May 2002
NSF 02/03/EPADWCTR

Environmental Technology Verification Report

Inactivation of MS2 virus in Drinking Water

Trojan Technologies, Inc.
UVSwift Ultraviolet System
Model 4L12
Chula Vista, California

Prepared by

NSF International

Under a Cooperative Agreement with

U.S. Environmental Protection Agency

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**MEDIUM-PRESSURE ULTRAVIOLET RADIATION TECHNOLOGY USED IN DRINKING WATER TREATMENT**
APPLICATION:	**INACTIVATION OF MS2 VIRUS IN DRINKING WATER**
TECHNOLOGY NAME:	**UVSWIFT MODEL 4L12**
COMPANY:	**TROJAN TECHNOLOGIES INCORPORATED**
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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 Systems (DWS) Center, one of 12 technology areas under ETV. The DWS Center recently evaluated the performance of a medium-pressure ultraviolet radiation system used in drinking water treatment system applications. This verification statement provides a summary of the test results for the Trojan Technologies Inc. UVSwift

4L12 System. Montgomery Watson Harza (MWH), an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of the Trojan Technologies UVSwift 4L12 system was conducted over a 45 day period from 9/1/01 to 10/15/01. The feedwater to the ultraviolet (UV) unit during the testing was the effluent from the Otay Water Treatment Plant (OWTP), a conventional plant with flocculation, sedimentation, and dual-media filtration of Otay lake water. In the first part of the testing, a virus seeding experiment was conducted at a flow rate of 695 gpm, UV transmittance of 84%, and at 81% lamp power setting. During this experiment the log inactivation of virus ranged from 2.1 logs to 3.0 logs as shown in Table below:

Virus Seeding Summary

Parameter	Unit	Count	Median	Range	Average	Standard Deviation	95 Percent Confidence Interval
Feed MS2 conc.	pfu/100mL	9	7E+04	5E+04 - 1.1E+05	8E+04	2E+04	6E+04 - 9E+04
Effluent MS2 conc.	pfu/100mL	9	2E+02	1E+02 - 4E+02	2E+02	1E+02	1E+02 - 3E+02
Log Inactivation	logs	9	2.7	2.1 - 3.0	2.6	0.3	2.4 - 2.9

UV estimated effective dose using MS2 virus is used as an indicator to obtain the inactivation of other microorganisms such as Cryptosporidium and Giardia. A collimated beam test was performed using feed water collected during the seeding experiment and a dose-response curve generated to determine the UV sensitivity of the MS2 virus used as the seed stock during the flow-through reactor challenge study. The dose response curve determined that an effective dose of 42.8 mJ/cm^2 was necessary to achieve 2-log inactivation of MS2. The log inactivation achieved during the virus seeding experiment was between 2.1 and 3.0 logs corresponding to an equivalent dose between 40.3 and 67.6 mJ/cm^2 obtained from the collimated beam dose response curve. The reactor was operated for a period of more than 27 days at a flow rate of 400 gpm and 81% lamp power setting with daily cleaning. During the first 320 hours the following operating parameters were monitored regularly: flow rate, total flow, UV sensor readings, lamp cleaning frequency, lamp hours, lamp shut-down periods, lamp electric power consumption, operating pressure and headloss through the UV unit. Data indicate that the system can operate reliably under these testing conditions. Water quality data collected from both the UV feedwater and UV effluent included: temperature, pH, total alkalinity, hardness, total organic carbon (TOC), UV-254 absorbance, turbidity, true color, nitrate, iron, free chlorine, and total chlorine. No significant change in these water quality parameters was seen from the feed water to the effluent water. Heterotrophic Plate Count (HPC) and total coliforms were both below the detection limit in both the feed and effluent water. Continuous monitoring of the UV irradiance did not indicate a clear fouling trend during the testing period since the UV irradiance measured is a strong function of the UV transmittance of the water, which varied between 81% and 90% (field measurements). However, at the end of the testing period visual inspection of the lamp and sensor sleeves indicated that while the lamp sleeves were relatively clean, the sensor sleeve had fouled. A 7% increase in the UV irradiance was observed when the fouled sensor sleeve was replaced by a new sensor sleeve. Replacing the lamp sleeve caused no further improvement. The sensor was found to drift from 1.8% to 11% of the reference sensor reading during the testing period but handling of the sensor window was found to contribute to approximately half of the sensor drift.

TECHNOLOGY DESCRIPTION

The technology tested during the ETV was the Trojan UVSwift Model 4L12 UV System. The UVSwift system utilizes UV light to disinfect waterborne microorganisms and is designed specifically for municipal drinking water applications. UV light is capable of disinfecting waterborne organisms including viruses, bacteria and protozoa. UV light accomplishes disinfection by altering the genetic material of the microbes and thus eliminating their ability to reproduce and cause infection (Jagger, 1967). *Giardia* and *Cryptosporidium*, two waterborne pathogens that are relatively resistant to chemical disinfection, are particularly susceptible to UV disinfection (Bukhari et al, 1998). This makes the use of UV technology an attractive alternative for drinking water treatment, especially in cases where the potential for formation of disinfection by-products, from chemical disinfectants, is high. UV units are typically tested for proper performance using surrogate microbes such as MS2 virus. UV estimated effective dose using MS2 virus is used as an indicator to obtain the inactivation of other microorganisms such as *Cryptosporidium* and *Giardia*.

The UVSwift line of reactors utilizes a compact, inline design that allows retrofitting into existing pipe galleries in a minimum of space. The UVSwift is available in sizes compatible with 12-inch, 18-inch, 24-inch and 30-inch pipe. The unit tested during the ETV utilized 4 UV lamps, specified by "4L" in the model number, and had flanged fittings for inline mounting in 12-inch pipe. The UVSwift 4L12 uses 2.8 kilowatt medium pressure lamps, housed in quartz sleeves, that produce a spectrum of UV and visible light and operate at a typical surface temperature of 300 °C. The lamp pinch temperature can be as high as 500 °C. Trojan specifies the UVSwift to be mounted with at least 5 pipe diameters of straight pipe length before the unit and at least 3 pipe diameters after. This ensures a minimum of reactor turbulence created by upstream and downstream pipe components. The UVSwift system includes a proprietary flow-modifying baffle plate that mounts on the inlet to the reactor. To control lamp fouling, the UVSwift system includes an automated cleaning mechanism. The cleaning mechanism uses an NSF certified food-grade acid and food-grade rubber seals to loosen and remove lamp foulants. The cleaning mechanism can be set to run at regular intervals. The unit includes one UV irradiance sensor and one UV transmittance sensor to continuously monitor lamp fouling and changes in the UV transmittance of the influent water respectively. The UV irradiance sensor measures the output from one lamp and can be verified against a calibrated reference sensor. Both the sensors have an automated cleaning mechanism, operating on the same schedule as the UV lamps. The UV-254 transmittance sensor was not used during the ETV test. The control panel includes adjustment of UV lamp output to any of 16 power settings and includes readouts for the UV irradiance sensors.

VERIFICATION TESTING DESCRIPTION

Test Site

The verification test site was the City of San Diego's Aqua 2000 Research Center located at the Otay Water Treatment Plant, 1500 Wueste Road, Chula Vista, California. The Research Center includes an office and lab trailer, a covered test pad and a dedicated operations staff with substantial experience. The source water for testing was Otay Lake water. Otay Lake receives water from natural runoff. In addition, Otay Lake can receive diversions from other reservoirs and the San Diego Aqueduct system, when needed.

Methods and Procedures

After an initial operations period of approximately 2 weeks to establish operating conditions, the unit was operated for approximately 30 days with all tasks being conducted concurrently. The objective of Task 1 was the characterization of the UV technology in terms of efficiency and reliability using the OWTP

effluent as the feedwater to the UV unit. The goal of this task was to operate the unit continuously for 320 hours or more. The following operating parameters were monitored regularly during this task: flow rate, total flow, UV sensor readings, lamp cleaning frequency, lamp hours, lamp shut-down periods, lamp electric power consumption, operating pressure and headloss through the UV unit. The objective of Task 2 was the characterization of the UV system feedwater and effluent. The following water quality parameters were sampled from both the UV feedwater and UV effluent: temperature, pH, total alkalinity, hardness, TOC, UV-254 absorbance, turbidity, color, nitrate, iron, free chlorine, total chlorine and HPC. Turbidity, pH and chlorine residuals were analyzed at an onsite laboratory. All other parameters were analyzed by City of San Diego water quality and microbiology laboratories, which are State Certified laboratories. All analyses were conducted using Standard Methods and EPA methods.

The objective of Task 3 was to evaluate the UV unit in terms of lamp fouling and cleaning efficiency. During this task, all parameters of Tasks 1 and 2 were monitored. In addition, UV sensor readings before and after cleaning, and changes in UV sensor readings that might indicate lamp fouling, lamp aging or sensor fouling were monitored.

Task 4, the inactivation of microorganisms by the UV system, was conducted on September 14th, prior to Tasks 2 and 3. Task 4 was conducted at a flow rate of 695 gpm (1 million gallons per day (MGD)/158 m^3/hr) and a UV lamp power setting of 81%. The lamp power setting was selected based on the manufacturer's estimate that the setting could produce a 2 log reduction of the challenge organism, MS2 virus. MS2 virus was selected as a challenge species as it is not a human pathogen (Havelaar et al, 1990) and is more resistant to UV light than *Giardia* and *Cryptosporidium* (Stolarik et al, 2001). MS2 was continuously added to the UV feedwater to produce a concentration of approximately 4 to 5 logs MS2 /L. During Task 4, the 2.5 mg/L combined chlorine residual (approximate) in the OWTP effluent was quenched using sodium metabisulfite. After passing through the UV unit, sodium hypochlorite was added to inactivate any remaining virus before discharging the effluent to the backwash water recovery basin. A set of negative control samples was collected at the beginning of the experiments, prior to seeding and with the UV lamps turned off, to confirm the absence of MS2 virus in the reactor. Three challenge experiments were conducted. In each, three feed samples and three effluent samples were collected. A set of positive control samples was collected with the UV lamps turned off to demonstrate the inactivation of the challenge organism was due only to the UV light. A 1-2 liter sample of dechloraminated feedwater was collected for conducting collimated beam tests. Samples of the feedwater used during the full-scale UV challenge testing were spiked with MS2 virus and exposed to UV doses of 20 to 145 millijoules per square centimeter (mJ/cm^2) using a collimated beam apparatus. The dose-response curve generated from the collimated beam data was used to determine the UV sensitivity of the MS2 virus used as the seed stock during the flow-through reactor challenge study. The response of the MS2 virus challenge organism in the Trojan unit was then converted to a dose equivalent value based on the collimated beam dose-response curve.

The objective of Task 5 was to develop a data management plan to ensure the accurate collection, transmission and compilation of all data generated during the ETV. The plan developed allowed for the tracking of all data from final report figures or summary tables to handwritten data collection form. Task 6 details the quality assurance and quality control (QA/QC) procedures followed during the ETV. These procedures ensure the defensibility of all operational and analytical results presented in the ETV.

VERIFICATION OF PERFORMANCE

System Operation

Verification testing was conducted under manufacturer specified operating conditions. The system was operated at 695 gpm (1 MGD) during the virus seeding experiments and at 400 gpm at other times. The

lamp power setting was at 81% throughout the testing period with the lamp cleaning frequency set at 24 hours. The system ran for more than 700 hours under these operating conditions between 9/14/01 and 10/15/01. During the first 320 hours the following operating parameters were monitored regularly: flow rate, total flow, UV sensor readings, lamp cleaning frequency, lamp hours, lamp shut-down periods, lamp electric power consumption, operating pressure and head loss through the UV unit. Data collected indicate that the system can operate reliably under the testing conditions. Also water quality data collected from both the UV feedwater and UV effluent included: temperature, pH, total alkalinity, hardness, TOC, UV-254 absorbance, turbidity, color, nitrate, iron, free chlorine, total chlorine and HPC and no significant change in these water quality parameters were seen from the feed water to the effluent water.

Summary of General Water Quality Parameters

Parameter	Unit	Count	Median	Range	Average	Standard Deviation	95 Percent Confidence Interval
Feed							
Alkalinity	mg/L as $CaCO_3$	7	148	127 - 168	149	N/A	N/A
Total Hardness	mg/L as $CaCO_3$	7	208	196 - 227	209	N/A	N/A
Calcium Hardness	mg/L as $CaCO_3$	7	132	120 - 146	131	N/A	N/A
Iron	µg/L	7	50	50 - 85.1	55	N/A	N/A
Manganese	µg/L	7	3.91	0.91 - 9.28	4.74	N/A	N/A
Nitrate	mg/L	7	0.2	0.2 - 0.573	0.3	N/A	N/A
TOC	mg/L	17	4.31	2.96 - 5.11	4.11	0.81	3.69 - 4.53
Color	Pt-Co	6	4	2 - 5	4	N/A	N/A
UV_{254}	1/cm	17	0.067	0.034 - 0.083	0.063	0.015	0.055 - 0.071
pH	std. Unit	38	8.4	7.3 - 8.9	8.4	0.39	8.3 - 8.5
Desktop Turbidity	NTU	38	0.1	0.10 - 0.20	0.10	0.03	0.10 - 0.10
Temperature	degC	38	21	20.3 - 24.7	22.1	1.4	21.6 - 22.6
Free Chlorine	mg/L	38	0.2	0.04 - 1.4	0.3	0.3	0.2 - 0.4
Total Chlorine	mg/L	38	2.2	1.5 - 3.0	2.2	0.3	2.1 - 2.3
Effluent							
Alkalinity	mg/L as $CaCO_3$	7	153	122 - 178	153	N/A	N/A
Total Hardness	mg/L as $CaCO_3$	7	213	199 - 220	210	N/A	N/A
Calcium Hardness	mg/L as $CaCO_3$	7	130	123 - 159	136	N/A	N/A
Iron	µg/L	7	50	50 - 131	68	N/A	N/A
Manganese	µg/L	7	3.41	1.18 - 9.07	4.64	N/A	N/A
Nitrate	mg/L	7	0.2	0.2 - 0.669	0.3	N/A	N/A
TOC	mg/L	17	4.12	2.98 - 12	4.52	2.08	3.45 - 5.59
Color	Pt-Co	6	3	1 - 5	3	N/A	N/A
UV_{254}	/cm	17	0.064	0.037 - 0.084	0.063	0.015	0.055 - 0.071
pH	std. Unit	38	8.4	7.3 - 8.9	8.4	0.40	8.3 - 8.5
Desktop Turbidity	NTU	38	0.10	0.10 - 0.20	0.10	0.03	0.10 - 0.10
Temperature	degC	38	22	20.4 - 24.8	22.2	1.4	21.7 - 22.7
Free Chlorine	mg/L	38	0.2	0.04 - 1.6	0.2	0.3	0.1 - 0.3
Total Chlorine	mg/L	38	2.1	1.6 - 3.0	2.1	0.3	2.0 - 2.2

Note: All calculations with below detection limit values used the detection limit value in the calculation as a conservative estimate.

Continuous monitoring of the UV irradiance did not indicate a clear fouling trend during the testing period as the UV irradiance measured is a strong function of the UV transmittance of the water, which varied between 81% and 90%. However at the end of the testing period visual inspection of the lamp and sensor sleeves indicated that while the lamp sleeves were relatively clean the sensor sleeve had fouled. A 7% increase in the UV irradiance was observed when the fouled sensor sleeve was replaced by a new sensor sleeve while replacing the lamp sleeve caused no further improvement. The sensor was found to drift from 1.8% to 11% from the reference sensor reading during the testing period. Handling of the sensor window was found to contribute to about half of the sensor drift.

