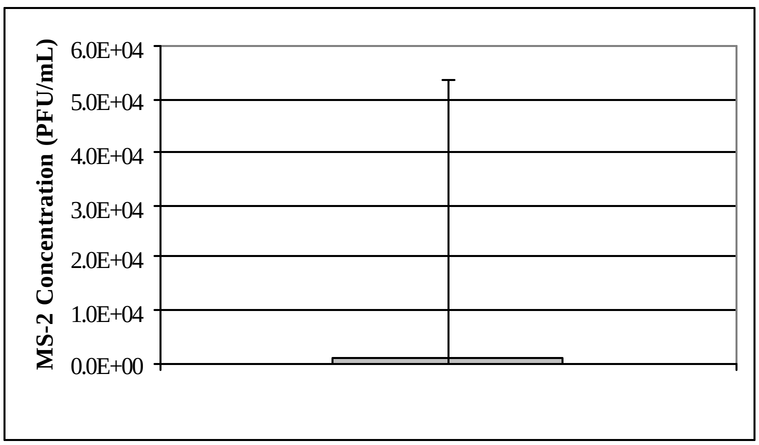

Figure 4-18. Mean Treated Sample Concentration for Viral Challenge Test with Two Pentaiodide Resin Tanks

<u>Challenge Test Conclusions</u>

As demonstrated, the PentaPure H-3000-I proved highly effective with regard to bacterial disinfection. The one and two pentaiodide resin tank *E. coli* challenge tests demonstrated a 6.9-log kill and a 6.3-log kill respectively. Figure 4-5 illustrates that treatment with one pentaiodide resin tank consistently disinfected the water being treated with all analytical results being within one order of magnitude and nearly rendered the water free of viable *E. coli* cells. Figure 4-9 shows the results of treatment through two pentaiodide resin tanks which would increase the HRT beyond that experienced by the water in the one pentaiodide resin tank challenge test. The *E. coli* enumeration results for this two pentaiodide resin tank test were more variable than the one tank results with the enumeration values spanning 3 orders of magnitude.

The one and two pentaiodide resin tank MS-2 challenge tests demonstrated a 3.6-log kill and a 3.2-log kill respectively. Considerable variability in the MS-2 concentrations in the disinfected water was seen in both the one and two pentaiodide resin tank viral challenge tests. The one pentaiodide resin tank test resulted in MS-2 enumerations spanning seven orders of magnitude.

The two pentaiodide resin tank test resulted in MS-2 enumerations spanning six orders of magnitude.

4.4 Treated Water Quality (Task 3)

This section presents results for water quality data that were collected during the test. Results of on-site sampling for raw, disinfected, and treated are reflected in Table 4-8.

Table 4-8. Water Quality Sampling Results

Sample	Units	Average	St. Dev.	Sample size	Min.	Max.	95% conf. Int. Min.	95% conf. Int. Max.
Iodine, Raw	mg/l	0.019	0.041	31	0.000	0.220	0.004	0.033
Iodine, Disinfected	mg/l	1.549	0.849	60	0.400	4.276	1.334	1.764
Iodine, Treated	mg/l	0.020	0.048	60	0.000	0.335	0.008	0.033
Iodine, Disinf. Backwash	mg/l	0.400	0.273	4	0.015	0.601	0.133	0.667
Iodide, Raw	mg/l	0.019	0.038	30	0.000	0.199	0.006	0.033
Iodide, Disinfected	mg/l	2.315	1.117	58	0.814	6.00	2.028	2.603
Iodide, Treated	mg/l	0.911	0.496	59	0.198	2.406	0.784	1.037
Iodide, Disinf. Backwash	mg/l	0.670	0.501	4	0.020	1.185	0.178	1.161
pH, Raw		7.05	0.21	30	6.17	7.41	6.97	7.13
pH, Pre-Filtered		6.99	0.46	14	6.32	8.37	6.75	7.23
pH, Disinfected		6.91	0.34	13	6.39	7.83	6.73	7.09
pH, Treated		6.92	0.20	31	6.41	7.31	6.85	6.99
pH, Backwash		7.03	0.14	4	6.84	7.14	6.90	7.16
Alkalinity, Raw	mg/l	21	7	6	15	33	15	26
Alkalinity, Treated	mg/l	15	3	6	11	19	13	18
Alkalinity, Backwash	mg/l	17	2	3	16	19	16	19
Temperature, Raw	°C	23	2	29	18	26.5	22	24
Temperature, Treated	°C	23	2	29	18	26.5	22	24
Temperature, Backwash	°C	21	3	4	18	23.2	18	23
Turb (grab), Raw	NTU	13.93	17.25	31	4.86	78.3	7.86	20.00
Turb (grab), Pre-Filtered	NTU	1.19	1.79	31	0.11	8.13	0.56	1.82
Turb (grab), Disinfected	NTU	1.02	1.45	31	0.084	5.39	0.50	1.53
Turb (grab), Treated	NTU	1.02	1.57	31	0.072	6.10	0.47	1.58
Turb (in-line), Disinfected	NTU	1.12	1.69	26	0.143	6.33	0.48	1.77
Turb (grab), Backwash	NTU	2.68	1.83	4	1.28	5.18	0.89	4.47
Total Coliforms, Raw	#/100 mL	840	677	25	0	3,100	556	1,098
Total Coliforms, Treated	#/100 mL	0	n/a	26	0	0	n/a	n/a
HPC, Raw	#/mL	1,926	1,517	23	124	7,020	1,306	2,546
HPC, Treated	#/mL	62	55	22	<30	250	39	85
H2S, Raw	µg/l	1.4	n/a	3	<0.1	4	n/a	n/a
TDS, Raw*	mg/l	64	n/a	1	n/a	n/a	n/a	n/a
TDS, Treated*	mg/l	88	n/a	1	n/a	n/a	n/a	n/a
TDS, Backwash	mg/l	68	n/a	2	64	72	n/a	n/a

