GREAT SHIPS INITIATIVE
BENCH-SCALE TEST FINDINGS
Technical Report - Public

AquaMost Ballast Water Treatment System

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ABSTRACT

The Great Ships Initiative (GSI) conducts bench-scale (i.e., laboratory) research to aid developers of innovative technologies which could have application as ballast water treatment systems (BWTSs). This report describes 2010-2011 findings from bench-scale evaluations of a BWTS proposed by AquaMost, Inc. of Madison, Wisconsin. The system utilizes a patented technology, photoelectrocatalytic oxidation (PECO), whereby a proprietary electrode is illuminated with ultraviolet (UV) light to produce highly reactive hydroxyl radicals. The BWTS is intended for use as a routine ballast treatment. GSI tested the proposed system to assess acute dose effectiveness and the generation of hydroxyl radicals in a variety of water qualities. Please see www.greatshipsinitiative.org for more information about GSI's bench-scale testing program.

The specific suite of tests reported here evaluated a small, bench-scale working model of the AquaMost BWTS set up according to vendor specifications. The BWTS was made up of three components: pump, PECO reactor and associated electronics (i.e., UV light ballasts and a power supply for the electrode), and plumbing. A 10.0 gallon per minute (gpm) submersible pump drew water from a 1000 L plastic tank through the BWTS and back into the plastic tank, thereby creating a recirculation-like scenario.

GSI dose effectiveness tests measured the effects of the AquaMost BWTS on freshwater organisms known to be relatively resilient to stressors in two water qualities: laboratory water (LW) and high organic content laboratory water (HOC-LW). Test organisms included the green alga *Selenastrum capricornutum* and the bacteria *Escherichia coli* and *Enterococcus faecalis.* In these tests, the BWTS proved effective at inactivating the green algae in LW only. In HOC-LW *S. capricornutum* were highly resilient with a rate of survival ranging from 81 - 98 %. In contrast, the bacteria *Enterococcus* and *E. coli* were significantly reduced following 180 minutes of exposure to the AquaMost BWTS in both water qualities.

GSI bench-scale chemical degradation tests were undertaken to determine the effect that the five water types had on the generation of hydroxyl radicals as measured indirectly by the degradation of the commercially available AQUASHADE® dye. Tests indicated that hydroxyl radicals were able to degrade in LW more effectively over a 180 minute BWTS exposure period compared to both HOC-LW and high organic content salt water (HOC-SW). Total residual oxidants were produced to significant levels (i.e., 1.6 mg/L) in salt water (SW) indicating that organic matter did impact the ability of the hydroxyl radicals to degrade.

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INTRODUCTION

This technical report presents qualitative findings from GSI bench-scale evaluations of a ballast water treatment system (BWTS) proposed by AquaMost, Inc. of Madison, Wisconsin, with possible application to the Great Lakes. The treatment involves a patented technology, photoelectrocatalytic oxidation (PECO), whereby a proprietary electrode is illuminated with ultraviolet (UV) light to produce highly reactive hydroxyl radicals such as hypochlorus acid (i.e., bleach). The BWTS is intended for use as a routine ballast treatment. GSI undertook these bench-scale tests during 2010-2011 at the Lake Superior Research Institute (LSRI) of the University of Wisconsin-Superior (UW-S) in Superior, Wisconsin. Preliminary testing of the system involved:

- Dose effectiveness tests, including determination of the effects of the treatment on the green alga *Selenastrum capricornutum* and the bacteria *Escherichia coli* and *Enterococcus faecalis* in laboratory water (LW) and high organic content laboratory water (HOC-LW).
- Chemical degradation tests to determine the effectiveness of the BWTS in a variety of water types.

BACKGROUND

Great Ships Initiative (GSI)

GSI is a regional effort devoted to ending the problem of ship-mediated invasive species in the Great Lakes-St. Lawrence Seaway System and globally. In support of that goal, GSI has established superlative freshwater ballast treatment evaluation capabilities at three scales—bench, land-based, and on board ship.