Microbial Inactivation Results

To demonstrate the microbial inactivation ability of the Trojan UVSwift System, one collimated beam test and seeding experiments were conducted with MS2 virus on 9/14/01. The collimated beam test was conducted on the same day as the seeding tests with water collected during the same time period. This test was performed to determine the UV sensitivity of the microbial cultures used in the seeding experiment. A dose response curve was constructed based on the results of the collimated beam test. The dose response curve determined an effective dose of 42.8 mJ/cm^2 was necessary to achieve 2-log inactivation of MS2. The MS2 seeding was conducted at a flow rate of 695 gpm and a lamp power setting of 81%. During the three challenge experiments, the feed MS2 virus concentration ranged from 5×10^4 plaque forming units (pfu)/100mL to 1.1×10^5 pfu/100mL, while the effluent MS2 concentration ranged from 4×10^2 pfu/100mL to less than 1×10^2 pfu/100mL. Consequently, the microbial inactivation observed during the challenge tests ranged from 2.1 to 3.0 logs. No removal was observed during the positive control tests with the lamps off.

Operation and Maintenance Results

The UV system was operated from a control panel where the power level setting of the lamps could be input along with the mode of operation of the reactor. During the verification testing the reactor was operated in manual reactor mode where the power level setting for the reactor did not change with changes in UV transmittance of the water. The cleaning frequency was set to 24 hours using the control panel in the fixed mode. Manual override cleaning was performed to test the manual mode of cleaning control and when it was required to clean for sensor calibrations. The power usage was 0.32 kwh/1000 gal at a flow rate of 400 gpm and a power setting of 81%.

A proprietary cleaning chemical obtained from the manufacturer was used along with the mechanical cleaning mechanism to assist in cleaning the lamp sleeves. The sensor sleeve was cleaned with the same mechanical mechanism but without cleaning chemical. The manufacturer provided an Operations and Maintenance manual that was helpful in explaining the setup, operation and maintenance of the ETV test system.

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E. Timothy Oppelt *06/07/02*	*Gordon Bellen* *06/10/02*
E. Timothy Oppelt Date	Gordon Bellen Date
Director	Vice President
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Office of Research and Development	NSF International
United States Environmental Protection Agency	

NOTICE: Verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and NSF make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate as verified. The end user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of corporate names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products. This report 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 Contaminants*, dated August 9, 1999, the Verification Statement, and the Verification Report (NSF Report #02/03/EPADWCTR) 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 Systems ETV Center Manager (order hard copy)
   NSF International
   P.O. Box 130140
   Ann Arbor, Michigan 48113-0140
2. NSF web site: http://www.nsf.org/etv/dws/dws_reports.html and from http://www.nsf.org/etv/dws/dws_project_documents.html (electronic copy)
3. EPA web site: http://www.epa.gov/etv (electronic copy)

May 2002

Environmental Technology Verification Report

Inactivation of MS2 Virus in Drinking Water

Trojan Technologies Inc. UVSwift Ultraviolet System Model 4L12

Chula Vista, California

Prepared for:

NSF International
Ann Arbor, MI 48105

Prepared by:

MWH and the City of San Diego
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Under a cooperative agreement with the U.S. Environmental Protection Agency

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Notice

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Foreword

The 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 MWH in cooperation with Trojan Technologies, Inc. The test was conducted in September and October 2001 at the Aqua 2000 Research Center in Chula Vista, California.

Throughout its history, the EPA has evaluated the effectiveness of innovative technologies to protect human health and the environment. The ETV 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.

The 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 Systems (DWS) ETV Center. 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) to conduct verification testing under the approved protocols.

The ETV DWS 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, 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

°C	Celsius degrees
CDHS	California Department of Health Services
CFD	Computational Fluid Dynamics
cfu	Colony forming unit(s)
cm	Centimeter
cm^2	Square-centimeter
d	Day(s)
DOC	Dissolved organic carbon
DBP(s)	Disinfection byproduct(s)
DWS	Drinking Water System
EPA	Environmental Protection Agency
ESWTR	Enhanced Surface Water Treatment Rule
ETV	Environmental Technology Verification
ft^2	Square foot (feet)
FTO	Field Testing Organization
gpm	Gallon(s) per minute
Hp	Horsepower
HPC	Heterotrophic Plate Count
hr	Hour(s)
HRT	Hydraulic Retention Time
Hz	Hertz
ICR	Information Collection Rule
IL	Intensity light
In	Inches
in Hg	Inch(es) of Mercury
kg	Kilogram(s)
kW	Kilowatts
L	Liter(s)
lb	Pounds
m^2	Square meter(s)
m^3/d	Cubic meter(s) per day
mgd	Million gallons per day
mg/L	Milligram(s) per liter
min	Minute(s)
mJ	MilliJoules
mL	Milliliter(s)
Mn	Manganese
MPN	Most probable number
NO_3	Nitrate
Nm	Nanometer
NSF	NSF International (formerly known as the National Sanitation Foundation)
NTU	Nephelometric turbidity unit(s)
OWTP	Otay water treatment plant
PCo. CU	Platinum Cobalt Color Units
PE	Performance evaluation
pfu	plaque forming units
PLC	Programmable logic controller
psi	Pound(s) per square inch
PSTP	Product Specific Test Plan
QA	Quality assurance
QC	Quality control
sec	Second(s)
SWTR	Surface Water Treatment Rule
T	Temperature
TC	Total coliform bacteria
TDS	Total dissolved solids
TOC	Total organic carbon
TSS	Total suspended solids
UV-254	Ultraviolet light absorbance at 254 nanometers
UV	Ultraviolet

Acknowledgements

The authors would like to thank the EPA, for sponsoring the ETV program and providing partial funding for the study. In particular, the authors would like to thank Jeffrey Q. Adams, project officer with the EPA, for his support throughout the project.

The authors would also like to thank NSF, for administrating the ETV program. The time and guidance provided by the following NSF personnel is gratefully acknowledged: Bruce Bartley, Carol Becker, Angela Smith and Kristie Wilhelm.

From the City of San Diego, the contributions of the following individuals are greatly appreciated: Paul Gagliardo, the manager of Aqua 2000 Research Center; Bill Pearce with the City Water Department for his efforts in test site preparation; Dana Chapin with the Water Quality Lab and Yildiz Chambers with the Marine Microbiology Lab. Also greatly appreciated were the contributions of Mike Kedzior and his operations staff at the Otay Water Treatment Plant.

The authors would also like to acknowledge the manufacturer of the equipment employed during the ETV program (Trojan Technologies Inc., Canada) for their assistance throughout the ETV test operation periods and for providing partial funding to the project. In particular, the authors would like to thank Jim Cosman from Trojan.

The contributions of the following individuals from MWH are gratefully acknowledged: James DeCarolis and Manish Kumar for conducting the field testing and data analysis, Lina Boulos for data management and report preparation, Karl Gramith for assistance in test site setup, Natalie Flores for financial administration, and Rene Lucero for report preparation.

Chapter 1
Introduction

1.1 Environmental Technology Verification (ETV) Purpose and Program Operation

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

ETV works in partnership with recognized standards and testing organizations; stakeholder groups 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 testing (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 Systems (DWS) Center, one of 12 technology areas under ETV. This DWS Center evaluated the performance of the Trojan Technologies, Inc. (Trojan) UVSwift ultraviolet (UV) radiation system used in drinking water treatment system applications. The evaluation was performed to assess the level of log inactivation of MS2 virus in a filtered water with a UV-254 transmittance of 85 ± 3% and a turbidity less than 5 NTU when operated at approximately 695 gpm (1 mgd) and at 81% of lamp power. This document provides the verification test results for the Trojan UVSwift unit Model 4L12 System.

1.2 Project Participants

Figure 1-1 is an organization chart showing the project participants and the lines of communication established for the ETV test. MWH, an NSF-qualified Field Testing Organization (FTO), provided overall management of the ETV. Trojan Technologies, Inc. manufactured and supplied the ultraviolet radiation system tested. The City of San Diego Water Department, Aqua 2000 Research Center in Chula Vista, California provided the test site facility and water treatment operations staff. Water quality analyses were provided by the City of San Diego State-certified analytical and marine microbiology laboratories. Data management and final report preparation were performed by the FTO, MWH.

1.3 Definition of Roles and Responsibilities of Project Participants

1.3.1 Field Testing Organization Responsibilities

The specific responsibilities of the FTO, MWH, were to:

- Provide the overall management of the ETV through the project manager and the project engineers.
- Provide all needed logistical support, the project communication network, and all scheduling and coordination of the activities of all participants.
- Evaluate the performance of the medium-pressure ultraviolet radiation technology according to the Product Specific Test Plan (PSTP) and the testing, operations, quality assurance/quality control (QA/QC), data management and safety protocols contained therein.
- Manage and report on data generated in the ETV.
- Provide all quality control (QC) information in the ETV report.
- Provide all data generated during the ETV in hard copy and electronic form in a common spreadsheet or database format.

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1.3.2 Manufacturer Responsibilities

The specific responsibilities of the ultraviolet radiation system manufacturer, Trojan, were to:

- Provide complete, field-ready equipment for the ETV at the testing site.
- Provide logistical and technical support as required throughout the ETV.
- Provide partial funding for the project.
- Attend project meetings as necessary.

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Email: jcosman@trojanuv.com

1.3.3 City of San Diego Staff Responsibilities

The specific responsibilities of the staff from the City of San Diego Water Department were to:

- Provide the necessary and appropriate space for the equipment to be tested in the ETV.
- Provide all necessary electrical power, feedwater and other utilities as required for the ETV.
- Provide all necessary drains to the test site.

1.3.4 Water Quality Analyst Responsibilities

The specific responsibilities of the water quality analytical staff from the City of San Diego Analytical Laboratory and Marine Microbiology Laboratory were to:

- Provide all off-site water quality analyses prescribed in the PSTP according to the QA/QC protocols contained therein.
- Provide reports with the analytical results to the data manager.
- Provide detailed information on the analytical procedures implemented.

Contact Information:

City of San Diego Analytical Laboratory
5540 Kiowa Drive
La Mesa, CA 91942
Phone: 619-668-3233
Fax: 619-668-3250
Contact: John Chaffin, Laboratory Manager

1.3.5 NSF Responsibilities

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 NSF to verify the performance of drinking water treatment systems through EPA's ETV Program. NSF is responsible for administration of the DWS testing program. Specific responsibilities of the NSF were to:

- Develop test protocols and qualify FTOs.
- Review and approve PSTPs.
- Conduct inspections and make recommendations based on inspections.
- Conduct financial administration of the project.
- Review of quality assurance data for laboratory procedures.
- Review all project reports and deliverables.

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

1.3.6 EPA Responsibilities

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

- Initiate the ETV program.
- Provide significant project funding.
- Review PSTPs and final reports.

1.4 Verification Testing Site

The verification testing was conducted at the City of San Diego's Aqua 2000 Research Center at the Otay Water Treatment Plant (OWTP) at 1500 Wueste Road in Chula Vista, California. The site provided water supply, electrical power, pipelines and drainage. An operations trailer was provided that included office space and on-site laboratory facilities. The UV manufacturer provided the UV equipment required for the verification testing.

Structural

- Enclosures appropriate to the NEMA rating of the unit.
- Potable water connections.
- Chemical containment area.
- Full electrical supply.
- Chemical feed systems used during MS2 seedings.
- Chemical safety shower and eyewash.
- Operations trailer with office space and on-site laboratory facilities.

Onsite Analytical Equipment

- Hach Pocket Colorimeter for chlorine analysis
- Hach 2100P Turbidimeter
- Accumet AR15 pH meter
- IL radiometer (1L1770/SED 240)

- Reference sensor supplied by manufacturer
- NIST certified immersion thermometer manufactured by ERTCO

1.4.1 Source Water

Particles and dissolved contaminants can interfere with UV light transmission and reduce inactivation efficiency. The NSF protocol is therefore applicable to the use of UV technology for treating high quality water (<5 NTU turbidity and >80% UV-254 transmittance at 1 cm) sources including treated surface water supplies of consistent high quality. The feedwater for the UV testing was full-scale plant effluent water from the OWTP. OWTP is a conventional water treatment plant with a design capacity of 40 MGD. The plant operates at an average flow rate of 30 MGD. The plant draws water from Otay Lake, and potassium permanganate is added as a pre-oxidant when necessary for taste and odor control. The water is then dosed with ferric chloride and cationic polymer at the rapid mix, and passed through flocculation basins to a sedimentation basin. The sedimentation basin effluent is dosed again with cationic polymer to act as a filter aid, and chlorinated. The water is then filtered through sand and anthracite filter beds, and then ammonium hydroxide and chlorine are added for chloramine formation, and the pH is adjusted to 8 with caustic for corrosion control. Feed water for the UVSwift System was plant effluent water, obtained directly after the filters and following the addition of ammonium hydroxide and chlorine to achieve a combined chlorine residual of 2.5 mg/L. During MS2 virus seedings, sodium bisulfite was added ahead of the UV system to quench residual combined chlorine.

Figure 1-2 illustrates Otay Filtration treatment plant effluent water quality for the period of September 2001 through October 2001. The stable quality of the water is apparent in all parameters illustrated in the figure. As shown in Table 4-6 total hardness in the feedwater ranged from 196 through 227 mg/L as $CaCO_3$, alkalinity ranged from 127 to 168 mg/L as $CaCO_3$ and calcium hardness ranged from 120 to 146 mg/L as $CaCO_3$. The hardness levels are quite high, with relatively high alkalinity as well. The UV-254 absorbance varied over a wide range from 0.034 cm^{-1} to 0.083 cm^{-1}. The UV-254 transmittance varied between 82.6% and 92.5%. The TOC ranged from 2.96 to 5.11 mg/L.

1.4.2 Pilot Effluent Discharge

All of the UV unit effluent was directed to the plant washwater recovery basin and returned to Otay Lake. UV effluent water was chlorinated and dechlorinated before discharge into Otay Lake during MS2 virus seeding tasks.

Chapter 2
Equipment Description and Operating Processes

The Trojan UVSwift family of inactivation systems is made up of cross-flow reactors, with medium pressure UV lamps housed in 1.5 in (3.8 cm) diameter quartz sleeves that are situated perpendicular to the flow of the water. Each lamp has sixteen settings, ranging from 30% to 100% lamp output. The reactor contains a flow-modifying device of proprietary design situated at the inlet of the reactor chamber.

The equipment that was tested in the ETV is a Trojan UVSwift Model 4L12, depicted in Figure 2-1. Utilizing medium pressure lamps that produce a spectrum of ultraviolet and visible light, the Trojan UVSwift System should be capable of disinfecting waterborne microorganisms including viruses, bacteria, and protozoa. Resistant waterborne pathogens such as rotavirus have previously been shown to undergo extensive inactivation at doses of 40 mJ/cm^2 (Modifi et al., 2001; Cotton et al., 2001).

The UVSwift reactor is 12 in (30 cm) in diameter and 21 in (53 cm) in length and has axial inlet/outlet. The system employs four medium pressure lamps with cross-flow arrangement and with an output that can be varied with flow requirements and water quality changes. In addition, the UV reactor incorporates two UV sensors that are used to measure the UV irradiance and the water's UV-254 transmittance. Each UV sensor is housed within a protective quartz sleeve in the UV reactor. The UV sensors are factory-calibrated against a traceable reference standard polychromatic source. The sensor was calibrated to mimic response from DNA and would measure the irradiance close to the most effective germicidal range (254nm). An additional sensor was provided by and manufactured by Trojan Technologies for the ETV testing as a reference to verify performance of the installed sensors.

The Trojan UVSwift System is capable of treating flow rates from 200 gpm to 3.6 MGD (1,100 m^3/d to 13,600 m^3/d). The maximum system pressure is 150 psi (10 bar).