n/a = not applicable.
* Two suspect, outlying raw water TDS values and one treated water TDS value dropped.

Because the PentaPure H-3000-I system uses a pentaiodide resin for disinfection, it was of interest to analyze iodine and iodide concentrations in the raw and treated water, as well as in the disinfected (pre-carbon filter) water. As a result of disinfection, the iodine concentration in the disinfected (semi-treated) water increased from 0.019 mg/L to 1.549 mg/L. However, all of this iodine was removed again in the post disinfection carbon filters. The final treated water concentration was 0.020 (standard deviation 0.048) mg/L, practically equal to the raw water concentration. The carbon filters were not as successful at removing iodide ions. The concentration in the water increased from 0.019 mg/L to 2.315 mg/L in the disinfected water, to drop to 0.929 (standard deviation 0.496) mg/L in the treated water. Iodine and iodide concentrations in the backwash were 0.400 and 0.670 mg/L respectively.

The PentaPure H-3000-I operated in an outdoor environment and had no apparent effect on the temperature of the water. The turbidity of the raw river water was effectively reduced by the coagulation/filtration step. Average raw water turbidity was 13.93 (standard deviation 17.25) NTU with a maximum value of 78.3 NTU. Average pre-filtered (post-coagulation) turbidity was 1.19 (standard deviation 1.79) NTU. TDS data was inconclusive as sampling and analytical problems were suspected causes of invalid, unused readings. In general, it did not appear that the unit, nor its backwash, had an effect on TDS.

The PentaPure unit had little effect on pH, but did reduce the alkalinity of the water somewhat. The raw water alkalinity was 21 (standard deviation 7) mg/L, whereas the treated water alkalinity was 15 (standard deviation 3) mg/L. The alkalinity of the disinfection column backwash was 17 mg/L. The pH of the backwash was 7.03.

As part of daily routine analysis, total coliforms were monitored and heterotrophic plate counts (HPC) were conducted for raw and treated water. The PentaPure unit was particularly effective in the removal of total coliforms with all treated water samples being below the detection limit of 20 CFU/100 mL. Using the value of 20, the log removal rate for total coliforms was at least 1.6. The log removal rate for HPC organisms was 1.5.

Table 4-9 includes data for samples that were analyzed off-site by EHL. According to this table, the PentaPure H-3000-I performed well in removing aluminum and performance was fair for removal of manganese. All measured aluminum and manganese[1] concentrations in the treated water were below 11 and 100 µg/L respectively. Also, iron was removed effectively by the unit, from 1.5 mg/L in the raw water down to 0.3 mg/L in treated water. The maximum raw water iron concentration was 2.8 mg/L, which was well below the 15 mg/L maximum, as specified by the vendor for the PentaPure unit. Because the PentaPure system uses silver-impregnated activated carbon for residual iodide removal, trace amounts of silver were detected in the treated water (0.3 µg/L with a standard deviation of 0.2 µg/L). The unit had a slightly lowering effect on true color and no apparent effect on UVA. Ammonia nitrogen was not detected in the raw water, nor in the treated water.