GSI awards its independent status-testing services to developers of BWTSs and processes determined to be promising. GSI status-testing is performed at the scale appropriate to the state of development of the target treatment system, with the goal of facilitating the rapid progression of meritorious BWTSs through the research and development and approval processes to a market-ready condition.

GSI has no involvement, intellectual or financial, in the mechanics, design or market success of the actual treatment systems it tests. To ensure that GSI tests are uncompromised by any real or perceived individual or team bias relative to test outcomes, GSI test activities are subject to rigorous QAQC procedures and documentation. This attention to QAQC assures high quality and credible evaluation of GSI and its findings.

Organization

GSI is a project of the Northeast-Midwest Institute (NEMWI)—a Washington, D.C-based private, non-profit, and non-partisan research organization dedicated to the economic vitality, environmental quality, and regional equity of Northeast and Midwest states. The project is carried out collaboratively with contracting entities including the University of Wisconsin-Superior (UW-S), AMI Consulting Engineers, Broadreach Services, and the University of Minnesota-Duluth (UM-D).

Ms. Allegra Cangelosi of NEMWI is GSI's Principal Investigator and Director (GSI PI). A GSI Advisory Committee comprising top-level officials of key stakeholder groups provides direct input to Ms. Cangelosi, advising on GSI award decisions, program direction, finances and fund-raising. The American Great Lakes Ports Association advises the project, assuring that the GSI is meeting the needs of the maritime industry; and coordinating maritime industry and supply chain outreach. Researchers from UW-S's Lake Superior Research Institute (LSRI) and the UM-D's Natural Resources Research Institute (NRRI), among others, provide critical scientific and technical expertise and implementation services to the GSI PI. Dr. Mary Balcer of LSRI is the project's lead zooplankton ecologist. She is also the team leader for LSRI staff engaged in GSI research activities. Mr. Matthew TenEyck of LSRI leads all bench-testing and Whole Effluent Toxicity (WET) tests. Mr. Tom Markee of LSRI is responsible for GSI chemical analysis. Ms. Heidi Saillard of LSRI is responsible for GSI microbial analysis. Ms. Nicole Mays of NEMWI is GSI's Senior Quality Systems Officer and Ms. Kelsey Prihoda of LSRI is GSI's Senior QAQC Officer

Projects and Activities

GSI's current suite of projects and activities includes independent third party BWTS evaluations at three scales—bench, land-based, and shipboard. Each scale is dedicated to addressing specific evaluation objectives. These include:

GSI Bench-Scale Tests

- Range finding for effective treatment dose against diverse freshwater taxa and water quality conditions;
- Generation of relevant freshwater chemical degradation curves; and
- Estimation of residual toxicity given diverse freshwater taxa and water quality conditions.

GSI Land-Based Tests

- Pre-certification testing, i.e., operational and biological performance (including residual toxicity) status-testing given scale-up and a range of challenge conditions; and

- Certification/verification testing, i.e., formal assessment of performance against IMO and other discharge standards.

GSI Shipboard Tests

- Confirmation of biological and operational treatment performance as expected in the ship environment;
- U.S. Coast Guard Shipboard Technology Evaluation Program (STEP) testing;
- Shipboard type approval testing;
- Ship discharge monitoring; and
- Methods development.

GSI BENCH-SCALE TESTS

GSI bench-scale tests take place year-round at the LSRI. The LSRI is amply equipped with staff expertise and resources to conduct the tests, and has a long history of successfully undertaking similar tests.

The overarching goals of GSI bench testing are to explore dose-effectiveness, chemical degradation, residual toxicity, and/or sensitivity to challenge conditions of a proposed treatment method about which little is known. To that end, the tests are "range-finding" missions, to determine the optimal treatment dose/intensity that would maximize effectiveness and minimize residual toxicity. Findings help treatment developers better design an effective system and/or to move to the next stage of treatment evaluation. The tests are also a form of trouble-shooting to encounter possible problems with the proposed treatment in advance of more extensive and larger scale tests.