The UVSwift System employs an automatic cleaning mechanism for all lamps and sensors in the reactor. The cleaning system operates on-line while the UV reactor is in operation (providing inactivation). The cleaning system consists of an internal stainless steel screw that is positioned perpendicular to the flow in the center of the reactor. The stainless steel screw is connected to an externally mounted electric motor as the direct drive (1/8 HP / 90 W motor power). A stainless steel wiper collar is fitted around each quartz sleeve. All collars are mounted on a common yoke and driven along the length of the sleeve by the same drive. The wiper collars contain a food-grade cleaning agent between two food-grade seals (63 mL cleaning agent housed within each of the four collars, for a total of 252 mL per reactor). The cleaning agent aids in the cleaning process by dissolving and loosening the foulant while the seals wipe the surface clean. This food-grade cleaning agent is a proprietary chemical developed by Trojan. Trojan has obtained NSF-Standard 60 certification for this agent. The chemical cleaning aid is changed out every 6 months. No change of the cleaning aid was needed during the testing period. The cleaning system may be operated manually via the operator interface on the control panel, may be set to operate at a fixed time interval, or can be run in automatic mode. The interval for the fixed interval mode is field

adjustable. In the auto mode, the system uses internal logic to calculate the fouling rate and adjusts the cleaning interval accordingly. A wiper collar is also provided for the two UV intensity sensor sleeves. The wiper collar uses a food-grade rubber wiper that is mounted on the same yoke, and driven by the same drive as the lamp sleeve collars, however these collars do not use the cleaning chemical. The automatic self-cleaning process enables the lamps in the UV system to operate for extended periods without manual mechanical or chemical cleaning. The cleaning system reduces fouling of the lamp surfaces and scaling of the quartz sleeves caused by particulate load and natural organic matter from runoff periods, algae blooms, hardness, iron and nitrate.

2.1 Description of the Treatment Train and Unit Processes

The treatment train that was tested included the following:

- Feed pump.
- Chemical feed pump (bisulfite addition for chloramine residual).
- Magmeter type flowmeter with flow totalizer.
- Virus injection port.
- UV influent sample port.
- Influent pressure gauge.
- Influent temperature gauge.
- Manometer setup.
- Trojan Swift UV reactor.
- UV effluent sample port.
- Two Flow rate control valves.
- Chemical feed pump (NaOCl addition for virus inactivation).
- Chlorine contact tank.
- Chemical feed pump (bisulfite addition for free chlorine).
- Data logger for flow rate and UV sensor outputs.
- Discharge to washwater recovery basin.

Figure 2-2 shows the experimental setup for the verification testing. Sodium metabisulfite is injected into the feed line immediately after the pump for dechloramination of the plant effluent. The virus injection port is located downstream of the metabisulfite injection port followed by an insertion type magmeter (flow meter). There is a flow control valve downstream of the flow meter followed by the influent sample port. Pressure and temperature gauges are placed next to the influent sample port. The UV reactor is placed next to the temperature and pressure gauges with a manometer setup across it to measure the pressure differential. The effluent sample port is downstream from the reactor followed by a flow control valve. Sodium hypochlorite is injected after this point for inactivation of any remaining virus. The contact time for this inactivation is provided by the contact tank. Sodium metabisulfite is injected into the overflow from this tank to dechlorinate the water before discharging it into the washwater basin.

2.2 Description of Physical Construction/Components of the Equipment

2.2.1 UV Reactor

Typical operating parameters for the UVSwift 4L12 are:

- Effluent flow: 200 gpm to 3.6 MGD
- Maximum system pressure: 150 psi (10 bar)
- Dose: 40 to 100 mJ/cm^2
- UV transmittance: 80% to 99%
- Head loss: Up to 12 inches of H2O
- Water temperature: 0°C to 50°C (32°F to 122°F)
- Ambient temperature: 0°C to 40°C (32°F to 104°F)
- Ambient relative humidity: 5 to 95%

The UV reactor is made of corrosion-resistant materials, including stainless steel and Ethylene Propylene Diene Monomer (EPDM) and Viton materials for the seals, and quartz for the sleeves. The main components of the UVSwift 4L12 system are:

- 12-in reactor chamber.
- Four medium-pressure lamps enclosed in quartz sleeves.
- 12-in, 150 lb ANSI flange pipe connection.
- Automatic cleaning system.
- Control panel for monitoring.
- Two UV intensity sensors (one installed and one reference).

The UV system has a total dry weight of 300 pounds. For shipping purposes, it can be moved with a forklift and transported by truck. The system requires 480 V, 21 Amps current, 60 Hz, three phase 4 wire (+ ground).

A description of the important components of the treatment train, excluding the UV reactor that was described previously, follows.

2.2.2 Flowmeter

UV reactor flow measurements were made during verification testing with a Signet 2550 insertion magmeter. The magmeter was factory calibrated before installation, and had repeatable flow measurements of ± 2 percent. The 4-20 mA magmeter output signal was wired to an electronic flow totalizer with digital display of both instantaneous flow and totalized flow. A 4-20 mA flow signal was also transmitted to the datalogger for storage and to the UV control panel for dose calculation using a model developed by the manufacturer.

2.2.3 Virus Injection

The virus injection port was located in a section of 8-inch (20-cm) diameter pipe before the UV reactor. The virus feed solution was added to the process flow through ¼ -inch stainless steel tubing extended 3 to 4 inches (7.6 to 10 cm) into the process pipe. Downstream piping components, that provided mixing before the UV reactor influent sample port, included 3-30 degree elbows, an 8-inch to 12-inch pipe coupling, 43 feet of 8-inch diameter pipe and 14 feet of 12-inch diameter pipe. A 250 revolutions per minute (RPM) peristaltic pump was used to add MS2 virus to the UV influent water during the microbial inactivation task. This pump was operated between 150 and 200 RPM during virus seeding tasks to minimize variations in the virus feed rate.

2.2.4 Sample Ports

UV reactor influent and effluent water was sampled from stainless steel ports constructed from ¼-inch stainless steel. These sample ports were flamed using a propane torch for microbiological sampling. The stainless tubing extended 3 to 4 inches into the process stream. The influent sample port was located 2.33 feet (0.66 m) before the UV reactor and the effluent sample port was located 13 feet (3.96 m) after the UV reactor. Piping components that provided mixing upstream of the effluent sample port include one 12 to 8 inch pipe coupling and the UV reactor.

2.2.5 Pressure and Temperature

The operating pressures at the influent and effluent of the UV reactor were measured using Wika 0-30 psi (0-2.07 bar) inline pressure gauges. The gauges have repeatability of +/- 1.5%. A 0-15 inch water-filled U-tube manometer was used to measure differential pressure between the UV reactor influent and effluent.

Operating temperatures were measured using a VWR brand bimetallic dial thermometer for the feed side. Once a day the feed and the effluent temperatures were also measured by directing the UV reactor influent and effluent flows into insulated containers and measuring the temperature of the water in the container with a NIST certified immersion thermometer. The thermometer was manufactured by ERTCO, with a scale from –2 to 68 °C graduated in 0.2 °C increments.

2.2.6 Datalogger

An ACR 12-bit, 4-20 milliamp portable process datalogger was used to acquire and store flow rate data from the magmeter and UV irradiance signals from the two UV irradiance sensors in the UVSwift unit. The datalogger was set to store readings every 2 minutes.

Chapter 3
Methods and Procedures

3.1 Environmental Technology Verification Testing Plan

This section describes the tasks completed for the ETV. The test equipment was operated 24 hours a day, seven days a week, with operations staff on-site Monday through Friday for one 8-hour shift each day and for 4-hour shifts during the weekend. Tasks that were performed by the operations and engineering staff are listed below:

Task A: Characterization of Feedwater Quality
Task B: Initial Operations
Task 1: Verification Testing Runs and Routine Equipment Operation
Task 2: Test Runs for Feed Water and Effluent Water Quality
Task 3: Documentation of Operating Conditions and Treatment Equipment Performance
Task 4: Documentation of Equipment Performance - Microbial Inactivation
Task 5: Data Management
Task 6: Quality Assurance/Quality Control

An overview of each task is provided below.

3.1.1 Task A: Characterization of Feedwater Quality

The objective of this recommended Initial Operations task was to obtain a chemical, biological and physical characterization of the feed water. Chapter 1 of this report includes the description of the source water quality during the course of the ETV testing in terms of key water quality parameters including: UV-254 absorbance and UV-254 transmittance, Total Chlorine, Total Organic Carbon, Total Alkalinity, Calcium, Magnesium, and Hardness.

3.1.2 Task B: Initial Operations

During a two-week shake-down period, the equipment Manufacturer verified the proper operation of the UV unit. The determination of the minimum UV irradiance below which equipment shutoff should occur to assure adequate inactivation at all times was also determined during the Initial Testing period. When the UV irradiance drops below this value, flow can be shut off or a signal given to the operator indicating the need for cleaning or lamp replacement. UV-254 absorbance was measured daily during the 2-week initial operations period. The UV reactor operating conditions employed during the remainder of verification testing were established during the Initial Operations period. It was agreed upon by the manufacturer and the FTO to conduct testing at a flow rate of 400 gpm for normal operations and 695 gpm for microbial challenge experiments at a lamp power setting of 81% throughout the testing period. This was based on information collected during the initial shakedown period.

All other components of the treatment train were tested. The range of achievable flows was determined and magmeter flow readings were verified volumetrically. Flow and UV intensity data acquired with the data logger were verified against digital readouts and calibration data. Chemical feed systems for dechloramination, chlorination and dechlorination were tested to verify adequate control.

A preliminary bench-scale collimated beam test was conducted during this period to verify the integrity of the virus stock solution and to evaluate the dose response curve for the Trojan UVSwift reactor. Procedures for the collimated beam test are described in Task 4 procedures.

3.1.3 Task 1: Verification Testing Runs and Routine Equipment Operation

The objective of this task was to characterize the technology in terms of efficiency and reliability. UV disinfection treatment system equipment that includes UV lamps, reactor and sensor for measuring UV irradiance were operated for Verification Testing purposes with the operational parameters based on the results of the Initial Operations testing (Task B) and based on Trojan's statement of performance capabilities. Trojan's unit is designed to operate at 200 gpm to 3.6 MGD. The testing was done using flow rates ranging from 400 gpm (during normal operation) to 695 gpm (during virus challenge testing).

After set-up and shakedown of the UV equipment, UV operation was established at the flowrate condition being verified in this ETV. Testing took place over one 13-day test period plus one 8-hr shift (320 hours). Measurements of the UV feedwater flowrate and UV irradiance were collected using a data logger and were recorded three times per day. The frequency of lamp cleaning was recorded. Lamp hours and system power were recorded on a daily basis.

3.1.4 Task 2: Test Runs for Feed Water and Effluent Water Quality

The objective of this task was to evaluate the quality of the water produced by the UV system and the effect the system had on feed water quality. Water quality data was collected for the feed water and effluent water. Some of the water quality parameters described in this task were measured on-site. Analysis of the remaining water quality parameters was performed by the City of San Diego Laboratory, a State-certified analytical laboratory and the City of San Diego Marine Microbiology Laboratory, also State-certified.

The parameters monitored during the ETV and the methods used for their measurement are listed in Table 3-1. Effluent water quality was evaluated relative to feedwater water quality and operational conditions, using the Trojan UVSwift unit.

3.1.5 Task 3: Documentation of Operating Conditions and Treatment Equipment Performance

The objective of Task 3 was to characterize the UVSwift unit with respect to efficiency and reliability while operating under the conditions established during the Initial Operations period and within the

design specification of the unit. The operation and performance of the UV equipment were documented over a 27-day test period.

The performance of the Trojan UVSwift 4L12 System was documented, including total water throughput (from a totalizer), total power usage (current supplied to each lamp was measured using an amp-clamp), UV irradiance as measured by the manufacturer's UV irradiance sensor (sensor signal inputted into a data logger), hours of lamp operation (included on the panel), decrease in intensity output (a measure of fouling rate), and frequency and type of mechanical cleaning. The performance of automatic mechanical wipers was assessed by recording the UV-254 intensity before and after cleaning on a regular basis. Table 3-2 provides the schedule of operating data recording.

3.1.6 Task 4: Documentation of Equipment Performance - Microbial Inactivation

The objective of Task 4 was to characterize the UVSwift 4L12 unit in terms of efficacy at inactivation of microorganisms. Inactivation of microorganisms is the primary purpose of UV drinking water treatment modules. UV estimated effective dose using MS2 virus is used as an indicator to obtain the inactivation of other microorganisms such as Cryptosporidium and Giardia. To accomplish this, a bench-scale collimated beam test was conducted to determine the UV sensitivity of the seed organism and full-scale challenge testing was conducted to determine the inactivation of the same seed organism by the UVSwift 4L12. The measurement of inactivation was calculated as the difference between the log concentration of viable organisms in the feed stream and the log concentration of viable organisms in the UV unit effluent.

Organisms for Seeding Experiments

The organism selected for seeding experiments was MS2 virus. MS2 virus is not a human pathogen; however, this organism is similar in size (0.025 microns), shape (icosahedron) and nucleic acid (RNA) to polio virus and hepatitis virus. Because MS2 is not a human pathogen, live MS2 virus was used in the seeding experiments. Organism stocks received from the supplier were stored refrigerated at 4°C in the dark until use (approximately 2 months) in the seeding experiments. The ATCC strain number of the virus was 15597-B1 and the bacterial host used was *E. coli* (ATCC#700891).

The collimated beam test and virus challenge test for evaluating the effectiveness of UV disinfection of MS2 virus are described below. The seeding experiments were performed at the test site and the samples collected during the seeding experiments were submitted to the City of San Diego Marine Microbiology Lab, a State-certified laboratory, for analysis of the seeded microorganisms.

Collimated Beam Testing

A collimated beam unit was supplied by Trojan. A photograph of this unit is presented in Figure 3-1. This simple unit consists of a low pressure UV lamp and a ballast with the lamp enclosed in a box with a hollow cylinder projecting from the central part. This cylinder delivers the collimated beam from the lamp to the sample that is placed in line with the cylinder. The box and cylinder can be raised or lowered using a rotating handle to deliver different levels of UV irradiance to the sample. Collimated

beam testing was conducted to ensure the integrity of the microbial cultures used to test the reactor. The purity of the MS2 virus stock was checked by a dose-response bioassay. To establish a dose-response curve, collimated-beam apparatus tests were carried out with the feed water used during seeding challenges within 24 hours of the challenge test. The initial concentration of MS2 was approximately 2 logs higher than the number of logs of inactivation that should be achieved at the maximum UV-254 dose to have a target concentration of 100 pfu/100 mL or more in the irradiated samples. Six (6) 50 mL sub-samples, prepared by pouring the MS2 virus stock diluted to get appropriate concentration into crystallizing dishes, were exposed for a range of times calculated to achieve a range of UV-254 doses from 20 to 145 mJ/cm^2, with a minimum interval of 25 mJ/cm^2. The crystallizing dishes are petridish like shallow glass dishes. The exposed samples were then plated in triplicate immediately after all the samples were collected (maximum holding time of two hours) on the same day as the collimated beam apparatus test. The water quality matrix used for collimated-beam apparatus testing was identical to that used in the UV reactor validation. The plating procedure used can be found in Appendix A. The UV-254 dose was calculated as follows:

$$D = I_o t\,[(1-e^{-kd})/kd]$$

Where: D = UV dose at 254 nm (mJ/cm^2)
t = Exposure time (seconds)
I_o = Incident intensity at the surface of the sample (mW/cm^2) = 0.975 x measured intensity on surface
k = Absorbance coefficient (1/cm) = 2.3 (multiplier for conversion from natural log to logarithm to the base 100) x UV-254 absorbance
d = Depth of the sample (cm) = 2.2 cm

The collimated-beam results were plotted on a graph of the UV-254 dose (mJ/cm^2) versus the log inactivation.

Microbial Challenge Tests

All microbial challenge experiments were conducted at a constant flowrate and a single UV lamp power setting on the UVSwift 4L12, recommended by the manufacturer to achieve 2-log inactivation of the MS2 virus. The flow rate was set at 695 gpm and the power level setting was 81%.