Only one sample each of raw and treated water was analyzed for TOC, chloride, bromide, and sodium. Based on this limited data set, the PentaPure unit had no effect on chloride and

[1] According to the vendor, manganese may interfere with the disinfection capabilities of the unit. The vendor-specified maximum limit for manganese in raw water is 5,000 µg/L.

bromide. The unit lowered the TOC loading from 2.2 mg/L to 1.1 mg/L and the sodium concentration was increased from 1.7 mg/L to 3.9 mg/L.

Table 4-9. Results of Off-Site Chemical Analysis

Parameter	Unit	Average	Stdev	Sample size	Min.	Max.	95% Conf. Int. Min.	95% Conf. Int. Max.
Aluminum, Raw	µg/l	660	675	3	79	1400	0	1423
Aluminum, Treated	µg/l	10	n/a	2	8.1	11	n/a	n/a
Manganese, Raw	µg/l	118	13	5	101	130	107	129
Manganese, Treated	µg/l	55	37	5	9.7	98	22	87
Silver, Treated	µg/l	0.3	0.2	5	<0.2	0.6	0.1	0.5
True Color, Raw	Pt/Co u	11	6	4	5	20	5	17
True Color, Treated	Pt/Co u	6	3	4	<5	10	4	9
Iron, Raw	mg/l	1.5	1.1	5	<0.1	2.8	0.5	2.5
Iron, Treated	mg/l	0.3	0.4	5	<0.1	1.1	0	0.7
Ammonia Nitrogen, Raw	mg/l	<0.3	n/a	4	<0.3	<0.3	n/a	n/a
Ammonia Nitrogen, Treated	mg/l	<0.3	n/a	4	<0.3	<0.3	n/a	n/a
UVA (UV 254), Raw	1/cm	0.028	0.005	4	0.022	0.034	0.023	0.033
UVA (UV 254), Treated	1/cm	0.025	0.012	4	0.012	0.21	0.013	0.036
TOC, Raw	mg/l	2.2	n/a	1	n/a	n/a	n/a	n/a
TOC, Treated	mg/l	1.1	n/a	1	n/a	n/a	n/a	n/a
Chloride, Raw	mg/l	3.4	n/a	1	n/a	n/a	n/a	n/a
Chloride, Treated	mg/l	5.0	n/a	1	n/a	n/a	n/a	n/a
Bromide, Raw	µg/l	27	n/a	1	n/a	n/a	n/a	n/a
Bromide, Treated	µg/l	27	n/a	1	n/a	n/a	n/a	n/a
Sodium, Raw	mg/l	1.7	n/a	1	n/a	n/a	n/a	n/a
Sodium, Treated	mg/l	3.9	n/a	1	n/a	n/a	n/a	n/a
Metals Backwash								
Antimony	µg/l	<0.2	n/a	1	n/a	n/a	n/a	n/a
Arsenic	µg/l	1.5	n/a	1	n/a	n/a	n/a	n/a
Barium	µg/l	13	n/a	1	n/a	n/a	n/a	n/a
Beryllium	µg/l	<0.2	n/a	1	n/a	n/a	n/a	n/a
Cadmium	µg/l	<0.2	n/a	1	n/a	n/a	n/a	n/a
Chromium	µg/l	0.5	n/a	1	n/a	n/a	n/a	n/a
Copper	µg/l	6.3	n/a	1	n/a	n/a	n/a	n/a
Lead	µg/l	<0.5	n/a	1	n/a	n/a	n/a	n/a
Mercury	µg/l	<0.50	n/a	1	n/a	n/a	n/a	n/a
Nickel	µg/l	1.2	n/a	1	n/a	n/a	n/a	n/a
Selenium	µg/l	<2.0	n/a	1	n/a	n/a	n/a	n/a
Silver	µg/l	<2.0	n/a	1	n/a	n/a	n/a	n/a
Thallium	µg/l	0.4	n/a	1	n/a	n/a	n/a	n/a
Zinc	µg/l	2.8	n/a	1	n/a	n/a	n/a	n/a

For statistical calculations: "<x" values entered as "x".
n/a = not applicable because sample size is too small.

In addition, single samples were taken to analyze metals concentration in the disinfection column backwash. Samples for antimony, beryllium, cadmium, lead, mercury, selenium, and silver were all below the detection limits. As indicated in Table 4-9, arsenic, barium, cadmium, copper, nickel, thallium, and zinc were detected in the backwash stream. Barium and copper had the highest concentrations and were 13 and 6.3 µg/L respectively.

