Proof of Concept Evaluation of Potable Water Generators as Options for Managing Ballast Water for Target Vessels

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1. Background and Objectives of MERC Technology Evaluations

The Maritime Environmental Resource Center (MERC) is a State of Maryland initiative that provides test facilities, information, and decision tools to address key environmental issues facing the international maritime industry. The Center's primary focus is to evaluate the mechanical and biological efficacy, associated costs, and logistical aspects of ballast water management systems (BWMSs) and the economic impacts of ballast water regulations and management approaches. A full description of MERC's structure, products, and services can be found at www.maritime-enviro.org.

To address the need for effective, safe, and reliable BWMSs to prevent the introduction of non-native species, MERC has developed as a partnership between the Chesapeake Biological Laboratory/University of Maryland Center for Environmental Science (CBL/UMCES), Maryland Port Administration (MPA), U.S. Maritime Administration (MARAD), Smithsonian Environmental Research Center (SERC), University of Maryland, College Park, (UMCP), University of Maryland Wye Research and Education Center (UMD/WREC) and Old Dominion University (ODU) to provide independent performance testing and to help facilitate the transition of new treatment technologies to shipboard implementation and operations.

MERC evaluated the performance characteristics of a potable water generator (PWG) through objective and quality assured land-based testing. The goal of this specific evaluation was to provide information on the performance of a standard marine PWG under the conditions specified in the test plan and to explore if the use of potable water generated onboard a vessel might be used as ballast for vessels that need to compensate for fuel consumption. The data and information on performance characteristics of the PWG are similar to an assessment of a BWMSs and compare numbers of live organisms in potable water discharged from mimic ballast tanks against the U.S. Coast Guard regulations and EPA's Vessel General Permit requirements for ballast water discharge.

It is important to note that MERC does not certify technologies nor guarantee that a treatment will always, or under circumstances other than those used in testing, operate at the levels verified. Our goal is not to conclude if this specific PWG is acceptable or unacceptable for use in producing ballast for targeted vessels. However, tests and results are in a format consistent with ballast water regulations (USCG and EPA) so the data can be used to determine compliance with discharge regulations. Sampling and analytical procedures utilized by the MERC team are also consistent with the EPA Environmental Technology Verification (ETV) Protocols (2010) and the current U.S. Federal Standards under the auspices of the U.S. Coast Guard. Final reports on PWG performance have been provided to the EPA and MARAD for review prior to public release.

2. Introduction to Technology

The PWG utilized a pre-filtration system consisting of a multimedia granular filter bed and bag and cartridge filters. Feed water was initially fed through a filter bed containing anthracite, garnet, flint, sand, and gravel filter media. The filtrate passed through a 5-micron filter bag and finally through a canister containing five 10-micron candle filters. The filter sizes were intentionally configured in this manner to maximize particulate filtration prior to the cartridge filter. This was done for the purpose of reducing the frequency of cartridge filter changes, which were labor intensive compared to bag filter changes. The pretreated water was then fed through a reverse osmosis (RO) membrane, disinfected with a 12.5% sodium hypochlorite solution (1 ppm dose), and then passed through two tanks containing calcite to neutralize the pH of the final product.

The PWG utilized a spiral-wound RO membrane filter made of a polyamide thin-film composite. The filter membrane, manufactured by Dow Chemical Company, has an active surface area of 440 ft^2 (41 m^2) and a salt rejection range of 99.65 to 99.80% (cited from the United States Environmental Protection Agency (EPA), *Onboard Potable Water Generator (PWG) Feasibility Analysis Report,* unpublished draft, 2014).

3. Summary of Ballast Water Discharge Standards

USCG Regulations and EPA Vessel General Permit both include the following ballast discharge standards:

1) Less than 10 live organisms per m^3, greater than or equal to 50 μm in minimum dimension;
2) Less than 10 live organisms per ml, less than 50 μm in minimum dimension and greater than or equal to 10 μm in minimum dimension; and
3) Culturable live organisms less than 10 microns, including the following:
    1. Toxigenic *Vibrio cholerae* (serogroups O1 and O139), less than one colony forming unit (cfu) per 100 ml;
    2. *Escherichia coli,* less than 250 cfu per 100 ml;
    3. Intestinal *Enterococci*, less than 100 cfu per 100 ml.

This report refers to and incorporates specifics requirements found in the ETV *Generic Protocols for the Verification of Ballast Water Treatment Technologies*, EPA/600/R-10/146 (2010).

4. Summary of Test Protocols and Sampling Design

4.1. Test Protocols

This report presents the results for the MERC performance evaluation of the PWG. Details on program policies and testing approaches/methodologies can be found in the MERC Quality Management Plan (QMP), Quality Assurance Project Plan (QAPP) and various Standard Operating Procedures (SOPs). These documents are available upon request. Additional details about the test protocol and sampling design can be found in the Test Plan (Appendix A).

MERC offers land-based testing on a Mobile Test Platform (MTP) that allows BWMSs to be evaluated in Baltimore Harbor, Maryland (salinity 5 - 12 PSU) and/or Norfolk, Virginia (salinity 20 - 25 PSU) with one system installation (Figure 1). Only Baltimore was used for this evaluation of the PWG. Some key facility features include:

- Testing tanks – Two with capacity 310 m^3 each;

- Pumps and piping – Two 60 hp centrifugal pumps with two 8-in (20.3 cm) piping systems for versatility in moving ballast water;
- Flow rates – Minimum of 100 m^3/hr and maximum of 310 m^3/hr for each pump;
- Pump discharge pressure – up to 50 psi;
- Working space – onboard office, laboratory (for live analyses, calibrations and water quality analyses), plus, sampling and storage containers; additional space minutes away;
- Capacity to amend intake challenge water to intensify challenge conditions;
- Facility sanitation before and between test cycles;
- High quality in-line and/or in-tank sampling; and
- WET testing and chemical analyses.

Figure 1. MERC Mobile Land-Based Test Facility.

Valve position and pump setting govern ballast water movement on the MTP. The system is variably configured for the various operational modes available and is controlled/monitored by an integrated monitoring and control (IMAC) system. IMAC employs industrial process software to provide a graphic/numerical user-interface for pipe and pump set-up as well as to initiate logging, plus manage, store, and present logged data on flow-rates, pressures, volumes, sampling, challenge condition modification, and valve-position. Depending upon the parameter, logging occurs in 15-second to one-minute intervals. Control and treated water quality are also monitored and recorded using in-tank multi-parameter sondes (temperature, salinity, dissolved oxygen, turbidity, chlorophyll, and pH).

Sample water for water quality and biological analysis is generally collected continuously throughout each intake and discharge operation via the facility's in-line sample points. Discrete samples for water chemistry and water quality analysis can also be collected during intake, tank retention and discharge. Onboard laboratories provide enough space to support time sensitive analyses associated with MERC land-based tests, including live analysis of organisms $\geq$ 50 µm (i.e., zooplankton). The laboratories are climate-controlled and have enough bench space to allow for simultaneous analysis of samples by multiple personnel. Other analyses are conducted in the laboratories of SERC, WREC, UMCES and UMCP with the longest transit time of 90 minutes.

Due to the significant flow rate differential between the PWG and a typical ballast water management system, modifications were made to the standard ETV testing protocols, consistent with the requirements of ETV. Modifications for this evaluation are described below.

4.1.1. Commissioning and Training

Prior to biological testing, mechanical commissioning of the PWG system was conducted in collaboration with an engineer from the PWG provider to assure appropriate treatment operations onboard the MERC MTP. A commissioning trial identified and corrected initial mechanical and operating issues. The parameters examined included: testing the power connections, testing the compressed air actuated valve system on the media tank skid, making the sodium hypochlorite solutions then adjusting the injection rate to specs, and checking all meters for accuracy.

The PWG provider engineer trained MERC and ERG personnel in the standard operating procedures and basic maintenance of this system. The trainer and trainees signed a customer training form. After the PWG system commissioning was completed and accepted by the provider, the engineer submitted a formal statement stating that the PWG was ready for biological testing.

4.1.2. Operations and Maintenance

In general, after the training period and with some consultations with the PWG provider, MERC staff found the system operations and maintenance (O&M) procedures clear and easy to follow. As stated in the PWG O&M manual, MERC staff recorded O&M data each day that MERC personnel were on site for either testing or maintenance. When off-site, MERC staff could check daily for operations data including flow rate into the test tank and test tank levels using a remote connection.

The delivery rate of potable water by the PWG to the MERC test tank was 12 ± 1 GPM. During uptake, the PWG system drew 25 Amps of electricity at 480 volts, 3-phase power. Using approved maintenance procedures, bag and cartridge filters were changed when the differential pressure reached a designated value. The bag filters were also changed out whenever the system was to be left running unattended for more than 1-2 days. The timing depended upon the existing concentrations of plankton and total suspended solids (TSS) in the ambient water.

The PWG system normally ran 24/7. However, since the timing between test 1 and test 2 was greater than 3 days, MERC stopped the PWG system and preserved the RO membranes using approved maintenance procedures and with the guidance of PWG provider by phone. MERC restarted the system the morning of the second test using the approved procedures for returning the system to normal operation, and then followed the normal startup procedures.

