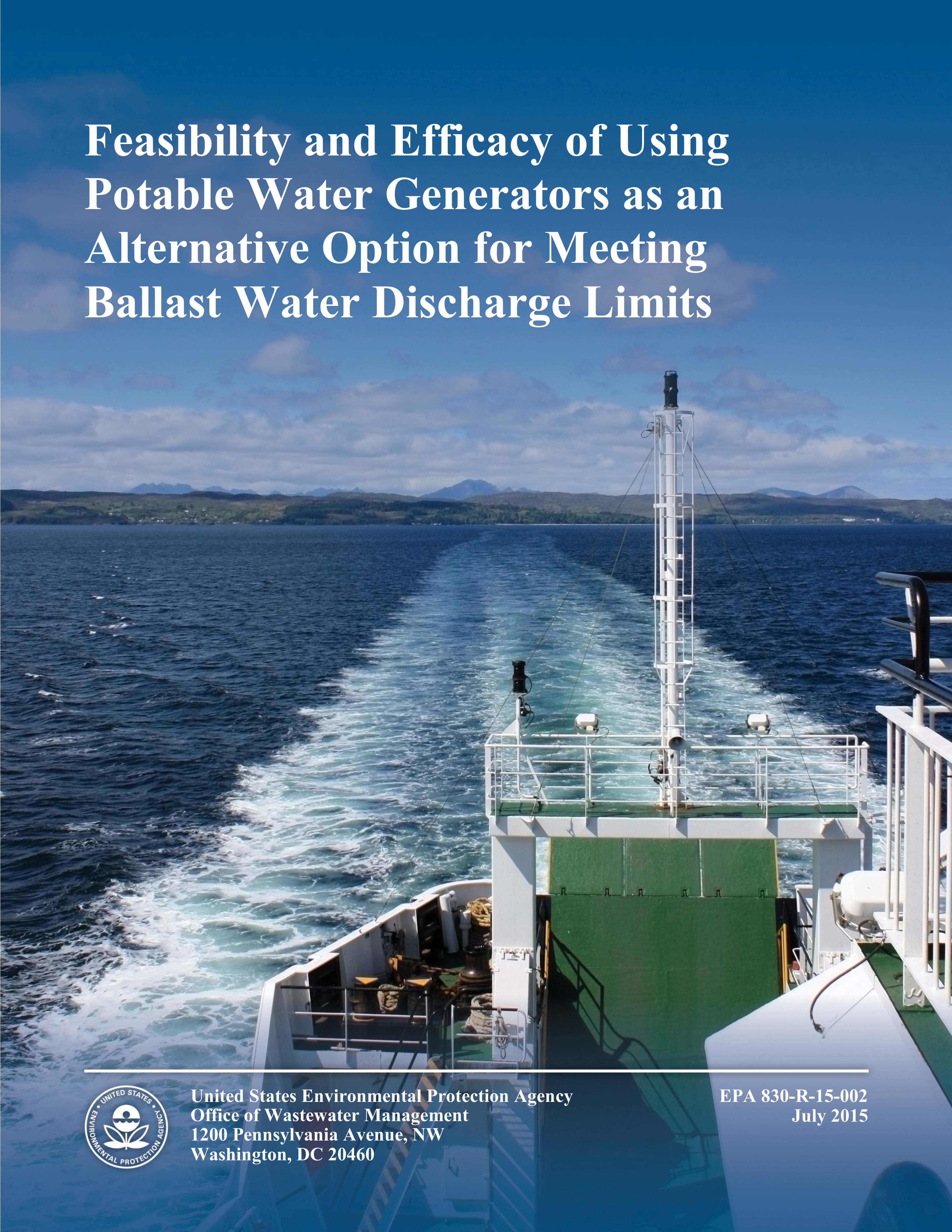

Feasibility and Efficacy of Using Potable Water Generators as an Alternative Option for Meeting Ballast Water Discharge Limits

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SECTION 1
INTRODUCTION

1.1 REGULATORY FRAMEWORK FOR BALLAST WATER DISCHARGES

On March 28, 2013, EPA reissued the Vessel General Permit (VGP) for discharges incidental to the normal operation of vessels. A key new provision of the permit is numeric discharge limits to control the release of non-indigenous invasive species in ballast water[1] discharges from inland and seagoing vessels greater than 1,600 gross registered tons (GRT), or 3,000 gross tons (GT), unless otherwise excluded.[2] The VGP specified that owners/operators of these vessels must use one of the following four ballast water management methods to meet the numeric ballast water discharge limits:

- Ballast water treatment system,
- Onshore treatment,
- Use of a public water supply for ballast, or
- No discharge of ballast water.

While not required by the 2013 VGP, the permit also encouraged owners and operators of "Lakers" (i.e., vessels built before January 1, 2009 and operating exclusively on the Laurentian Great Lakes) and inland and seagoing vessels smaller than 1,600 GRT (3,000 GT) to use alternative management measures to reduce the number of living organisms in their ballast water discharges.

1.2 EVALUATING THE FEASIBILITY AND EFFICACY OF USING A POTABLE WATER GENERATOR (PWG) TO MEET BALLAST WATER NUMERIC DISCHARGE LIMITS

EPA is assessing whether additional options may be available for meeting ballast water numeric discharge limits in future iterations of the VGP, or other regulatory mechanisms, as appropriate. One option the Agency is considering is the use of onboard potable water generators (PWGs). This report provides an overview of a study performed by EPA, in partnership with the U.S. Maritime Administration (MARAD), to assess the feasibility and efficacy of using PWGs to manage ballast water.[3] The study considered:

[1] Ballast water means any water taken onboard into ballast water tanks that assists with vessel draft, buoyancy, and stability (USEPA, 2013a).

[2] As specified in Part 2.2.3.5.3 of the 2013 VGP, the following types of vessels are excluded from having to meet the numeric standards: (1) vessels engaged in short-distance voyages that operate in or take on and discharge ballast water exclusively in one Coast Guard Captain of the Port (COPT) zone; (2) vessels that do not travel more than 10 nautical miles and do not cross any physical barriers or obstructions; (3) unmanned and unpowered barges (such as hopper barges); and (4) vessels that operate exclusively on the Laurentian Great Lakes (known as Lakers) that were built before January 1, 2009.

[3] For this report, EPA considers a PWG to be any system that produces purified water from fresh, brackish, or saltwater sources using distillation or reverse osmosis technologies, with the purified water then being disinfected with chemicals or ultraviolet radiation to neutralize any remaining living organisms and pathogens and make the water potable.

- Applicable vessel types and the amount of ballast water needed,
- PWG design characteristics and costs,
- Feasibility of installing a PWG onboard a vessel, and
- Efficacy of a PWG to meet ballast water numeric discharge limits.

SECTION 2
VESSEL TYPES FOR WHICH A PWG OPTION IS POSSIBLE

To assess whether onboard PWGs are a feasible option for managing ballast water discharges, EPA evaluated typical ballasting operations, volumes, and flow rates required for various vessel types. EPA then compared vessel ballast requirements against what is achievable using commercially available PWGs to determine under what conditions this technology could apply to vessels. This section presents the information EPA gathered on vessel ballasting operations and PWG capacities and discusses the conditions under which PWG technologies may appropriate for ballast water management.

2.1 BALLASTING OPERATIONS BY TYPE OF VESSEL

According to the United States Coast Guard (USCG, 2012), large commercial vessels (e.g., container ships, bulk carriers, other cargo vessels, and tankers) load and offload ballast water in large quantities at high rates over relatively short periods. For example, large commercial vessels have ballast water capacities ranging from 1,700 m^3 to approximately 215,000 m^3 and ballast water pump capacities ranging from 250 m^3/hr to 6,500 m^3/hr (USCG, 2012). These rates far exceed the capacity of existing onboard PWGs; although in some instances, such generators are currently used aboard vessels to satisfy daily fresh water demands for drinking, laundry, galley, dishwashing, sinks, showers, and sanitary water. Commenters responding to the proposed 2013 VGP indicated that PWGs may be a viable option for satisfying ballast water requirements for certain small commercial vessels that ballast to compensate for fuel burn (e.g., towboats) and for certain large vessels with relatively modest ballasting requirements (e.g., passenger vessels and fishing vessels). Accordingly, EPA's data collection for this analysis focused on these vessel types and operations for which PWG ballasting may be applicable. Table 2-1 summarizes the information EPA collected on ballasting operations by vessel type.

Table 2-1. Small Commercial Vessel Types and their Ballasting Operations

Vessel Type	Description	Ballasting Operations	Ballast Volume (gal)	Ballast Volume (m^3)
Utility: Tugboats	Tugboats or towboats	Tugboats carry relatively small volumes of ballast water and have low ballasting rates in the 20 to 250 gallon/minute (gpm) range.[1] Using potable water as ballast is common practice for inland towing vessels. These types of vessels do use potable water for accommodating changes in displacement and balance as fuel is consumed during the voyage. For these operations the ballast is discharged prior to refueling. Some tugboats may also use permanent ballast.	Inland tug: 20,000 to 40,000[2] Coastal tug: 20,000 to 70,000[2] Small harbor tug: 2,000 to 3,000[2]	Inland tug: 76 to 151[2] Coastal tug: 76 to 265[2] Small harbor tug: 8 to 11[2]
Utility: Off-Shore Support Vessels (OSVs)	Supply vessels that support off-shore oil and gas operations. Includes crew boats, lift boats, and tugs and barges that carry equipment, supplies, and workers.	OSVs generally have designated ballast tanks, take on fresh municipal water as ballast, and offload ballast at the off-shore rig or back in port. These types of vessels do not use seawater for ballast and do not discharge ballast water to the sea. Lift boats take on and discharge seawater as ballast in the exact same location.	26,000 to 1,321,000[3]	100 to 5,000[3]
Small Passenger Vessels	Dinner cruise vessels, sightseeing and excursion vessels, passenger and vehicular ferries, private charter vessels, whale watching and eco-tour operations, windjammers, gaming vessels, amphibious vessels, water taxis, and overnight cruise ships	Very few commercial passenger vessels carry or discharge ballast water. Passenger vessels that do carry ballast water carry 2,000 to 21,000 gallons, and ballast at rates ranging from 180 to 800 gpm.[3] Recreational charter boats generally do not have ballast water tanks.	0 to 21,000 [4]	0 to 79[4]
Fishing Vessels	Vessels 65 to 297 feet (ft) in length	Smaller fishing vessels do not require and are not equipped with ballast tanks (but would be equipped with fish holding tanks). Among fishing vessels equipped with ballast tanks, some use PWG as ballast, others are permanently ballasted, and others ballast/deballast routinely.	0 to 566,000[4]	0 to 2,100[4]
Research Vessels	Coastal and oceangoing vessels 86 to 470 ft in length[3]	Vessel profile is relatively stable, generally requiring only minor adjustments to maintain trim, often managed using fuel. Larger vessels that perform longer-term surveys may ballast to compensate for fuel burn.	0 to 1,268,000[4]	0 to 4,800[4]

Source: USEPA, 2012
[1] AWO, 2012
[2] AWO, 2009
[3] IMO, 2012
[4] USEPA, 2013b, rounded to the nearest thousand gallons

2.1.1 Ballasting Operations for Tugboats and Towboats

EPA obtained information and data regarding tugboats and towboats and their ballasting operations from comments submitted in response to the proposed 2013 VGP, as well as telephone contacts with vessel owners/operators, as described below:

- The American Waterways Operators (AWO) is the national trade association for the tugboat, towboat, and barge industry. AWO's member companies include owners and operators of barges and towing vessels operating on the U.S. inland and intracoastal waterways; the Atlantic, Pacific, and Gulf coasts; and the Great Lakes. According to AWO:
  - Towing vessels use relatively small volumes of ballast water – a typical inland towboat can carry 20,000 to 40,000 gallons (gal) of ballast water, and a typical coastal tugboat has a ballast water capacity of 20,000 to 70,000 gal (AWO, 2012). A small harbor tug might have a capacity of 2,000 to 3,000 gal (AWO, 2009).
  - Towing vessels have very low ballasting rates, usually ranging from 20 to 250 gpm (AWO, 2012).

  AWO acknowledges that using potable water as ballast is common practice for inland towing vessels, but not universal. In particular, this practice is not operationally or economically feasible for towing vessels that carry ballast water to maintain stability and trim (i.e., accommodate changes in vessel displacement and balance) as fuel is consumed during a voyage. As an example, AWO describes that a towboat may need to take up 3,000 to 5,000 gal of ballast water per day to offset fuel consumption. The percentage of these vessels that use potable water as ballast is unknown.

  AWO acknowledges that some tugboats use permanent ballast and never discharge that water, but others need to take on and discharge ballast water for safe operation. The percentage of vessels that use permanent ballast is unknown (AWO, 2012).

- Canal Barge Company operates a fleet of 32 inland towboats and more than 800 barges that operate on the Intracoastal Waterway, Lower Mississippi River, Illinois River, and Ohio River. Canal Barge Company describes a large towing vessel as one that takes on ballast to compensate for burning 10,000 gal of fuel per day (equivalent to 8,320 gal of ballast water, assuming a diesel fuel density of 0.832 kilograms per liter) (Canal Barge Company, 2012).
- Allied Transportation Company owns and operates 8 oceangoing tugboats and 13 barges on the East and Gulf Coasts of the United States. Their towing vessels take on ballast only to compensate for fuel consumed and only discharge ballast prior to refueling. Their largest capacity tugboat carries a maximum of 178 m^3 of ballast water (47,022 gal) (Allied Transportation Company, 2012). According to EPA's VGP Notice of Intent (NOI) database, this vessel is 863 GT and 124 ft long. Other Allied Transportation Company vessels (non-barge) in the NOI

database range from 95 to 700 GT, from 80 to 128 ft, and from 0 to 50,400 gal of ballast water capacity.

- American River Transportation Co. (ARTCO) operates a fleet of 1,835 barges, 28 linehaul vessels, and over 50 local harbor vessels on the inland river system. ARTCO described a typical voyage for a linehaul vessel operating on the Lower and Upper Mississippi River, below St. Louis:
  - Departs St. Louis southbound full of fuel with approximately 18,500 gal of ballast on board.
  - About two days later (Memphis), the crew adds another 18,500 gal of ballast.
  - In New Orleans, the crew discharges 22,000 gal of ballast when adding fuel.
  - About three days later (Rosedale), the crew adds 18,000 gal of ballast.
  - About three days later (New Madrid), the crew adds 18,000 gal of ballast.
  - In St. Louis, the crew fully fuels the vessel and discharges all ballast except for 18,500 gal (ARTCO, 2012).
- Great Lakes Towing Company tugboats operate in harbors and do not require ballast water; their vessels are not equipped with ballast tanks (ERG, personal communications, May 17, 2013).
- Sause Bros. operates: (1) harbor vessels such as assist/general towing/escort vessels and tugs/crew boats that shuttle crews to offshore production facilities, and (2) oceangoing unmanned barges and towing vessels operating on the West Coast. Harbor vessels do not carry ballast water and many are not equipped with ballast tanks. Oceangoing towing vessels maintain trim by shifting fuel between tanks; ballast water is rarely used and only under such conditions as operating in heavy seas when the vessel is light on fuel (ERG, personal communications, May 14, 2013).
- AEP River Operations provides barge transportation services of dry bulk commodities throughout the inland river system. AEP's inland towing vessels ballast and deballast to compensate for fuel consumption or refueling. A voyage may run five to seven days from Memphis to St. Louis. Fuel is taken on every four or five days; after about two days of fuel burn, the vessel trim is affected, at which point ballast water is added from time to time at a slow rate. Other towing vessels are able to add fuel every day, and it is not critical for them to use ballast water to maintain trim (ERG, personal communications, March 26, 2014).