Eight total trihalomethanes (TTHMs) and 12 haloacetic acids (HAAs) were also analyzed as part of the ETV test project as a one-time event and the results are included in Table 4-10. All analytes registered below the detection limits except for chloroform in the treated water (0.8 µg/L). Because the PentaPure technology uses or produces no chlorine, simulated distributed system testing was not performed.

Table 4-10. TTHMs and HAAs

Parameter	Concentration (µg/L)
TTHMs	
Bromodichloromethane, Raw	<0.1
Bromodichloromethane, Treated	<0.1
Chloroform, Raw	<0.1
Chloroform, Treated	0.8
Bromoform, Raw	<0.1
Bromoform, Treated	<0.1
Dibromochloromethane, Raw	<0.1
Dibromochloromethane, Treated	<0.1
HAAs	
Bromochloroacetic acid, Raw	<1.0
Bromochloroacetic acid, Treated	<1.0
Dibromoacetic acid, Raw	<1.0
Dibromoacetic acid, Treated	<1.0
Dichloroacetic acid, Raw	<1.0
Dichloroacetic acid, Treated	<1.0
Monobromoacetic acid, Raw	<1.0
Monobromoacetic acid, Fin.	<1.0
Monochloroacetic acid, Raw	<2.0
Monochloroacetic acid, Fin.	<2.0
Trichloroacetic acid, Raw	<1.0
Trichloroacetic acid, Treated	<1.0

Chapter 5
Quality Assurance

5.1 Calculation of DQI Goals

Table 5-1 shows the data quality indicator (DQI) goals established for accuracy and precision, as presented in the PentaPure FOD. Calculated DQIs for the majority of measurements made during the PentaPure demonstration are presented in Table 5-2. These DQIs were calculated using data from replicate analysis of laboratory or field QA/QC checks for each parameter. Obtained values represent the average of all replicate measurements. The number of replicates for each parameter is shown in parentheses. Accuracy was assessed by calculating recovery of spikes or surrogates or by calculating the bias from an obtained value compared to a known standard. Precision is expressed as percent relative standard deviation (RSD) and is calculated by dividing the standard deviation of replicate measurements by the mean. The 95 percent confidence intervals have also been calculated for data sets that contained at least three replicate measurements. It can be seen in Table 5-2 that DQI goals were met for iron, ammonia-nitrogen, sodium, bromide, chloride, TOC, manganese, aluminum, silver, turbidity, and color measurements. Average iodide recoveries for the 2 mg/L standard were slightly below the 85% recovery goal at 82.5%. The precision goal of 20% for iodine measurements was slightly exceeded with an average of 21%. This average is elevated due to one daily calibration check that was not within acceptable range and was not repeated. One interpretation of the iodide QA/QC data would result in the conclusion that iodide was underestimated in the treated effluent during the latter portion of the verification interval from 8/21/00 through the completion of the verification interval due to decline in the sensitivity of the analytical method being employed. Measurements not included in Table 5-2 are discussed later in this section.

Table 5-1. Data Quality Indicator Goals for Planned Measurements

Parameter	Method	Accuracy	Precision (%RPD)
Flow Rates	Flow controllers	± 2 g/min	N/A
pH	SM 4500 H	± 0.1 pH unit	Not listed
Temperature	SM 2550B	N/A	10
Raw Water Turbidity	SM 2130B	80-120% Rec.	25
Hydrogen sulfide	SM 4500-S2-A4c	90-110% Rec.	50
Alkalinity	SM 2320B	75-120% Rec.	30
Total dissolved solids	SM 2540C	80-120% Rec.	25
Ammonia-N	SM 4500-NH3 G	80-120% Rec.	25
Iodine	SM 4500-I B	80-120% Rec.	20
Iodide	ASTM D3869	85-115% Rec.	15
Total organic carbon	SM 5310C	80-120% Rec.	25
Color	SM 2120B	N/A	20
Iron	EPA Method 236.1	85-115% Rec.	20
Manganese	EPA Method 200.8	85-115% Rec.	20
Aluminum	EPA Method 200.8	90-110% Rec.	30
Silver	EPA Method 200.8	90-110% Rec.	30
Sodium	EPA Method 273.1	85-115% Rec.	20
Bromide	EPA Method 300	90-110% Rec.	20
Chloride	EPA Method 300	90-110% Rec.	20
Total coliform	SM 9222B	N/A	200
HPC bacteria	SM 9215B	N/A	N/A
TTHMs	EPA Method 524.2	70-130% Rec.	40
HAAs	EPA Method 552.1	70-130%	40