GSI bench-scale dose effectiveness tests help determine the range of concentrations of an active substance that is harmful to a variety of robust freshwater zooplankton, algae and bacteria known to be relatively resilient to stressors. Dose effectiveness test results for zooplankton and algae are expressed as percent survival, percent mortality, and/or percent hatch. Where applicable, results may also expressed in terms of a series of absolute quantifications: LC99, i.e., the experimentally derived concentration of an active substance estimated to kill 99 percent of the test population following 24 or 48 hours of continuous exposure; No Observed Effect Concentration (NOEC), i.e., the highest concentration of an active substance shown to have no significantly adverse effect on the test population compared to controls; and Lowest Observed Effect Concentration (LOEC), i.e., the lowest concentration of an active substance known to have a significantly adverse effect on the test population compared to controls.

GSI bench-scale chemical degradation tests determine the effect that various water quality or environmental parameters may have on the rate of chemical degradation of a BWTS involving active substances. No organisms are used in association with these analytical assays; instead test solutions are analyzed for their concentration of active substance (or active component of the substance). Test results are typically expressed as the percent change in active ingredient concentration.

GSI bench-scale residual toxicity tests help estimate the effect that treated water (following neutralization of the active substance, a degradation period, a dilution step, or no treatment at all) may have on non-target organisms in the receiving system. These test results are expressed in a manner similar to those for dose effectiveness assays. The principal difference between these tests and dose effectiveness tests is that the concentration of the active substance is adjusted to be consistent with potential discharge levels, and the tests are performed on sensitive organisms rather than robust species.

Please note that GSI's bench-scale tests do not by themselves provide adequate information to assess a prospective BWTS's ability to meet a particular discharge standard or to achieve environmental soundness under shipboard application. Instead, these tests provide initial insights for developers of systems into possible strengths and weaknesses of the proposed treatment—information that can be used by developers to better design a more effective system and/or to move to the next stage of treatment evaluation. The tests are also a form of trouble-shooting to encounter possible problems with the proposed treatment in advance of more extensive and larger scale tests

METHODS

Treatment System

The AquaMost BWTS consists of a patented technology called photoelectrocatalytic oxidation (PECO) and involves use of a germicidal ultraviolet (UV) light source to activate a proprietary light-activated catalyst that is capable of generating powerful oxidants *in situ*, including hydroxyl radicals, hydrogen peroxide, and if chloride ions are present in the water, hypochlorus acid (i.e., bleach), which can be measured as total residual oxidants (TRO). In tests reported here, the BWTS was made up of three components: pump, PECO reactor and associated electronics (i.e., UV light ballasts and a power supply for the electrode), and plumbing. A 10.0 gallon per minute (gpm) submersible pump drew water from a 1000 L plastic tank through the BWTS and back into the plastic tank, thereby creating a recirculation-like scenario.

Experiments took place in an LSRI laboratory equipped with adequate ventilation, electrical connections, and climate control. Test apparatus generally consisted of several 300 mL borosilicate high-form beakers housed within environmental chambers set to the appropriate temperature and light regime.

General Methods

Five experimental water qualities were prepared in the laboratory as follows:

- Laboratory water (LW): Treated water from the City of Superior, Wisconsin that was passed through an activated carbon cartridge. Alkalinity ranged from 45 - 55 mg/L as $CaCO_3$. Non-purgeable organic carbon (NPOC) ranged from 0.3 – 1.1 mg/L. The water had a percent transmittance (%T) measured at 254 nm in a 1 cm cell of 94 %.
- High organic content laboratory water (HOC-LW): LW as described above with addition of humic acid (20 mg/L) to adjust the NPOC to approximately 5.8 - 6.4 mg/L. The water is darker and has a lower light transmittance when compared to LW. The enriched NPOC level is also reflective of Duluth-Superior Harbor water. The HOC water had a %T measured at 254 nm in a 1 cm cell of 36 %.
- Brackish water (BW): LW as described above with addition of Instant Ocean (3 g/L).
- Salt water (SW): LW as described above with addition of Instant Ocean (32 g/L).
- High organic content water salt water (HOC-SW): LW as described above with addition of Instant Ocean (32 g/L) and humic acid (20 mg/L).