During each MS2 seeding experiment, three samples from the UV feedwater and three samples of UV effluent water were collected. The first sample during each treatment cycle was collected after a minimum of five theoretical hydraulic detention times had passed through the system from injection point to effluent sampling port. The hydraulic detention time was calculated by dividing the volume of pipe from the injection port to the sampling port by the flow rate. Each sample was collected in sterile 250-mL bottles, stored at 1°C and processed within 24 hours. MS2 virus was continuously added to the influent sample stream using a 0 to 250 RPM peristaltic pump. The pump was operated at a high rate (> 150 RPM) during seeding to minimize the effects of pulsing. Samples were collected from flamed stainless steel sample ports over a period of 5 to 10 seconds. Both sample ports were adjusted to

approximately the same flow rate to ensure that both feed and effluent samples represented the same aliquot of water and the sampling from both the ports was conducted at the same time. A seed stock sample was taken from the seeding tank and the sample diluted 25 times as a trip control. The seeding tank was kept continuously mixed during the seeding test. A seed start sample was taken from the seeding tank (no dilution).

Three experiments (replicates) were performed, plus one additional seeding challenge with all reactor lamps turned off. Two negative control samples, feed water samples with no virus addition, were also collected, for a total of 26 MS2 samples. The sample collection detail is presented in Table 3-3. In addition, both positive control and negative control virus samples were submitted for quality control. A negative control sample was taken before the seeding commenced from the feed sample port to enumerate the indigenous phage count. After the seeding the lamps were turned off, three samples each were taken from the feed and effluent sample port as a positive control. A seed stop sample was collected from the seeding tank (no dilution). After this, chlorine was added to the seeding tank and the system was disinfected. After five minutes, chlorine addition was stopped and two samples were taken from the effluent to show that the system was completely disinfected. Each challenge was hydraulically independent of any previous challenge because a minimum of five theoretical hydraulic detention times were allowed between challenge experiments.

3.1.7 Task 5: Data Management

The objective of this task was to establish the protocol for management of all data produced in the ETV and for data transmission between the FTO and NSF.

A datalogger was used for automatic acquisition of on-line process flow rate and UV irradiance sensor data to computer databases. This data was then downloaded for importation into Excel as a comma delimited file. In spreadsheet form, data were manipulated into a convenient framework to allow analysis of UV equipment operation. For those parameters not recorded by the datalogger, field-testing operators recorded data and calculations by hand in laboratory notebooks. Daily measurements were recorded on specially prepared data log sheets as appropriate.

The database for the project was set up in the form of custom-designed spreadsheets. The spreadsheets were capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. Data from the log sheets were entered into the appropriate spreadsheet. Following data entry, the spreadsheet was printed out and the print-out was checked against the handwritten data sheet. Any corrections were noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet was printed out. Each step of the verification process was initialed by the field testing operator or engineer performing the entry or verification step.

Data from the outside laboratory were received and reviewed by the field testing operator. Data from the onsite lab and City of San Diego Marine Microbiology lab were entered into the data spreadsheets, corrected, and verified in the same manner as the field data. Data from the City of San Diego Water

Quality lab were received both electronically and in hardcopy printouts generated from the electronic data.

3.1.8 Task 6: Quality Assurance/Quality Control

An important aspect of verification testing was the protocol developed for quality assurance and quality control. The objective of this task was to assure the high quality of all measurements of operational and water quality parameters during the ETV.

Equipment flow rates and associated signals were documented and recorded on a routine basis. A routine daily walk-through during testing was performed to verify that each piece of equipment or instrumentation was operating properly. On-line monitoring equipment, such as flow meters and UV-254-irradiance sensor signals, were checked to confirm that the read-out matched the actual measurement (i.e., flow rate or UV output on the control panel) and that the signal being recorded was correct. Below is a list of the verifications conducted.

Monitoring Equipment

System Flow Rate
System flow rate was verified volumetrically on a weekly basis and near the beginning and end of the testing period. System flow to the 1100-gallon chlorine contact tank was monitored for approximately two minutes. The measured flow rate was compared with flows indicated on the flowmeter.

UV Sensor
UV irradiance sensor readings were calibrated against a calibrated sensor provided by and manufactured by Trojan Technologies on a weekly basis. The UV-254 Transmittance sensor was not used during the testing.

System Piping Components
All system piping, tubing and valves were examined every day during the walkthrough inspection to ensure that no leaks were present.

Pressure and Temperature Gauges
The feed pressure gauge was verified against a standard Ashcroft pressure gauge during the testing period. The readings from the VWR brand temperature gauge were checked using the ERTCO NIST certified immersion thermometer.

Analytical Methods

pH
An Accumet Research Model AR15 laboratory pH meter was used to conduct routine pH readings at the test facility. Analyses for pH were performed according to Standard Method 4500-H+. A three-point calibration of the pH meter used in this study was performed once a day when the instrument was

in use. Certified pH buffers in the expected range (4.0, 7.0 and 10.0) were used. The slope obtained after calibration was recorded. The temperature of the sample when reading sample pH was also recorded. The pH probe was stored in the appropriate solution as defined in the instrument manual.

Temperature

Operating temperatures were measured using a VWR brand bimetallic dial thermometer with temperature range of 0-50°C and accuracy ±1% over range for the feed side. Once a day the feed and the effluent temperatures were also measured by directing the UV reactor influent and effluent flows into insulated containers and measuring the temperature of the water in the container with a NIST certified immersion thermometer. The thermometer was manufactured by ERTCO, with a scale from –2 to 68 °C graduated in 0.2 °C increments. Readings for temperature were conducted in accordance with Standard Method 2550B. Calibration verifications were made at the process temperature.

Turbidity

A Hach 2100N desktop turbidimeter was used to perform daily onsite turbidity analyses of feed water and effluent samples in accordance with Standard Method 2130B. Readings were recorded in non-ratio operating mode. The following quality assurance and quality control procedures were followed to ensure the integrity and accuracy of onsite laboratory turbidity data.

Initial and weekly calibrations were performed with primary standards of 0.1, 20, 100 and 800 NTU. Secondary standard calibration verification was performed on a daily basis. Three secondary standards (approx. 5.69 NTU, 56 NTU and 544 NTU) were recorded after primary calibration and on a daily basis for the remaining 6 days until the next primary calibration. Proficiency samples with a known turbidity were purchased from a commercial supplier. Turbidity proficiency samples were prepared and analyzed every week.

Chemical and Microbial Water Quality Parameters

The analytical work for the testing was performed by the City of San Diego Analytical and Marine Microbiology Laboratories, which are State of California certified water laboratories. All water samples were collected in appropriate containers (containing preservatives as applicable) prepared by the City of San Diego Analytical Laboratory. Samples for analysis of Total Coliforms (TC) and Heterotrophic Plate Count (HPC) analysis were collected in bottles supplied by the City of San Diego Marine Microbiology Laboratory and transported with an internal cooler temperature of approximately 2 to 8°C to the laboratory. All samples were preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times. All reported results had acceptable QA and met EPA QC guidelines, which was confirmed by letters from the City of San Diego Laboratory (Appendix A).

3.2 Calculation of UV Operating Parameters

3.2.1 UV Irradiance

UV irradiance is the rate at which UV energy is incident on a unit area (e.g., 1 cm^2) in the water and described in terms of UV power per unit area, e.g., microwatts per square centimeter ($\mu W/cm^2$) or milliwatts per square centimeter (mW/cm^2). The UV irradiance was measured using irradiance sensors provided by the manufacturer as part of their system. The system irradiance measurements were verified through weekly crosschecks with the reference sensor.

3.2.2 UV Dose

The UV energy is quantified to a dose by multiplying the UV Irradiance by the actual exposure time:

Dose (mJ/cm^2) = UV Irradiance (mW/cm^2) x Time (seconds)

The definition of dose provided is a theoretical definition and the dose was not calculated in this manner during the testing. UV dose during the testing was obtained based on the bioassay seeding results that are then assigned a corresponding dose value on the basis of the collimated beam results. Also, UV dose was provided by the manufacturer on the basis of a model that was developed based on the integration of reactor hydraulics and intensity field distribution for the unit.

3.2.3 UV-254 Transmittance

UV-254 transmittance is the ability of water to transmit UV light. UV-254 transmittance of a water sample is generally measured as the percentage of incident light with a wavelength of 254nm transmitted through an operationally defined pathlength (L). Many commercially available spectrophotometers actually report the Absorbance (A) for a fixed pathlength (L) of the sample. Percent Transmittance and Absorbance can be related as:

$$\%T = 100 \times 10^{-(A/L)}$$

Many naturally occurring organic and inorganic constituents (e.g., natural organic matter, iron, and nitrate) will absorb energy in the UV wavelengths, thus reducing the UV-254 transmittance of the water. This reduced UV-254 transmittance often interferes with the inactivation efficiency of an UV system.

3.3 Calculation of Data Quality Indicators

3.3.1 Precision

As specified in Standard Methods (Method 1030 C), precision is the standard deviation of the results of replicate analyses. An example of replicate analyses in this ETV was the weekly analysis of turbidity proficiency samples. The overall precision of a study includes the random errors involved in sampling as

well as the errors in sample preparation and analysis. Precision was calculated for the water quality parameters monitored with eight or more samples.

$$\text{Precision} = \text{Standard Deviation} = \left([\sum_{I=1}^{N} (\overline{X}_I - \overline{X})^2 \div (n-1)]\right)^{1/2}$$

Where: $\overline{X}$ = sample mean
$\overline{X}_I$ = *i*th data point in the data set
n = number of data points in the data set

3.3.2 Relative Percent Deviation

For this ETV, duplicate samples were analyzed to determine the overall precision of an analysis using relative percent deviation. An example of duplicate sampling in this ETV is the daily duplicate analysis of turbidity samples using the bench-top turbidimeter.

$$\text{Relative Percent Deviation} = 100 \times [(x_1 - x_2) \div \overline{X}]$$

Where: $\overline{X}$ = sample mean
x_1 = first data point of the set of two duplicate data points
x_2 = second data point of the set of two duplicate data points

3.3.3 Accuracy

Accuracy is quantified as the percent recovery of a parameter in a sample to which a known quantity of that parameter was added. An example of an accuracy determination in this ETV was the analysis of a turbidity proficiency sample and comparison of the measured turbidity to the known level of turbidity in the sample.

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

Where: X_{known} = known concentration of measured parameter
$X_{measured}$ = measured concentration of parameter

3.3.4 Statistical Uncertainty

For the water quality parameters monitored with 8 samples or more, 95 percent confidence intervals were calculated. The following equation will be used for confidence interval calculation:

$$\text{Confidence Interval} = \overline{X} \pm [t_{n-1,1-(\alpha/2)} \times (S/\sqrt{n})]$$

Where: $\overline{X}$ = sample mean
S = sample standard deviation

n = number of independent measurements included in the data set
t = Student's t distribution value with n-1 degrees of freedom
α = significance level, defined for 95 percent confidence as: 1 – 0.95 = 0.05

According to the 95 percent confidence interval approach, the α term is defined to have the value of 0.05, thus simplifying the equation for the 95 percent confidence interval in the following manner:

$$95 \text{ Percent Confidence Interval} = \overline{X} \pm [t_{n-1,0.975} \times (S/\sqrt{n})]$$

3.3.5 Data Completeness and Representativeness

Data completeness refers to the amount of data collected during the ETV study as compared to the amount of data that were proposed in the PSTP. Calculation of data completeness was made for onsite water quality measurements, laboratory water quality measurements, and operational data recording. These calculations are presented in Appendix A of this report.

All water quality samples were collected according to the sampling procedures specified by the NSF protocols, which ensured the representativeness of the samples.

3.4 Testing Schedule

The ETV schedule is illustrated in Figure 3-2. The field testing took place in September and October 2001. One testing period was conducted.

Chapter 4
Results and Discussion

This chapter presents the data obtained under each task of the ETV program of the Trojan UVSwift system.

4.1 Task B: Initial Operations

This phase of the testing was conducted between 9/1/01 and 9/13/01. During this testing phase the manufacturer's representative and the FTO field personnel evaluated equipment operations under various operating conditions to determine operational conditions for the verification testing. These operational conditions included flow rates, lamp power settings, and cleaning frequency. Based on these initial tests the following conditions were recommended by the manufacturer for verification testing:

- Flow rate at 400 gpm during verification testing and 695 gpm during microbial inactivation tests.
- Lamp power at 81% for the entire testing period.
- Cleaning frequency of once every 24 hours.
- Lamp age of 100 ± 20 hours for the microbial inactivation testing.

Samples for several onsite and laboratory water quality parameters were also collected to verify sampling and laboratory procedures. QA/QC procedures were also followed during this period.

The chemical feed and MS2 virus addition pumps used during the microbial inactivation testing were set up and tested during this period. The flow rates and concentrations required for the chemical pumps were calculated and tested to ensure the feed water to the UV reactor was dechloraminated before addition of MS2 virus and that adequate free chlorine residuals were achieved through the chlorine contact tank for virus inactivation.

A preliminary bench scale test was performed with the UV feed water using the collimated beam testing apparatus to determine the UV sensitivity of the MS2 virus stock. The dose response curve from this test is presented in Figure 4.1. Based on the best-fit line, the figure shows that a 2-log inactivation of MS2 virus requires an effective UV-254 dose of 41 mJ/cm^2.

An inspection of field operations, sampling activities and on-site analyses was conducted at the end of this phase by the NSF Project Engineer and the procedures were found to be satisfactory. The sampling and analysis schedules and the data collection forms were also finalized during the inspection.

4.2 Task 1: Verification Testing Runs and Routine Equipment Operation

The verification testing run was conducted between 9/14/01 and 10/3/01 for a period of over 320 hours in lamp operational hours. During this period the unit was operated at the operating conditions determined by the manufacturer during the initial testing period. The unit was operated in the manual

reactor mode where the power level to the lamps was fixed and changes in water quality or fouling of the lamps would not cause the power level to increase. The unit has a proprietary model to calculate the effective UV dose based on the UV-254 absorbance of the water, the flow rate and the sensors measured UV irradiance. The UV-254 absorbance was measured onsite using a Hach DR4000 spectrophotometer and the UV-254 transmittance calculated. These values were entered into the control panel to get the calculated dose. The unit operated continuously except for three shutdowns due to power outages and weekly shutdowns for sensor and flow calibration. A list of these shutdown periods is provided in Appendix C. Onsite water quality parameters and laboratory water quality parameters were sampled for during this period. The summary of these parameters is provided in Section 4.3.

The operational data collected during this period included flow rates and UV irradiance collected by the data logger. This data is presented in Figure 4-2. The flow was maintained within 10% of 400 gpm during the entire length of the testing except for periods of shutdown. These periods of shutdown included periods of low flow (100-150 gpm) on 9/24/01 and 9/28/01. It was observed during testing that the UV irradiance reached a minimum value during the cleaning cycles and a maximum just after a shutdown period. As presented on Figure 4-2, these extremes in UV irradiance serve to indicate system shutdowns, and can be explained as follows. During a cleaning cycle the wiper assembly passes over the quartz window of the irradiance sensor and shadows the UV light resulting in minimum values if this value was recorded by the datalogger (which recorded readings every 2 minutes). After a shutdown period when the unit was restarted the power level setting was reset to the maximum value (100%) resulting in high UV irradiance value until the power setting was lowered to 81% by the operator.

The cleaning cycles are also indicated on Figure 4-2. All three modes of cleaning auto, manual and fixed mode were tested and were found to operate reliably. After the first week, fixed interval mode cleaning, with an interval of 24 hours, was used the majority of the time except when sensor calibration was being performed. Table 4-1 summarizes the cleaning cycles and the percentage increase in UV irradiance due to cleaning throughout the testing period. UV irradiance values in Table 4-1 are based on manual operator readings immediately before and after lamp cleaning. Readings not available (N/A) on Table 4-1 can be approximated from the UV irradiance data of Figure 4-2. The percent increase in the UV irradiance after cleaning ranged from –0.03 to 9.4 percent with an average increase of 2.6 percent. This indicates that the fouling of the lamp sleeves on a day to day basis was minimal. The cleaning cycles could be observed and the control panel provides an indication of the time interval to the next cleaning cycle.