These comments and communications regarding tugboat and towing vessels and NOI data indicate that:

- Inland and coastal tugboats and towboats of all sizes routinely carry ballast water. Many of these vessels use potable water as ballast; however, the percentage of vessels that use potable water as ballast is unknown. In addition, an unknown percentage of vessels are not equipped with ballast tanks or use permanent ballast that is never discharged.

- Vessels that take on ballast while underway use ballast to compensate for fuel burned during a voyage. This ballast is discharged when refueling. The percentage of vessels with these ballasting operations is unknown.
- The amount of ballast water varies by vessel type. A typical inland towboat can carry 20,000 to 40,000 gal of ballast water, a typical coastal tugboat has a ballast water capacity of 20,000 to 70,000 gal, and a small harbor tug may have a capacity of 2,000 to 3,000 gal.

2.1.2 Ballasting Operations for Offshore Workboats

EPA obtained information and data regarding offshore workboats and their ballasting operations from comments submitted in response to the proposed 2013 VGP and the USCG proposed ballast water discharge standard rulemaking (2012), as described below:

- The Offshore Marine Service Association (OMSA) represents owners and operators of approximately 1,200 vessels (offshore supply vessels, crewboats, liftboats, and tugs and barges) that carry equipment, supplies, and workers in support of offshore oil and gas exploration and development in the Gulf of Mexico. According to OMSA, vessels in their membership have designated ballast tanks that take on only fresh municipal water that is then offloaded to an offshore rig or to a facility once back in port (OMSA, 2012a and 2012b). They do not take on seawater for ballast, and they do not discharge ballast water to the sea. Coastwise vessel operators specifically do not allow seawater in ballast tanks due to its corrosivity (OMSA, 2009).

  Also, according to OMSA, liftboats take on seawater, referred to as “preload” water, to firmly attach their legs to the seafloor to work alongside a rig. The vessel discharges the preload water completely (as mandated by their USCG certified Operations Manual) before moving and navigating to its next point. Therefore, liftboats take on and discharge seawater in the exact same location (OSMA, 2009).

  Per OSMA, 2009, more than 80 percent of membership vessels operate within two COTP zones (New Orleans and Morgan City, Louisiana).

- Rowan Companies, Inc. requested that EPA consider adding an option to use freshwater generated from seawater (from watermakers, desalinization units, reverse osmosis units, etc.) as a source of ballast water. According to Rowan Companies, freshwater generated from seawater is often used for potable water on mobile offshore drilling units and as a source of ballast water for vessels with moderate ballast water requirements (~84,000 gal) (Rowan Companies, Inc., 2012).
- Hornbeck Offshore Operators, LLC provides offshore supply vessels serving the oil and gas industry in the Gulf of Mexico. They also operate tugboats and barges

to transport petroleum products in northeastern United States and the Gulf of Mexico. Hornbeck Offshore states that the majority of their vessels use municipal water as their primary source of ballast water (Hornbeck Offshore Operators, 2009).

These comments regarding offshore workboats indicate that:

- The vast majority of offshore workboats use municipal potable water as their primary or sole source of ballast water.
- A typical offshore workboat ballasting requirement may be 84,000 gal.
- Liftboats take on and discharge ballast at the exact same location.
- An estimated 80 percent of offshore workboats operate within two COTP zones, in Louisiana.

2.1.3 Ballasting Operations for Passenger Vessels

EPA obtained information and data regarding passenger vessels and their ballasting operations from comments submitted on the proposed 2008 VGP and proposed 2013 VGP, as well as telephone contacts with vessel owners/operators, as described below:

- The Passenger Vessel Association represents U.S.-flagged passenger vessels of all types (dinner cruise vessels, sightseeing and excursion vessels, passenger and vehicular ferries, private charter vessels, whale-watching and eco-tour operators, windjammers, gaming vessels, amphibious vessels, water taxis, and overnight cruise ships), with nearly 600 vessel and associate members. According to the association, very few commercial passenger vessels either carry or discharge ballast water (PVA, 2008).
- The National Association of Charterboat Operators represents over 3,300 charter boat owners and operators of for-hire vessels ranging from 15-ft center console outboards to 120-ft triple engine headboats. The commenter states that recreational charter boats do not have ballast water tanks (NACO, 2008).
- Argosy Cruises operates 11 vessels in and around the Seattle harbor and Lake Washington, performing sightseeing tours and private charters. These vessels do not carry ballast water or leave local waters. The Argosy Cruises website (Argosy Cruises, 2012) describes 9 vessels ranging in length from 36 to 180 ft (Argosy Cruises, 2008).
- The Boat Company operates two vessels with overnight accommodations on week-long conservation/education cruises in Southeast Alaska Inside Passage waters. Both vessels are 150 ft in length; one vessel is less than 100 GRT and the other is 403 GRT. Neither vessel carries ballast water (The Boat Company, 2008).
- According to Maryland's Pride, sailing school vessels (limited to 500 GRT) and sail and auxiliary sail vessels (limited to 100 GRT) operating under Subchapter T do not have water ballast tanks (fixed ballast only). Voyages are typically short and frequent (Maryland's Pride, 2008).

- River Cruises operates a 157-ft Riverboat with two-day overnight cruises on the Upper Mississippi River. According to River Cruises, while the vessel has ballast water tanks, they have never been used; if the ballast tanks were to be used, they would be filled with fresh water from shore (River Cruises, 2008).
- Seabourn Cruise Line operates 6 oceangoing cruise vessels that carry between 130 and 450 passengers. Seabourn vessels do not take on seawater for ballasting, but manage trim by adding advanced wastewater treatment permeate, untreated graywater, or treated blackwater to ballast tanks. These ships may add ballast using these water sources to compensate for fuel consumption or for bad weather (ERG, personal communications, May 28, 2013).
- According to EPA's VGP NOI database, medium cruise ships carrying 100 to 499 passengers have an average ballast water capacity of approximately 135,000 gal (512 cubic meters (m^3)). Large cruise ships carrying more than 500 passengers have an average ballast water capacity of approximately 1,000,000 gal (3,900 m^3).

These comments and communications regarding passenger vessels and NOI data indicate that:

- Very few passenger vessels either carry or discharge ballast water; however, the percentage of vessels that do not carry or discharge ballast water is unknown.
- Among the passenger vessels that do carry ballast water, some use bunkered potable water as ballast. The percentage of these vessels that use potable water is unknown.
- Among the smaller passenger vessels that do carry ballast water, the amount of ballast water carried is unknown; however, available information regarding ballast capacities suggest the amount may range from less than 2,100 gal (8 m^3) to 20,700 gal (78 m^3).
- Many larger passenger vessels have ballasting options other than seawater and municipal potable work, depending on onboard sanitary systems. Medium and large cruise ships have average ballast water capacities of approximately 135,000 gal (512 m^3) to 1,000,000 gal (3,900 m^3), respectively.

2.1.4 Ballasting Operations for Commercial Fishing Vessels

EPA obtained information and data regarding commercial fishing vessels and their ballasting operations from comments submitted in response to the proposed 2013 VGP, as well as telephone contacts with vessel owners/operators, as described below:

- United Fisherman of Alaska (UFA) is the largest statewide commercial fishing trade association, representing 37 commercial fishing organizations participating in fisheries throughout the state and its offshore federal waters. According to UFA, in 2007, the Alaska commercial fishing fleet included 9,828 commercial fishing vessels ranging in length from 7 to 635 ft, including 497 vessels over 79 ft. In a comment, UFA requested that EPA make explicit that water taken on board in a fish hold for purposes of fishing and tendering (fish and shellfish) is not defined as ballast water. Further, UFA stated that ballast tanks on some fishing vessels are filled with potable water or are permanently filled (UFA, 2012).

- United Catcher Boats and Pacific Seafood Processors Association provided joint comments. United Catcher Boats represents owners of vessels that trawl for groundfish in the Bering Sea, Gulf of Alaska, and West Coast commercial fisheries. Their 72 member vessels range from 75 to 190 ft and range between 100 and 500 GT. Pacific Seafood Processors Association corporate members are major seafood processing companies with operations in Alaska and Washington. Their only comment regarding ballast water was to request that EPA exempt re-circulating seawater tanks from ballast water requirements (UCBA and PSPA, 2012).
- At-sea Processors Association, the Freezer Longline Coalition, and the Ground Fish Forum provided collective comments. At-sea Processors Association represents six companies that own and operate 16 U.S.-flag catcher processor vessels that participate in the Alaska pollock fishery, accounting for more than one-third of all fish harvested in the United States. These vessels range in size from approximately 250 to 340 ft and approximately 1,500 to 5,000 GT. The Freezer Longline Coalition represents owners and operators of 30 U.S.-flag vessels that participate in the freezer longline or catcher/processor hook-and-line sector of the Pacific cod fishery in the federal waters of the Bearing Sea, Aleutian Islands, and the Gulf of Alaska. These vessels range in size from approximately 110 to 180 ft and approximately 140 to 900 GT. The Ground Fish Forum represents 5 companies and 17 vessels/licenses that are part of the "Amendment 80" sector in the Bering Sea/Aleutian Islands and operate in the Gulf of Alaska. These vessels range in size from 100 to 295 ft in length and from 180 to 1,600 tons. The commenters stated that most of their members' vessels are equipped with ballast tanks and will be subject to VGP ballast water requirements. The commenters described the need to ballast/deballast when operating in severe weather and rough seas. The commenters also stated that several vessels currently use potable water generated on board for ballast water (APA, FLC, and GFF, 2012).
- An anonymous commenter stated that smaller Alaskan commercial fishing vessels discharge 70,000 gal or less of ballast water (Anonymous, 2012).
- iWorkWise provides consulting services to the commercial fishing industry in the Pacific Northwest and Alaska. According to iWorkWise, commercial fishing vessels primarily deballast as they use fuel and catch fish, which they stow in their cargo holds. They also ballast to control trim when they are transiting to and from Alaska (ERG, personal communications, April 9, 2014).

These comments and communications regarding fishing vessels indicate that:

- Many of the fishing vessels within this group, especially the smaller fishing vessels, do not require and are not equipped with ballast tanks (they are equipped with fish hold tanks, which are typically not used to maintain the trim and stability of the vessel). The percentage of these vessels without ballast tanks is unknown.

- Among the fishing vessels equipped with ballast tanks, some use potable water (either bunkered municipal water or potable water generated on board) as ballast, or they are permanently ballasted. Some may never use or discharge ballast water. However, others ballast and deballast frequently and routinely when conducting fishing operations and burning fuel.

2.1.5 Ballasting Operations for Research and Other Potentially Relevant Vessels

EPA obtained information and data regarding other types of small vessels or other vessels with modest ballasting requirements from comments submitted in response to the proposed 2013 VGP, as well as telephone contacts with vessel owners/operators, as described below:

- Cetacean Marine operates and maintains research, training, and offshore support vessels. According to Cetacean Marine, the only time Great Lakes non-cargo vessels must ballast is at the commencement of the sailing season and when the accumulation of onboard sewage or the consumption of fuel requires shifting, uptaking, or discharging of ballast water. Cetacean Marine requested that EPA consider the use of onboard PWGs such as an onboard reverse osmosis watermaker as another compliance alternative (Cetacean Marine, 2012).
- The ocean survey vessel *Bold* is a 224-ft oceangoing research vessel previously owned by EPA. This vessel's trim is adjusted to sit low in the water to provide greater stability; trim is generally maintained using fuel (250,000-gal fuel capacity). The vessel uses ballast water to compensate for fuel consumption. Ballasting is performed once or twice during a 2-week survey with a typical ballasting volume of about 3,000 gal (ERG, personal communications, May 29, 2013).
- *R/V Lake Guardian* is a 180-ft Great Lakes research vessel owned by EPA. In 2010, the vessel's ballast tanks were converted to potable water tanks. At the onset of the season (April), the vessel operators fill the Guardian's potable water tanks with municipal potable water. Potable water, fuel, and sewage are shifted between tanks as necessary to maintain stability and trim. Additional ballasting and deballasting is minimized, and no ballast water has been discharged over the last several years (ERG, personal communications, June 7, 2013).
- *R/V Savannah* is a 92-ft oceangoing research vessel that operates primarily in the South Atlantic, Cape Hatteras, and Cape Canaveral. The vessel has a 27,000-gal capacity for freshwater ballast. The vessel's stability profile is fairly standard, requiring only minor adjustments during the voyage, primarily made with fuel. Only rare conditions would require seawater ballasting, such as if the peak tank was low and the vessel encountered rough seas (ERG, personal communications, June 30, 2013).
- *R/V Hugh R. Sharp* is a 146-ft coastal research vessel that operates in the Delaware and Chesapeake Bays and adjacent coastal waters out to 200 nautical

miles. The vessel does not have ballast water tanks or use water as ballast; fuel is used to maintain trim (ERG, personal communications, July 11, 2013).

These comments and communications indicate that:

- Non-cargo vessels in the Great Lakes ballast infrequently. Vessels maintain trim by shifting potable water, fuel, or sewage.
- Research vessels internally ballast fuel to maintain trim. Some also use ballast water to compensate for fuel consumption. The percentage of vessels that use ballast water to compensate for fuel consumption is unknown.

2.2 Ballast Discharge Rates by Type of Vessel

To assess ballast discharge rates, EPA gathered information on eight vessels and seven vessel classes ranging from 138 to 32,000 GT. Table 2-2 summarizes the information for each vessel or vessel class. The information is grouped by vessel type (e.g., research, utility, passenger, etc.), and presents general information about the vessel, typical vessel ballast pump ratings in gpm, and fuel burn rates in gpm.

Most operators indicated their vessels or vessel classes take on ballast to compensate for fuel consumption, while some operators reported taking on ballast to level out the vessel or to compensate for cargo loads (Rowan EXL jackup rigs and the NPS vessel *M/V Ranger III*, respectively) (GA, 2011 and ERG, personal communications, June 11, 2013). Overall, vessel ballast rates range from 155 to 800 gpm. These rates largely are determined by the ballast pump (i.e., vessels take on ballast as quickly as their ballast pumps allow).