Experimental Methods

Dose Effectiveness Experiments

GSI dose effectiveness tests measured the effects of the AquaMost BWTS on freshwater organisms known to be relatively resilient to stressors in two water qualities (LW and HOC-LW). Test organisms included the green alga *Selenastrum capricornutum* and the bacteria *Escherichia coli* and *Enterococcus faecalis.*

Dose effectiveness was examined using the 1000 L influent tank filled to 500 L with 25 °C ± 1.0 ºC LW or 25 °C ± 1.0 ºC HOC-LW. Test organisms were added to the tank and mixed well to ensure homogeneity prior to initial sampling.

The *S. capricornutum* dose effectiveness test was conducted according to *GSI/SOP/BS/RA/DE/5 – Procedure for Assessing Dose Effectiveness of a Ballast Treatment System using Selenastrum capricornutum*. Briefly, 1 L of *S. capricornutum* inoculum at a concentration of 1.0 x 10^8 cells/mL was added to the 1000 L plastic tank to achieve the desired initial concentration of approximately 200,000 cells/mL. Triplicate samples were collected from tank following 0 minutes (i.e., BWTS turned off), 90 minutes and 180 minutes of exposure to the treatment. Mortality counts were made of the triplicate samples immediately after collection.

To examine delayed mortality, 50 mL aliquots of sample were placed into sterile 125 mL Erlenmeyer flasks fitted with foam plugs. Samples were placed on a shaker table set at 100 rpm and 25 °C ± 1.0 ºC in complete darkness. Subsamples were collected and analyzed for live and dead cells at 24 hours and 48 hours after collecting the initial 0, 90 and 180 minute samples.

Similarly, samples were enumerated following 0, 90 and 180 minutes of exposure to the BWTS for the two bacteria test organisms (*E. coli* and *Enterococcus)* with Colilert® and Enterolert™ assays using the Quanti-Tray/2000 and the Quanti-Tray sealer from IDEXX Laboratories, Inc. (Westbrook, Maine). The Colilert® test can detect *E. coli* at 1 cfu/100 mL (see *GSI/SOP/BS/RA/MA/4 - Procedure for the Detection and Enumeration of Total Coliforms and E. coli Using IDEXX's Colilert®*), and the Enterolert™ test can detect *Enterococci* at 1cfu/100mL (see *GSI/SOP/BS/RA/MA/3 - Procedure for the Detection and Enumeration of Enterococcus using Enterolert™*). Both tests use Defined Substrate Technology® (DST) in which the bacteria metabolize the enzymes in the specific media causing the sample to fluoresce. Samples were analyzed according to *GSI/SOP/BS/RA/MA/4* and *GSI/SOP/BS/RA/MA/3*. Results are expressed as Most Probable Number (MPN) per 100mL. MPN is a common method of obtaining quantitative data on concentrations of discrete items from positive/negative (incidence) data and in this case is directly related to cfu which correlates well with colony forming units.

Chemical Degradation Experiments

GSI bench-scale chemical degradation tests were undertaken to determine the effect that the five water types (i.e., LW, HOC-LW, BW, SW and HOC-SW) have on the generation of hydroxyl radicals as measured indirectly by the degradation of the commercially available AQUASHADE® dye. AQUASHADE® dye is a blend of blue and yellow dyes that can be oxidized so a loss of color can be observed.

For each test, 500 L of approximately 25°C ± 1.0 ºC LW was added to the 1000 L plastic tank. Once the tank had been filled, the appropriate quantity of humic acid or aquarium salt was added to achieve the desired water type and the tank was mixed well by hand. 5 mL of AQUASHADE® dye was then added and the water pumped through the BWTS for 1-2 minutes using the submersible pump to further mix the test water throughout the entire BWTS prior to activating both the UV lights and PECO system.