During the uptake event for Trial PW-4, one of the three media tanks on the PWG failed. MERC was able to finish Trial PW-4; however, Trial PW-5 was canceled because of a PWG system failure. See appendix B for details.

4.1.3. Biological Efficacy Trials

MERC conducted a total of four biological efficacy trials focused on all USCG and EPA regulated taxonomic categories, including live organisms (LO) ≥ 50 μm, LO ≥10 - <50 μm, and culturable organisms <10 μm.

4.2. Sampling Design Overview

Water was collected for biological examination for the following parameters: ≥ 50μm size fraction (nominally zooplankton), ≥10 to <50 μm size fraction (nominally phytoplankton), <10 μm culturable organisms, whole effluent toxicity testing, chlorinated by-products analyses,

and water quality analyses, including TSS, particulate organic carbon (POC), dissolved organic carbon (DOC) and chlorophyll (Chl).

During the PWG trials, only one MERC pump/pipe system and one test tank were used. The test tank was filled to a minimum of 150 m^3 over a 5 or 6-day period using a 1-inch hose connected between the PWG RO supply pipe and a bottom flange-connection on the MERC test tank.

At the completion of each discharge event, the MERC pump/piping system and test tank were immediately flushed with fresh municipal water prior to conducting a subsequent trial. The test tank was scrubbed clean to remove any remaining particles. See SOPs for additional details on test operations and discharge sampling. See below for uptake sampling protocols. The analyses of all samples (regardless of how collected) followed the ETV Protocols and MERC SOPs.

4.2.1. Water quality measurements

1. *In Situ* measurements: During the entire testing period, a calibrated YSI 6600V2-4 multi-parameter water quality sonde was deployed from the MTP at a depth of one meter. The sonde collected challenge water data every 15 minutes. Data included temperature, conductivity, salinity, dissolved oxygen, pH, turbidity (NTU), and chlorophyll fluorescence. Post-calibration detected any drifting of parameter readings.

2. Discrete measurements: During each uptake, a YSI Pro Plus multi-parameter instrument was used to collect challenge and potable water measurements of temperature, conductivity, salinity, and dissolved oxygen. Free and total chlorine were measured using a HF Scientific chlorine pocket photometer. Litmus paper was used to estimate pH.

3. Test tank measurements: At the start of the uptake, a YSI 6600V2-4 multi-parameter sonde was placed into the test tank. Every 15 minutes the sonde measured temperature, conductivity, salinity, dissolved oxygen, oxygen reduction potential, pH, chlorophyll and turbidity. It was removed from the test tank just prior to discharge.

4.2.2. Uptake event sampling

To characterize both the challenge water and the potable water generated during a tank uptake event, discrete samples were collected both upstream (challenge water) and downstream (potable water) of the PWG. This once-per-day uptake sampling occurred on three uptake days (start day, a midpoint day and the final uptake day). The sample methods were modified to accommodate the slow flow rates (12 GPM), which did not allow for the ETV protocol recommended time-integrated isokinetic sampling.

1. Uptake challenge water (UT Challenge): Ambient, non-augmented Baltimore Harbor water supplied to the PWG system. For UT Challenge water sample collection, MERC deployed a submersible pump and hose next to and at the exact depth of the PWG uptake submersible pump. The sample collection hose free-flowed during sample collection. These two pumps were located on the forward port corner of the MTP.

2. Uptake potable water (UT Potable): Potable water coming from the PWG system. Samples were collected at a port located just after the PWG product pipe, and before going into the test ballast tank. For PW-1-UT1 only, this sampling point was located a distance away from the

PWG product pipe. After PW-1-UT1, the sample point was relocated immediately after the PWG product pipe.

A specific volume of sample water was pumped into carboys and bottles as described in Table 1 below.

Table 1. Uptake sample volumes collected.

	UT Challenge	**UT Potable**
≥50 Live Organisms	1 20L carboy	1 20L carboy
≥10 - <50 Live Organisms	3 500 ml bottles	3 500 ml bottles
Microbial (all tests)	3 1L bottles	3 1L bottles
***Water Chemistry – Chl, TSS, DOC, and POC**	2 7L carboys	3 7L carboys
Free/Total Chlorine	1 1L bottle	1 1L bottle
Temperature/Conductivity/Salinity Dissolved Oxygen	YSI instrument	YSI instrument
pH	Litmus paper	Litmus paper
Whole Effluent Toxicity	Glass carboys as needed	Glass carboys as needed

*2-L max per filter pad for potable water chemistry samples

4.2.3. Discharge event sampling

Sampling of the potable water upon discharge (DC Potable) occurred after a 5 to 6-day hold time in the MERC test ballast tank. All samples were obtained through the MERC MTP piping system set in the discharge configuration at 150 to 250 m^3/hr. Discharge and discharge sampling of the potable water test tank followed ETV techniques. Statistically-validated (Miller et al., 2011), continuous, time-integrated samples were collected through sample ports located on the system pipes. All sample ports include a valve and sample tube with a 90^o bend towards the direction of flow, placed in the center of the piping system (based on the design developed and validated by the US Naval Research Laboratory, Key West Florida, see ETV protocols). Sample volumes and details of the physical, chemical, and biological analyses for each sample are described in Table 2 below. During the discharge events, samples were also collected for whole effluent toxicity testing and chlorinated by-products analyses.

Table 2. Discharge sample volumes collected.

	DC Potable
≥50 Live Organisms	7 m^3 filtered through 37 µm mesh net integrated over the entire discharge
≥10 - <50 Live Organisms	3 500 ml bottles from *IS cylinder
Microbial (all tests)	3 1L bottles from IS cylinder
Water Chemistry - Chl, POC, DOC	3 7L carboys from IS cylinder
Water Chemistry – TSS	2 7L carboys from sample port, 3 time points
Free/Total Chlorine	1 1L bottle from IS cylinder
Temp/Cond/DO	YSI instrument - 3 time points
pH	Litmus paper - 3 time points
Chemical by-products	2-L carboy from toxics IS cylinder
Whole Effluent Toxicity	Glass carboys from IS toxics cylinder

*integrated sample cylinder

5. Deviations from ETV Sample Handling and Analyses

Due to the significant flow rate differential between the PWG and a typical ballast water management system, modifications were made to the standard ETV testing protocols, consistent with the requirements of ETV. Modifications for this evaluation are described below. Also, since the PWG product was fresh water and not salt water, the tests used to culture live organisms >10 microns and to perform toxicity tests were also modified to reflect this alteration.

5.1. Live Organisms ≥50 µm

Uptake events only

Each 20L sample was filtered through a 37-micron mesh sieve and examined live under a microscope.

5.2. Live Organisms ≥10 - <50 µm

Uptake events only

1. Challenge water: Ambient water was analyzed using standard methods. A dilution series was used at 1/10 for each ambient sample. The entire dilution (100 µl) was analyzed on standard Sedgewick rafter (each grid is 1 mm square).

2. Potable water: using a 2.0 µM membrane filter, 500 mls of sample was gently filtered into a clean flask. The membrane was then placed into a 30 ml bottle along with 20 mls of filtrate and shaken to dislodge the organisms from the filter. The 1 mL subsample was counted completely.

5.3. Culturable Organisms <10 µm

Potable water samples during uptake and discharge events

Freshwater media, R2A, was used to test the growth of total heterotrophic bacteria (THB) from the potable water sample. Analysis followed Standard Methods for the Examination of Water and Wastewater, 20th Edition, Method 9215 with R2A Medium. IDEXX Colilert was used to measure the growth of E. coli in the potable water sample. Analysis followed *Standard Methods for the Examination of Water and Wastewater, 20th Edition, Methods 9221D and 9221E*. Although these specific MERC trials were examining ballast water, these analyses are also used for drinking water

5.4. Freshwater Toxicity Tests

Water samples treated with PWG RO system were tested for chronic toxicity with three freshwater species: a fish (*Pimephales promelas*), an invertebrate (*Ceriodaphnia dubia*) and an algae (*Selenastrum capricornutum*). Details of toxicity test methods and results can be found in a separate report (PWG Toxicity Testing Report, University of MD/WREC, Report No. WREC-14-37). Treated water samples from a total of four treatment events (PW-1 through PW-4) were tested with fish, daphnia, and algae.

Toxicity tests were conducted on discharge water after holding time (PW-X-DC) for all trials, while uptake water (PW-X-UT) was only tested during the first trial (PW-1). Ceriodaphnia were not tested in samples from the second trial (PW-2-DC) due to problems with cultures leading up to the trial.

All three species were also used to test a de-chlorinated uptake sample (PW-1-UT Dechlor). The uptake sample was de-chlorinated with a nominal dose of sodium thiosulfate thought to be in excess of any residual chlorine remaining in the treated sample.

Finally, algae toxicity tests were conducted on de-chlorinated (also with nominal sodium thiosulfate addition) discharge samples from the final three trials, PW-2 through PW-4.