For commercial fishing vessels, EPA did not receive information on typical vessel ballasting rates. However, comments from the VGP docket and iWorkWise indicate that fishing vessels ballast to compensate for fuel use, satisfying ballasting requirements by managing cargo holds, using ballast tanks filled with potable water, or using permanently filled ballast tanks.

For comparative purposes, EPA estimated fuel burn rates for those vessels that indicated they ballast solely for compensating for fuel burn off. This rate, shown in Table 2-2, represents the minimum ballasting rate required to maintain vessels at a steady draft or trim. These rates range from approximately 0.3 to 3.4 gpm for research vessels, and from approximately 3.4 to 18.3 gpm for utility (towing) vessels. These values are based on fuel consumption estimates provided by vessel operators, and have been adjusted to reflect an assumed specific gravity of 0.82 for fuel oil. In general, fuel burn rates are one to two orders of magnitude lower than ballast pump rates.

2.3 Capacity of Onboard PWGs

To determine if commercially available PWGs can provide enough water for ballasting, EPA researched and contacted PWG vendors and used publicly available data sources. Table 2-3 summarizes the number of PWG vendors and systems available by the range of water production rating (in gpm). The information provided in Table 2-3 indicates that most PWGs are designed to generate potable water in the 0 to 30 gpm range. Above 30 gpm, the number of system options are reduced. The largest PWG on the market was designed to handle generation rates up to about 400 gpm.

Information on PWGs, their sizes, and their potable water generation rates are included in Section 3.

Table 2-2. Summary of Gathered Vessel Data and Ballasting Rates

Vessel Name/Class	Vessel Information					Vessel Ballast Data		
	Length (ft)	Breadth (ft)	Gross Tonnage	Gross Registered Tonnage	Detailed Drawings? (Y/N)	Ballast Pump Rating (gpm)	Fuel Burn Rate (gpm)	Ballasting Notes
Research Vessels								
NSF UNOLS Pelican (Geared Diesel Engine)	116	27	--	261	Y	200	0.3	Based on fuel burn rate of 0.4 gpm and fuel SG of 0.82.
NSF UNOLS Savannah (Geared Diesel Engine)	92	27	265	--	Y	170	0.3	Assume similar fuel burn rate as the *Pelican*.
NOAA FSV Class Vessels[1] (Diesel Electric Engine)	209	49	2,218	--	Y	176 or 353	1.4	Based on fuel burn rate of 1.8 gpm and fuel SG of 0.82.
NOAA T-AGOS Class Vessels[2] (Diesel Electric Engine)	224	43	1,914	--	Y	175	1.5	Based on fuel burn rate of 1.9 gpm and fuel SG of 0.82.
NSF UNOLS Endeavor	176	40	292	--	N	140 to 150	2.9 to 3.4	Based on fuel burn rate of 3.5 to 4.2 gpm and fuel SG of 0.82.
EPA Bold	224	20	1,914	--	N	155 to 175	--	3,000 gal, intermittently.
EPA GLNPO Lake Guardian	180	40	299	--	N	--	--	Ballast discharges kept to a minimum; use fuel and sewage as ballast.
NSF UNOLS Hugh R. Sharp	146	32	495	--	N	--	--	--
Utility Vessels								
AEP River Operations Towing Vessels	85 to 195	--	138 to 839	232 to 1,415	N	20 to 250	3.4 to 4.6	Based on fuel burn rate of 4.2 to 5.6 gpm and fuel SG of 0.82.
Sause Bros. Towing Vessels	96 to 143	--	82 to 199	139 to 280	N	250	3.4 to 18.3	Based on fuel burn rate of 4.2 to 22.3 gpm and fuel SG of 0.82.
Marquette Transportation Towing Vessels	52 to 200	--	50 to 1,103	--	N	--	--	--
Rowan EXL Jackup Rigs	--	--	--	--	Y	--	--	~83,000 gal per ballasting event.
Passenger Vessels								
NPS M/V Ranger III	150	34	648	--	N	180	--	Ballasts over short intervals, hence sizeable rating.
Seabourn Cruise Line (Cruise Vessels)	--	--	10,000 to 32,000	--	N	800	--	79,250 to 317,000 gal per voyage. Ballasts over short intervals.

Table 2-2. Summary of Gathered Vessel Data and Ballasting Rates

Vessel Name/Class	Vessel Information					Vessel Ballast Data		
	Length (ft)	Breadth (ft)	Gross Tonnage	Gross Registered Tonnage	Detailed Drawings? (Y/N)	Ballast Pump Rating (gpm)	Fuel Burn Rate (gpm)	Ballasting Notes
Training Vessels								
TS Golden Bear (Geared Diesel Engine)	466	72	13,574	--	Y	350 to 550	--	53,800 to 80,700 gal every few weeks.

Sources: ABS, 2014a; LUMCON, no date; NOAA, no date a and b; SIO, 2013; USEPA, 2009 and 2013b.
SG – Specific gravity
[1] Based on vessel information for the *Henry B. Bigelow*.
[2] Based on vessel information for the *McArthur II*.

Table 2-3. Summary of Available PWGs Aggregated by Water Production Capacity

Water Production Rating	No. of Vendors[1]	No. of Vendor Systems[2]
<10 gpm	13	144
10 to 20 gpm	11	30
20 to 30 gpm	7	12
30 to 40 gpm	3	5
40 to 50 gpm	2	3
50 to 60 gpm	3	3
60 to 70 gpm	1	1
70 to 80 gpm	3	3
80 to 90 gpm	0	0
90 to 100 gpm	2	2
>100 gpm	3	7
>200 gpm	1	2
>300 gpm	1	1

[1] EPA identified a total of 13 PWG vendors. This table double counts vendors offering multiple PWGs with different ratings.
[2] EPA identified a total of 213 vendor systems.

2.4 VESSELS FOR WHICH PWGS ARE POSSIBLE FOR BALLAST WATER REPLACEMENT

A comparison of large vessel ballasting rates to potable water generation rates indicates that it is impractical to generate potable water at rates high enough to compensate for large, rapid changes in displacement, such as those seen in cargo operations of many larger ship types. A small oil tanker has ballast discharge rates of tens of thousands of gallons per minute. Bulk carriers have ballast discharge rates of several hundred to over a thousand tons per hour. Small container ships that unloaded at the rate of 20 to 30 (or more) containers per hour require ballasting rates of between 800 to 1,200 gpm, assuming an average container weighs approximately 20,000 pounds and they are not able to internally ballast.[4] PWG use by any of these vessel types likely would not be feasible due to needed pumping rates.

For small vessels, comparing the ballast pump rates (Table 2-2) to possible PWG production rates (Table 2-3) indicates that using PWGs as an all-purpose source of ballast water (e.g., when loading and unloading cargo or fighting fires) may not be feasible. Overall, the ballast pump rates in Table 2-2 show that these vessels take on hundreds of gallons of water per minute. Of the 213 PWGs listed in Table 2-3, only 10 systems (5 percent) could meet ballast water demands at this order of magnitude. The size of these 10 PWGs likely would preclude them from being feasible for small vessels. However, it would be more realistic for vessels to maintain draft or trim using PWGs with production capacities comparable to their fuel burn rates. EPA has analyzed PWG feasibility using fuel burn rates for vessels for the following reasons:

- Ballast water pumps also serve as firemain pumps, with firefighting capacity driving pump design requirements.
- Steady-state filling represents a best-case scenario. If the analysis is not successful under this condition, it is reasonable to conclude that it would not be able to meet the surges in demand associated with non-steady-state scenarios.
- While steady-state filling of ballast tanks is not typical, EPA believes vessel stability concerns can be managed using the steady-state generation rates of PWGs.

Based on this initial analysis of ballasting rates versus PWG rates, using PWGs to generate onboard ballast water would appear to be limited primarily to smaller vessel types to maintain draft or trim or to compensate for fuel burn unless those vessels also use other ballasting management strategies (e.g., internal ballasting or using public water supply water) to complement use of PWGs. Therefore, the remainder of this report focuses on the feasibility of using PWG’s to generate onboard ballast water for smaller commercial vessels.

[4] Containers typically are 20 or 40 ft long, with a height and width of just under 8 ft (WSC, 2014).

SECTION 3
PWG AND DISINFECTION TECHNOLOGIES APPLICABLE TO VESSELS

As discussed in Section 1, this report evaluates the feasibility of using onboard PWGs to meet vessel ballasting requirements. Vessel generation of potable water requires both purification of the water source and subsequent disinfection to remove harmful microorganisms to ensure the water is safe for human consumption. As a result, the onboard PWGs considered in this report represent a composite of two primary subsystems: the PWG and the disinfection system. Together, these two subsystems would generate potable water that would be supplied directly to vessel ballast or potable water storage tanks. The following section provides an overview of PWG and disinfection technologies, including their technical specifications and associated capital and operating and maintenance (O&M) costs.

PWGs use either vacuum distillation or reverse osmosis (RO) technologies to draw fresh, brackish, or salt water into the PWG for purification. The treated water is then typically passed through disinfection systems to remove microorganisms (MCA, 1999). Operational factors that can impact the efficiency of PWGs include inlet water temperatures and contamination (e.g., hydrocarbons can foul RO filter membranes).

Vacuum distillation systems use heat and low pressure to purify fresh or seawater. The heat source used for this process is waste heat produced by the vessel's main engine. This waste heat is delivered to the distiller through the main engine's cooling water and has a typical temperature of about 65°C. Because the distiller operates under vacuum, the boiling point of water is reduced to less than 45°C. In this manner, approximately half of the seawater fed into the distiller is converted into distilled water (McGeorge, 1995).

RO systems use semipermeable membranes to physically separate dissolved solids from water. These membranes have pore sizes that range from approximately 0.2 to 1 nanometers (nm) (KMS, 2012). A pump continually forces feedwater (i.e., fresh, brackish, or salt water) against the semipermeable membrane; dissolved salts in the feedwater are too large to pass through the pores and are continually rejected from the system as a brine discharge, while the treated water passes through the membrane (McGeorge, 1995).

Product water from distillation and RO processes typically are passed through disinfection systems to remove harmful microorganisms that would make the water unsafe for human consumption. Typical technologies used for water disinfection include chlorination/bromination, electro-katadyn, and ultraviolet (UV) technologies. Chlorination, bromination, and electro-katadyn disinfection systems are installed between the PWG and the potable water storage tank(s). UV disinfection systems, on the other hand, are installed downstream of storage tank(s) (McGeorge, 1995).

Chlorination and bromination disinfection systems deliver a fixed amount of chlorine or bromine to kill microorganisms. Chlorine is supplied as calcium hypochlorite powders or pellets, as a sodium hypochlorite solution, or as a gas that is generated onboard through electrolysis of sodium chloride solutions. In systems using dry powders or pellets, the chlorine is dropped directly into a water tank. Systems using hypochlorite solutions or chlorine gas dose chlorine continuously through a metering pump.

The electro-katadyn process is used as an alternative method for disinfecting water. In this method, silver ions, which are toxic to bacteria, are dissolved into water as it passes through a chamber containing a silver anode. The amount of silver released from the anode and into the water is governed by the intensity of the current passing through the silver anode.

UV sterilizers use ultraviolet radiation to eliminate microorganisms present in water. These units are typically positioned as close to tap supply points as possible (McGeorge, 1995). UV sterilizers are most effective when treating water with a higher UV transmittance such as treated water. This is because any suspended solids present in the water can block UV light. The reduced UV dose resulting from the presence of suspended solids would mean that more microorganisms could pass through the sterilizer without being neutralized or inactivated.

3.1 OVERVIEW OF TECHNICAL SPECIFICATIONS FOR PWG AND DISINFECTION SYSTEMS

The information presented in this section is based on EPA's review of vendor literature. EPA identified these vendors through general internet searches for PWG and disinfection systems and through searches of marine supply websites, as guided by previous EPA efforts supporting the ballast water best available technology analysis for small vessels (USEPA, 2012). From the vendor websites, EPA collected technical data about vendor systems, including their dimensions, weight, and power requirements. This information is provided in Attachment A.

In addition to reviewing vendor literature, EPA contacted several vendors directly for supplemental information about their systems and to discuss the feasibility and availability of PWG and disinfection systems. Attachment B summarizes the information gathered from those conversations.

3.1.1 Summary of Available PWGs

EPA identified 13 vendors offering a total of 213 unique PWG systems. Of this total, 4 vendors offered 35 distillation systems while the remaining vendors offered 178 RO systems. Only one vendor provided both distillation and RO systems (this particular vendor provided ten distillation systems and six RO systems). Based on these observations, there appears to be a greater availability of PWG vendors and vendor systems utilizing RO technologies than distillation-based PWGs.

Table 3-2 summarizes the technical specifications associated with each of the PWGs identified by EPA. The data are aggregated by PWG technology (i.e., distillation or RO) and by water production rate, in gpm. Overall, the table shows water production rates spanning from <10 gpm up to 400 gpm. Of the PWGs identified by EPA, the greatest production rates are associated with RO systems, with rates ranging from <10 gpm up to 400 gpm. Distillation systems provide rates that are an order of magnitude lower (<10 gpm up to 20 gpm).

In comparing RO and distillation system dimensions, there does not appear to be a significant difference when comparing similarly rated systems. However, distillation systems tend to be heavier than RO systems. For example, the 10- to 20-gpm distillation systems in Table

3-2 weigh 2,006 to 18,000 lb; however, similarly rated RO systems weigh only 1,350 to 10,200 lb.

Power requirements represent a second distinguishing feature between the two PWG technologies. As mentioned previously, distillation systems must recover heat from vessel engines. These systems also use electrical power, but only to the extent needed to run ancillary distillation equipment. Heat input requirements for the distillation systems in Table 3-2 range from 75,000 to 7,165,000 British thermal units per hour (BTU/hr), while electrical requirements range from 0.6 to 1.6 kilowatts (kW). RO systems, on the other hand, rely solely on electricity and therefore have significantly greater electrical power requirements than their distillation-based counterparts. Comparing 10- to 20-gpm systems, Table 3-2 shows that distillation-based PWGs consume 1.6 kW while similarly rated RO systems consume 15.3 to 40 kW.

3.1.2 Summary of Available Disinfection Systems

EPA identified 10 vendors offering a total of 99 unique disinfection systems. These systems are sold independently of PWGs and use one of four disinfection technologies: bromination, chlorination, electro-katadyn, or UV. Table 3-1 lists the number of vendors and vendor systems for each of the four technologies. Based on Table 3-1, there appears to be greater availability of chlorination and UV systems than of bromination and electro-katadyn systems.

Table 3-1. Summary of Disinfection Systems Aggregated by Disinfection Technology

Disinfection System Technology	No. of Vendors[1]	No. of Vendor Systems
Bromination	1	8
Chlorination	5	21
Electro-Katadyn	2	6
UV	6	64
Total	*14*	*99*

[1] EPA identified a total of 10 vendors. This table double counts vendors offering more than one technology.