Initial water quality parameters within the plastic tank were measured including temperature, dissolved oxygen, pH, alkalinity, hardness, total residual oxidants (TROs), total residual chlorine (TRC), NPOC, %T at 254 nm, and absorbance at 630 nm. The BWTS was then turned on, allowing water from the tank to be pumped through the treatment system and back into the tank, thereby providing a recirculation-like test scenario. The system was allowed to run for a 180 minutes exposure period. In some instances it was decided to run the treatment another 60 minutes, i.e., for a total test period of 240 minutes, to help gauge if 180 minutes was an appropriate exposure period. Temperature, dissolved oxygen, pH, TRO, TRC and absorbance at 630 nm were measured every 30 minutes during this period, while NPOC and %T at 254 nm were measured at 90 minute intervals.

Concentrations of TROs were determined according to *GSI/SOP/BS/RA/C/2, v.2 – Procedure for Determining Total Residual Oxidants (TRO) in Water*. Sample water was added to a beaker containing the contents of a Hach DPD Total Chlorine Reagent powder pillow (Hach Company; Loveland, Colorado). If TROs were present, the water turned a red color which was proportional to the TRO concentration. A calibration curve, prepared by measuring the absorbance at 515 nm of chlorine standards reacted with the Hach DPD reagent, was used to determine the concentration of TROs (as chlorine in the sample).

The % T of sample water was determined at 254 nm using a UV-VIS spectrophotometer and following *GSI/SOP/BS/RA/C/4 – Procedure for Determining Percent Transmittance (%T) of Light in Water at 254 nm*. The instrument was turned on, wavelength set to 254 nm, allowed to warm up and readout mode set to %T. Deionized water was placed in the reference and sample cuvettes (1 cm light path) and the readout adjusted to 100% T. Cuvettes were rinsed twice with sample prior to recording the %T of the sample. Absorbance of samples was measured using the same instrument with wavelength set to 630 nm and the readout mode adjusted to absorbance.

TRC concentrations were measured using a Thermo Orion Model 97-70 Residual Chlorine Electrode connected to an Orion Model 290A pH/mV/ISE meter, according to *GSI/SOP/BS/RA/C/6, v.2 – Procedure for Analyzing Total Residual Chlorine Concentrations in Water*.

Organic carbon analysis was conducted on a Shimadzu Model TOC-5050A Total Organic Carbon Analyzer by following *GSI/SOP/BS/RA/C/3, v.1 – Procedures for Measuring Organic Carbon in Aqueous Samples*. Before analysis, the samples were acidified to 0.2 % acid using concentrated hydrochloric acid. Samples were then purged with high purity air to remove the inorganic carbon and purgeable organic carbon, and injected into the analyzer An organic carbon stock solution having a concentration of 1000 mg/L carbon was used to prepare a series of working standards (i.e. 2.5, 5.0, 10.0, 25.0 and 50.0 mg/L C. Each standard was made to be 0.2% in hydrochloric acid. The standards were used to generate a calibration curve which was then used to determine the concentration of organic carbon in the samples.

Statistical Analysis

Statistical analysis was performed with SigmaStat (v. 3.5, Systat Software Inc., Chicago, IL) statistical software where applicable. Prior to ANOVA analysis the data was tested for normality and homogeneity of variance. If data were normally distributed and homogenous, survival was analyzed by ANOVA followed by either Dunnett's, Dunn's or Student-Newman-Keul's methods of means comparison test to determine the difference from control data. Significance level was tested at $\alpha=0.05$. Statistics were not used to report significances in cases where the results were either 0 % or 100 % survival with no error.

FINDINGS

Dose Effectiveness Experiments

Results of GSI bench-scale dose effectiveness tests involving the AquaMost BWTS on the freshwater algae *Selenastrum* are presented in Table 1. The system control (i.e., no active treatment component operating) had no effect on algae survival at any of the three observation periods (i.e., 0, 90 and 180 minutes of operation). In addition, no significant (p<0.05) reduction in control survival was observed for either water type tested 48 hours after initial sample collection.

In LW, algae survival measured at 0 hours post-treatment was reduced to 68 % following 90 minutes of treatment exposure and significantly reduced to 13 % following 180 minutes of treatment exposure (p<0.05; Table 1). Further, algae survival in this water type was significantly reduced (p<0.05) to 0 - 1 % for samples collected at 24 and 48 hour post-treatment following both the 90 and 180 minute BWTS exposure periods (Table 1). In contrast, algae survival in the HOC-LW was high at the 48 hour post-treatment observation period for both the 90 and 180 minute treatment exposures (81% and 86%, respectively; Table 1).