Table 3. **Overview of toxicity tests performed on PWG treated water.**

Event	Start Date	Sample	Tests Performed
PW-1	5/13/14	PW-1-UT	all
		PW-1-UT Dechlor	all
		PW-1-DC	all
PW-2	5/28/14	PW-2-DC	fish and algae only
		PW-2-DC Dechlor	algae only
PW-3	6/3/14	PW-3-DC	all
		PW-3-DC Dechlor	algae only
PW-4	6/10/14	PW-4-DC	all
		PW-4-DC Dechlor	algae only

6. Sampling and Analyses of Discharge Chemicals Including By-Products Compounds

Potable water samples were collected during each discharge event from the integrated sample toxics cylinder for analysis of 21 by-product compounds. MERC used sampling methodology supplied by the analytical company, Analytical Laboratory Services (ALS) Environmental. The analytical methods used by ALS are summarized below. More information can be found on the following websites: www.alsglobal.com or www.caslab.com.

- Trihalomethanes: THMs (5 compounds), VOCs EPA Method 524.2
- Haloacetic Acids: HAAs (8 compounds), Method 552.2 *(subcontracted to Eurofins|Eaton Analytical)*
- Acetonitriles: ACETOCNs (5 Compounds), Method 551 *(subcontracted to Weck Laboratories Inc.).*
- Sodium, Method 200.7
- Bromate/chlorate, Method EPA 300.1; sodium, bromate and chlorate concentrations are used to calculate sodium chlorate and sodium bromate concentrations.
- Dalapon, herbicide, EPA Method 515.3

All samples were initially shipped overnight to ALS Environmental (Middletown, PA, USA). ALS performed chemical analysis on nine substances (bromodichloromethane, bromoform, chlorodibromomethane, chloroform, 1,2,3-trichloropropane, dalapon, bromate, chlorate and sodium (total)) for all four discharge samples (PW-1-DC through PW-4-DC).

Additional analysis was performed by two subcontract laboratories, Weck Laboratories Inc. (Middletown, PA, USA) and Eurofins|Eaton Analytical (South Bend, IN, USA). Weck Laboratories analyzed for ten substances (1,1,1-trichloro-2-propanone, 1,1-dichloro-2-propanone, bromochloroacetonitrile, chloral hydrate, chloropicrin, dibromoacetonitrile, dichloroacetonitrile, trichloroacetonitrile, bromoacetonitrile, and chloroacetonitrile). Eurofins Analytical analyzed for eight haloacetic acids (bromochloroacetic acid, chlorodibromoacetic acid, dibromoacetic acid, dichloroacetic acid, monobromoacetic acid, monochloroacetic acid, tribromoacetic acid, and trichloroacetic acid).

ALS performed analysis on nine substances (see above) for all four samples (PW-1-DC through PW-4-DC). Weck Laboratories performed analysis on ten substances (see above) for samples PW-1-DC, PW-3-DC, and PW-4-DC while only five substances (chloropicrin, dibromoacetonitrile, dichloroacetonitrile, bromoacetonitrile, and chloroacetonitrile) were analyzed for PW-2-DC sample. Eurofins analyzed for eight HAAs (see above) for samples PW-1-DC through PW-3-DC while no analysis of HAAs was conducted on the PWG-4-DC sample.

7. Summary of Discharge Results

MERC conducted four land-based trials of the PWG system during the spring of 2014. This performance evaluation was based on the physical and biological characterization of challenge versus potable water. During the fourth trial, one of the three PWG media tanks cracked and failed on uptake day 3. As a result, samples for PW-4-UT5 (third uptake sample collection) were not collected. However, the discharge event (PW-4-DC) was possible since the MERC test tank was full enough to discharge. The fifth trial of the PWG was canceled. See Appendix B for further discussion concerning causes of the failure and implications for results.

Table 4. Discharge data summary for live organisms*

Trial	LO ≥50 µm/m^3	LO ≥10-<50 µm/ml	THB (cells/ 10ml)	E.coli (cfu/ 100 ml)	Entercocci (cfu/ 100 ml)	V. cholerae (#of colonies)
PW-1	0.14	BDL	0	DQS	<1	0
PW-2	0	BDL	0	<1	<1	0
PW-3	0	BDL	0	<1	<1	0
PW-4	0	BDL	0	<1	<1	0

*See tables 1 and 2 above for sample volumes.
DQS: Data did not meet MERC quality standards.
BDL: Below detection limits of 0.04 cells/ml
LO: Live organisms

Table 5. Discharge data summary for chlorine concentrations

Trial	Free Cl (mg/l)	Total Cl (mg/l)
PW-1	0.06 ± 0.01	0.10 ± 0.01
PW-2	ND	ND
PW-3	0.20 ± 0.03	0.14 ± 0.01
PW-4	0.11 ± 0.01	0.09 ± 0.02

7.1 Summary of Freshwater Toxicity Test Results

Results showed that water samples were toxic when tested immediately after treatment (PW-1-UT) with a negative effect on survival or growth for all test species. De-chlorination with nominal amounts of sodium thiosulfate (PW-1-UT Dechlor) decreased the toxic effect with all three tested species, although some toxicity remained in fish and daphnia tests. Toxicity tests on discharge water with a holding period after treatment (DC samples) revealed a reduction in toxic effects in most cases compared to uptake sample toxicity tests with the same species.

All toxicity tests on discharge samples (PW1-DC through PW4-DC) showed an absence of toxic effects with fish. Toxicity of discharge samples with daphnia and algae tests was reduced in most cases compared to uptake samples from the first trial (PW-1-UT). However, all daphnia and algal toxicity tests revealed some level of toxicity for all discharge samples.

Table 6. Whole effluent toxicity test results for potable water during uptake and discharge events. Overview of toxicity results of potable water samples directly after treatment (UT) and after tank holding time (DC). IC_{25}s are for endpoint (i.e. survival, reproduction, growth or cell density) with the lowest observed effect.

			Survival		Growth		Lowest effect
Event	**Organism**	**Sample**	**Effect (Y/N)**	**NOEC**	**Effect (Y/N)**	**NOEC**	**IC_{25}**
PW-1	Fish	PW-1-UT	Y	56%	N	56%	71.0%
		PW-1-UT Dechlor	N	100%	Y	<100%	n/a
		PW-1-DC	N	100%	N	100%	>100%
	Ceriodaphnia	PW-1-UT	Y	32%	N	32%	38.2%
		PW-1-UT Dechlor	N	100%	Y	<100%	n/a
		PW-1-DC	Y	56%	N	56%	68.9%
	Algae	PW-1-UT	n/a	n/a	Y	18%	22.4%
		PW-1-UT Dechlor	n/a	n/a	N	100%	>100%
		PW-1-DC	n/a	n/a	Y	<100%	5.41%
PW-2	Fish	PW-2-DC	N	100%	N	100%	>100%
	Algae	PW-2-DC	n/a	n/a	Y	32%	34.7%
	Algae	PW-2-DC Dechlor	n/a	n/a	N	100%	n/a
PW-3	Fish	PW-3-DC	N	100%	N	100%	>100%
	Ceriodaphnia	PW-3-DC	N	100%	Y	32%	25.6%
	Algae	PW-3-DC	n/a	n/a	Y	18%	25.1%
	Algae	PW-3-DC Dechlor	n/a	n/a	Y	<100%	<100%
PW-4	Fish	PW-4-DC	N	100%	N	100%	>100%
	Ceriodaphnia	PW-4-DC	N	100%	Y	32%	45.9%
	Algae	PW-4-DC	n/a	n/a	Y	56%	73.6%
	Algae	PW-4-DC Dechlor	n/a	n/a	N	100%	>100%

n/a: Not available because of type or lack of test concentrations.
NOEC: No Observed Effect Concentration – The highest concentration of toxicant to which organisms are exposed in a full life-cycle or partial life-cycle test, which causes no statistically significant adverse effect on the observed parameters (usually hatchability, survival, growth, and reproduction).
IC_{25}: Concentration of effluent which has an inhibitory effect on 25% of the test organisms for the monitored effect, as compared to the control (expressed as % effluent).
<100%: NOEC when toxicity tests was only conducted on 100% treated sample.

7.2 Discharge Chemistry Including By-Products Compounds

Chlorate and sodium were found in all samples (PW-1-DC through PW-4-DC) while bromoform was only found in PW-2-DC, PW-3-DC, and PW-4-DC. All other analytes were below detection limits (BDL). The average concentrations were 43.1 µg/L, 1.06 µg/L, and 6.2 mg/L for chlorate, bromoform and sodium, respectively (Table 6).

Table 7. Concentrations of detectable by-products and other compounds substances found in the four potable water discharge samples. All other substances were *BDL for all samples.

Sample	Chlorate (µg/L)	Bromoform (µg/L)	Sodium (mg/L)
PW-1-DC	34.2	BDL*	4.4
PW-2-DC	40.9	1.2	7.4
PW-3-DC	49.6	0.57	5.6
PW-4-DC	47.7	1.4	7.4
Mean concentration	43.1	1.06	6.2

BDL* Below detection limit- Not used in calculating mean concentration.

8. Trial PW-1 Results

See Sections 4.2.2. and 4.2.3. for definitions of UT Challenge, UT Potable and DC Potable.

Water Quality Conditions

Challenge and potable water quality conditions

	UT Challenge	UT Potable	DC Potable
Temperature (°C)	17.4	18.0	19.9
Conductivity (µS)	7,864.8	76.7	66.0
Salinity (psu)	4.1	0.0	0.03
DO (mg/l)	11.2	11.4	10.8
DO (%)	119.0	120.0	118.0
pH	8.0	8.0	7.8

Average water quality conditions of the test tank PWG-treated water 5h after uptake.