Table 3-3 summarizes the technical specifications associated with each of the disinfection systems identified by EPA. The data are aggregated by disinfection technology and by disinfection rate, in gpm. It is important to note that disinfection rates in Table 3-3 represent the maximum flow rate that a given disinfection system can accommodate when installed alongside a PWG as a turnkey system. In this regard, the systems listed in Table 3-3 represent only those turnkey systems identified by EPA. Disinfection systems can also be independently built from individual components. For example, a marine engineer could design and assemble a chlorination system from separately purchased components (i.e., metering pumps and hypochlorite solution storage tanks). However, to simplify the assumptions for this feasibility study, EPA excluded individual disinfection system components from the scope of the vendor system reviews.

Overall, Table 3-3 shows disinfection rates ranging from <10 gpm to 158,500 gpm. Of the systems identified by EPA, the greatest rates are associated with chlorine- and UV-based systems (900 to 158,500 gpm and <10 to 6,000 gpm, respectively). Electro-katadyn and bromination systems represent the lower end of the spectrum (30 to 300 gpm and <10 to 40 gpm, respectively). Compared to PWG water production rates, chlorine- and UV-based systems are capable of meeting and exceeding the rates in Table 3-2 (i.e., <10 gpm to 400 gpm). Vessels using bromination and UV systems would need to install multiple units operating in parallel to achieve the upper-end PWG production rates (i.e., 70 to 400 gpm).

In terms of overall dimensions and weights, disinfection systems are significantly smaller and lighter than PWGs. Disinfection systems also have significantly lower electrical power requirements than PWGs. Overall requirements for disinfection systems range from 0.04 to 3.3 kW, compared to 0.6 to 180 kW for PWGs. While EPA did not identify data for specific bromination system power requirements, for the purposes of this analysis, the Agency expects their power requirements to be comparable to chlorination systems, given that these two technologies operate similarly (i.e., continuous, metered dispensation of a dilute chemical solution into the PWG water product stream). Based on these observations, disinfection system overall dimensions, weights, and power requirements are not expected to be a significant factor in feasibility considerations.

In comparing disinfection systems, the overall dimensions of each system in Table 3-3 do not differ significantly, although it appears that chlorination systems tend to require the most space while electro-katadyn systems tend to be the most compact. Of the disinfection systems in Table 3-3, UV systems require the most power (0.03 to 3.3 kW) as compared to the other three system types (0.04 kW).

A key distinction among disinfection system technologies pertains to the types of consumables associated with each. Bromination systems use consumable cartridges that contain bromine and have an expected life of 55,000 gal per cartridge. Electro-katadyn systems use silver anodes that must be replaced approximately every 1,060,000 gal. UV systems use UV lamps that must be replaced every 9,000 hours. Chlorination systems typically dispense chlorine from a solution tank containing a dilute solution of sodium hypochlorite. The frequency of solution replenishment depends on both the concentration of the sodium hypochlorite solution and the desired chlorine dose. For this reason, Table 3-3 does not include the expected life of chlorination system consumables.

Table 3-2. Summary of Technical Specifications for PWGs

Water Production Rate	No. of Vendors	No. of Vendor Systems	System Dimensions (ft) Height		Width		Depth		System Cubic Volume (ft^3)		Weight (lb)		Electrical Requirement (kW)		Heat Input Requirement (BTU/hr)	
			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Distillation																
<10 gpm	4	29	1.9	9.6	0.9	9.7	1.7	10.5	2.9	671.6	125	15,000	0.6	6.5	75,000	5,971,000
10 to 20 gpm	3	6	4.5	9.6	2.8	9.7	7.1	10.5	90.0	671.6	2,006	18,000	1.6	1.6	5,800,000	7,165,000
Reverse Osmosis																
<10 gpm	10	115	1.0	13.3	1.7	13.2	1.2	6.2	2.3	450.7	80	6,544	1.5	30.5	N/A	N/A
10 to 20 gpm	8	24	1.8	16.3	3.5	13.2	2.7	10.3	17.1	900.0	1,350	10,234	15.3	40	N/A	N/A
20 to 30 gpm	7	12	2.6	19.3	6.0	19.0	2.7	8.2	114.8	1,253.8	1,550	6,520	28	48	N/A	N/A
30 to 40 gpm	3	5	5.5	23.3	5.0	13.2	6.0	6.7	450.7	840.0	5,400	6,800	49	49	N/A	N/A
40 to 50 gpm	2	3	6.0	23.3	6.0	14.0	2.7	6.7	224.0	933.3	2,400	12,000	-	-	N/A	N/A
50 to 60 gpm	3	3	7.4	19.6	5.0	18.6	2.7	9.5	276.9	1,361.7	3,200	7,160	100	100	N/A	N/A
60 to 70 gpm	1	1	23.3	23.3	6.0	6.0	6.7	6.7	933.3	933.3	13,000	13,000	-	-	N/A	N/A
70 to 80 gpm	3	3	7.4	29.2	6.0	14.0	2.7	7.3	276.9	1,166.7	3,200	14,000	140	140	N/A	N/A
90 to 100 gpm	2	2	7.4	23.3	6.0	14.0	2.7	6.7	276.9	933.3	3,500	15,000	-	-	N/A	N/A
100 to 200 gpm	3	7	7.4	29.2	6.0	25.8	6.0	7.5	1,149.6	1,666.7	5,900	19,000	180	180	N/A	N/A
200 to 300 gpm	1	2	29.2	29.2	7.1	7.1	6.7	6.7	1,377.3	1,377.3	21,000	21,000	-	-	N/A	N/A
300 to 400 gpm	1	1	29.2	29.2	7.1	7.1	6.8	6.8	1,394.5	1,394.5	22,000	22,000	-	-	N/A	N/A

N/A – Not applicable

Table 3-3. Summary of Technical Specifications of Disinfection Systems

Water Disinfection Rate	No. of Vendors	No. of Vendor Systems	System Dimensions (ft) Height Min	Height Max	Width Min	Width Max	Depth Min	Depth Max	System Cubic Volume (ft^3) Min	Max	System Weight (lb) Min	Max	Electrical Requirement (kW) Min	Max	Expected Life of System Consumables (gal/cartridge)	(hr/lamp)	(gal/anode)
Bromination																	
<10 gpm	1	1	-	-	-	-	-	-	-	-	30	30	-	-	55,000	N/A	N/A
10 to 20 gpm	1	5	3.7	3.7	1.2	1.2	1.7	1.7	7.2	7.2	141	141	-	-	55,000	N/A	N/A
20 to 30 gpm	1	1	2.3	2.3	2.0	2.0	0.7	0.7	3.1	3.1	45	45	-	-	55,000	N/A	N/A
30 to 40 gpm	1	1	2.3	2.3	3.1	3.1	1.3	1.3	8.7	8.7	44	44	-	-	55,000	N/A	N/A
Chlorination																	
900 to 1,000 gpm	1	3	1.6	3.1	1.7	1.7	1.7	1.7	4.8	9.1	18	35	-	-	-	-	-
2,000 to 3,000 gpm	2	4	3.1	3.1	1.7	1.7	1.7	1.7	4.8	9.1	22	35	0.04	0.04	-	-	-
3,000 to 4,000 gpm	1	3	2.3	2.3	1.7	1.7	1.7	1.7	2.3	6.3	40	40	-	-	-	-	-
15,000 gpm	1	3	2.3	2.3	1.7	1.7	2.0	2.0	3.3	7.6	28	28	-	-	-	-	-
42,000 gpm	1	1	2.9	2.9	3.3	3.3	2.0	2.0	19.3	19.3	60	70	-	-	-	-	-
158,500 gpm	1	1	2.9	2.9	3.3	3.3	2.0	2.0	19.3	19.3	60	70	-	-	-	-	-
Electro-Katadyn																	
30 to 40 gpm	1	1	1.6	1.6	0.2	0.2	0.2	0.2	0.1	0.1	19	19	0.04	0.04	N/A	N/A	1,056,688
60 to 70 gpm	1	1	-	-	-	-	-	-	-	-	-	-	-	-	N/A	N/A	-
70 to 80 gpm	1	1	2.0	2.0	0.5	0.5	0.5	0.5	0.4	0.4	42	42	0.04	0.04	N/A	N/A	1,056,688
100 to 200 gpm	1	2	2.0	2.0	0.5	0.5	0.5	0.5	0.4	0.4	43	43	0.04	0.04	N/A	N/A	1,056,688
200 to 300 gpm	1	1	2.0	2.0	0.5	0.5	0.5	0.5	0.4	0.4	45	45	0.04	0.04	N/A	N/A	1,056,688
Ultraviolet																	
<10 gpm	3	4	3.1	3.1	0.7	0.7	0.7	0.7	1.6	1.6	4	33	0.03	0.09	N/A	9,000	N/A
10 to 20 gpm	3	5	1.8	3.2	0.7	1.4	0.5	0.7	1.3	1.6	23	23	0.03	0.08	N/A	-	N/A
20 to 30 gpm	4	5	2.7	3.2	0.8	1.6	0.7	1.0	1.8	4.4	53	53	0.08	0.48	N/A	9,000	N/A
30 to 40 gpm	3	3	3.2	3.2	0.8	0.8	0.7	0.7	1.8	1.8	-	-	0.12	0.13	N/A	-	N/A
40 to 50 gpm	1	1	2.7	2.7	1.6	1.6	1.0	1.0	4.4	4.4	55	55	0.18	0.18	N/A	9,000	N/A
50 to 60 gpm	1	1	-	-	-	-	-	-	-	-	-	-	-	-	N/A	-	N/A

Table 3-3. Summary of Technical Specifications of Disinfection Systems

Water Disinfection Rate	No. of Vendors	No. of Vendor Systems	System Dimensions (ft)						System Cubic Volume (ft^3)		System Weight (lb)		Electrical Requirement (kW)		Expected Life of System Consumables		
			Height		Width		Depth										
			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	(gal/cartridge)	(hr/lamp)	(gal/anode)
60 to 70 gpm	3	3	-	-	-	-	-	-	-	-	-	-	0.16	0.16	N/A	-	N/A
70 to 80 gpm	1	1	4.1	4.1	1.2	1.2	1.0	1.0	4.8	4.8	-	-	0.20	0.20	N/A	-	N/A
80 to 90 gpm	1	1	-	-	-	-	-	-	-	-	-	-	0.20	0.20	N/A	-	N/A
100 to 200 gpm	2	5	-	-	-	-	-	-	-	-	55	55	0.29	0.40	N/A		N/A
200 to 300 gpm	1	2	-	-	-	-	-	-	-	-	-	-	0.48	0.60	N/A	-	N/A
300 to 400 gpm	1	3	-	-	-	-	-	-	-	-	-	-	0.64	0.75	N/A	-	N/A
400 to 500 gpm	1	1	-	-	-	-	-	-	-	-	-	-	0.90	0.90	N/A	-	N/A
500 to 600 gpm	1	2	-	-	-	-	-	-	-	-	-	-	0.80	0.80	N/A	-	N/A
600 to 700 gpm	1	1	-	-	-	-	-	-	-	-	-	-	1.20	1.20	N/A	-	N/A
700 to 800 gpm	1	1	-	-	-	-	-	-	-	-	-	-	-	-	N/A	-	N/A
800 to 900 gpm	1	1	-	-	-	-	-	-	-	-	-	-	0.96	0.96	N/A	-	N/A
900 to 1,000 gpm	1	1	-	-	-	-	-	-	-	-	-	-	1.50	1.50	N/A	-	N/A
1,000 to 2,000 gpm	1	6	-	-	-	-	-	-	-	-	-	-	1.20	2.25	N/A	-	N/A
2,000 to 3,000 gpm	1	3	-	-	-	-	-	-	-	-	-	-	2.70	3.30	N/A	-	N/A
3,000 to 4,000 gpm	1	1	-	-	-	-	-	-	-	-	-	-	-	-	N/A	-	N/A
5,000 to 6,000 gpm	1	1	-	-	-	-	-	-	-	-	-	-	-	-	N/A	-	N/A

N/A – Not applicable

3.2 OVERVIEW OF PWG AND DISINFECTION SYSTEM COSTS

This section provides an overview of the capital and O&M costs associated with PWG and disinfection systems applicable to small vessels.

3.2.1 Capital Costs

The capital investment costs presented in this section include both direct and indirect capital costs. Direct capital costs (i.e., the costs associated with purchasing the equipment) are based on quotes provided directly by vendors. EPA assumes that vessel owners will contract out equipment installation. Therefore, indirect capital costs related to equipment installation, but which are not technology-specific, are included. Indirect costs are based on a cost factor analysis previously developed by EPA (USEPA, 2011a). Table 3-4 lists each of the component costs and cost factors included in the analysis and describes which specific costs are associated with each factor.

Table 3-4. Components of Technology Option Total Capital Investment

Item	Component	Cost Escalation	Description
1	Equipment capital costs	Direct capital cost	Direct capital cost obtained from technology option vendors.
2	Control systems	17.7% of Item 1	Costs for additional control systems, programmable logic controllers, software interface, sensors, and wiring that would be incorporated into vessels' existing control systems. The escalation rate is based on the Department of Defense (DOD) Military Construction (MILCON) estimating procedures (USDOD, 2001).
3	Space	$305/ft^2	Costs for potential compartment rearrangement, demolition, or retrofitting necessary to accommodate installation of new equipment (USEPA, 2011a).
4	Shipboard installation	27% of Items 1-3	Installation costs estimated for equipment, based on published, land-based construction data. This escalation factor accounts for the complexities associated with shipboard construction and installation (USEPA, 2011a).
5	Installed capital costs	Sum of Items 1-4	Sum of direct capital cost of equipment, plus costs associated with control system, space rearrangement, and shipboard installation.
6	Engineering	8% of Item 5	Engineering costs associated with administrative support, process design and general engineering, communications, consultant fees, legal fees, travel, supervision, and inspection of installed technology equipment (USEPA, 2011a).
7	Contractor overhead and profit	10% of Item 5	Costs incurred by the contractor to operate their business, such as general and administrative expenses, office rent, equipment purchase/rental, depreciation on office equipment, licenses, and advertising (USEPA, 2011a).
8	Classification/ certification	2% of Item 5	Costs for activities such as classification and certification services and on-site survey and construction monitoring. Classification services are used to verify that a vessel meets the safety and pollution prevention rules set forth by a specific classification society. Certification services are used to verify

Table 3-4. Components of Technology Option Total Capital Investment

Item	Component	Cost Escalation	Description
			that a vessel complies with various international codes such as the International Convention for the Prevention of Pollution from Ships (MARPOL) and the International Convention for the Safety of Life at Sea (SOLAS) (USEPA, 2011a).
9	Performance bonds	2.5% of Item 5	Costs for performance bonds, which are contracts guaranteeing performance and demonstrating that the contractor is reliable and able to carry out the construction project (USEPA, 2011a).
10	Scheduling	0.8% of Item 5	Cost to prepare construction progress documents, update Gantt charts, and develop monthly progress reports (USEPA, 2011a).
11	Insurance	2.3% of Item 5	Costs for insurance on the construction project, insurance on heavy equipment used during construction, and public liability for property damage or non-employee injury (USEPA, 2011a).
12	Contractor markup	10% of Item 5	Costs added by the contractor to the base price of materials for handling, procurement, subcontracting, and equipment costs (USEPA, 2011a).
13	Contingency	20% of Items 5-12	Costs that may result from incomplete design, unforeseen and unpredictable conditions, or the complexity and uncertainty involved, at a conceptual level, in estimating costs (USEPA, 2011a).