Table 1. Mean Percent Survival (Standard Deviation) of the Green Algae *Selenastrum* Exposed to the AquaMost BWTS in Laboratory Water (LW) and High Organic Content Laboratory Water (HOC-LW) Over a 3 Hour Exposure Period.

Water Type	Exposure Duration (mins)	Survival (%)		
		0 Hours	24 Hours	48 Hours
Control (LW)	0	100 (0)	99 (1)	99 (1)
	180	99 (1)	99 (0.4)	98 (0.3)
LW	0	100 (0)	99 (1)	99 (1)
	90	68 (5)	1 (1)*	1 (0)*
	180	13 (9)*	0 (0)*	NM
HOC-LW	0	100 (0)	100 (1)	100 (0)
	90	100 (0)	100 (1)	81 (5)*
	180	98 (2)	99 (1)	86 (5)*

*Either Dunnett's or Student-Newman-Keuls method indicates a statistically significant difference compared to the control within the time period ($p < 0.05$). NM equals not measured because previous sample exhibited complete mortality.

Results from the bacteria tests indicate the MPN for both *Enterococcus* and *E. coli* in LW and HOC-LW water were significantly reduced following 180 minutes of exposure to the AquaMost BWTS (Tables 2-3). There was also a reduction in MPN at 90 minutes for both species in these two water qualities (Tables 2-3). However, this reduction was found not to be significant when compared to the controls, likely because of the small sample size tested.

Table 2. Mean Most Probable Number (Standard Error) of *Enterococcus sp*. Exposed to the AquaMost BWTS in Laboratory Water (LW) and High Organic Content Laboratory Water (HOC-LW) Over a 3 Hour Exposure Period.

Water Type	Exposure Duration (mins)	Most Probable Number (MPN)
		0 Hours
LW	0	777833 (152758)
	90	1855 (297)
	180	11 (2)*
HOC	0	1651000 (172419)
	90	2033 (606)
	180	25 (8)*

*Dunn's method indicates a statistically significant difference compared to the control within the time period ($p < 0.05$).

Table 3. Mean Most Probable Number (Standard Error) of *E. coli* Exposed to the AquaMost BWTS in BWTS in Laboratory Water (LW) and High Organic Content Laboratory Water (HOC-LW) Over a 3 Hour Exposure Period.

Water Type	Exposure Duration (mins)	Most Probable Number (MPN)
		0 Hours
LW	0	282733 (110395)
	90	1507 (291)
	180	3 (1)*
HOC-LW	0	1072083 (23936)
	90	2700 (907)
	180	5 (3)*

*Dunn's method indicates a statistically significant difference compared to the control within the time period ($p < 0.05$).

Chemical Degradation Experiments

GSI bench-scale chemical degradation measured the effect that water quality and environmental parameters had on the generation of hydroxyl radicals as measured indirectly by the degradation of AQUASHADE® dye. Initial absorbance values were greater than 0.20 absorbance units (AU) in all five water types tested (Figure 1). Results show LW, BW, and SW had absorbance values less than 0.05 AU after 180 minutes treatment. In contrast, the HOC-LW water had an absorbance of 0.06 AU and the HOC-SW had an absorbance of 0.08 AU, indicating that organic matter did impact the ability of the hydroxyl radicals to degrade (Figure 1). The rates of absorbance decrease over time in the LW trials indicate the BWTS performed similarly over the different trials.

Disinfection byproducts such total residual chlorine (TRC) and total residual oxidants (TRO) were also of concern. TRC was found to be below detection 3.0 µg/L after 180 minutes of operating the AquaMost BWTS in LW, HOC-LW, BW and HOC-SW water types (Figure 2). However, in SW the TRO concentration rose from below detection to 1.6 mg/L after 180 minutes (Figure 2).