Test Tank	Mean ± SD	Max	Min
Temperature (°C)	16.8 ± 0.47	17.5	16.1
Salinity (psu)	0.02 ± 0.00	0.03	0.02
DO (mg/l)	7.7 ± 0.1	7.9	7.5
DO (%)	78.8 ± 1.5	82.3	77.3
Turbidity (NTU)	0.02 ± 0.04	0.10	0.00

Average water conditions of the test tank PWG-treated water up to 5h prior to discharge.

Test Tank	Mean ± SD	Max	Min
Temperature (°C)	19.5 ± 0.04	19.6	19.5
Salinity (psu)	0.02 ± 0.00	0.02	0.02
DO (mg/l)	11.0 ± 0.1	11.1	10.9
DO (%)	120.1 ± 0.6	121.0	119.0
Turbidity (NTU)	0.00 ± 0.00	0.00	0.00

Chlorine measurements from the test tank, challenge water, and potable water prior to entering the test tank. Chlorine samples were not collected from the tank on UT1 or from the challenge sample port on discharge.

Free chlorine

Trial	Tank Mean ± SD (mg/l)	Challenge Mean ± SD (mg/l)	Potable Mean ± SD (mg/l)
PW-1-UT1	0.25 ± 0.06	0.01 ± 0.01	0.30 ± 0.01
PW-1-UT2	0.01 ± 0.01	0.00 ± 0.01	0.32 ± 0.01
PW-1-UT5	0.11 ± 0.03	0.14 ± 0.02	0.31 ± 0.02
PW-1-DC	0.05 ± 0.02	N/A	0.06 ± 0.01

Total chlorine

Trial	Tank Mean ± SD (mg/l)	Challenge Mean ± SD (mg/l)	Potable Mean ± SD (mg/l)
PW-1-UT1	0.22 ± 0.01	0.02 ± 0.00	0.33 ± 0.02
PW-1-UT2	0.01 ± 0.01	0.03 ± 0.00	0.32 ± 0.02
PW-1-UT5	0.10 ± 0.01	0.10 ± 0.01	0.35 ± 0.02
PW-1-DC	0.10 ± 0.00	N/A	0.10 ± 0.01

Total Suspended Solids (TSS) content of challenge water and potable water during the 5-day uptake. Potable water TSS samples were collected at three different time points: beginning, middle, and end (1, 2, and 3, respectively) during the discharge.

Trial		Challenge Mean ± SD (mg/l)	Potable Mean ± SD (mg/l)
PW-1-UT1		3.1 ± 0.1	BDL
PW-1-UT2		5.0 ± 0.2	BDL
PW-1-UT5		9.2 ± 0.3	BDL
PW-1-DC	**1**	N/A	BDL
	2	N/A	BDL
	3	N/A	BDL

BDL: Below Detection Limit
TSS maximum detection limit: 2.4 mg/l

Dissolved Organic Carbon (DOC) content of challenge water and potable water during the 5-day uptake. On discharge, samples were collected from the time-integrated sampling cylinder.

Trial	Challenge Mean ± SD (mg/l)	Potable Mean ± SD (mg/l)
PW-1-UT1	3.0 ± 0.1	BDL
PW-1-UT2	2.5 ± 0.1	BDL
PW-1-UT5	2.9 ± 0.1	BDL
PW-1-DC	N/A	BDL

BDL: Below Detection Limit
DOC maximum detection limit: 0.24 mg/l

Particulate Organic Carbon (POC) content of challenge water and potable water during the 5-day uptake. On discharge, samples were collected from the time-integrated sampling cylinder.

Trial	Challenge Mean ± SD (mg/l)	Potable Mean ± SD (mg/l)
PW-1-UT1	0.41 ± 0.01	0.06 ± 0.00
PW-1-UT2	1.00 ± 0.02	BDL
PW-1-UT5	2.50 ± 0.01	BDL
PW-1-DC	N/A	BDL

BDL: Below Detection Limit
PC maximum detection limit: 0.0633 mg/l

Active Chlorophyll content of challenge water and potable water during the 5-day uptake. On discharge, samples were collected from the time-integrated sampling cylinder.

Trial	Challenge Mean ± SD (µg/l)	Potable Mean ± SD (µg/l)
PW-1-UT1	4.1 ± 0.2	BDL
PW-1-UT2	20.1 ± 0.7	BDL
PW-1-UT5	53.2 ± 0.4	BDL
PW-1-DC	N/A	BDL

BDL: Below Detection Limit
Chl (active) maximum detection limit: 0.18 µg/l

Live Organisms ≥50 µm

Trial	Challenge Mean ± SD (LO/m^3)	Potable Total (LO/m^3)
PW-1-UT1	165,050 ± 6,240	0
PW-1-UT2	193,352 ± 4,085	0
PW-1-UT5	67,565 ± 3,603	0
PW-1-DC	N/A	0.14

Taxa and observations
Eight (8) taxa were present in the challenge sample. These were copepod nauplii, barnacle nauplii, eggs, Rotifera, bivalves, Calanoida, diatoms, and Cyclopoida. One taxa, a live bivalve veliger larvae, was observed in the discharge samples. Rust, flakes, and fibers were present in all samples.

Live Organisms ≥10 - <50 µm

Trial	Challenge Mean ± SD (cells/ml)	Potable Total (cells/ml)
PW-1-UT1	1,409 ± 176	DRC
PW-1-UT2	6,707 ± 1,083	BDL
PW-1-UT5	49,863 ± 1,154	BDL
PW-1-DC	N/A	BDL

DRC: Data rejected due to contamination. See note below.
BDL: Below Detection Limits
LO ≥10 - <50 µm detection limit is 0.04 cells/ml

Taxa and observations
UT1 - small unknown flagellates many pennate diatoms
UT2 - Bloom begins, *P. minimum* dominant (harmful algal bloom (HAB) species) but many cells of *G. estuarale*. Also detected numbers of centric and pennate diatoms, small chains of *Chaetoceros sp*., and a few chains of *Asterionella sp.*
UT5 - Bloom takes off over weekend with warm weather (*P. minimum* still dominant)
G. estuarale still present in moderate numbers *Thalassiosira sp*. and *Chaetoceros sp.* in small chains. *Asterionella sp*. observed in partial formations.

NOTE: Suspected contamination came from RO sampling hose, first located some distance from the RO discharge pipe. This potential problem was eliminated before PW-1-UT2 sampling by changing the sample location to directly after the PWG RO supply pipe. No further contamination was observed.

Culturable Organisms < 10 µm
HPC-Total heterotrophic bacteria (THB) – Marine (marine media)

Trial	Challenge Mean ± SD (cfu/10 ml)
PW-1-UT1	800 ± 419
PW-1-UT2	838 ± 105
PW-1-UT5	3,550 ± 1,078 (cfu/100mL)
PW-1-DC	N/A

HPC-Total heterotrophic bacteria (THB) – R2A (freshwater media)

Trial	**Challenge Mean ± SD (cfu/10 ml)**	**Potable Mean ± SD (cfu/10 ml)**
PW-1-UT1	1,200 ± 96	0
PW-1-UT2	4,717 ± 788 (cfu/100 ml)	0
PW-1-UT5	4,833 ± 1,366 (cfu/100 ml)	0
PW-1-DC	N/A	0

Enterococci

Trial	**Challenge Mean ± SD (cfu/100 ml)**	**Potable Mean ± SD (cfu/100 ml)**
PW-1-UT1	<1	<1
PW-1-UT2	0	0
PW-1-UT5	<1	<1
PW-1-DC	N/A	<1

E. coli – IDEXX Colilert-18 (marine media)

Trial	**Challenge Mean ± SD (cfu/100 ml)**
PW-1-UT1	<1
PW-1-UT2	5 ± 2
PW-1-UT5	2 ± 1
PW-1-DC	N/A

E. coli – IDEXX Colilert (freshwater media)

Trial	**Challenge Mean ± SD (cfu/100 ml)**	**Potable Mean ± SD (cfu/ 100 ml)**
PW-1-UT1	2 ± <1	<1
PW-1-UT2	3 ± 2	<1
PW-1-UT5	3 ± 0	<1
PW-1-DC	N/A	DQS

DQS: Data rejected because it did not meet MERC quality standards. See note below.
One of the replicates in this sample had unusually high counts. The data was considered outside of MERCs data quality objectives and was therefore discarded.

Vibrio cholerae – DFA

Trial	Challenge Mean ± SD (#colonies)	Potable Mean ± SD (#colonies)
PW-1-UT1	0	0
PW-1-UT2	0	0
PW-1-UT5	0	0
PW-1-DC	N/A	0

Whole Effluent Toxicity

Uptake water sample

The PW-1 uptake water sample (taken after the PWG, but before entering the test ballast tank) was toxic to all three species tested. For the fish toxicity test, the 100% uptake water sample had a survival of only 37.5% (Table 6) with no additional survival or growth effect for lower dilutions (18% - 56%). Daphnia tests resulted in reduced survival of adults in the top two dilutions with survival of 20 and 0% for 56% and 100% dilutions, respectively. The algae, *Selenastrum capricornutum*, were the most sensitive species with a reduction in growth down to the 32% dilution treatment. This resulted in an NOEC of 18% and an IC_{25} of 22.4%

De-chlorinated uptake water sample

De-chlorination with sodium thiosulfate either eliminated toxicity (algae test) or reduced toxicity (fish and daphnia tests). Toxicity testing with all three species was only conducted on a 100% de-chlorinated sample (i.e. no dilution series). The fish toxicity test had a slight, but statistically significant, effect on larval growth. There was also a similar slight but significant effect on the daphnia neonate production. No toxicity was observed in the algae test.