3.2.1.1 PWG Capital Costs

Table 3-5 provides total capital investment costs by PWG technology. Costs have been adjusted to account for installed capital costs (i.e., those associated with control systems, space, and shipboard installation) as well as the total indirect costs associated with equipment installation, as discussed in Section 3.2.1.

In comparing total capital costs between the distillation and RO PWG technologies, it appears that RO systems are less expensive than distillation systems. For example, the total capital investment cost associated with a 1.7-gpm distillation system is approximately $170,000. However, at just over half of this capacity, a 1-gpm RO system would cost only one quarter of the total capital investment cost (i.e., approximately $44,000). Based on these figures, a vessel owner would be able to install 4, 1-gpm RO systems (total capacity of 4 gpm) for approximately the same total capital investment cost as a single 1.7-gpm distillation system. This difference is not a result of cost escalation, as a comparison of direct capital costs reveals the same relationship.

Table 3-5. Total Capital Investment Costs by PWG Technology

System Technology	System Generation Capacity (gpm)	Direct Capital Cost	Installed Capital Cost	Total Indirect Capital Costs	Total Capital Investment Cost
Distillation	1.7	$40,000	$68,000	$103,000	$171,000
Distillation	5.0	$47,500	$80,000	$122,000	$202,000
Distillation	2.6	$100,000	$155,000	$236,000	$391,000
Reverse Osmosis	1.0	$11,000	$17,000	$26,000	$43,000
Reverse Osmosis	15.3	$37,000	$59,000	$90,000	$149,000
Reverse Osmosis	29.9	$152,845	$260,000	$395,000	$655,000

3.2.1.2 Disinfection System Capital Costs

Table 3-6 provides total capital investment costs by disinfection system technology. As in the previous section, costs have been adjusted to account for installed capital costs as well as total indirect costs associated with equipment installation.

In comparing capital costs among the four technologies (i.e., bromination, chlorination, electro-katadyn, and UV disinfection), there do not appear to be disparities in cost to the extent observed with PWGs. Based solely on the total capital investment cost, it appears that chlorination systems represent the least expensive disinfection technology. The total capital investment costs of chlorination systems are one order of magnitude lower than those of the other three technologies; in addition, their disinfection capacities are greater than those of the other three technologies by one to two orders of magnitude. Based on these observations, it appears that chlorination systems are the least expensive of the four technologies, particularly for vessels requiring significant ballasting volumes.

Table 3-6. Total Capital Investment Costs by Disinfection System Technology

System Technology	System Disinfection Capacity (gpm)[1]	Direct Capital Cost	Installed Capital Cost	Total Indirect Capital Costs	Total Capital Investment Cost
Bromination	19	$13,278	$21,000	$31,000	$52,000
Bromination	35	$6,577	$11,000	$17,000	$28,000
Chlorination	917	$712	$2,000	$3,000	$5,000
Chlorination	138	$765	$2,000	$3,000	$5,000
Electro-Katadyn	66	$4,300	$7,000	$10,000	$17,000
Ultraviolet	6	$2,550	$4,000	$6,000	$10,000
Ultraviolet	31	$3,550	$6,000	$9,000	$15,000

[1] These values represent the maximum water flow rate that a given system can disinfect. They are not a measure of output from the unit itself.

3.2.2 O&M Costs

O&M costs comprise all costs related to operating and maintaining PWG and disinfection systems and components. In this analysis, O&M costs specifically include:

- PWG maintenance (e.g., descaling distillation systems or cleaning and replacing RO filter membranes).
- Replacing disinfection system consumables.
- Electricity costs.

PWG maintenance and disinfection system consumables costs are based on estimates provided by vendors. Electricity costs are based on technology-specific power requirements and an assumed unit cost of electricity of $0.08/kWh (USEPA, 2011a).

3.2.2.1 PWG O&M Costs

Table 3-7 summarizes the O&M costs associated with powering and maintaining distillation- and RO-based PWGs. The electricity costs in Table 3-7 assume continuous system operation over a 24-hour period. This analysis also assumes no operating costs are incurred from distillation system heat input requirements, since the heat is recovered in a manner that is coincidental to the continuous operation of vessel engines. EPA received annual maintenance costs ranging between 2 and 3 percent of direct capital costs from vendors. The costs in Table 3-7 assume a maintenance cost of 3 percent. Since ballasting volumes over the course of a year vary significantly by vessel type, function, and length of operating season, EPA normalized the vendor estimates over 365 days per year to establish maintenance costs in terms of dollars per day.

For distillation-based PWGs, Table 3-7 suggests that overall daily maintenance costs are similar, although the cost data are limited to a narrow range of 1.7 to 5 gpm. Electricity costs for distillation-based PWGs are attributed solely to its ancillary systems, such as feedwater and distillate pumps. The electricity costs for the distillation systems are inconclusive, as the table suggests that a 5-gpm system would incur smaller electricity costs than a 1.7-gpm system. For RO-based PWGs, system maintenance costs increase with system capacity, as do electricity costs. Given that RO systems have greater electrical requirements than distillation systems, EPA expects that RO systems will incur the greatest electricity costs overall. Based on these observations, it appears that O&M costs for RO-based PWGs are greater than those for distillation-based systems, particularly for vessels requiring significant ballasting volumes.

Table 3-7. Total O&M Cost by PWG Technology[1]

Technology	System Capacity (gpm)	Electrical Requirement (kW)	Direct Capital Cost ($)	System Maintenance Cost ($/day)[2]	Electricity ($/day)	Total O&M Cost ($/day)
Distillation	1.7	6.5	40,000	3.29	12.48	15.77
Distillation	5	1.6	47,500	3.90	3.07	6.98
Reverse Osmosis	1	2.4	11,000	0.90	4.59	5.50
Reverse Osmosis	15	15.3	37,000	3.04	29.3	32.34
Reverse Osmosis	30	30.5	153,000	12.56	58.62	71.18

[1] Assumes continuous operation over 24 hours per day.
[2] Daily system maintenance cost based on 3% of direct capital cost, normalized over 365 days per year.

3.2.2.2 Disinfection System O&M Costs

Table 3-8 summarizes the O&M costs associated with powering and replacing consumables for each type of disinfection system. Since ballasting volumes over the course of a year vary significantly by vessel type, function, and length of operating season, EPA estimated O&M costs solely in terms of dollars per day, and assumed continuous system operation over the entire day.

Overall, Table 3-8 shows that O&M costs are driven by the type of disinfection system that would be used onboard vessels. The daily O&M cost of a given system is largely determined by the cost and frequency of consumables replacement and not by daily electricity costs. Based on conversations with vendors, EPA determined that bromination and electro-katadyn systems require cartridge/anode replacements approximately every 55,000 and 1,057,000 gal, respectively (Everpure, LLC, no date and Aquafides, no date). UV lamps, on the other hand, require replacement every 9,000 hours (DOE, no date). Chlorination system replacement/replenishment rates will depend on the strength of the solution used to disinfect water. Electrical requirements will depend on the capacity of a given system; however, based on Table 3-8, there does not appear to be a significant difference in electrical costs when comparing systems of various capacities.

Based solely on total O&M costs, it appears that ultraviolet-based disinfection systems are the most economically feasible of the four technologies. Chlorination-based disinfection systems appear to be the second most economically feasible option, and have the greatest overall disinfection capacities of all systems listed. Given this observation, it appears that both UV- and chlorination-based disinfection systems would be best suited for vessels with large ballasting requirements.

Table 3-8. Total O&M Cost by Disinfection System Technology[1]

Disinfection Technology	System Disinfection Capacity (gpm)	Electrical Requirement (kW)	Electrical Cost ($/day)	System-Specific Consumables Costs[2]: Bromine Cartridges ($/day)	Sodium Hypochlorite Solution[3] ($/day)	UV Lamps ($/day)	Silver Anodes ($/day)	Total O&M Cost ($/day)
Bromination	19	0.04	0.08	53.73	N/A	N/A	N/A	53.80
Bromination	35	0.04	0.08	98.97	N/A	N/A	N/A	99.04
Chlorination	138	0.04	0.08	N/A	79.20	N/A	N/A	79.28
Chlorination	917	0.04	0.08	N/A	528.00	N/A	N/A	528.08
Electro-Katadyn	66	0.04	0.08	N/A	N/A	N/A	88.20	88.28
Ultraviolet	6	0.04	0.07	N/A	N/A	0.52	N/A	0.59
Ultraviolet	31	0.12	0.23	N/A	N/A	0.52	N/A	0.75

N/A – Not applicable
[1] Assumes 24-hour-per-day operation of each system at the listed system capacity.
[2] Assumes the following costs based on estimates provided by vendors: $108/cartridge (bromination), $24/gal solution (chlorination), $980/anode (electro-katadyn), and $195/lamp (ultraviolet).
[3] Assumes chlorine dosing at 2 parts per million (ppm) using a 12% sodium hypochlorite solution.

3.2.3 Combined Costs for PWG and Disinfection Systems

Table 3-9 summarizes the capital costs associated with each combined PWG-disinfection system. The figures represent the sum of Table 3-5 and Table 3-6 values (capital costs for individual PWG and disinfection systems, respectively). Overall, PWGs utilizing RO technologies are significantly less expensive than distillation systems. For example, the direct capital cost of a 15-gpm RO PWG is $37,000. At approximately the same cost ($40,000), a distillation PWG has a capacity of only 1.7 gpm. For disinfection systems, chlorine-based systems have the lowest capital costs overall, while bromine-based systems have the greatest capital costs.

For a given PWG technology (i.e., distillation or RO), the total capital investment cost is a function of the system's production capacity. However, the type of disinfection system used in conjunction with the PWG is also a major driver. This is most apparent when comparing costs for a given PWG. For example, the total capital investment cost of a 15-gpm RO PWG ranges from approximately $154,000 to $200,000. This differential is directly attributed to the greater direct capital cost of bromine-based systems over that of the other three types (i.e., chlorine-, electro-katadyn-, and ultraviolet-based systems).

Table 3-10 summarizes the O&M costs associated with each combined PWG-disinfection system, as gathered from correspondence from system vendors. The figures represent the sum of Table 3-7 and Table 3-8 values (O&M costs for individual PWG and disinfection systems, respectively). Looking solely at the PWG component, O&M costs are proportional to production capacity. Similar to what was observed with capital costs, the type of disinfection system drives total O&M costs for a given PWG. Of the four disinfection technologies, ultraviolet- and chlorine-based systems are the least expensive, while bromine tends to be the most expensive. The cost differential is largely due to consumables costs, as the combined electrical and system maintenance costs are relatively consistent among all four disinfection technologies.

Table 3-9. Total Capital Investment Cost for PWG and Disinfection Systems Combined

PWG Capacity (gpm)	DS Technology	DS Capacity (gpm)	Direct Capital Cost ($)			Installed Capital Cost ($)			Total Indirect Capital Cost ($)			Total Capital Investment Cost ($)		
			PWG	DS	Both	PWG	DS	Both	PWG	DS	Both	PWG	DS	Both
Distillation														
1.7	Bromination	19	40,000	13,278	53,278	68,000	21,000	89,000	103,000	31,000	134,000	171,000	52,000	223,000
	Bromination	35	40,000	6,577	46,577	68,000	11,000	79,000	103,000	17,000	120,000	171,000	28,000	199,000
	Chlorination	917	40,000	712	40,712	68,000	2,000	70,000	103,000	3,000	106,000	171,000	5,000	176,000
	Chlorination	138	40,000	765	40,765	68,000	2,000	70,000	103,000	3,000	106,000	171,000	5,000	176,000
	Electro-Katadyn	66	40,000	4,300	44,300	68,000	7,000	75,000	103,000	10,000	113,000	171,000	17,000	188,000
	Ultraviolet	6	40,000	2,550	42,550	68,000	4,000	72,000	103,000	6,000	109,000	171,000	10,000	181,000
	Ultraviolet	31	40,000	3,550	43,550	68,000	6,000	74,000	103,000	9,000	112,000	171,000	15,000	186,000
5	Bromination	19	47,500	13,278	60,778	80,000	21,000	101,000	122,000	31,000	153,000	202,000	52,000	254,000
	Bromination	35	47,500	6,577	54,077	80,000	11,000	91,000	122,000	17,000	139,000	202,000	28,000	230,000
	Chlorination	917	47,500	712	48,212	80,000	2,000	82,000	122,000	3,000	125,000	202,000	5,000	207,000
	Chlorination	138	47,500	765	48,265	80,000	2,000	82,000	122,000	3,000	125,000	202,000	5,000	207,000
	Electro-Katadyn	66	47,500	4,300	51,800	80,000	7,000	87,000	122,000	10,000	132,000	202,000	17,000	219,000
	Ultraviolet	6	47,500	2,550	50,050	80,000	4,000	84,000	122,000	6,000	128,000	202,000	10,000	212,000
	Ultraviolet	31	47,500	3,550	51,050	80,000	6,000	86,000	122,000	9,000	131,000	202,000	15,000	217,000
Reverse Osmosis														
1	Bromination	19	11,000	13,278	24,278	17,000	21,000	38,000	26,000	31,000	57,000	43,000	52,000	95,000
	Bromination	35	11,000	6,577	17,577	17,000	11,000	28,000	26,000	17,000	43,000	43,000	28,000	71,000
	Chlorination	917	11,000	712	11,712	17,000	2,000	19,000	26,000	3,000	29,000	43,000	5,000	48,000
	Chlorination	138	11,000	765	11,765	17,000	2,000	19,000	26,000	3,000	29,000	43,000	5,000	48,000
	Electro-Katadyn	66	11,000	4,300	15,300	17,000	7,000	24,000	26,000	10,000	36,000	43,000	17,000	60,000
	Ultraviolet	6	11,000	2,550	13,550	17,000	4,000	21,000	26,000	6,000	32,000	43,000	10,000	53,000
	Ultraviolet	31	11,000	3,550	14,550	17,000	6,000	23,000	26,000	9,000	35,000	43,000	15,000	58,000
15	Bromination	19	37,000	13,278	50,278	59,000	21,000	80,000	90,000	31,000	121,000	149,000	52,000	201,000
	Bromination	35	37,000	6,577	43,577	59,000	11,000	70,000	90,000	17,000	107,000	149,000	28,000	177,000
	Chlorination	917	37,000	712	37,712	59,000	2,000	61,000	90,000	3,000	93,000	149,000	5,000	154,000
	Chlorination	138	37,000	765	37,765	59,000	2,000	61,000	90,000	3,000	93,000	149,000	5,000	154,000
	Electro-Katadyn	66	37,000	4,300	41,300	59,000	7,000	66,000	90,000	10,000	100,000	149,000	17,000	166,000
	Ultraviolet	31	37,000	3,550	40,550	59,000	6,000	65,000	90,000	9,000	99,000	149,000	15,000	164,000