The UV-254 absorbance of the feed water was measured onsite and the UV-254 transmittance calculated. The UV sensor irradiance and transmittance data is presented against lamp hours in Figure 4-3. Shutdown periods are not displayed in Figure 4-3 since the lamp hours did not change during shutdown periods. In addition, the maximum and minimum values due to shutdowns and cleaning cycles have been removed. Figure 4-3 shows the relationship between the UV-254 transmittance of the feed water and the UV irradiance sensor measurement. Because UV irradiance is so strongly influenced by the UV-254 transmittance of the feed water, no inference can be made regarding the fouling of the

lamps from the UV irradiance data collected during this period. If cleanings were ineffective and long term fouling of the lamps was occurring the UV irradiance would lose sensitivity towards changes in water transmittance, and this does not appear to be occurring.

The UV Irradiance sensor reading was compared against a calibrated reference sensor once each week during the testing period. The percent difference between the system sensor and reference sensor readings are presented in Table 4-2. The table shows that the system sensor readings were consistently lower than the reference sensor readings over the testing period while the difference in the readings increased from 1.78% at 37 hours of lamp operation to 10.94% at 820 hours of lamp operation. Based on this finding, the manufacturer recommended testing for contamination of the system sensor at the end of the testing. The sensor windows were cleaned with alcohol and the 820-hour sensor calibration reading was repeated. The difference in sensor readings decreased from 10.94% to 7.21% as a result indicating that the actual sensor drift was less than 5% during the testing period of 820 hours.

After the completion of testing, the sleeve for Lamp 1 (the lamp affecting the irradiance sensor) and the irradiance sensor sleeve were removed and visually examined. The lamp sleeve was observed to be clean while the sensor sleeve had white deposits along the length. A photograph of the lamp and sensor sleeve is presented in Figure 4-4. Sensor readings were taken to characterize the extent of this sensor sleeve fouling. First a sensor reading was taken with the original lamp sleeve and sensor sleeve. The sensor sleeve was then replaced with a new, clean sleeve and an increase in UV irradiance of 7.2% percent was observed. The lamp sleeve was replaced with a new sleeve next. No further increase in UV irradiance was observed, indicating that lamp fouling was minimal and the decline in UV irradiance measurement was due to sensor sleeve fouling. These data are presented in Table 4-3.

An attempt was made to quantify lamp aging based on UV irradiance sensor measurements taken near the beginning of the testing and the end of the testing (with clean sensor sleeves and lamp sleeves). The average UV irradiance readings were identical for both the initial and final reading, while the UV-254 transmittance of the feed water during the initial reading was marginally lower, at 84.1%, than during the final reading when UV-254 transmittance was 86.1%. This indicates only a very small decrease in lamp performance from lamp aging over the test period. These data are presented in Table 4-4.

4.3 Task 2: Test Runs for Feed Water and Effluent Water Quality

Several water quality parameters were monitored during the UV testing. The following provides a summary of the water quality data collected over the testing period.

4.3.1 UV-254 Absorbance and UV-254 Transmittance

Figure 4-5 and Appendix A present feed and effluent values, respectively for UV-254 Absorbance and calculated UV-254 Transmittance as provided by the City of San Diego Laboratory for samples taken throughout the testing period. The UV-254 transmittance values calculated from the City of San Diego laboratory UV-254 absorbance data were found to be consistently higher than the transmittance values from onsite UV-254 absorbance measurements using the Hach DR4000 spectrophotometer. A small

study was conducted to determine potential causes. The higher UV-254 transmittance figures from the City Lab were found to be attributed to the sample hold time required to transport samples to the laboratory. The sample hold times were not uniform and the travel time was also not consistent, though they were below the maximum hold time of 24 hours and the samples were held at a temperature of 4^0C. As shown in Figure 4-5, feed water UV-254 absorbance (UV-254 transmittance) values measured between 9/14/01 and 10/3/01 ranged from 0.083 cm^{-1} (82.6%) to 0.034 cm^{-1} (92.5%). Figure 4-5 shows the effluent UV-254 absorbance (UV-254 transmittance) measured during the testing period ranged from 0.084 cm^{-1} (82.4%) to 0.037 cm^{-1} (91.8%). Comparison of the feed and effluent UV-254 absorbance indicate the UV-254 absorbance was not altered as the water passed through the UVSwift reactor. The decrease in the feed and effluent UV-254 absorbance shown in Figure 4-5 on 9/27/01 was due to a change in feed water composition used by the Otay Water Filtration Plant. Specifically, the plant feed water source changed from Otay Lake Water to a 50%-50% blend of Otay Lake Water and County Water Authority (CWA) aqueduct water, respectively. Due to the lower organic content of the CWA water, the average feed UV-254 absorbance (UV-254 transmittance) after 9/27/01 decreased from 0.071 cm^{-1} (89.3%) to 0.049 cm^{-1} (84.9%). Similarly, the average effluent UV-254 absorbance (UV-254 transmittance) measured after 9/27/01 decreased from 0.071 cm^{-1} (89.7%) to 0.047 cm^{-1} (84.9%).

4.3.2 Indigenous Bacterial Inactivation

The inactivation of naturally occurring bacteria present in the feed water was monitored during the ETV study. However, as shown in Table 4-5, results from the Marine Micro Laboratory for samples taken during the test period indicate all measurements of total coliform bacteria in both the feed and effluent water were below the detection limit (2 most probable number (MPN)/100 ml). In addition, all measurements of HPC bacteria measured in both the feed and effluent water were also below the detection limit of 1 colony forming units (cfu)/100 ml. The absence of both coliform and HPC are expected since the feed water to the UV reactor, Otay Treatment Plant effluent, had been exposed to free chlorine through the full-scale plant filters.

4.3.3 Other Water Quality Parameters

Table 4-6 summarizes the results of all water quality parameters sampled in the feed water and effluent of the Trojan UV system during the test period. The table presents count, median, range, and average of the water quality parameters sampled. Standard deviation and 95 percent confidence interval values were calculated for parameters collected 8 or more times. Based on the results, the feed water to the UV system over the testing period can be characterized as moderate in alkalinity and high in hardness with significant levels of iron and manganese. The feed water pH ranged from 7.3 to 8.9. Organics are also relatively high, with TOC ranging from 3.0 mg/L to 5.1 mg/L. The UV-254 absorbance ranged from 0.03 to 0.08, corresponding to a range of UV-254 transmittance from 83 percent to 93 percent. The turbidity was very low, as expected for a filtered water, averaging 0.1 NTU. No significant change was observed in the alkalinity, total hardness, calcium hardness, iron, manganese, nitrate, and color across the reactor. No apparent reduction of TOC and UV-254 was observed.

4.4 Task 3: Documentation of Operating Conditions and Treatment Equipment

The UVSwift unit was operated at a flow rate of 400 gpm and a power setting of 81%, with daily cleaning, for a period of more than 27 days (720 hours). System flow and UV irradiance data were collected every two minutes using a datalogger. The operational data is summarized in Table 4-7. The table presents count, median, range, average, standard deviation and 95 percent confidence interval of the operational parameters monitored. The operational data summarized include the power consumption for each lamp as measured with an amp clamp and volt meter. Total power consumption was calculated by summing the power consumption readings from the four individual lamps. The power consumption for the lamps remained stable during the period of the testing. The average power input was 7.7 kW corresponding to 81% lamp power. The time required to treat 1000 gallons at 400 gpm flow will be 1000/(400*60) = 0.042 hours. So, energy supplied to this volume = 7.7*0.042= 0.32kWh. The system pressure was a function of the relative positioning of valves before and after the UV unit and varied slightly with each adjustment. A total of 8 lamp on/off cycles occurred during the period of testing. The cleaning effectiveness data and the sensor verification data are presented in Section 4.2.

4.5 Task 4: Documentation of Equipment Performance: Microbial Inactivation

To demonstrate the microbial inactivation ability of the Trojan UVSwift System, one collimated beam test and three full-scale challenge tests were conducted with MS2 virus on 9/14/01. The collimated beam test was conducted on the same day as the challenge tests, with UV system feed water collected during the same time period, and using a portion of the MS2 virus stock used during the challenge tests. The collimated beam test was performed to ensure the integrity the MS2 stock used in the challenge tests and to determine the MS2 UV sensitivity. The results of the collimated beam test are presented in Table 4-8. A dose response curve was constructed based on the results. This dose response curve is presented in Figure 4-6. Based on the best-fit line for the data of Figure 4-6, an effective dose of 42.8 mW/cm^2 was necessary to achieve 2-log inactivation of MS2. The UV estimated effective dose using MS2 virus can be used as an indicator to obtain the inactivation of other organisms such as Cryptosporidium and Giardia.

The MS2 challenge tests were conducted at a flow rate of 695 gpm and a lamp power setting of 81%. Three sets of feed and effluent samples were collected in each of the three challenge tests conducted. The feed and effluent concentrations and log removal of virus during the seeding are presented in Table 4-9. Figure 4-7 presents the log removal results graphically. Negative control samples taken before addition of MS2 virus, demonstrated no MS2 virus was in the feed water to the UV system before the beginning of challenge testing. Positive control samples, taken after the completion of the challenge tests, demonstrated there was no inactivation of MS2 virus with the system UV lamps off. The dose values recorded from the UVSwift user interface screen during the three challenge experiments ranged from 50 to 51 mJ/cm^2 (Appendix C). During the three challenge experiments, the feed MS2 virus concentration ranged from 5×10^4 pfu/100mL to 1.1×10^5 pfu/100mL, while the effluent MS2 concentration ranged from 4×10^2 pfu/100mL to less than 1×10^2 pfu/100mL. The microbial

inactivation observed during the challenge tests ranged from 2.1 to 3.0 logs. The 95 percent confidence interval for MS2 virus log inactivation was from 2.4 logs to 2.9 logs.

4.6 Task 5: Data Management

4.6.1 Data Recording

Data were recorded manually on operational and water quality data sheets prepared specifically for the study. In addition, other data and observations such as the system calibration results were recorded manually on data forms and laboratory notebooks. All of the raw data sheets and laboratory notebook entries are included in Appendix B of this report.

4.6.2 Data Entry, Validation, and Reduction

Data were first entered from raw data sheets into similarly designed data entry forms in a spreadsheet. Following data entry, the spreadsheet was printed and all entries were checked against the handwritten datasheets. All corrections were noted on the electronic hard copies and then corrected on the screen. The hardcopy of the electronic data are included in Appendix C of this report.

4.7 Task 6: Quality Assurance/Quality Control (QA/QC)

The objective of this task is to assure the high quality and integrity of all measurements of operational and water quality parameters during the ETV program. Below is a summary of the procedures followed to ensure the correctness of the data.

4.7.1 Data Correctness

Data correctness refers to data quality, for which there are five indicators:

- Representativeness
- Statistical Uncertainty
- Completeness
- Accuracy
- Precision

Calculation of the above data quality indicators were outlined in the Methods and Procedures section (Chapter 3). All water quality samples were collected according to the sampling procedures specified by the NSF protocols, which ensured the representativeness of the samples. Below is a summary of the calculated indicators.

4.7.2 Statistical Uncertainty

Ninety-five percent confidence intervals were calculated for the raw and effluent water quality parameters of the Trojan 4L12 UVSwift system where eight or more samples were collected. These include onsite lab data: pH, temperature, turbidity, free and total chlorine; and laboratory data including UV-254, total organic carbon (TOC), total coliform and heterotrophic plate counts. Ninety-five percent confidence intervals were presented in summary tables in the discussion of Task 2 – Raw and Finished Water Quality.

4.7.3 Completeness

Data completeness refers to the amount of data collected during the ETV study as compared to the amount of data that were proposed in the PSTP. Calculation of data completeness was made for onsite water quality measurements, laboratory water quality measurements, and operational data recording. These calculations are presented in Appendix A of this report.

4.7.4 Accuracy

Accuracy is quantified as the percent recovery of a parameter in a sample to which a known quantity of that parameter was added. An example of an accuracy determination in this ETV is the analysis of a turbidity proficiency sample and comparison of the measured turbidity to the known level of turbidity in the sample. Calculations of data accuracy were made to ensure the accuracy of the onsite desktop turbidimeter used in the study. All accuracy calculations are presented in Appendix A.

4.7.5 Precision and Relative Percent Deviation

Duplicate water quality samples were analyzed to determine the consistency of sampling and analysis using relative percent deviation. Precision was calculated from the standard deviation of replicate analyses. Relative percent deviation calculations were also performed on online and desktop turbidity measurements. Calculations of relative percent deviation are included in Appendix A of this report.

4.8 Additional ETV Program Requirements

4.8.1 Operation and Maintenance (O&M) Manual

The O&M manual for the Trojan 4L12 UVSwift system supplied by the manufacturer was reviewed during the ETV testing program. The review comments for the O&M manual are presented in Table 4-10. The review found the O&M manual to be an extremely useful resource. The manual is very well organized, well written, clear and complete. The manual makes excellent use of tables and graphics to organize and clarify the presentation of material.

4.8.2 System Efficiency and Chemical Consumption

The system efficiency can be defined in terms of the power input to the system that produces unit inactivation of the virus during the challenge tests. From Table 4-7 the average power input was 7.6 kW corresponding to 81% lamp power. The time required to treat 1000 gallons at 695 gpm flow during seeding was 1000/(695*60) = 0.024 hours. So, energy supplied to this volume = 7.6*0.024= 0.18 kWh.

The average log inactivation achieved during the challenge tests, as indicated in Table 4-9, was 2.6 log inactivation of MS2 virus. Therefore, the efficiency of the UV unit during the challenge tests was 0.07 kWh/log virus inactivation / 1000 gallons treated. The UV-254 transmittance of the feed water was 84% (Table 4-9) during the virus seeding.

During other times the flow rate was 400 gpm and the average power input was the same at 7.6 kW. The time required to treat 1000 gpm was 1000/(400*60) = 0.042 hours. The energy consumption thus was = 7.6*0.042= 0.32 kwh/1000 gal.

The UV system uses a proprietary chemical to assist the mechanical wiper during lamp sleeve cleaning. Each of the four cleaning collars holds 64 mL of this chemical. The cleaning chemical is estimated to last for six months. No other chemical consumption is associated with the UV system.

4.8.3 Equipment Deficiencies Experienced During the ETV Program

At the end of the testing period, the UV irradiance sensor sleeve was found to be somewhat fouled with white deposits. When the UV irradiance sensor sleeve was replaced with a clean sleeve, the UV irradiance reading increased by 7 %. After discussions with the manufacturer, it was concluded that fouling may be a result of the actual wiper design. The residual from the wiper may be fouling the sleeve. No other UV equipment deficiencies were experienced during the ETV testing. A table summarizing the equipment deficiencies encountered and any corrective actions taken is presented in Appendix A

Chapter 5
References

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Tables and Figures

Table 3-1. Water Quality Analytical Methods

Parameter	Sample Frequency	Facility	Method
General Water Quality			
pH	Twice Daily	On-Site	SM 4500H+
Total Alkalinity	Semi Weekly	Laboratory	SM 2320 B
Total Hardness	Semi Weekly	Laboratory	SM 2340 C
Temperature	Twice Daily	On-Site	SM 2550 B
Iron	Semi Weekly	Laboratory	SM 3111 B
Manganese	Semi Weekly	Laboratory	EPA 200.8
Nitrate	Semi Weekly	Laboratory	SM 4110 B
Free and Total Chlorine	Twice Daily	On-Site	Hach/ SM 4500 CL:G
Particle Characterization			
Turbidity (Bench-Top)	Twice Daily	On-Site	SM 2130 B
Organic Material			
TOC	Daily	Laboratory	SM 5310 C
True Color	Semi Weekly	Laboratory	SM 2120 at 455 nm
UV Absorbance at 254 nm	Daily	Laboratory	SM 5910 B
Microbiological Analyses			
Total Coliform	Occasionally	Laboratory	SM 9221 B
HPC	Daily	Laboratory	SM 9215 B
MS2 Virus	During seeding	Laboratory	SM 9224 F

Table 3-2. UV Disinfection System Operating Data Recording Schedule

Operations Parameter	Action
Flow Rate	Checked and recorded at least 3 times a day on weekdays and once a day on weekends. Recorded on a datalogger every 2 minutes. Adjusted when 10% above or below target. Recorded both before and after adjustment.
Exposure Time*	Recorded retention or cycle times when applicable. If variable, record degree of variation.
UV Irradiance	Checked and recorded at least 3 times a day on weekdays and once a day on weekends. Recorded on a datalogger every 2 minutes.
UV Sensor	Recorded output from in-line monitors. Recorded changes in lamp UV irradiance following each cleaning. Verified internal UV sensors against a reference sensor on a weekly basis.
Lamp Fouling/Cleaning System	Recorded frequency of sleeve cleaning.
Lamp Hours	Recorded daily for each lamp
Electric Power	Recorded daily the power level that reactor was operating at and recorded current use by each lamp and voltage across each lamp.
Lamp Cycles	Recorded frequency of lamp on/off cycles

* Exposure time was determined from the internal volume of UV inactivation chamber (55 L) and from the flowrate.