Discharge sample testing

No survival or growth effect was observed in the fish test for PW-1-DC sample. Daphnia tests resulted in a survival effect in the 100% discharge sample with a 7-d survival of only 30%. Algae tests sample revealed toxicity in the 56 and 100% treatments. In fact, the NOEC was unbounded as there was an effect at the lowest test dilution of 56%.

Toxicity Test Results Summary

			Survival		Growth		Lowest effect
Event	**Organism**	**Sample**	**Effect (Y/N)**	**NOEC**	**Effect (Y/N)**	**NOEC**	**IC_{25}**
PW-1	Fish	PW-1-UT	Y	56%	N	56%	71.0%
		PW-1-UT Dechlor	N	100%	Y	<100%	n/a
		PW-1-DC	N	100%	N	100%	>100%
	Ceriodaphnia	PW-1-UT	Y	32%	N	32%	38.2%
		PW-1-UT Dechlor	N	100%	Y	<100%	n/a
		PW-1-DC	Y	56%	N	56%	68.9%
	Algae	PW-1-UT	n/a	n/a	Y	18%	22.4%
		PW-1-UT Dechlor	n/a	n/a	N	100%	>100%
		PW-1-DC	n/a	n/a	Y	<100%	5.41%

Discharge Chemistry Including By-Product Compounds

Chlorate and sodium were the only substances found above the minimum detection limit. Chlorate concentration was 34.2 µg/L and sodium was 4.4 mg/L.

9. Trial PW-2 Results

See Sections 4.2.2. and 4.2.3. for definitions of UT Challenge, UT Potable and DC Potable.

Water Quality Conditions

Challenge and potable water quality conditions

	UT Challenge	**UT Potable**	**DC Potable**
Temperature (°C)	19.9	20.5	21.2
Conductivity (µS)	9,677.3	82.5	78.9
Salinity (psu)	5.5	0.0	0.04
DO (mg/l)	7.4	6.5	7.5
DO (%)	84.0	72.3	78.0
pH	7.5	7.7	7.5

Average water quality conditions of the test tank PWG-treated water 5h after uptake.

Test Tank	**Mean ± SD**	**Max**	**Min**
Temperature (°C)	18.8 ± 0.3	19.4	18.5
Salinity (psu)	0.03 ± 0.00	0.03	0.02
DO (mg/l)	5.2 ± 0.2	5.7	4.9
DO (%)	56.2 ± 2.4	60.9	52.8
Turbidity (NTU)	1.9 ± 0.1	2.1	1.9

Average water conditions of the test tank PWG-treated water up to 5h prior to discharge.

Test Tank	Mean ± SD	Max	Min
Temperature (°C)	21.0 ± 0.02	21.0	20.9
Salinity (psu)	0.03 ± 0.00	0.03	0.03
DO (mg/l)	7.4 ± 0.04	7.5	7.3
DO (%)	83.1 ± 0.4	83.6	82.1
Turbidity (NTU)	1.8 ± 0.04	1.8	1.7

Chlorine measurements from the test tank, challenge water, and potable water prior to going into the test tank. Chlorine samples were not collected from the tank on UT1 or from the challenge sample port on discharge.

Free chlorine: No data due to contaminated reagent

Total chlorine

Trial	Tank Mean ± SD (mg/l)	Challenge Mean ± SD (mg/l)	Potable Mean ± SD (mg/l)
PW-2-UT1	N/A	0.04 ± 0.01	0.23 ± 0.01
PW-2-UT5	0.17 ± 0.00	0.04 ± 0.01	0.27 ± 0.03
PW-2-UT6	ND	ND	ND
PW-2-DC	ND	ND	ND

ND: no data due to contaminated reagent

Total Suspended Solids (TSS) content of challenge water and potable water during the 6-day uptake. Challenge water samples were not collected on discharge. Potable water TSS samples were collected at three different timepoints, beginning, middle, and end (1, 2, and 3, respectively) during the discharge.

Trial		Challenge Mean ± SD (mg/l)	Potable Mean ± SD (mg/l)
PW-2-UT1		6.67 ± 0.06	BDL
PW-2-UT5		4.03 ± 0.12	BDL
PW-2-UT6		3.03 ± 0.06	BDL
PW-2-DC	**1**	N/A	BDL
	2	N/A	BDL
	3	N/A	BDL

BDL: Below Detection Limit
TSS maximum detection limit: 2.4 mg/l

Dissolved Organic Carbon (DOC) content of challenge water and potable water during the 6-day uptake. On discharge, samples were collected from the time-integrated sampling cylinder.

Trial	Challenge Mean ± SD (mg/l)	Potable Mean ± SD (mg/l)
PW-2-UT1	2.8 ± 0.2	BDL
PW-2-UT5	2.6 ± 0.2	BDL
PW-2-UT6	2.5 ± 0.3	BDL
PW-2-DC	N/A	BDL

BDL: Below Detection Limit
DOC maximum detection limit: 0.24 mg/l

Particulate Organic Carbon (POC) content of challenge water and potable water during the 6-day uptake. On discharge, samples were collected from the time-integrated sampling cylinder.

Trial	Challenge Mean ± SD (mg/l)	Potable Mean ± SD (mg/l)
PW-2-UT1	1.17 ± 0.01	BDL
PW-2-UT5	1.15 ± 0.03	BDL
PW-2-UT6	0.79 ± 0.01	BDL
PW-2-DC	N/A	BDL

BDL: Below Detection Limit
PC maximum detection limit: 0.0633 mg/l

Active Chlorophyll content of challenge water and potable water during the 6-day uptake. On discharge, samples were collected from the time-integrated sampling cylinder.

Trial	Challenge Mean ± SD (µg /l)	Potable Mean ± SD (µg/l)
PW-2-UT1	16.3 ± 0.5	BDL
PW-2-UT5	12.1 ± 0.2	BDL
PW-2-UT6	7.5 ± 0.2	BDL
PW-2-DC	N/A	BDL

BDL: Below Detection Limit
Chl (active) maximum detection limit: 0.18 µg/l

Live Organisms ≥50 µm

Trial	Challenge Mean ± SD (LO/m^3)	Potable Total (LO/m^3)
PW-2-UT1	270,965 ± 14,881	0
PW-2-UT5	418,960 ± 26,553	0
PW-2-UT6	293,960 ± 37,271	0
PW-2-DC	N/A	0

Taxa and observations

Nine (9) taxa were present in the challenge sample: Rotifera, copepod nauplii, diatoms, tintinnid, barnacle nauplii, Calanoida, polychaete, bivalves, and trochophore.
Rust, flakes, and fibers were present in all samples.

Live Organisms ≥10 - <50 µm

Trial	Challenge Mean ± SD (cells/ml)	Potable Total (cells/ml)
PW-2-UT1	12,520 ± 1,412	BDL
PW-2-UT5	3,490 ± 853	BDL
PW-2-UT6	3,280 ± 450	BDL
PW-2-DC	N/A	BDL

BDL: Below Detection Limits
LO ≥10 - <50 µm detection limit is 0.04 cells/ml

Taxa and observations

UT1 - *G. estuarale* dominated the sample. Large numbers of small, unknown dinoflagellates and diatoms. Small chains of *Chaetoceros sp.,* some *Amphidium sp.* and a few tintinnids, both live and empty lorica, were observed.
UT5 - *P. minimum* was again dominant (start of second bloom occurred between UT1 and UT5). *G. estuarale* observed in small numbers, short chains of *Chaetoceros sp*. and few small unknown pennate diatoms were observed.
UT6 – *P. minimum* still dominant; little change from UT5.

Culturable Organisms <10 µm

HPC-Total heterotrophic bacteria (THB) – Marine (marine media)

Trial	Challenge Mean ± SD (cfu/10 ml)
PW-2-UT1	1,205 ± 103
PW-2-UT5	273 ± 61
PW-2-UT6	143 ± 37
PW-2-DC	N/A

HPC-Total heterotrophic bacteria (THB) – R2A (freshwater media)

Trial	Challenge Mean ± SD (cells/10 ml)	Potable Mean ± SD (cells/10 ml)
PW-2-UT1	1,353 ± 158	1 ± 1
PW-2-UT5	1,168 ± 207	0
PW-2-UT6	723 ± 179	0
PW-2-DC	N/A	0

Enterococci

Trial	Challenge Mean ± SD (cells/100 ml)	Potable Mean ± SD (cells/ 100 ml)
PW-2-UT1	1 ± 1	0
PW-2-UT5	<1	<1
PW-2-UT6	<1	<1
PW-2-DC	N/A	<1

E. coli – IDEXX Colilert-18 (marine media)

Trial	Challenge Mean ± SD (cells/100 ml)
PW-2-UT1	42 ± 42
PW-2-UT5	6 ± 0
PW-2-UT6	2 ± 1
PW-2-DC	N/A

E. coli – IDEXX Colilert (freshwater media)

Trial	Challenge Mean ± SD (cells/100 ml)	Potable Mean ± SD (cells/ 100 ml)
PW-2-UT1	25 ± 4	<1
PW-2-UT5	3 ± 2	<1
PW-2-UT6	3 ± 3	<1
PW-2-DC	N/A	<1

Vibrio cholerae – DFA

Trial	Challenge Mean ± SD (#colonies)	Potable Mean ± SD (#colonies)
PW-2-UT1	0	0
PW-2-UT5	0	0
PW-2-UT6	0	0
PW-2-DC	N/A	0

Whole Effluent Toxicity

Discharge sample testing

No statistically significant survival or growth effect was observed in the fish test. Algae tests revealed significant toxicity in the top two treatments, 56 and 100%. There was also a dose dependent reduction in algal growth in each successive treatment as the dilution percentage of discharge water increased. The reduction in algal growth resulted in an NOEC of 32% and an IC_{25} of 34.7%.