Table 3-9. Total Capital Investment Cost for PWG and Disinfection Systems Combined

PWG Capacity (gpm)	DS Technology	DS Capacity (gpm)	Direct Capital Cost ($)			Installed Capital Cost ($)			Total Indirect Capital Cost ($)			Total Capital Investment Cost ($)		
			PWG	DS	Both	PWG	DS	Both	PWG	DS	Both	PWG	DS	Both
30	Bromination	35	152,845	6,577	159,422	260,000	11,000	271,000	395,000	17,000	412,000	655,000	28,000	683,000
	Chlorination	917	152,845	712	153,557	260,000	2,000	262,000	395,000	3,000	398,000	655,000	5,000	660,000
	Chlorination	138	152,845	765	153,610	260,000	2,000	262,000	395,000	3,000	398,000	655,000	5,000	660,000
	Electro-Katadyn	66	152,845	4,300	157,145	260,000	7,000	267,000	395,000	10,000	405,000	655,000	17,000	672,000
	Ultraviolet	31	152,845	3,550	156,395	260,000	6,000	266,000	395,000	9,000	404,000	655,000	15,000	670,000

DS – Disinfection System

Table 3-10. Total Daily and Annual O&M Cost for PWG and Disinfection Systems Combined

PWG Capacity (gpm)	DS Technology	DS Capacity (gpm)	PWG Electrical Cost ($/day)	DS Electrical Cost ($/day)	Combined Electrical Cost ($/day)	System Maintenance Cost ($/day)	Consumables Cost ($/day)	Total Daily O&M Cost ($/day)	Total Annual O&M Cost ($/year)
Distillation									
1.7	Bromination	19-35	12.48	0.08	12.56	3.29	4.81	20.66	7,500
	Chlorination	138-917	12.48	0.08	12.56	3.29	0.98	16.83	6,100
	Electro-Katadyn	66	12.48	0.08	12.56	3.29	2.27	18.12	6,600
	Ultraviolet	6.2	12.48	0.07	12.55	3.29	0.52	16.36	6,000
	Ultraviolet	31	12.48	0.23	12.71	3.29	0.52	16.52	6,000
5	Bromination	19-35	3.07	0.08	3.15	3.9	14.14	21.19	7,700
	Chlorination	138-917	3.07	0.08	3.15	3.9	2.88	9.93	3,600
	Electro-Katadyn	66	3.07	0.08	3.15	3.9	6.68	13.73	5,000
	Ultraviolet	6.2	3.07	0.07	3.14	3.9	0.52	7.56	2,800
	Ultraviolet	31	3.07	0.23	3.3	3.9	0.52	7.72	2,800
Reverse Osmosis									
1	Bromination	19-35	4.59	0.08	4.67	0.9	2.83	8.4	3,100
	Chlorination	138-917	4.59	0.08	4.67	0.9	0.58	6.15	2,200
	Electro-Katadyn	66	4.59	0.08	4.67	0.9	1.34	6.91	2,500
	Ultraviolet	6.2	4.59	0.07	4.66	0.9	0.52	6.08	2,200
	Ultraviolet	31	4.59	0.23	4.82	0.9	0.52	6.24	2,300
15	Bromination	19-35	29.3	0.08	29.38	3.04	42.42	74.84	27,300
	Chlorination	138-917	29.3	0.08	29.38	3.04	8.64	41.06	15,000
	Electro-Katadyn	66	29.3	0.08	29.38	3.04	20.05	52.47	19,200
	Ultraviolet	31	29.3	0.23	29.53	3.04	0.52	33.09	12,100
30	Bromination	29.9-35	58.62	0.08	58.7	12.56	84.84	156.1	57,000
	Chlorination	138-917	58.62	0.08	58.7	12.56	17.28	88.54	32,300
	Electro-Katadyn	66	58.62	0.08	58.7	12.56	40.09	111.35	40,600
	Ultraviolet	31	58.62	0.23	58.85	12.56	0.52	71.93	26,300

SECTION 4
FEASIBILITY OF DESIGN – CASE STUDIES

Section 4 presents an assessment of PWGs that are commercially available for vessel use and that could feasibly be used to generate potable water sufficient for ballasting. It assesses whether the equipment size, weight, and system operating/maintenance space requirements of these PWGs are suitable for use on smaller vessels, and considers vessel space and access limitations, piping considerations, impacts to vessel stability, and impacts to vessel energy usage. Because every vessel is ultimately unique in its machinery space design and equipment placement, a naval architect conducted a series of specific vessel case studies to analyze these design criteria and engineering considerations.

EPA requested vessel design and equipment drawings from vessel owners and operators, specifically for this study, and looked for drawings in published sources. Using these drawings, EPA conducted PWG retrofit analyses for one research vessel (the *R/V Pelican*), one inland river towboat (a 150-ft, U.S. Army Corps of Engineers (USACE) towboat), and a Fast Support Vessel (FSV) class vessel (the *Oscar Dyson*). These analyses are discussed in Sections 4.1 through 4.3. Section 4.4 provides an extrapolation analysis assessing PWG feasibility for small vessel classes in general.

4.1 RESEARCH VESSEL

This section provides a brief characterization of the *R/V Pelican* and its machinery arrangement, as well as an analysis of PWG retrofit requirements and impacts on space, stability, and PWG service connections. This vessel operates in the Mississippi River, Mississippi River Delta, and in coastal and open ocean waters.

4.1.1 Vessel Characteristics

The *R/V Pelican* is a research vessel operated by the Louisiana Universities Marine Consortium (LUMCON) and is used to perform a variety of oceanographic research functions. The vessel measures roughly 116 by 27 ft (length and beam, respectively) and has an internal volume of 261 GRT. The vessel is equipped with two diesel engines and a twin-screw propulsion system. Table 4-1 summarizes relevant vessel characteristics and mechanical systems.

Table 4-1. Summary of *R/V Pelican* Vessel Characteristics and Mechanical Systems

Vessel Characteristic	Dimension or Mechanical System Description
Length (overall)	116.3 ft
Beam	26.5 ft
Depth	12 ft
Draft (full load)	9.5 ft
Displacement	514.6 long tons
Gross registered tonnage	261

Table 4-1. Summary of *R/V Pelican* Vessel Characteristics and Mechanical Systems

Vessel Characteristic	Dimension or Mechanical System Description
Total persons aboard	21
Fresh water tank volume	6,231 gal
Ballast tank volume	15,656 gal (59 m^3)
Fuel tank volume	18,499 gal
Propellers	2 (twin-screw propulsion)
Propulsion system	2 geared, 3412 Caterpillar diesel engines
Power	850 horsepower (425 per engine)
Generators	2, 99-kilowatt diesel generators

Sources: ABS, 2014a; LUMCON, no date

Machinery Space

The *Pelican* has two adjacent machinery spaces, the main machinery space and the auxiliary machinery space (Figure 4-1). The main machinery space is located just aft of amidships. Vessel diagrams provided by LUMCON (ERG, personal communications, September 3, 2013) indicate that this room is 26 ft long and spans the breadth of the boat. The auxiliary machinery space is located immediately forward of the main machinery space, and has dimensions of 10 by 13.5 ft (length and breadth, respectively).

The machinery arrangement for both spaces (Figure 4-2) is in many ways representative of similarly sized and powered vessels of various types (e.g., fishing and small passenger vessels). The machinery space is somewhat larger than similar vessels in order to accommodate hydraulic power units required for its oceanographic mission.

The main machinery space contains the following major items, as shown in Figure 4-2:

- Two main engines (including their associated gear boxes).
- Two diesel generators.
- Fuel oil system (including pumps, filters, and manifold).
- Bilge system (including pumps and manifold).
- Ballast system (including ballast and fire pump and manifold).
- Air compressor (including air storage tanks).
- Electrical switchboard.
- Steering gear hydraulic system.
- Mission hydraulic systems (including hydraulic power units and hydraulic control panel).

As shown in Figure 4-2, the auxiliary machinery space contains the following major items:

- Sewage system.
- Potable water system (including PWG, pressure tank, and water heater).
- Refrigeration machinery.
- Transducer housings (for sonar and other scientific instruments).
- Workbench.

Ballast System

The *Pelican* holds five ballast tanks, which are located aft of the main machinery space (Figure 4-1), and have a combined volume of 15,656 gal (ABS, 2014a). The corresponding ballast capacity ranges from 58.3 long tons (59.3 metric tons) (fresh water) to 59.8 long tons (60.8 metric tons) (salt water) based on standard conversion factors.[5,6] All ballast piping is run to the ballast manifold located in the forward port corner of the main machinery space. Also located in this area are the ballast pump and the seachest serving the ballast system.

PWG System

The *Pelican* currently has a 0.6-gpm, Sea Recovery® PWG (ERG, personal communications, September 3, 2013), which is located on the aft bulkhead of the auxiliary machinery space (Figure 4-2). The potable water tanks are located outboard (port and starboard) of the auxiliary machinery space.

[5] This document uses the following standard conversion factors provided by the Society of Naval Architects and Marine Engineers: 8.34 pounds per gallon (lb/gal) for fresh water and 8.56 lb/gal for salt water. These densities are taken at 60°F and, for salt water, at a salinity of 3.5 percent (Comstock, 1967).

[6] Fresh water: (15,656 gal)(8.34 lb/gal)/(2,240 lb/long ton) = 58.3 long tons.
Salt water: (15,656 gal)(8.56 lb/gal)/(2,240 lb/long ton) = 59.8 long tons.

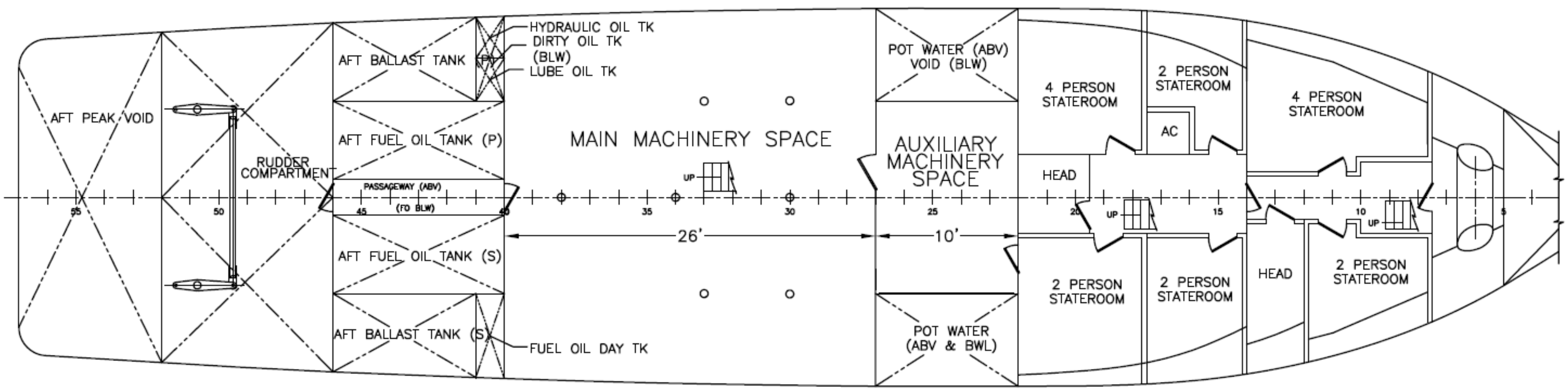


Figure 4-1. Hold Arrangement for the *R/V Pelican*

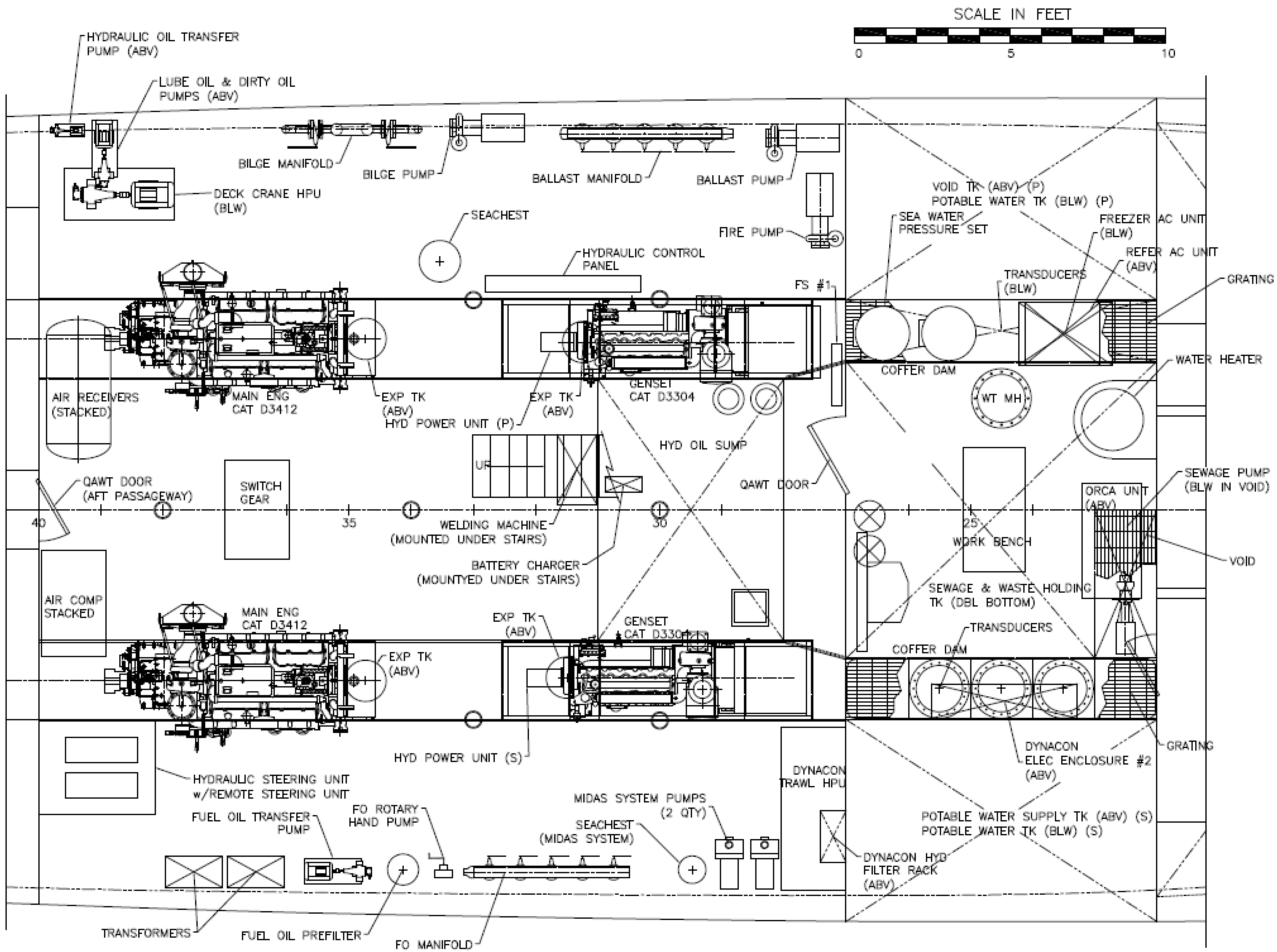


Figure 4-2. Machinery Arrangement for Existing Equipment on the *R/V Pelican*

4.1.2 PWG Retrofit Analysis

The PWG retrofit analysis for this vessel evaluated the following considerations:

- Machinery space – consideration of PWG space requirements, accessibility to the intended installation space, and PWG accessibility to any existing ballast and potable water systems.
- Service requirements – consideration of PWG accessibility to electrical power, sea water, and brine discharge connections.
- Stability and trim – consideration of PWG installation impacts on vessel weight and center of gravity.