Table 5-2. Calculated DQIs for Obtained Measurements

Analyte	Actual Conc.	Avg. Obtained (# points)	Recovery/Bias* (Average %)	Precision (%RSD)	95% Conf. Interval
Iodine	1 mg/L	0.996 (8)	99.6	21	0.18
Iodide	1 mg/L	0.88 (6)	88	8	0.08
	2 mg/L	1.65 (5)	82.5	7.9	0.16
Iron	2.5 mg/L	2.51 (17)	100.4	2.4	0.03
Ammonia-N	5 mg/L	4.91 (6)	98.2	4.3	0.22
Sodium	2 mg/L	2.08 (5)	104	2.9	0.08
Bromide	100 ug/L	97.4 (3)	97.4	1.7	4.1
	250 ug/L	237.17 (3)	94.9	0.7	4.3
Chloride	25 mg/L	25.6 (3)	102.2	1.7	1.1
Total Organic Carbon	10 mg/L	10.88 (1)	108.8	N/A	N/A
Manganese	50 ug/L	49.9 (12)	99.8	4.7	1.5
Aluminum	50 ug/L	47.3 (9)	94.6	3.6	1.3
Silver	50 ug/L	50.5 (12)	101	3.3	1.1
Turbidity	1.43 NTU	1.44 (17)	100.7	0.9	0.007
	17.2 NTU	17.3 (8)	100.6	0.7	0.1
Color	5.0 Pt/Co	5.0 (2)	100	0	N/A

* - Indicates that the result is "Bias"

Performance of instrumentation used to measure flow, pH and temperature were confirmed daily with known standards or NIST-certified equipment. These confirmations were noted on daily log sheets. In addition to the metals included in Table 5-2, the laboratory performed an EPA Method 200.8 analysis on samples for chromium, nickel, zinc, cadmium, antimony, barium, lead and aluminum concentration. All recoveries of surrogates for these analyses ranged from 93-106.7 percent.

Table 5-3 presents the TTHM recovery results from QC checks performed by the laboratory on analysis days. Surrogate recoveries from samples spiked by EHL prior to sample analysis by EPA Method 524.2 ranged from 84.7 to 109.2%. The surrogate standards are purchased by EHL from AccuStandard, Inc. Representative Certificates of Analysis for the surrogate standards have been provided by EHL and are included in Appendix E. Acceptance criteria for QC checks and surrogate recoveries established in the method are 70-130 percent. All compounds met the acceptance criteria.

Table 5-3. Trihalomethane Recoveries (70-130% criteria)

Date	Spiked Conc. (ug/L)	Bromodichloromethane Obtained	Bromodichloromethane %Rec	Bromoform Obtained	Bromoform %Rec	Chloroform Obtained	Chloroform %Rec	Dibromochloromethane Obtained	Dibromochloromethane %Rec
10/17	5	5.52	110.4	5.29	105.7	5.92	118.4	5.65	113.0
10/17	10	9.38	93.8	9.33	93.3	9.68	96.8	9.39	93.9

Table 5-4 shows the HAA recoveries of a 20 µg/L standard analyzed by EPA Method 552.2. Acceptance criteria are established as 70-130 percent. All compounds fell within the acceptance criteria for this analysis except trichloroacetic acid analyzed on 10/03, which had a recovery value of 139.7%. A surrogate standard (2-Bromopriopionic acid) is spiked in each sample prior to analysis and recoveries ranged from 79.6 to 88.5%. The acceptable recovery criteria for this surrogate compound are also 70-130 percent.

Table 5-4. Haloacetic Acid Recoveries for 20 ug/L Standard (70-130% criteria)

Sample Date	Bromochloro Acetic Acid Obtained	Bromochloro Acetic Acid %Rec	Dibromo Acetic Acid Obtained	Dibromo Acetic Acid %Rec	Dichloro Acetic Acid Obtained	Dichloro Acetic Acid %Rec
10/03	21.98	109.9	17.8	89.0	19.67	98.3
10/03	19.17	95.8	17.08	85.4	17.86	89.3

Sample Date	Monobromo Acetic Acid Obtained	Monobromo Acetic Acid %Rec	Monochloro Acetic Acid Obtained	Monochloro Acetic Acid %Rec	Trichloro Acetic Acid Obtained	Trichloro Acetic Acid %Rec
10/03	20.66	103.3	18.41	92.1	27.95	139.7
10/03	17.57	87.8	17.07	85.4	23.39	116.9

5.2 Blanks, Duplicates and Hold Times

Deionized water blank samples were submitted to EHL on 9/27/00 for analysis of manganese, iron, aluminum, silver, TOC, chloride, ammonia-nitrogen, and UVA. The SJWD laboratory also ran laboratory blanks as a part of their QA/QC procedures. Results from analysis of field and laboratory blanks did not indicate contamination problems for any analyte in this study.