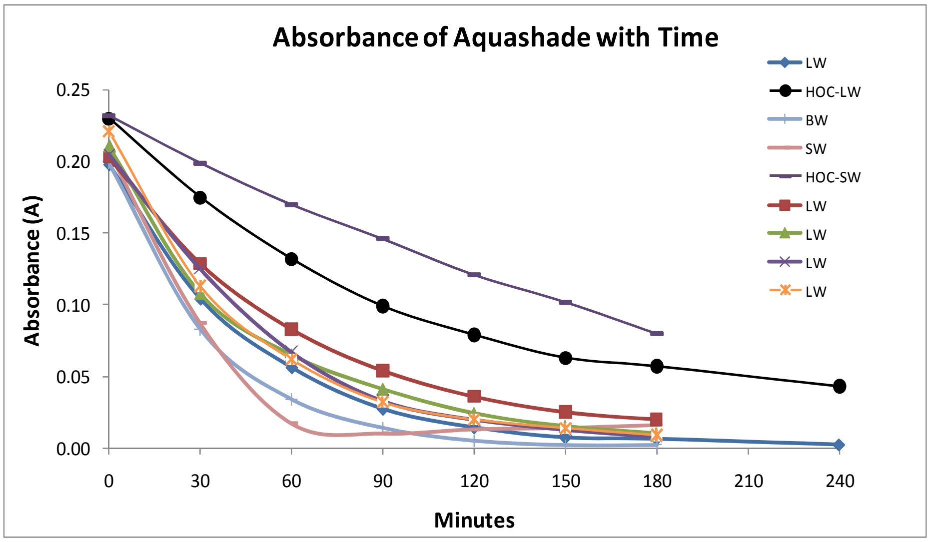

Figure 1. Absorbance of AQUASHADE® in Laboratory Water (LW), High Organic Content Laboratory Water (HOC-LW), Brackish Water (BW), Salt Water (SW), and High Organic Content Salt Water (HOC-SW) Over the 240 Minute Test Period.

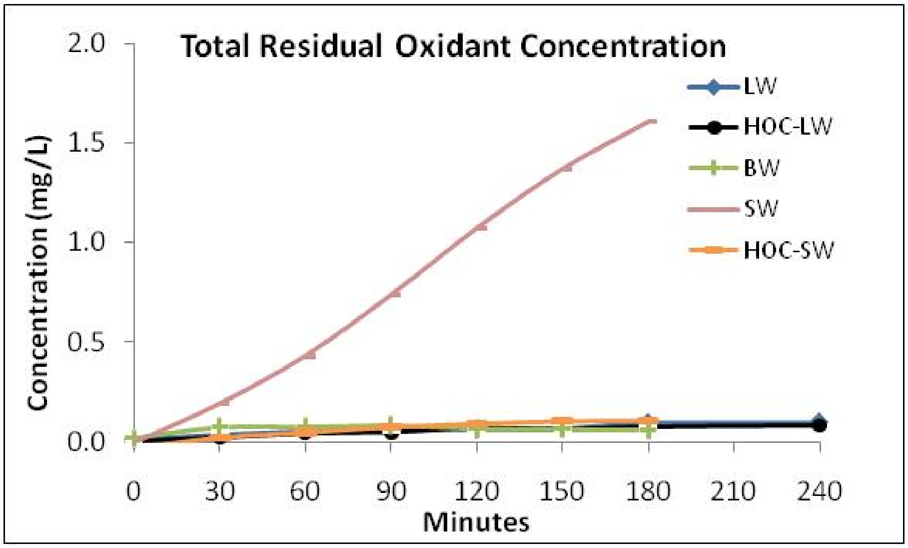

Figure 2. Total Residual Oxidant (TRO) Concentrations in Laboratory Water (LW), High Organic Content Laboratory Water (HOC-LW), Brackish Water (BW), Salt Water (SW), and High Organic Content Salt Water (HOC-SW) Over the 240 Minute Test Period.