For the purpose of this study, the PWG must be sized to allow ballasting at a rate equal to that of the vessel's fuel consumption rate, plus any additional capacity needed to meet existing potable water demands. In this case, the vessel's reported fuel consumption rate is 0.4 gpm of diesel fuel (ERG, personal communications, September 3, 2013), which is equivalent to 2.9 pounds per minute (lb/min) based on an assumed No. 2 diesel oil density of 7.2 lb/gal. The equivalent PWG rate necessary to offset 2.9 lb/min would be 0.35 gpm (2.89 lb/min/8.34 lb/gal). The existing PWG generates potable water at a rate of 0.6 gpm (ERG, personal communications, September 3, 2013). Therefore, the total PWG production capacity needed to compensate for fuel consumption and existing PWG capacity would be 1.0 gpm (i.e., 0.35 gpm for fuel consumption plus 0.6 for existing PWG capacity).

The reported fuel consumption of 0.4 gpm represents a typical consumption rate. A conservative estimate would consider the vessel's maximum fuel consumption rate. The maximum fuel consumption rate for the engines would be 0.4 pounds per horsepower hour (lb/hp-hr) (Caterpillar, 2008). Based on the installed power of 850 horsepower (hp), the engines' fuel consumption rate would be 5.66 lb/min [(850 hp)(0.4 lb/hp-hr)/(60 min/hr)]. Using the same conservative assumption for the two 99-kilowatt (kW) diesel generators, EPA estimates a generator fuel consumption rate of 1.77 lb/min [(198 kW)/(0.746 hp/kW)(0.4 lb/hp-hr)/(60 min/hr)]. Therefore, the maximum fuel consumption rate for the vessel is 7.43 lb/min (i.e., 5.66 lb/min for the engines plus 1.77 lb/min for the generators).

The equivalent PWG rate necessary to offset 7.43 lb/min would be 0.9 gpm (7.43 lb/min/8.34 lb/gal). As stated previously, the existing PWG generates potable water at a rate of 0.6 gpm; therefore, the total PWG production capacity needed to compensate for fuel consumption and existing PWG capacity would be 1.5 gpm (i.e., 0.9 gpm for fuel consumption plus 0.6 for existing PWG capacity).

Machinery Space

Based on the typical and conservative fuel consumption scenarios discussed above, the *Pelican* would require a PWG capable of producing 0.95 gpm to 1.5 gpm. A representative PWG used in the marine industry is the Axeon S-3 Series Reverse Osmosis System (AXEON Water Technologies, 2013a). This unit can be configured to provide 0.4 to 1.5 gpm, depending on the number of membranes provided with the unit. All configurations have the same overall dimensions and approximately the same weight. The PWG has a length of 48 inches (in), a depth of 14 in, and a height of 27 in. The vendor recommends clearances of two ft on each side of the unit and two to three ft in front of the unit. No clearance is required behind the unit. This analysis uses the four-membrane S3-4125 model configuration, which provides up to 1.5 gpm. While this analysis assumes four membranes, vessel operators may choose to select systems with redundant capacity (i.e., additional membrane filters, beyond the minimum required). This would allow the system to operate below 100 percent capacity and would increase pump, seal, and membrane life.

An issue that could impact PWG technology selection is the environment in which the vessel operates. In river and commercial ports, the water can include chemical contaminants and hydrocarbon products. Most operating procedures require RO systems to be used only in clean waters; therefore, adding an oil separator and one-micron filter would need to be considered for any proposed configuration.

The new PWG would replace the existing unit and would be located in the same approximate location, as shown in Figure 4-3. In addition to the PWG, a chlorinator is included in the study to ensure potable water quality. The chlorinator consists of a cylindrical, 30-gal tank with a peristaltic pump mounted on top of the tank. The tank has a 21-in diameter and a height of 36 in. The vendor recommends a clearance of two ft above the tank and two to three ft in front of the tank. No clearance is required on the sides or rear of the tank. The chlorinator would be located outboard of the PWG above the grating, which provides access to the transducer housing (Figure 4-3). The chlorinator would be mounted on the bulkhead to allow access beneath the unit.

Given the dimensions of the PWG and chlorinator systems, and the vessel's available machinery space, there is sufficient clearance to remove the existing PWG and install the new PWG and chlorinator units. Access to the space would be through the main machinery ladder way and the watertight door into the auxiliary machinery space. Piping from the chlorinator to the ballast system would be routed through the watertight bulkhead at frame 27, athwartships through the void located under the operating level between frames 27 and 28, and then to the ballast manifold.

Stability and Trim

The combined weight of both the PWG and the chlorinator is 545 lb. This is the sum of the PWG weight (175 lb (AXEON Water Technologies, 2013a)) and the chlorinator tank weight, including water (370 lb). The weight of the chlorinator tank is based on the assumption that the 30-gal tank is constructed of ¼-in steel (80 lb) and includes miscellaneous fittings (20 lb), a 20-lb pump, and 30 gal of water (250 lb; 30 gal x 8.34 lb/gal). The weight of the existing PWG is approximately 200 lb, based on a review of similarly rated Sea Recovery PWGs. The lightship weight of the *Pelican* is approximately 280 long tons, or 627,200 lb, based upon data for similarly sized vessels. Therefore, the total weight change (sum of additions and subtractions) from PWG retrofitting is only 0.1 percent of the total lightship weight [(545 lb - 200 lb)/627,200 lb)]. Such a change would have negligible impact on vessel stability and trim.

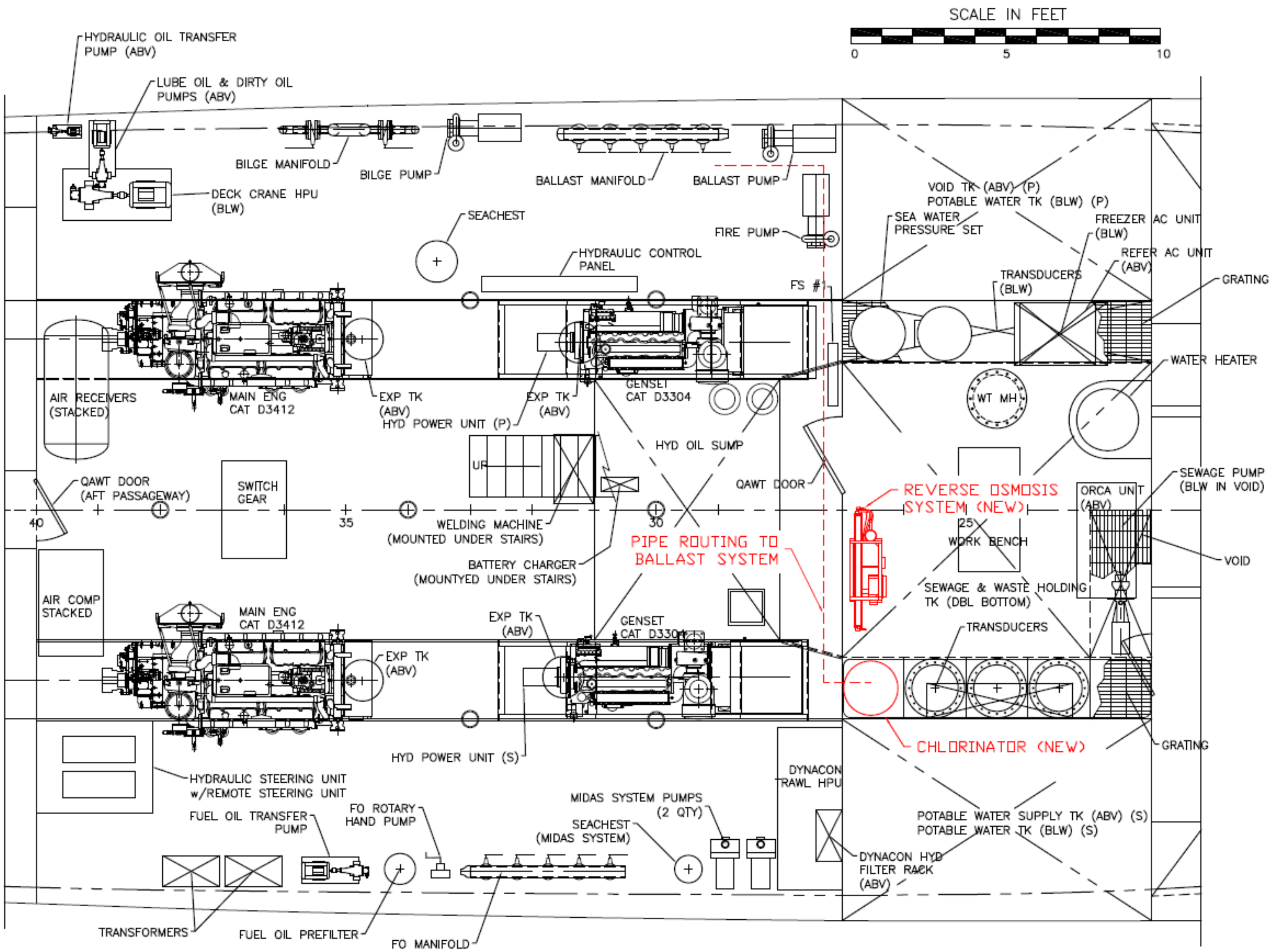


Figure 4-3. Machinery Arrangement after Retrofitting the *R/V Pelican*

PWG service requirements

Because the new unit is replacing the existing unit at the same location, tying into the existing potable water system would be straightforward since it would use the current PWG's existing electrical, seawater, and brine connections. The new PWG draws 11.5 to 12.5 amps at 220 volts (AXEON Water Technologies, 2013a), resulting in a connected load of just less than 3 kW (12.5 amps x 220 volts = 2,750 watts). This load would account for approximately 1.5 percent of the vessel's current electrical capacity of 198 kW (LUMCON, no date).

4.1.3 Alternative Arrangement

An alternative arrangement would retain the existing PWG and install a new unit, independent of the existing potable water system (Figure 4-4). In this case, the new PWG could be installed on a rack above the bilge manifold, with the new chlorinator located adjacently. This arrangement would have the advantage of grouping together all ballast-related components and would avoid the possibility of contaminating the onboard potable water system. Further, this alternative would allow the *Pelican* to produce potable water at a greater overall rate, assuming installation of the 0.4- to 1.5-gpm PWG discussed previously. Installing the new PWG in this manner, while retaining the existing system, also would eliminate costs associated with removing the existing PWG. The disadvantages associated with having two PWGs onboard would be the increased power consumption and greater frequency of PWG maintenance operations.

4.1.4 Conclusion

Overall, the analysis demonstrates it is feasible to retrofit the *R/V Pelican* with a PWG capable of generating potable water at rates that would compensate for fuel consumption and that also would meet additional potable water demands met by the currently installed PWG. The machinery space provides sufficient clearance for PWG installation and subsequent operation/maintenance. The impact on vessel stability and trim from the weight differential associated with the retrofit would be negligible since it would result in a change of only 0.1 percent. Finally, the PWG electrical load is relatively small compared to the vessel's electrical capacity.

The total capital investment cost for retrofitting the *Pelican*, based on a linear interpolation of Table 3-9 cost data for 1.0- and 15-gpm PWG-chlorination systems, would be \$53,000. The daily O&M cost would be approximately \$7 per day, or approximately \$2,600 per year (assuming 365 days per year). The O&M costs are similarly derived from linear interpolation of Table 3-10 cost data.

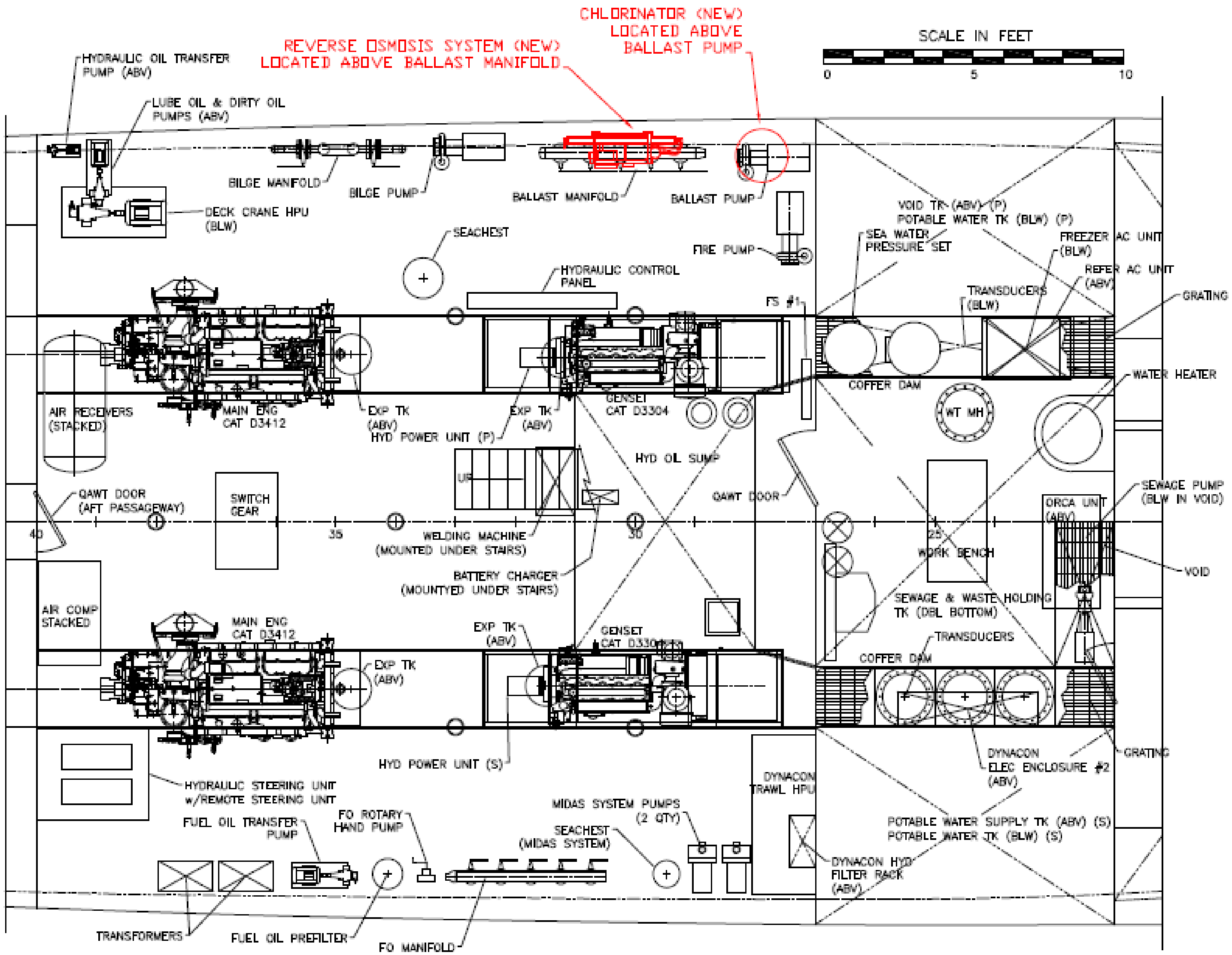


Figure 4-4. Machinery Arrangement after Retrofitting the *R/V Pelican* (Alternate Arrangement)

4.2 INLAND RIVER TOWBOAT

This section provides a brief characterization of a 150-ft towboat owned by the USACE, its machinery arrangement, and an analysis of PWG retrofit requirements and impacts on space, stability, and PWG service connections.