Table 3-3. Seeding Challenge Details

Experiment	# Feedwater Samples	# Effluent Samples
Negative Control (no virus)	2	0
Challenge # 1	3	3
Challenge # 2	3	3
Challenge # 3	3	3
Positive Control (lamps off)	3	3

Table 4-1. Lamp Cleaning Data

Cleaning Date	Lamp Hours	Average UV Irradiance (mW/cm^2)		% Increase	Cleaning Type	Cleaning Interval (lamp hours)
		Before Cleaning	After Cleaning			
9/14/01	108	425.2	432.7	1.76	Manual	40
9/15/01	129	N/A	N/A	N/A	Auto	21
9/16/01	153	N/A	N/A	N/A	Auto	24
9/17/01	177	N/A	N/A	N/A	Auto	24
9/18/01	205	410.7	417.9	1.74	Manual	28
9/19/01	222	N/A	N/A	N/A	Auto	17
9/20/01	246	396.9	396.8	-0.03	Fixed	24
9/21/01	270	371.2	399.3	7.55	Fixed	24
9/22/01	294	N/A	N/A	N/A	Fixed	24
9/23/01	317	377.4	390.3	3.40	Fixed	23
9/24/01	341	371.2	377.4	1.67	Fixed	24
9/25/01	351	383.8	390.3	1.69	Manual	10
9/26/01	375	390.3	396.8	1.67	Fixed	24
9/27/01	399	456.4	473.2	3.69	Fixed	24
9/28/01	423	432.7	473.2	9.37	Fixed	24
9/29/01	440	N/A	N/A	N/A	Fixed	17
9/30/01	464	N/A	N/A	N/A	Fixed	24
10/1/01	488	432.7	440.4	1.78	Fixed	24
10/2/01	510	456.4	464.7	1.82	Fixed	22
10/3/01	534	464.7	473.2	1.84	Fixed	24
10/4/01	558	425.2	432.7	1.76	Fixed	24
10/5/01	582	397.0	410.7	3.47	Fixed	24
10/6/01	606	N/A	N/A	N/A	Fixed	24
10/7/01	630	N/A	N/A	N/A	Fixed	24
10/8/01	654	N/A	N/A	N/A	Fixed	24
10/9/01	678	403.8	417.9	3.49	Fixed	24
10/10/01	701	448.3	456.4	1.81	Fixed	23
10/11/01	725	440.4	448.3	1.79	Fixed	24
10/12/01	749	440.4	440.4	0.00	Fixed	24
10/13/01	773	N/A	N/A	N/A	Fixed	24
10/14/01	797	N/A	N/A	N/A	Fixed	24
10/15/01	820	390.3	397.0	1.72	Manual	23
			Average Increase	2.60		

N/A = Not Available (values for irradiance for these dates can be obtained from Figure 4-2)

Table 4-2. Sensor Calibration Data

		Average UV Irradiance (mW/cm ^{2})		
Date	**Lamp Hours**	**Sensor**	**Reference Sensor**	**% Difference**
9/4/01	37	432.7	440.4	1.78
9/18/01	205	417.9	440.4	5.38
9/25/01	351	396.9	425.2	7.11
10/2/01	511	473.2	509.8	7.73
10/9/01	678	417.9	456.4	9.21
10/15/01	820	396.9	440.4	10.94
10/15/01 [1]	820	410.7	440.4	7.21

[1] System and reference sensor windows cleaned with alcohol between the two readings on 10/15/01

Table 4-3. Lamp Sleeve and UV Irradiance Sensor Sleeve Fouling Data

	UV Irradiance (mW/cm^2)				
Configuration	**Low**	**Mid**	**High**	**Average**	**% Increase**
Old sensor sleeve, old lamp sleeve	403.7	410.7	417.8	410.7	reference
New sensor sleeve, old lamp sleeve	432.6	440.3	448.2	440.4	7.2
New sensor sleeve, new lamp sleeve	432.6	440.3	448.2	440.4	7.2

Table 4-4. Lamp Aging Data

	UV Irradiance (mW/cm^2)					
Condition	**Low**	**Mid**	**High**	**Average**	**% increase**	**UVT(%)**
Initial (68 hours)	432.6	440.3	448.2	440.4	reference	84.07
Final (820 hours)	432.6	440.3	448.2	440.4	0.0	86.12

Initial reading values from after cleaning on 9/12/01, 11:48
New lamp sleeve and sensor sleeves were used for final reading

Table 4-5. Summary of Microbiological Water Quality Parameters for the Trojan 4L12 UVSwift System

Parameter	Unit	Count	Median	Range	Average	Standard Deviation	95 Percent Confidence Interval
Feed							
Total Coliforms	MPN/100mL	10	<2	<2 - <2	<2	0	NA
HPC	cfu/mL	17	<1	<1 - <1	<1	0	NA
Effluent							
Total Coliforms	MPN/100mL	10	<2	<2 - <2	<2	0	NA
HPC	cfu/mL	17	<1	<1 - <1	<1	0	NA

Table 4-6. Summary of General Water Quality Parameters for the Trojan 4L12 UVSwift System

September 14, 2001 – October 5, 2001

Parameter	Unit	Count	Median	Range	Average	Standard Deviation	95 Percent Confidence Interval
Feed							
Alkalinity	mg/L as $CaCO_3$	7	148	127 - 168	149	N/A	N/A
Total Hardness	mg/L as $CaCO_3$	7	208	196 - 227	209	N/A	N/A
Calcium Hardness	mg/L as $CaCO_3$	7	132	120 - 146	131	N/A	N/A
Iron	µg/L	7	50	50 - 85.1	55	N/A	N/A
Manganese	µg/L	7	3.91	0.91 - 9.28	4.74	N/A	N/A
Nitrate	mg/L	7	0.2	0.2 - 0.573	0.3	N/A	N/A
TOC	mg/L	17	4.31	2.96 - 5.11	4.11	0.81	3.69 - 4.53
Color	Pt-Co	6	4	2 - 5	4	N/A	N/A
UV_{254}	1/cm	17	0.067	0.034 - 0.083	0.063	0.015	0.055 - 0.071
pH	std. Unit	38	8.4	7.3 - 8.9	8.4	0.39	8.3 - 8.5
Desktop Turbidity	NTU	38	0.1	0.10 - 0.20	0.10	0.03	0.10 - 0.10
Temperature	degC	38	21	20.3 - 24.7	22.1	1.4	21.6 - 22.6
Free Chlorine	mg/L	38	0.2	0.04 - 1.4	0.3	0.3	0.2 - 0.4
Total Chlorine	mg/L	38	2.2	1.5 - 3.0	2.2	0.3	2.1 - 2.3
Effluent							
Alkalinity	mg/L as $CaCO_3$	7	153	122 - 178	153	N/A	N/A
Total Hardness	mg/L as $CaCO_3$	7	213	199 - 220	210	N/A	N/A
Calcium Hardness	mg/L as $CaCO_3$	7	130	123 - 159	136	N/A	N/A
Iron	µg/L	7	50	50 - 131	68	N/A	N/A
Manganese	µg/L	7	3.41	1.18 - 9.07	4.64	N/A	N/A
Nitrate	mg/L	7	0.2	0.2 -0.669	0.3	N/A	N/A
TOC	mg/L	17	4.12	2.98 - 12	4.52	2.08	3.45 - 5.59
Color	Pt-Co	6	3	1 - 5	3	N/A	N/A
UV_{254}	/cm	17	0.064	0.037 - 0.084	0.063	0.015	0.055 - 0.071
pH	std. Unit	38	8.4	7.3 - 8.9	8.4	0.40	8.3 - 8.5
Desktop Turbidity	NTU	38	0.10	0.10 - 0.20	0.10	0.03	0.10 - 0.10
Temperature	degC	38	22	20.4 - 24.8	22.2	1.4	21.7 - 22.7
Free Chlorine	mg/L	38	0.2	0.04 - 1.6	0.2	0.3	0.1 - 0.3
Total Chlorine	mg/L	38	2.1	1.6 - 3.0	2.1	0.3	2.0 - 2.2

Note: All calculations with below detection limit values used the detection limit value in the calculation as a conservative estimate.

Table 4-7. Operational Data Summary

Parameter	Unit	Count	Median	Range	Average	Standard Deviation	95% Confidence Interval
Lamp 1 Power	kW	36	1.9	1.9 - 2.0	1.9	0.037	1.9 - 1.9
Lamp 2 Power	kW	36	1.9	1.9 - 2.0	1.9	0.037	1.9 - 1.9
Lamp 3 Power	kW	36	1.9	1.9 - 2.1	1.9	0.040	1.9 - 1.9
Lamp 4 Power	kW	36	1.9	1.8 - 1.9	1.9	0.024	1.9 - 1.9
Total Power	kW	36	7.6	7.5 - 7.9	7.6	0.10	7.6 - 7.6
Differential Pressure	in of water	45	1.0	0.60 - 1.8	1.0	0.28	0.92 - 1.1
Feed Pressure	psi	96	5.3	3.6 - 20	5.5	1.6	5.2 - 5.8
UV Irradiance	mW/cm^2	21446	410	300 - 520	410	29	410 - 410
Flow	gpm	21446	390	110 - 680	390	33	390 - 390

Power (kW) = Voltage (V) x Current (I) x Power Factor(0.98)/1000 based on 81% lamp power setting

Table 4-8. Collimated Beam Testing Results (9/14/01)

UV Dose mJ/cm^2	MS2 Count MS2/100mL	Log Inactivation
20	4.60E+08	1.0
45	3.40E+07	2.2
70	4.60E+06	3.0
95	3.40E+05	4.2
120	5.70E+04	5.0
145	3.20E+03	6.2
Feed 1	3.90E+09	
Feed 2	6.30E+09	
Feed Average	5.10E+09	

Table 4-9. MS2 Virus Microbial Challenge Test Results

Flow Rate: 695 gpm
Lamp Power Setting: 81.3%
Feedwater UVT: 83.8%

Sample #	Feed (pfu/100ml)	Effluent (pfu/100mL)	Log Inactivation*	Equivalent Dose**(mJ/cm)^2
Negative Control				
1	<1	N/A	N/A	
2	2	N/A	N/A	
Challenge 1				
1	8 E+04	<1 E+02	>2.9	>65
2	6 E+04	3 E+02	2.3	50
3	5 E+04	4 E+02	2.1	45
Challenge 2				
1	1.1 E+05	2 E+02	2.7	60
2	7 E+04	<1 E+02	>2.8	63
3	5 E+04	2 E+02	2.4	53
Challenge 3				
1	1.1 E+05	1 E+02	3.0	68
2	7 E+04	1 E+02	2.8	63
3	8 E+04	2 E+02	2.6	58
Average Log Removal	(Challenge 1,2 and 3)		2.6	
Positive Control (Lamps off)* **				
1	7 E+04	7 E+04	0	
2	3 E+04	4 E+04	-0.1	
3	5 E+04	1 E+05	-0.3	

*Log removal to the tenths place value is only an estimate as micro lab reports have only one significant figure in most cases

** Equivalent dose is dose calculated using dose response curve developed from collimated beam test

*** The results of the positive control test are considered acceptable if the max difference between the feed and the effluent values (5E+4) are less than the maximum variability in the feed concentrations during the challenge experiments and positive control experiments (8E+4 in this case)

Table 4-10. Review of Manufacturer's Operations and Maintenance Manual for the Trojan 4L12 UVSwift System

O & M Manual	Grade	Comment
Overall Organization	+	• The O&M manual is very well organized. The table of contents includes the following main sections: Introduction to UV Theory, System Overview, Start –up and Shut-Down Procedures, UV Reactor Description, Control Power Panel (CPP) Description, UV Sensor(s) Description, and Automatic Cleaning System Description. • The manual also includes the following preface information: General Information, Important Contacts, Warnings and Precautions, General Lockout Procedures, List of Acronyms/Glossary, and Operator's Kit. • Lastly, the manual includes the following appendices: Project Description, System Description, Layout Drawings, Electrical Drawings, Controls Philosophy, Material Safety Data Sheets, Manufacturer's Manuals, and Replacement Parts Lists.
Operations Sections	+	• Includes start up and shut down procedures including a pre-start checklist and step-by-step procedures for starting and stopping the UV system using the CPP. • The Operations Overview section includes several paragraphs describing how the system operates. Specifically, general information is provided on the CPP, operator interface, automatic dose paced control system, and automatic control of the UV lamps. • Further operational information is provided under the Control Power Panel Section. This section contains information regarding the use of the operator interface. Specifically, detailed information is provided on how to use the control screen, and access the display screens, settings screen and the system information screen. Step by step procedures and examples are provided regarding the use of the above screens. The control screen allows the user to power Up/down the UV reactor and initiate a manual wipe of the lamp and sensor sleeves. The display screens include: POWER, DOSE, UV INT, WIPER, LAMP, ALARMS and VALVE. Lastly, the settings screen allows the user to adjust Time and Date, Wiper settings and set dose, flow, UVT and alarms. Lastly the setting screens also contain a PASSWORD setting screen and a sensor and lamps setting screen. • The operations sections are well organized and make excellent use of tables, labeled photos and examples.
Maintenance Sections	+	• The system includes a table detailing specific maintenance checks for the CPP, UV Reactor, and the Automatic Cleaning System. The table provides the frequency and specific notes for each maintenance check. • Additional maintenance information s provided for the UV sensor and Automatic Cleaning System in the respective sections of the manual
Troubleshooting Section	+	• Provides a table titled "Troubleshooting Conditions", which contains the following column headings: Alarm Condition, Possible Cause and What to do? The table addresses 24 possible alarm conditions and possible remedies.

Table 4-10. Review of Manufacturer's Operations and Maintenance Manual for Trojan 4L12 UVSwift System (contd.)

O & M Manual	Grade	Comment
Internal references between sections containing both Operation and Maintenance information.	–	• System operation information is provided in the following sections: System Overview, Start up and Shut down, and Control Power Panel. These sections should contain references to each other to allow the reader to quickly review all information regarding operation. Similarly, maintenance information is provided in the following sections: System overview, UV Sensor, and Automatic Cleaning System. These sections should contain references to each other to allow the reader to quickly review all information regarding maintenance.
Ancillary Equipment Information	+	• Equipment manufacturers literature included as an appendix for all system components.
Labeled Photos and Diagrams	+	• Makes excellent use of labeled photos and diagrams to identify various system components. • Includes visual representation of actual user interface screens and provides examples on setting parameters.
Use of Tables	+	• Manual makes good use of tables to organize and present information.
Overall Comment	+	• An excellent O&M manual. It is very well organized, well written, clear and complete. An excellent table of contents makes locating information in the manual a simple process. • The manual includes a good use of graphics to assist the reader's understanding. • The manual includes as an appendix a list of components used on the pilot such as pumps, flow meters, valves and pressure gauges including manufacturer and model number.