De-chlorinated discharge water sample

There was a statistically significant decrease in cell density in the de-chlorinated sample compared to the control density of $3.31x10^6$ cells/ml.

			Survival		Growth		Lowest effect
Event	**Organism**	**Sample**	**Effect (Y/N)**	**NOEC**	**Effect (Y/N)**	**NOEC**	**IC_{25}**
PW-2	Fish	PW-2-DC	N	100%	N	100%	>100%
	Algae	PW-2-DC	n/a	n/a	Y	32%	34.7%
	Algae	PW-2-DC Dechlor	n/a	n/a	N	100%	n/a

Discharge Chemistry Including By-Product Compounds

Chlorate, bromoform and sodium were the only substances found above the minimum detection limit. Chlorate concentration was 40.9 µg/L, bromoform concentration was 1.2 µg/L and sodium was 7.4 mg/L.

10. Trial PW-3 Results

See Sections 4.2.2. and 4.2.3. for definitions of UT Challenge, UT Potable and DC Potable.

Water Quality Conditions

Challenge and potable water quality conditions

	UT Challenge	UT Potable	DC Potable
Temperature (°C)	20.4	20.9	21.2
Conductivity (µS)	8,904.3	74.6	63.7
Salinity (psu)	5.0	0.0	0.03
DO (mg/l)	8.0	7.2	8.4
DO (%)	91.0	81.3	93.3
pH	7.8	8.0	7.5

Average water quality conditions of the test tank PWG-treated water 5h after uptake.

Test Tank	Mean ± SD	Max	Min
Temperature (°C)	18.3 ± 0.5	19.5	17.8
Salinity (psu)	0.03 ± 0.0	0.0	0.0
DO (mg/l)	7.0 ± 0.3	7.7	6.6
DO (%)	74.7 ± 2.9	80.8	71.1
Turbidity (NTU)	1.4 ± 0.1	1.7	1.3

Average water conditions of the test tank PWG-treated water up to 5h prior to discharge.

Test Tank	Mean ± SD	Max	Min
Temperature (°C)	21.1 ± 0.02	21.2	21.1

Salinity (psu)	0.03 ± 0.00	0.03	0.03
DO (mg/l)	8.3 ± 0.04	8.4	8.2
DO (%)	93.5 ± 0.5	94.1	92.6
Turbidity (NTU)	1.2 ± 0.02	1.3	1.2

Chlorine measurements from the test tank, challenge water, and potable water prior to going into the test tank. Chlorine samples were not collected from the tank on UT1 or from the challenge sample port on discharge.

Free chlorine

Trial	Tank Mean ± SD (mg/l)	Challenge Mean ± SD (mg/l)	Potable Mean ± SD (mg/l)
PW-3-UT1	N/A	0.02 ± 0.02	0.33 ± 0.02
PW-3-UT2	0.19 ± 0.02	0.07 ± 0.06	0.25 ± 0.06
PW-3-UT5	0.06 ± 0.01	0.06 ± 0.01	0.26 ± 0.02
PW-3-DC	0.19 ± 0.02	N/A	0.20 ± 0.03

Total chlorine

Trial	Tank Mean ± SD (mg/l)	Challenge Mean ± SD (mg/l)	Potable Mean ± SD (mg/l)
PW-3-UT1	N/A	0.06 ± 0.03	0.35 ± 0.03
PW-3-UT2	0.21 ± 0.03	0.01 ± 0.02	0.45 ± 0.13
PW-3-UT5	0.15 ± 0.01	0.07 ± 0.02	0.27 ± 0.01
PW-3-DC	0.17 ± 0.02	N/A	0.14 ± 0.01

Total Suspended Solids (TSS) content of challenge water and potable water during the 5-day uptake. Challenge water samples were not collected on discharge. Potable water TSS samples were collected at three different timepoints, beginning, middle, and end (1, 2, and 3, respectively) during the discharge.

Trial		Challenge Mean ± SD (mg/l)	Potable Mean ± SD (mg/l)
PW-3-UT1		7.1 ± 0.2	BDL
PW-3-UT2		4.1 ± 0.1	BDL
PW-3-UT5		6.3 ± 0.5	BDL
PW-3-DC	**1**	N/A	BDL
	2	N/A	BDL
	3	N/A	BDL

BDL: Below Detection Limit
TSS maximum detection limit: 2.4 mg/l

Dissolved Organic Carbon (DOC) content of challenge water and potable water during the 5-day uptake. On discharge, samples were collected from the time-integrated sampling cylinder.

Trial	Challenge Mean ± SD (mg/l)	Potable Mean ± SD (mg/l)
PW-3-UT1	2.89 ± 0.05	BDL
PW-3-UT2	IM	IM
PW-3-UT5	IM	IM
PW-3-DC	N/A	IM

BDL: Below Detection Limit
IM: Instrument malfunction during analysis; data flagged as suspect
DOC maximum detection limit: 0.24 mg/l

Particulate Organic Carbon (POC) content of challenge water and potable water during the 5-day uptake. On discharge, samples were collected from the time-integrated sampling cylinder.

Trial	Challenge Mean ± SD (mg/l)	Potable Mean ± SD (mg/l)
PW-3-UT1	1.45 ± 0.03	BDL
PW-3-UT2	1.32 ± 0.01	BDL
PW-3-UT5	2.21 ± 0.04	BDL
PW-3-DC	N/A	BDL

BDL: Below Detection Limit
PC maximum detection limit: 0.0633 mg/l

Active Chlorophyll content of challenge water and potable water during the 5-day uptake. On discharge, samples were collected from the time-integrated sampling cylinder.

Trial	Challenge Mean ± SD (µg /l)	Potable Mean ± SD (µg/l)
PW-3-UT1	16.1 ± 2.3	BDL
PW-3-UT2	17.0 ± 1.0	BDL
PW-3-UT5	30.4 ± 0.7	BDL
PW-3-DC	N/A	BDL

BDL: Below Detection Limit
Chl-a (active) maximum detection limit: 0.18 µg/l

Live Organisms ≥50 µm

Trial	Challenge Mean ± SD (LO/m^3)	Potable Total (LO/m^3)
PW-3-UT1	208,298 ± 18,720	0
PW-3-UT2	412,111 ± 18,611	0
PW-3-UT5	497,213 ± 25,593	0
PW-3-DC	N/A	0

Taxa and observations
Nine (9) taxa were present in the challenge sample. These were Rotifera, copepod nauplii, tintinnid, diatoms, trochophore, polychaete, harpacticoid, bivalves, and barnacle nauplii. Rust, flakes, detritus and fibers were present in all samples.

Live Organisms ≥10 - <50 µm

Trial	Challenge Mean ± SD (cells/ml)	Potable Total (cells/ml)
PW-3-UT1	3,830 ± 423	BDL
PW-3-UT2	6,060 ± 1,486	BDL
PW-3-UT5	9,253 ± 709	BDL
PW-3-DC	N/A	BDL

BDL: Below Detection Limits
LO ≥10 - <50 µm detection limit is 0.04 cells/ml

Taxa and observations
UT1 - *P. minimum* still dominant and increasing in density. *G. estuarale* was observed in small numbers
UT2 - *P. minimum* still dominant and increasing in density. *G. estuarale* decreasing in density (though one detected live in PWG sample rep 2)
UT5 - Same numbers increasing
During UT2 and UT5, cells of *G. estruale* and *P. minimum* were detected in small numbers (1-3 cells) in the potable water samples.