EHL performed both positive and negative controls on the agar and filters used for the enumeration of *E. coli*. Growth was detected on the positive controls and the negative controls remained sterile. BioVir performed both positive and negative controls and on the bacterial host and the MS-2 phage.

Duplicate measurements were taken daily for iodine and iodide measurements. Duplicate samples were taken daily for iodine and iodide measurements. Relative Percent Difference (RPD) was calculated by dividing the difference between the duplicate measurements by the mean. There were 21 duplicate samples taken for iodine analysis. All but one measurement fell within the DQI goal of 20% (range 0 to 14%). The one measurement that did not meet acceptance criteria was slightly above 20% and was a sample at a very low concentration. There were 22 duplicate samples taken for iodide analysis and the percent difference was <2% in all cases.

For total coliform counts routine samples taken by SJWD were used as duplicates. SJWD samples were taken from the same raw water intake where water for the ETV test was taken. During the test, the same person collected raw water coliform samples for both SJWD and the PentaPure ETV verification project at the same time of day. ARCADIS chose four dates randomly (7/31/00, 8/4/00, 8/21/00, and 9/4/00) and compared the total coliform counts. Total Coliform counts for the SJWD routine samples ("duplicates") for these dates were 1,600 CFU/100 mL, 700 CFU/100 mL, 700 CFU/100 mL, and 700 CFU/100 mL; whereas total coliform counts for the PentaPure raw water samples were 1,600 CFU/100 mL, 1,600 CFU/100 mL, 950 CFU/100 mL, and 800 CFU/100 mL respectively. The RPDs for these comparisons ranged from 0 percent to 78 percent.

Hold times specified in the methods were met for all samples.

5.3 Daily and Bi-Weekly QA/QC Verifications

As indicated in the FOD, certain parameters associated with verification testing required daily or bi-weekly verification. Raw water flow rates were confirmed daily using a timed subtraction of flow totalizer readings. The totalizer used on the PentaPure H-3000-I is factory calibrated to +/- 1.5%. The totalizer manufacturer guarantees performance for 2 years or 2,100,000 gallons at +/- 5%. The flow rate to the turbidimeter was verified daily using a timed, volumetric collection method. A minimum of 200 mL/min flow to the turbidimeter is considered critical to assure accurate readings. The flow to the turbidimeter was verified on 26 out of 30 test days. On September 15, 2000, the flow rate to the turbidimeter fell to 165 mL/min. All other turbidimeter flow measurements exceeded 200 mL/min. This data can be found in Appendix C. In-line turbidimeter readings were compared on a daily basis to readings from a calibrated bench-top turbidimeter and recorded on the data sheets in Appendix C. Comparison data exists for 25 out of 30 test days. It is known within the drinking water industry that agreement between in-line and bench-top turbidimeters is problematic (personal communication with Doug Waldrop, SJWD). The Relative Percent Differences (RPDs) range from 1 percent to 124 percent. Tubing and piping were visually inspected on a daily basis. Repairs and troubleshooting required by the PentaPure-3000-I are noted in Table 4-1.

5.4 Internal Audits

Dr. Jane McLamarrah of ARCADIS performed an internal technical systems audit at the demonstration site on August 17, 2000. Results from the audit were reported to the ARCADIS Project Manager in an audit report, which is included in Appendix A. There were no major findings reported as a result of the on-site technical systems audit. There were some operational differences from the original FOD that have been noted on the checklist included in Appendix A (i.e., backflushing sequence). These modifications were made to reduce system failures and improve the overall operation of the system.

An internal data quality assessment was done on the raw field and laboratory data. QA/QC data supplied by the field crew and contract laboratories was reviewed and data quality indicators including accuracy and precision were calculated. Calibration curves were reviewed and calculation verified for at least 10 percent of all the analytical data. Laura Beach, ARCADIS QA Manager/Durham Office, performed this assessment.

Chapter 6
References

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