GSI QUALITY MANAGEMENT

Standard Operating Procedures (SOPs)

Standard operating procedures (SOPs) are used to implement GSI bench-scale test activities. This facilitates consistent conformance to technical and quality system requirements increases comparability if multiple bench-scale trials are conducted on one treatment system. The SOPs include both programmatic and technical processes and procedures such as organism culturing; sample collection, labeling, analysis and custody; and safety. GSI SOPs follow a common format and include specific QAQC procedures and metrics. They are grounded in published standard methods. They are also consistent with international and domestic guidelines where they exist. All GSI SOPs are subject to periodic review and revision to assure that the most up to date approaches are employed. Table 4 outlines the GSI SOPs utilized for these tests.

Table 4. GSI Bench-Scale Standard Operating Procedures (SOPs) Utilized for Tests of the AquaMost BWTS.

SOP Category	Subcategory	SOP Title	SOP Code
General	Administration	Procedure for Record Keeping	GSI/SOP/G/A/RK/1
		Procedure for Data Entry, Data Quality Control and Database Management	GSI/SOP/G/RA/DM/1
Research Activities	Sample Custody	Procedure for Labeling GSI Bench-Scale Samples	GSI/SOP/G/RA/SC/4
	General Laboratory	Procedure for Verification of Laboratory Balances	GSI/SOP/BS/RA/GL/1
	Chemical Degradation	Bench-Scale Procedure for Examining the Aquatic Degradation of Active Substance(s) in a Ballast Treatment System (DRAFT)	GSI/SOP/BS/RA/CD/1
	Dose Effectiveness	Procedure for Assessing Dose Effectiveness of a Ballast Treatment System Using *Selenastrum capricornutum*	GSI/SOP/BS/RA/DE/5
		Procedure for the Detection and Enumeration of Enterococcus using Enterolert™	GSI/SOP/BS/RA/MA/3
		Procedure for the Detection and Enumeration of Total Coliforms and E. coli Using IDEXX's Colilert®	GSI/SOP/BS/RA/MA/4
		General Microbiology Preparation Procedures	GSI/SOP/BS/RA/MP/1
		Procedure for Assessing Antimicrobial Activity Using Time-Kill Method (DRAFT)	GSI/SOP/BS/RA/MA/2

Quality Assurance/Quality Control (QA/QC)

Test conditions were monitored daily for parameters that might affect the outcome of the test (i.e., temperature, and dissolved oxygen). Daily (e.g., pH meters) or weekly (e.g., dissolved oxygen meters, conductivity meter, and thermometers) calibration of test meters also ensured optimal performance.

The results of the duplicate analysis and spike recovery assays were consistent with GSI QAQC criteria. The following tables (Table 5-6) provide results of the QC samples for absorbance measurements and TRC analysis.

Table 5. Duplicate Agreement for Absorbance.

Analysis –QC Data
Relative Percent Difference (%)
Mean = 6.8 (n=5)

Table 6. Spike Recovery for Total Residual Chlorine (TRC).

Analysis –QC Data
Spike Recovery (%)
Mean = 88 (n=5)

Data Audits, Management and Archiving

Data were recorded on data collection forms or in specific laboratory notebooks. The GSI QA/QC Officer performed inspections of datasheet, logbooks, recorded measurements, and instrumentation used during the tests. All hard- and electronic-copies of data and records will be maintained by LSRI and archived for a period of seven years.

CONCLUSION

In conclusion, the AquaMost bench-scale BWTS had a significant effect on the mortality of the green algae *Selenastrum capricornutum* in laboratory water (LW), but not in water with high organic carbon (HOC-LW). In HOC-LW, algae mortality was low, even following the maximum 48 hour post-treatment observation period. In contrast, the BWTS significantly reduced bacteria *Enterococcus* and *E. coli* following 180 minutes of treatment exposure in both LW and HOC-LW water types.

Chemical degradation experiments indicated that hydroxyl radicals, as measured indirectly by the degradation of the commercially available AQUASHADE® dye, degraded best in LW over the 180 minute BWTS exposure period; degradation in either HOC-LW and high organic content salt water (HOC-SW) was less. The BWTS produced total residual oxidants at significant levels (1.6 mg/L) in salt water (SW) indicating that organic matter did impact the ability of the hydroxyl radicals to degrade.