Culturable Organisms <10 µm
HPC-Total heterotrophic bacteria (THB) – Marine (marine media)

Trial	Challenge Mean ± SD (cfu/10 ml)
PW-3-UT1	1,292 ± 162
PW-3-UT2	892 ± 755
PW-3-UT5	183 ± 22
PW-3-DC	N/A

HPC-Total heterotrophic bacteria (THB) – R2A (freshwater media)

Trial	Challenge Mean ± SD (cfu/10 ml)	Potable Mean ± SD (cfu/10 ml)
PW-3-UT1	5,450 ± 647 (cfu/100 ml)	0
PW-3-UT2	1,062 ± 168	0
PW-3-UT5	510 ± 94	0
PW-3-DC	N/A	0

Enterococci

Trial	Challenge Mean ± SD (cfu/100 ml)	Potable Mean ± SD (cfu/100 ml)
PW-3-UT1	3 ± 2	<1
PW-3-UT2	1	<1
PW-3-UT5	<1	<1
PW-3-DC	N/A	<1

E. coli – IDEXX Colilert-18 (marine media)

Trial	Challenge Mean ± SD (cells/100 ml)
PW-3-UT1	45 ± 1
PW-3-UT2	11 ± 2
PW-3-UT5	<1
PW-3-DC	N/A

E. coli – IDEXX Colilert (freshwater media)

Trial	Challenge Mean ± SD (cells/100 ml)	Potable Mean ± SD (cells/100 ml)
PW-3-UT1	16 ± 6	<1
PW-3-UT2	3 ± 1	<1
PW-3-UT5	3 ± 2	<1
PW-3-DC	N/A	<1

Vibrio cholerae –DFA

Trial	Challenge Mean ± SD (#colonies)	Potable Mean ± SD (#colonies)
PW-3-UT1	0.2 ± 0.4	0
PW-3-UT2	0	0
PW-3-UT5	0	0
PW-3-DC	N/A	0

Whole Effluent Toxicity

Discharge sample testing

No survival or growth effect was observed in the fish test. Daphnia tests resulted in a reduction in neonate production in the top two treatments (56 and 100%) while there was no survival effect. This resulted in an NOEC of 32% and an IC_{25} of 25.6%. Algae tests revealed a significant reduction in growth in the top three dilutions. The reduction in algal growth resulted in an NOEC of 18% and an IC_{25} of 25.1%.

De-chlorinated discharge water sample

The algal growth rate in the 100% de-chlorinated sample (PW-3-DC Dechlor) was substantially greater than without de-chlorination (PW-3-DC). However, there was still a statistically significant decrease in cell density in the in the de-chlorinated sample compared to the control density of $3.49x10^6$ cells/ml.

			Survival		**Growth**		**Lowest effect**
Event	**Organism**	**Sample**	**Effect (Y/N)**	**NOEC**	**Effect (Y/N)**	**NOEC**	**IC_{25}**
PW-3	Fish	PW-3-DC	N	100%	N	100%	>100%
	Ceriodaphnia	PW-3-DC	N	100%	Y	32%	25.6%
	Algae	PW-3-DC	n/a	n/a	Y	18%	25.1%
	Algae	PW-3-DC Dechlor	n/a	n/a	Y	<100%	<100%

Discharge Chemistry Including By-Product Compounds

Chlorate, bromoform and sodium were the only substances found above the minimum detection limit. Chlorate concentration was 49.6 µg/L, bromoform concentration was 0.57 µg/L and sodium was 5.6 mg/L.

11. Trial PW-4 Results

See Sections 4.2.2. and 4.2.3. for definitions of UT Challenge, UT Potable and DC Potable.

Water Quality Conditions

Challenge and potable water quality conditions

	UT Challenge	**UT Potable**	**DC Potable**
Temperature (°C)	22.2	22.7	23.3
Conductivity (µS)	9,189.0	80.7	70.5
Salinity (psu)	4.6	0.04	0.03
DO (mg/l)	7.4	5.8	7.4
DO (%)	87.5	68.0	85.7
pH	7.5	7.5	7.0

Average water quality conditions of the test tank PWG-treated water 5h after uptake.

Test Tank	**Mean ± SD**	**Max**	**Min**
Temperature (°C)	22.9 ± 0.2	23.2	22.7
Salinity (psu)	0.03 ± 0.00	0.03	0.03
DO (mg/l)	8.5 ± 0.2	8.8	8.3
DO (%)	98.8 ± 2.1	102.4	96.6
Turbidity (NTU)	1.2 ± 0.02	1.2	1.1

Average water conditions of the test tank PWG-treated water up to 5h prior to discharge.

Test Tank	**Mean ± SD**	**Max**	**Min**
Temperature (°C)	23.1 ± 0.01	23.1	23.1
Salinity (psu)	0.03 ± 0.0	0.03	0.03
DO (mg/l)	7.6 ± 0.01	7.6	7.6
DO (%)	88.5 ± 0.1	88.6	88.3
Turbidity (NTU)	1.0 ± 0.1	1.0	0.9

Chlorine measurements from the test tank, challenge water, and potable water prior to going into the test tank. Chlorine samples were not collected from the tank on UT1 or from the challenge sample port on discharge.

Free chlorine

Trial	**Tank Mean ± SD (mg/l)**	**Challenge Mean ± SD (mg/l)**	**Potable Mean ± SD (mg/l)**
PW-4-UT1	N/A	0.08 ± 0.02	0.24 ± 0.02
PW-4-UT2	0.14 ± 0.01	0.05 ± 0.02	0.33 ± 0.01
PW-4-DC	0.07 ± 0.01	N/A	0.11 ± 0.01

Total chlorine

Trial	**Tank Mean ± SD (mg/l)**	**Challenge Mean ± SD (mg/l)**	**Potable Mean ± SD (mg/l)**
PW-4-UT1	N/A	0.15 ± 0.02	0.25 ± 0.03
PW-4-UT2	0.17 ± 0.01	0.03 ± 0.01	0.29 ± 0.00
PW-4-DC	0.09 ± 0.01	N/A	0.09 ± 0.02

Total Suspended Solids (TSS) content of challenge water and potable water during the 3-day uptake. Challenge water samples were not collected on discharge. Potable water TSS samples were collected at three different timepoints, beginning, middle, and end (1, 2, and 3, respectively) during the discharge.

Trial		**Challenge Mean ± SD (mg/l)**	**Potable Mean ± SD (mg/l)**
PW-4-UT1		11.5 ± 0.1	BDL
PW-4-UT2		3.8 ± 0.3	BDL
PW-4-DC	**1**	N/A	BDL
	2	N/A	BDL
	3	N/A	BDL

BDL: Below Detection Limit
TSS maximum detection limit: 2.4 mg/l

Dissolved Organic Carbon (DOC) content of challenge water and potable water during the 3-day uptake. On discharge, samples were collected from the time-integrated sampling cylinder.

Trial	Challenge Mean ± SD (mg/l)	Potable Mean ± SD (mg/l)
PW-4-UT1	2.9 ± 0.1	BDL
PW-4-UT2	2.9 ± 0.1	BDL
PW-4-DC	N/A	BDL

BDL: Below Detection Limit
DOC maximum detection limit: 0.24 mg/l

Particulate Organic Carbon (POC) content of challenge water and potable water during the 3-day uptake. On discharge, samples were collected from the time-integrated sampling cylinder.

Trial	Challenge Mean ± SD (mg/l)	Potable Mean ± SD (mg/l)
PW-4-UT1	2.55 ± 0.07	BDL
PW-4-UT2	0.78 ± 0.01	BDL
PW-4-DC	N/A	BDL

BDL: Below Detection Limit
PC maximum detection limit: 0.0633 mg/l

Active Chlorophyll content of challenge water and potable water during the 3-day uptake. On discharge, samples were collected from the time-integrated sampling cylinder.

Trial	Challenge Mean ± SD (µg /l)	Potable Mean ± SD (µg/l)
PW-4-UT1	30.7 ± 5.3	BDL
PW-4-UT2	6.3 ± 0.2	BDL
PW-4-DC	N/A	BDL

BDL: Below Detection Limit
Chl (active) maximum detection limit: 0.18 µg/l

Live Organisms ≥50 µm

Trial	Challenge Mean ± SD (LO/m^3)	Potable Total (LO/m^3)
PW-4-UT1	193,144 ± 13,268	0
PW-4-UT2	147,743 ± 4,766	0
PW-4-DC	N/A	0

Taxa and observations
Ten (10) taxa were present in the challenge sample. These were copepod nauplii, polychaete, diatoms, Calanoida, barnacle nauplii, Rotifera, Cyclopoida, tintinnid, bivalves, and trochophore. Rust, flakes, mineral grains, detritus and fibers were present in all samples.

Live Organisms ≥10 - <50 µm

Trial	Challenge Mean ± SD (cells/ml)	Potable Total (cells/ml)
PW-4-UT1	14,573 ± 319	0.2 ± 0.1
PW-4-UT2	3,790 ± 572	0 ± 0.02
PW-4-DC	N/A	BDL

BDL: Below Detection Limits
LO ≥10 - <50 µm detection limit is 0.04 cells/ml

Taxa and observations
UT1 - *P. minimum* dominated the sample. Small numbers of *G. estuarale* were observed. (Peak of second bloom likely occurred over weekend.)
UT2 - Same species number in decline.