Note: Grade of "+" indicates acceptable level of detail and presentation, grade of "-" indicates the manual would benefit from improvement in this area.

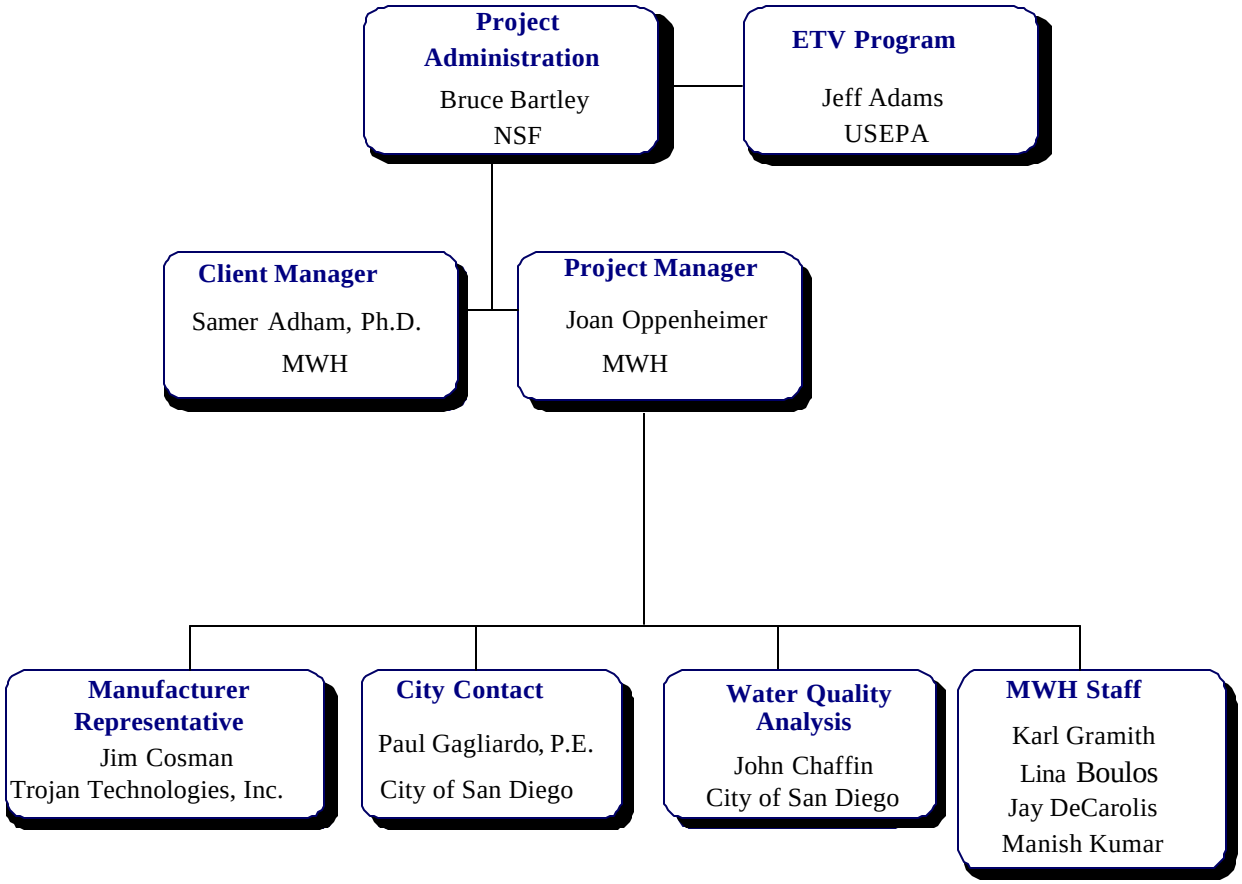

Figure 1-1. Organizational Chart Showing Lines of Communication

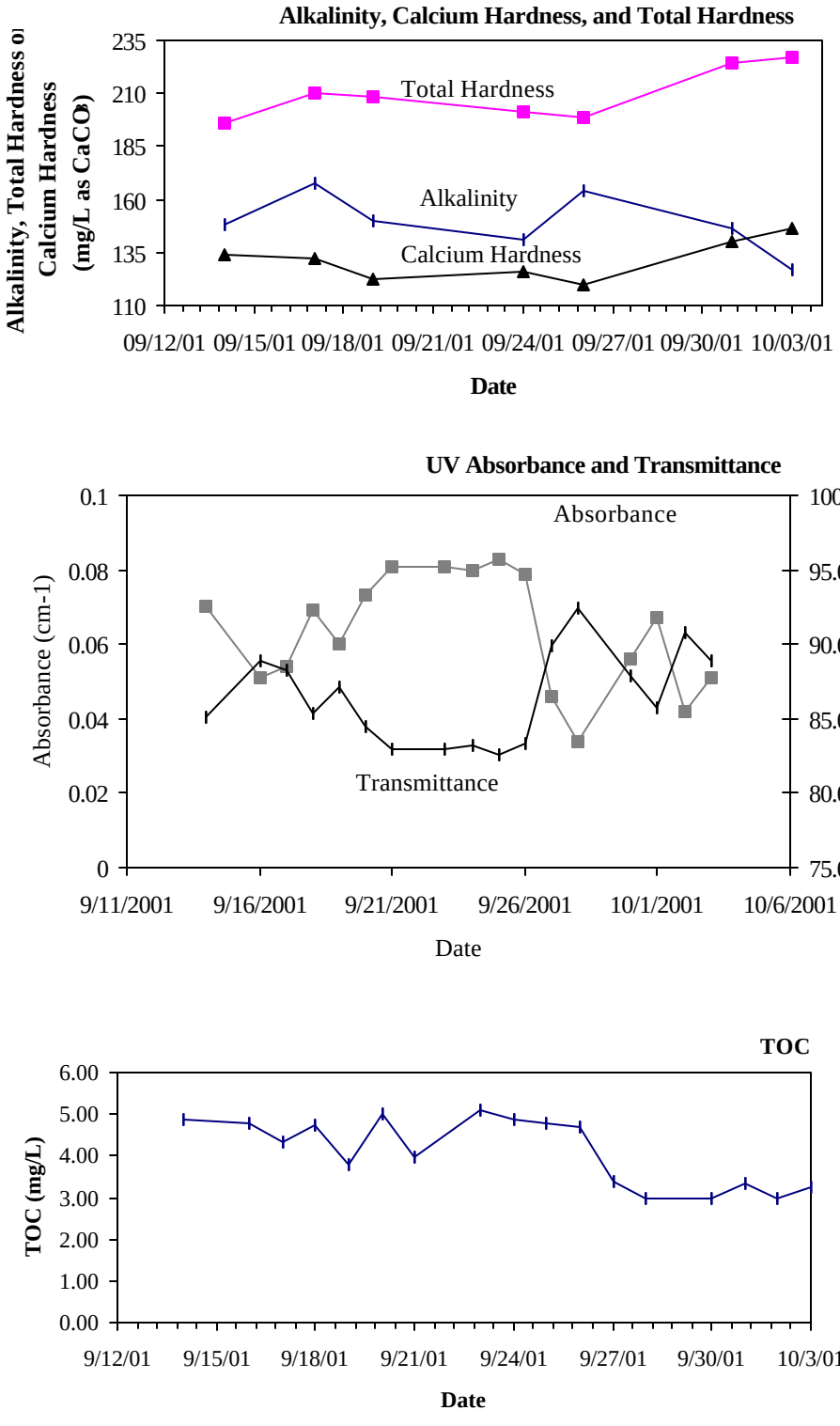

Figure 1-2. Source Water Characteristics for Trojan 4L12 UVSwift Verification Testing

Figure 2-1. Photograph of UVSwift Unit

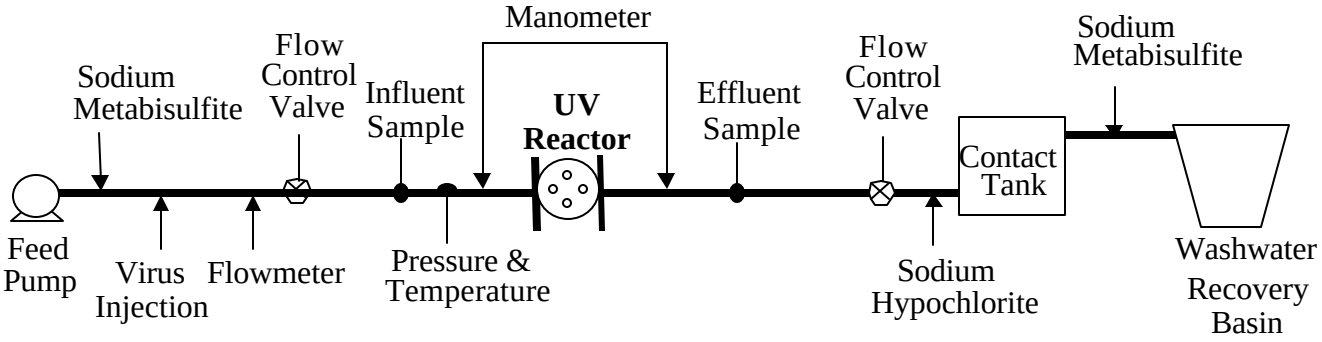

Figure 2-2. Schematic of Treatment Process

Figure 3-1. Photograph of Collimated Beam Unit

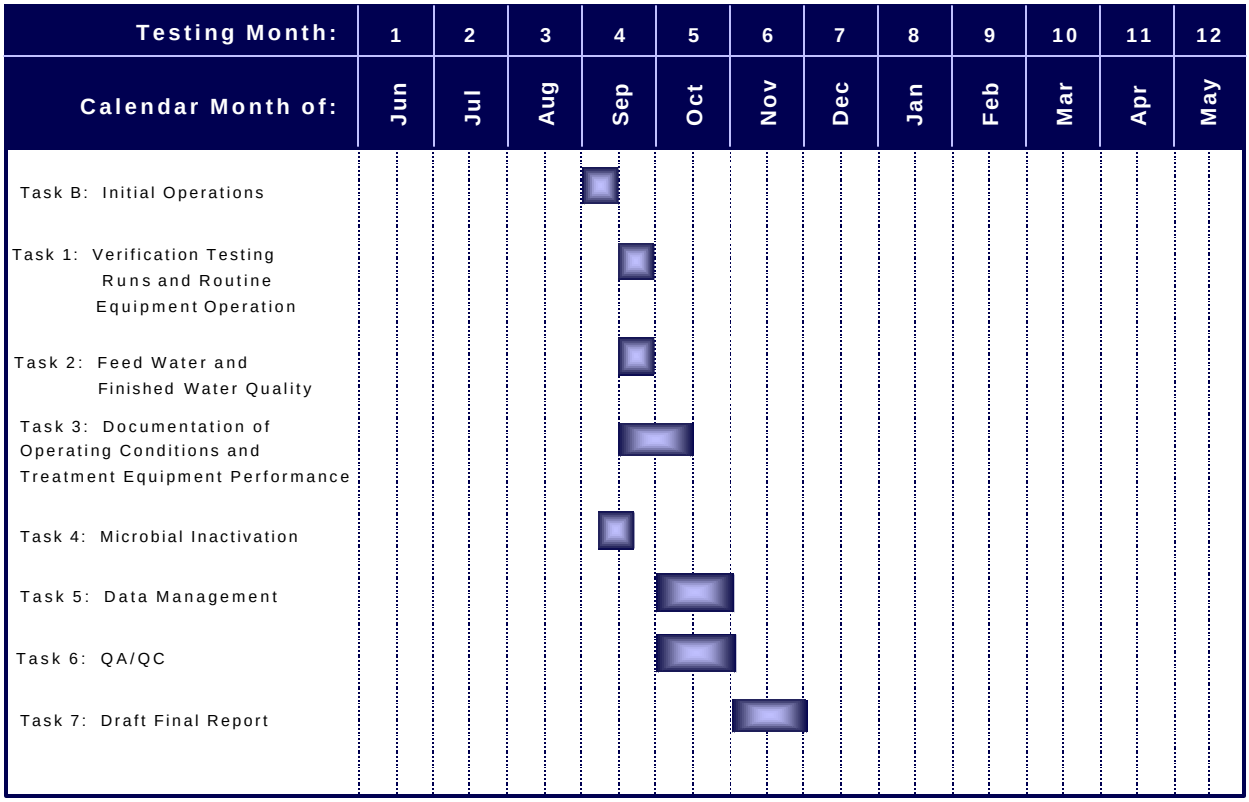

Figure 3-2. UV Verification Testing Schedule

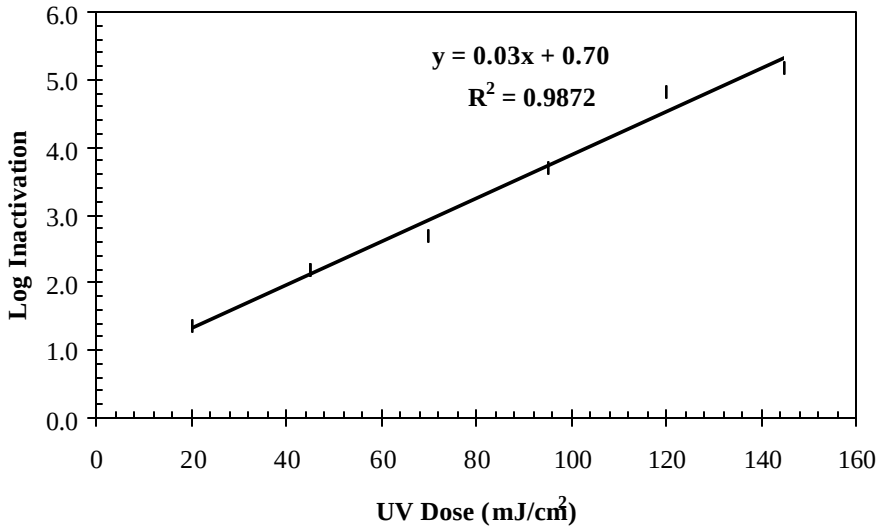

Figure 4-1. Dose Response Curve for Preliminary Collimated Beam Test (9/5/01)