Culturable Organisms <10 µm
HPC-Total heterotrophic bacteria (THB) – Marine (marine media)

Trial	Challenge Mean ± SD (cfu/10 ml)
PW-4-UT1	1,537 ± 180
PW-4-UT2	162 ± 41
PW-4-DC	N/A

HPC-Total heterotrophic bacteria (THB) – R2A (freshwater media)

Trial	Challenge Mean ± SD (cfu/10 ml)	Potable Mean ± SD (cfu/10 ml)
PW-4-UT1	3,367 ± 638 (cfu/100 ml)	0
PW-4-UT2	183 ± 78	0
PW-4-DC	N/A	0

Enterococci

Trial	Challenge Mean ± SD (cells/100 ml)	Potable Mean ± SD (cells/100 ml)
PW-4-UT1	<1	<1
PW-4-UT2	<1	<1
PW-4-DC	N/A	<1

E. coli - IDEXX Colilert-18 (marine media)

Trial	Challenge Mean ± SD (cells/100 ml)
PW-4-UT1	3 ± 0.1
PW-4-UT2	2 ± 1
PW-4-DC	N/A

E. coli - IDEXX Colilert data (freshwater media)

Trial	Challenge Mean ± SD (cells/100 ml)	Potable Mean ± SD (cells/100 ml)
PW-4-UT1	3 ± 1	<1
PW-4-UT2	3 ± 1	<1
PW-4-DC	N/A	<1

Vibrio cholerae – DFA

Trial	Challenge Mean ± SD (#colonies)	Potable Mean ± SD (#colonies)
PW-4-UT1	0	0
PW-4-UT2	0	0
PW-4-DC	N/A	0

Whole Effluent Toxicity

Discharge sample testing

No statistically significant survival or growth effect was observed in the fish test. Daphnia tests resulted in a reduction in neonate production in the top two treatments with 21.2 and 18.0 neonates per adult for 56 and 100% dilutions, respectively. This resulted in an NOEC of 32% and an IC_{25} of 45.9% for 7-d daphnia reproduction endpoint. Algae tests revealed a significant reduction in growth in only the 100% treatment. The reduction in algal growth resulted in an NOEC of 56% and an IC_{25} of 73.6%.

De-chlorinated discharge water sample

There was no significant reduction in growth for the de-chlorinated sample.

			Survival		**Growth**		**Lowest effect**
Event	**Organism**	**Sample**	**Effect (Y/N)**	**NOEC**	**Effect (Y/N)**	**NOEC**	**IC_{25}**
PW-4	Fish	PW-4-DC	N	100%	N	100%	>100%
	Ceriodaphnia	PW-4-DC	N	100%	Y	32%	45.9%
	Algae	PW-4-DC	n/a	n/a	Y	56%	73.6%
	Algae	PW-4-DC Dechlor	n/a	n/a	N	100%	>100%

Discharge Chemistry Including By-Product Compounds

Chlorate, bromoform and sodium were the only substances found above the minimum detection limit. Chlorate concentration was 47.7 µg/L, bromoform concentration was 1.4 µg/L and sodium was 7.4 mg/L.

12. Quality Assurance and Quality Control

Quality Assurance and Quality Control policies and procedures, data recording processing and storage, and detailed roles and responsibilities are found in the MERC QMP, QAPP and SOPs. There were no adverse findings in data collection and reporting or at either the test facility or associated laboratories. There were a few minor modifications to the Test Plan due to operational requirements of the PWG system being evaluated, which did not affect the overall test. These modifications were documented by MERC test personnel in accordance with MERC QAPP.

13. Acknowledgements and Approvals

The MERC Testing Team for the PWG trials included: E. Bailey, J. Barnes, M. Carroll, T. Mullady, G. Ruiz, G. Smith, D. Sparks, M. Tamburri, G. Ziegler, and K. Ziombra. MERC thanks the U.S. Maritime Administration for funding and supporting this performance evaluation and Edward Viveiros and Debra Falatko from Eastern Research Group (ERG) for their guidance and support.

Appendix A. MERC Analysis of Media Tank Failure

System Problem(s) and Findings
One (of three) media tanks failed on the PWG provided system (see attached photos). The fourth MERC test was halted. Thus, samples for PW-4-UT5 (third out of three uptake sample collection dates for PW-4) were not collected. PW-4-DC (discharge) was possible since the MERC test tank was full enough for a discharge. The full PW5 test was canceled.

Possible Causes and Major Area/Situations Investigated
The following three causes were discussed with the engineer from the PWG provider:
1. Direct hit to the media tank.
2. High vacuum to the media tank.
3. High pressure to the media tank.

Findings and Causes from Investigation
Upon inspection MERC observed the following:

Findings (see attached photos and details)
A skid was fitted with 3 cylindrical reinforced and painted fiberglass media tanks, which were domed-shaped at the top and bottom ends. Each tank sat in its own stand and was further stabilized at the top with wood, line and piping. When MERC personnel remotely observed by computer that the PWG system had automatically shut down, MERC personnel drove to the MTP to change the filters (the usual reason for a shutdown) and restart the system. When the submersible pump was turned on to re-prime the PWG system, water was observed flowing vigorously out of the top of one of the media tanks. The submersible pump was quickly shut off.

Upon inspection, MERC personnel observed that one-half of the top fiberglass dome of the forward-most media tank was cracked open. The fiberglass cracked in eggshell fashion with very jagged edges. The crack traveled horizontally ½-way around the domed top, but did not extend down into the sides of the tank. A jagged section of the upper portion of the fiberglass was lifted up just enough so that blue reinforcement material could be observed.

Possible Causes
1. Direct hit to the media tank by an object. There is no clear evidence of a direct hit to the top of the media tank. However, MERC speculates that even a minor hit in the right place (such as directly on the top pipe fitting when the tanks were not in the skid) might weaken the fiberglass.

Note that MERC was on board during the skid loading by crane by McLean. Loading was accomplished carefully and gently. MERC does not know about historical movements.

2. High vacuum to the media tank. The PWG engineer stated that a vacuum pressure could possibly have been created via reverse suction from the discharge hose, which was submerged 3-4 feet into the ambient water. However, the engineer also observed that the media tank would have exhibited signs of implosion, which was not the case. Plus, the engineer would have expected an implosion to most likely occur at the center of a tank and not at the top. The PWG engineer also noted at the time that he thought safety valves were in place to prevent the hose from reverse suction into the media tanks (See the Findings section below).

3. Excessive positive pressure to the media tank. The PWG engineer speculated that this was the most probable cause; however the exact mechanism is still to be determined by the PWG provider and reported to ERG, the firm contracted by EPA to rent the potable water system.

Four possible causes for excessive positive pressure are:
3.1. The submersible pump providing water to the media tanks could send too much pressure to the media tanks.
Observations: This specific pump deadheads at 120 psi. Each media tank is rated to 150 psi (tank label), but are supposed to withstand 4 times that pressure or 600 psi (manufacturer's website via personal communication with ERG).

3.2. The media tanks were outdated and had deteriorated.
Observations: The tanks were constructed in 2008 (tank label) with a 5-year warranty (website observation by ERG personnel). However, the PWG engineer thought that the paint on the outside of the tanks would prevent the fiberglass from deteriorating.

3.3. Malfunction of one or more of the compressed air-actuated valves located on the media skid used during back-flush cycle to clean the tanks.
Observations: MERC could not test the valves. This was to be determined upon inspection when the system was returned to the PWG provider.

3.4. Malfunction of one or more of the two manual valves located on the RO skid, with hoses running between the media and RO skids.
Observations: These valves were positioned in-line and appeared to be working when MERC tested them. As stated above, the maximum pressure would have been 120 psi from the submersible pump.

Note: A 2-3 inch crack was observed on a second tank in the same location. No water was observed leaking from that tank. However, the tank still may be compromised.

Conclusion and Corrective Action

Conclusion
As of 27 June 2014, **t**he equipment was in transit to PWG provider. When the company received the shipment, they trouble-shot the tank failure.

Corrective Action(s)
PWG provider offered to 2-day ship a new media skid to MERC at no cost. However, MERC or ERG/EPA would have incurred the expenses of moving the MTP, unloading the old media skid and loading the new media skid. Also, ERG's rental contract with PWG provider would have to be extended. EPA and MERC decided the costs were not worth the benefit of conducting a fifth test.

Followup
Follow-up with PWG provider was conducted by ERG who emailed the findings to EPA and MERC. See the Findings Section below. This MERC report notes that the third uptake of PW4 (UT5) and all of the fifth trial (PW5) were canceled.

Findings
Email from ERG engineer dated 1 July 14

"I wanted to forward a quick summary of what caused the PWG tank rupture, based on my understanding from conversations with PWG [sic] Engineer. The short version of the story is that the tanks ruptured because of a buildup in vacuum pressure in the overboard discharge line.

To help with visualizing how this happened, "I have provided the attached schematic for the potable water generator" (See ERG report). (I copied this schematic directly from the operation manual PWG provider provided; see page 9 of the manual for a complete version of the schematic). I highlighted in red the portions of the system that come into play. As the discharge line drains, it has a siphoning affect all the way up the line and into the media tanks. Depending on the vertical height of the discharge line, it is possible to create enough of a vacuum to rupture the media tanks.

Typically, the tanks can withstand this stress if/when such a vacuum occurs. However, ours did not, and it is likely because of their age. To prevent tanks from rupturing in this manner, PWG provider typically installs a vacuum breaker on the discharge line (as reflected in the PWG provider schematic). However, our system [the system tested by MERC] was an older unit that did not have one installed. Also, based conversations they had with us, PWG provider did not expect there to be an appreciable height differential in the discharge line, and thus did not expect that it would produce enough of a vacuum to compromise the integrity of the tank."

Photos of the cracked media tank.

Appendix B. MERC Potable Water Generator Test Plan

The detailed test approach, procedures and methods are attached as PDF files. MERC SOPs are also available upon request.

Appendix C. Chemistry Including By-Products Compounds - Full Analyses

The original compound analyses for all four PWG trials (discharge events, potable water only) are attached as PDF files.