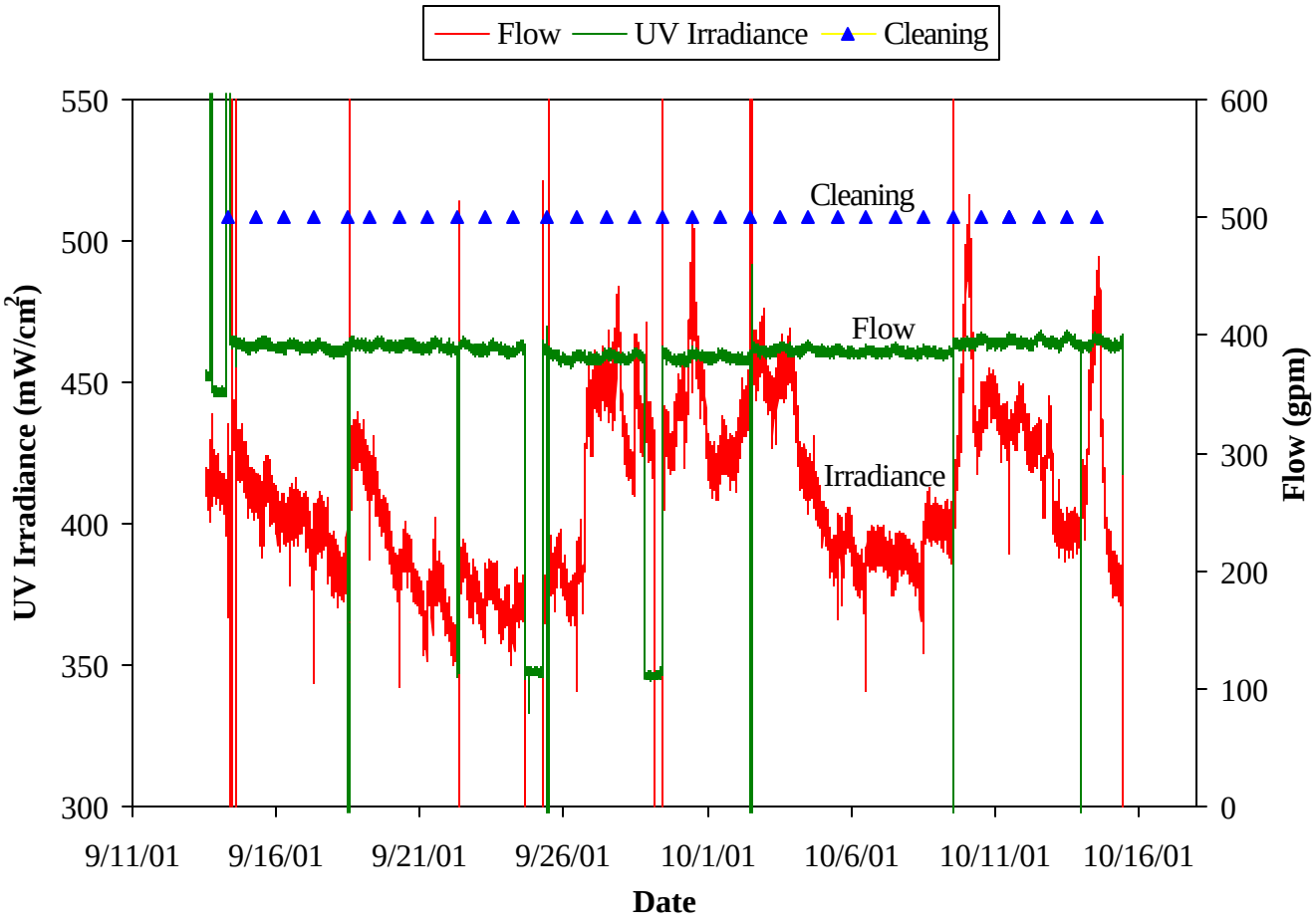

Figure 4-2. Operational Data during Testing Period

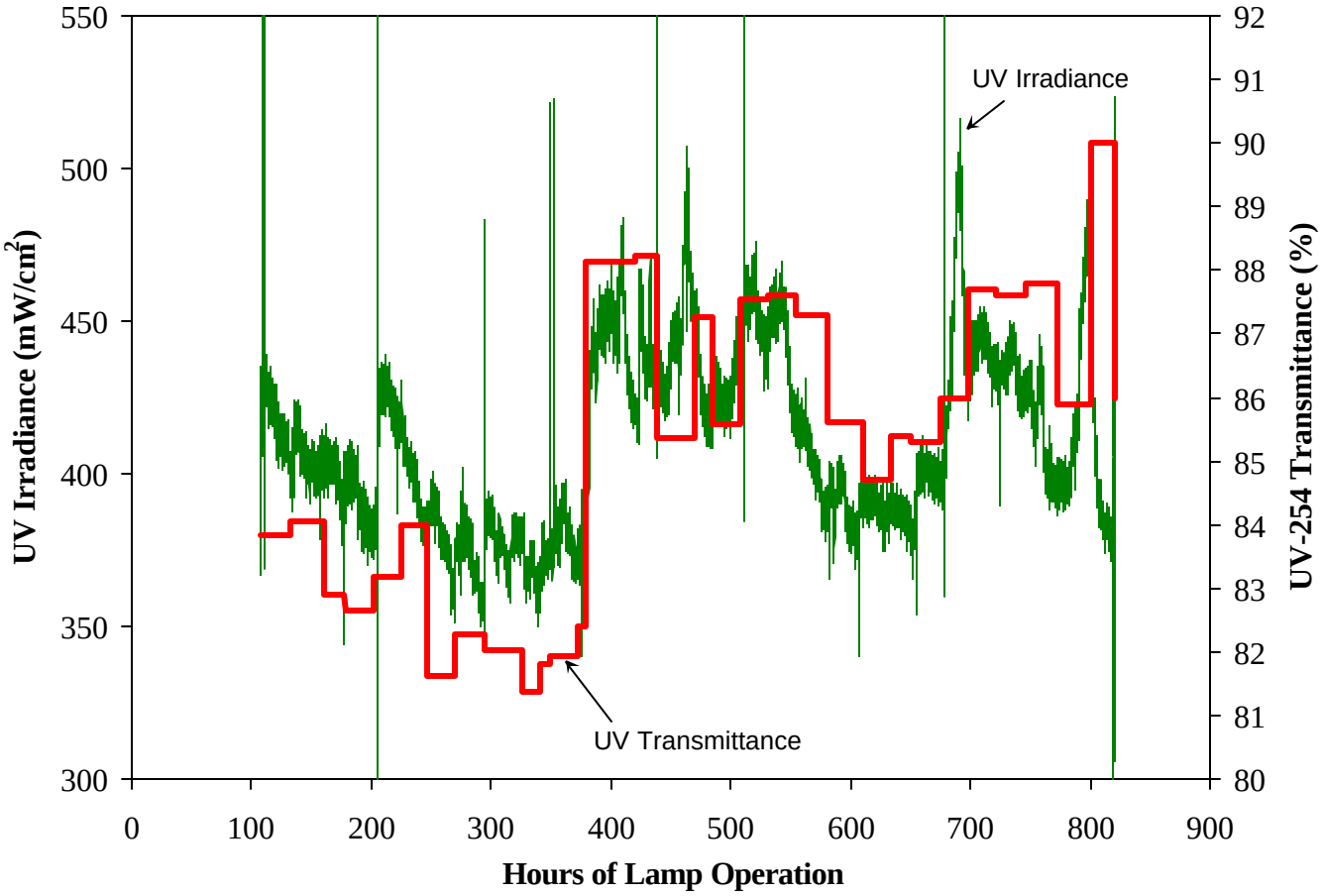

Figure 4-3. Onsite UV Irradiance and UV-254 Transmittance During Testing Period

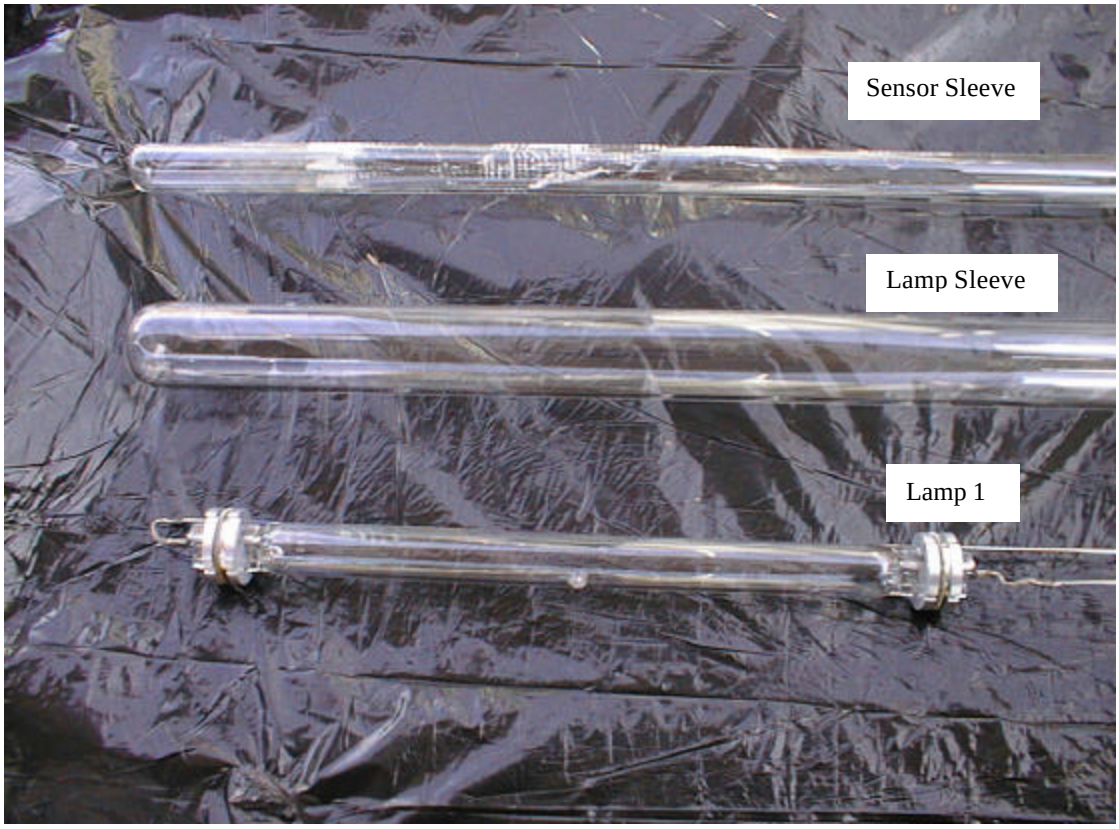

Figure 4-4. Sensor Sleeve, Lamp 1 sleeve, and Lamp 1 After 820 Hours of Operation

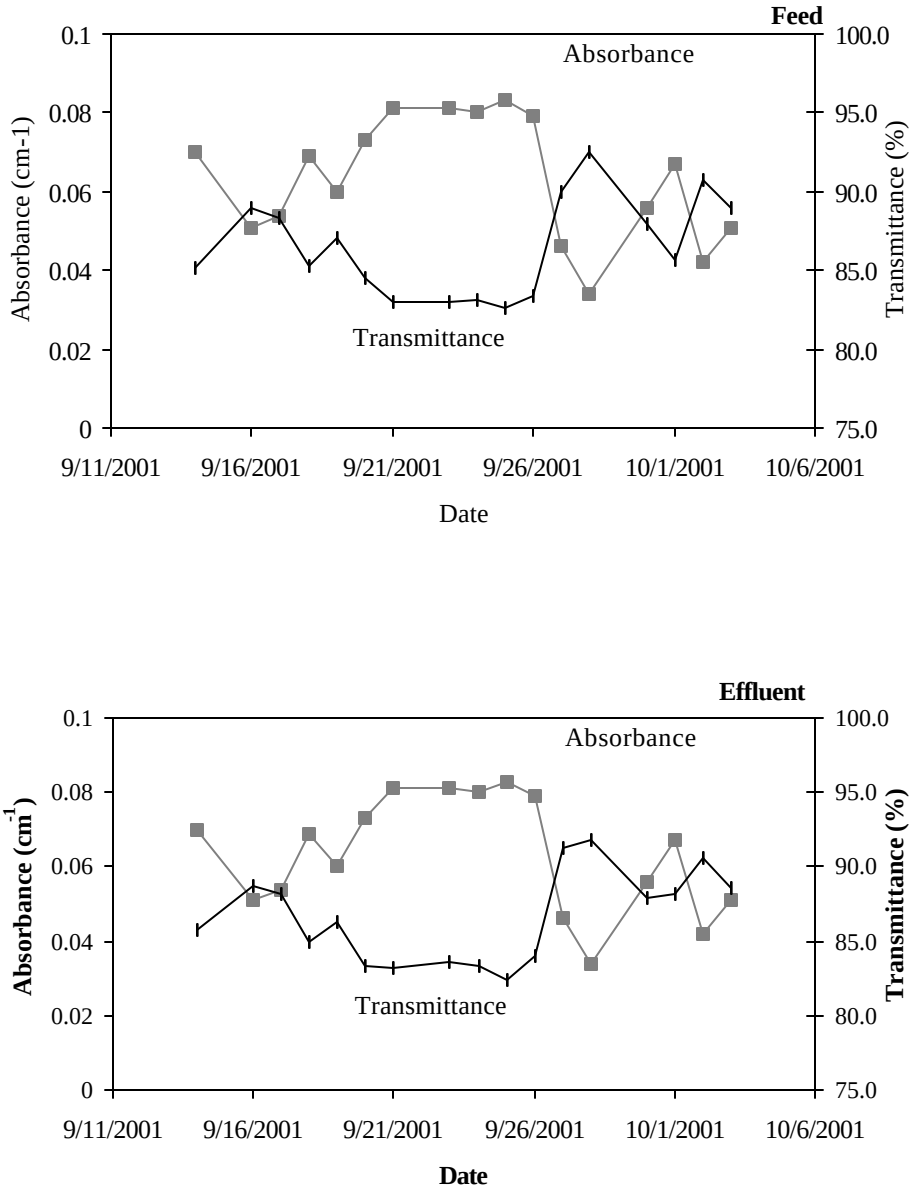

Figure 4-5. Laboratory UV Absorbance and Transmittance for Feed and Effluent Water

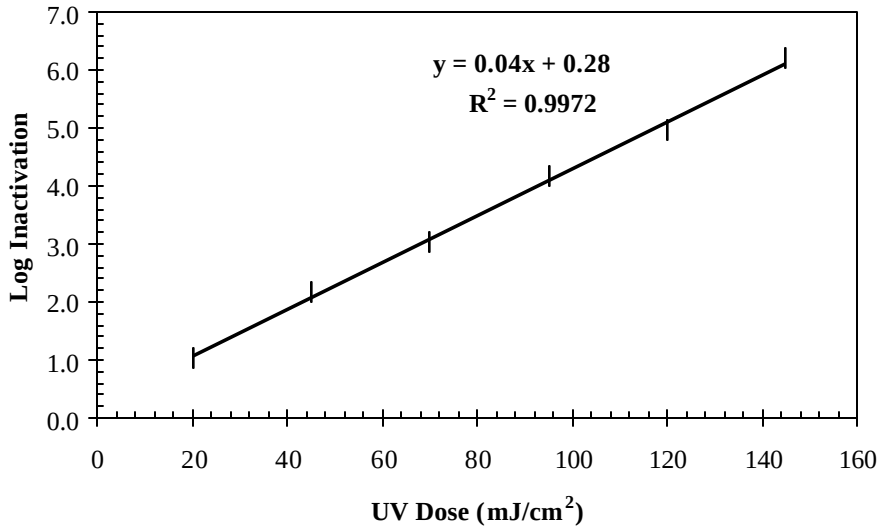

Figure 4-6. Dose response Curve from Collimated Beam Testing (9/14/01)

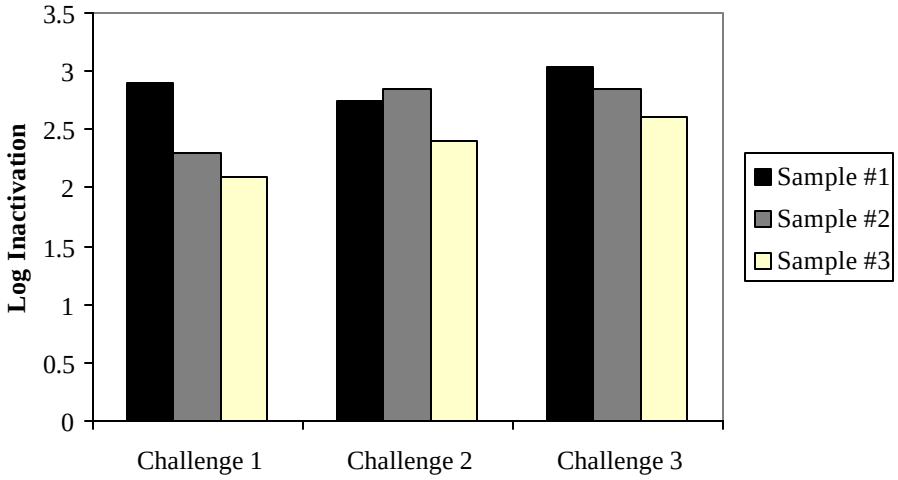

Figure 4-7. MS2 Virus Seeding Experiment Results