4.2.1 Vessel Characteristics

The USACE vessel operates in the Great Lakes, western rivers, and other inland waterways and ports, and is representative of commercial towboats of its size operated on the inland river system of the United States. It measures roughly 150 by 42 ft (length and beam, respectively). The vessel is propelled by twin propellers, each driven by a geared diesel engine. Table 4-2 summarizes relevant vessel characteristics and mechanical systems.

Table 4-2. Summary of USACE Vessel Characteristics and Mechanical Systems

Vessel Characteristic	Dimension or Mechanical System Description
Length (overall)	150.0 ft
Beam	42.0 ft
Depth	11.7 ft
Draft (full load)	Unknown
Displacement	736 long tons
Gross registered tonnage	Unknown
Total persons aboard	14
Fresh water tank volume	12,500 gal
Ballast tank volume	Unknown
Fuel tank volume	60,000 gal
Propellers	Two (twin-screw propulsion)
Propulsion system	Geared diesel engines
Shaft Horsepower	2,320 each shaft, 4,640 total
Generators	Two 175-kW generators

Source: ERG, personal communications, December 24, 2013

Machinery Space

The USACE vessel has a main machinery room and two auxiliary machinery rooms located below the main deck, as well as an auxiliary machinery room located on the main deck, as indicated in Figure 4-5. The main machinery room is located about amidships. Vessel diagrams provided by USACE indicate that this room has dimensions of 34 by 34 ft (length and breadth, respectively). Auxiliary machinery rooms are located immediately aft of the main machinery space, forward of the main machinery room, and on the main deck level. Their respective lengths and breadths are 20 by 30 ft, 16 by 30 ft, and 40 by 30 ft.

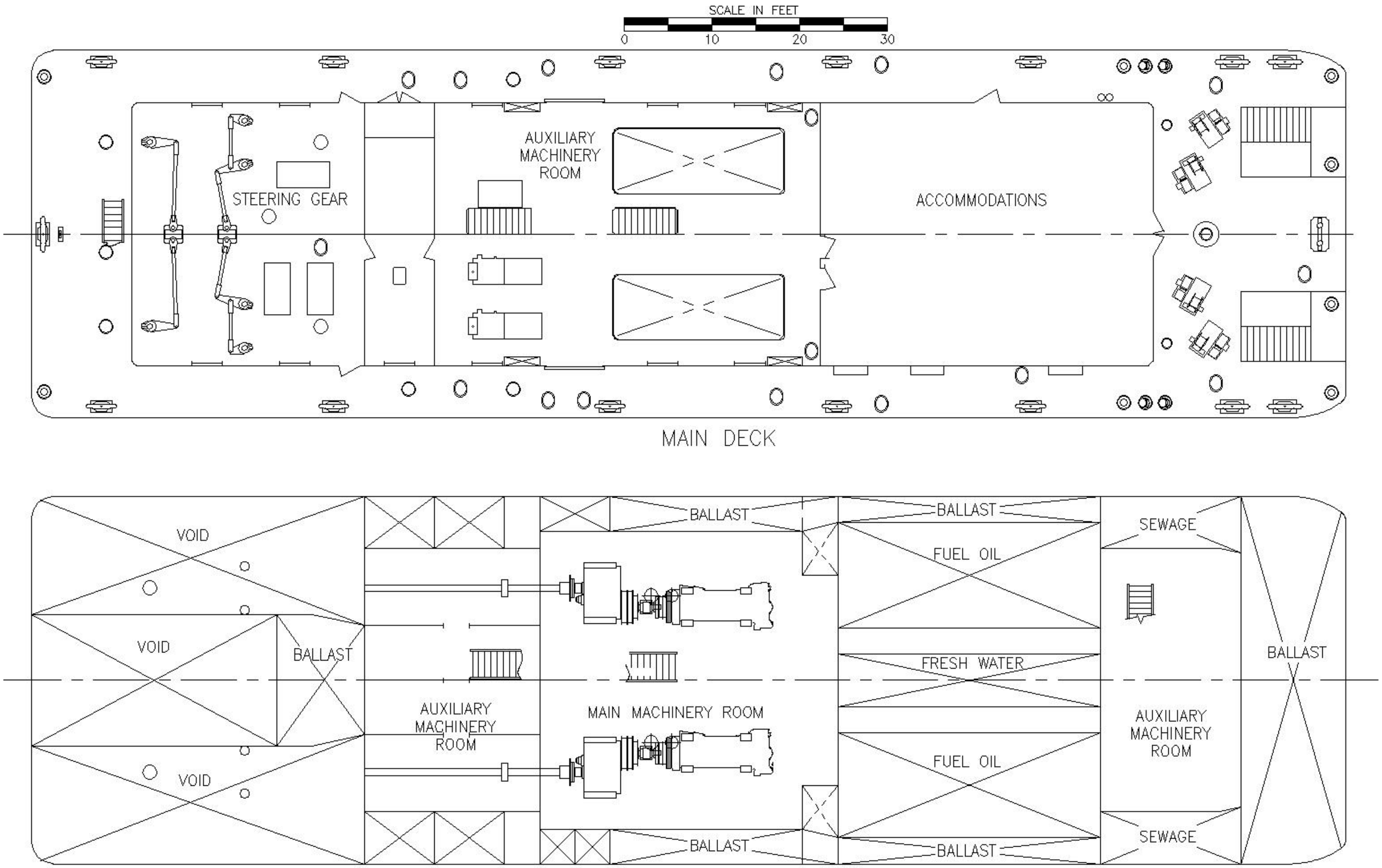


Figure 4-5. Hold and Main Deck Arrangement for the USACE Vessel

The main machinery room contains the following major items:

- Two diesel engines.
- Two reduction gears.
- Fuel oil system (including pumps and strainers).

The aft auxiliary machinery room contains the following major items:

- Two air receivers.
- Two propulsion shafts.
- Ballast system (pumps).

The forward auxiliary machinery room contains the following major items:

- Marine sanitation device.
- Potable water system (pumps, pressure tank, and water heater).

The auxiliary machinery room located on the main deck has cutouts for the main engines, which are located in the deck below, and contains the following major items:

- Two diesel generators.
- Exhaust system for main engines.

The existing equipment on the main machinery room and aft auxiliary machinery room is shown in Figure 4-6.

Ballast System

The vessel has six ballast tanks as shown in Figure 4-5. All ballast piping is run to the aft auxiliary machinery space. Also located in this area are two ballast/fire pumps.

PWG System

The vessel currently does not have a PWG. Operating on inland rivers, the vessel has ready access to municipal water supplies, which it uses to fill its potable water tanks.

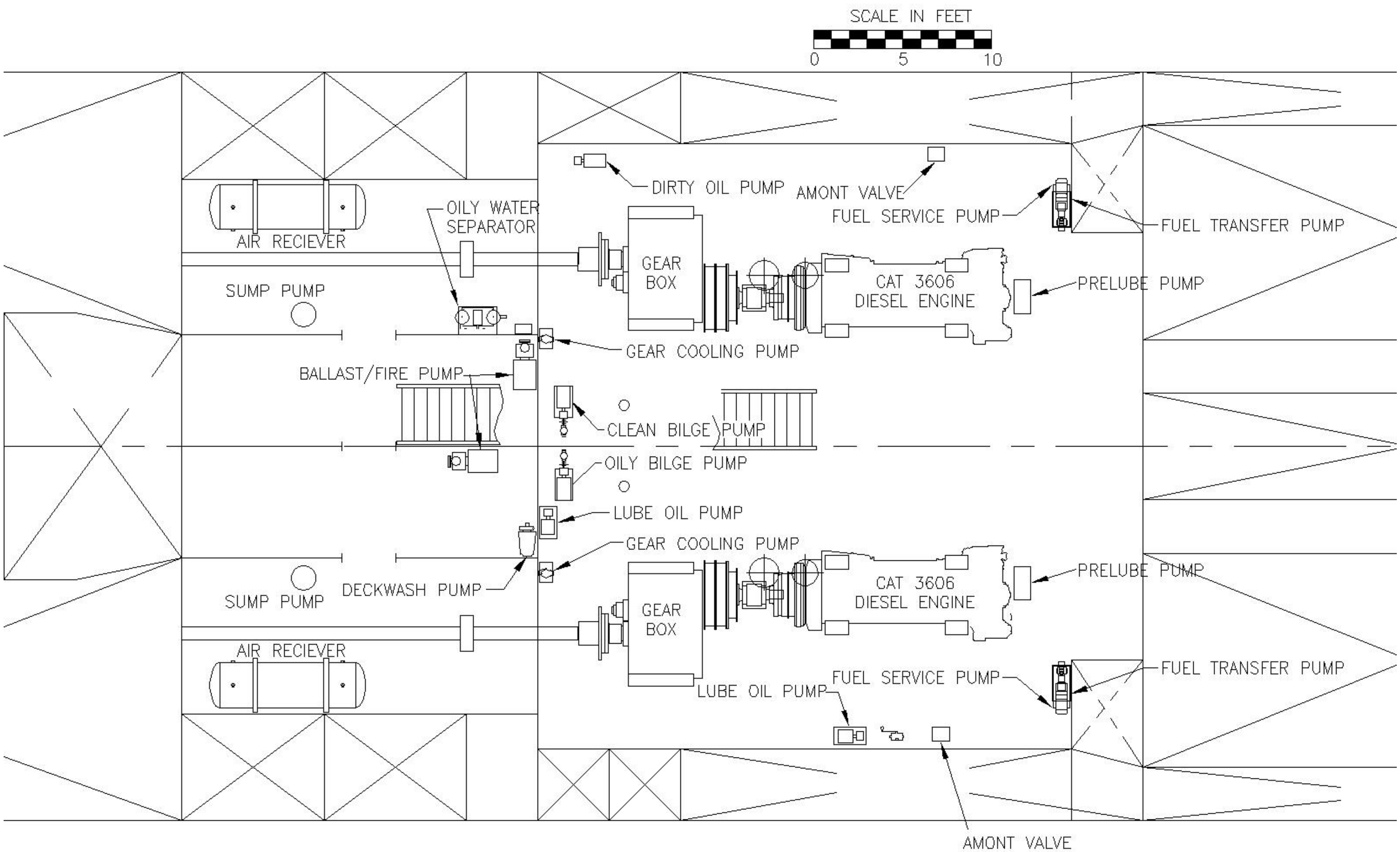


Figure 4-6. Machinery Arrangement for Existing Equipment on the USACE Vessel

4.2.2 PWG Retrofit Analysis

The PWG retrofit analysis for this vessel evaluated the following considerations:

- Machinery space – consideration of PWG space requirements, accessibility to the intended installation space, and PWG accessibility to any existing ballast and potable water systems.
- Stability and trim – consideration of PWG installation impacts on vessel weight and center of gravity.
- Service requirements – consideration of PWG accessibility to electrical power, seawater, and brine discharge connections.

For the purpose of this study, the PWG must be sized to allow ballasting at a rate equal to that of the vessel's fuel consumption rate, plus any additional capacity needed to meet existing potable water demands. Specific fuel consumption for the main engines is 0.33 lb/hp-hr (Caterpillar, 2002). Therefore, main engine fuel consumption is1,540 lb/hr (2,320 hp/engine x 2 engines x 0.33 lb/hp-hr). This is equal to 25.7 lb/min (1,540 lb/hr/60 min/hr) or 3.6 gpm based on an assumed No. 2 diesel oil density of 7.2 pounds per gallon (lb/gal). The full load fuel consumption for each diesel generator is 12.8 gal/hr, or 0.2 gpm (12.8 gpm/60 min/hr). Based upon two generators and a typical load factor of 50 percent, the fuel consumed by the generators is 2 x 0.2 x 0.5 = 0.2 gpm. The load factor is based on the fact that the ship's service generators are usually sized to allow the complete load to be carried with one generator off-line.

Overall fuel consumption for the vessel is 3.8 gpm (3.6 gpm for the main engines plus 0.2 gpm for the generators). This rate is equivalent to 27.1 lb/min based on an assumed No. 2 diesel oil density of 7.2 lb/gal. The equivalent PWG rate necessary to offset 27.1 lb/min would be 3.3 gpm (27.1 lb/min/8.3 lb/gal). There is no existing PWG generator. Therefore, the total PWG production needs only to compensate for fuel consumption, which is 3.3 gpm.

Machinery Space

Based on the fuel consumption scenario discussed above, the USACE vessel would require a PWG capable of producing 3.3 gpm. A representative PWG used in the marine industry is the Axeon R2 Series Reverse Osmosis System (AXEON Water Technologies, 2013b). This unit can be configured to provide from 1 to 6.3 gpm, depending on the number of membranes provided with the unit. All configurations have the same overall dimensions and approximately the same weight. The PWG has a length of 32 in, a depth of 26 in, and a height of 61 in. This analysis considered the four-membrane, R2-4140 model configuration, which provides up to 4.2 gpm. While this analysis assumes four membranes, vessel operators may choose to select systems with redundant capacity (i.e., additional membrane filters, beyond the minimum required). This would allow the system to operate below 100 percent capacity and would increase pump, seal, and membrane life.

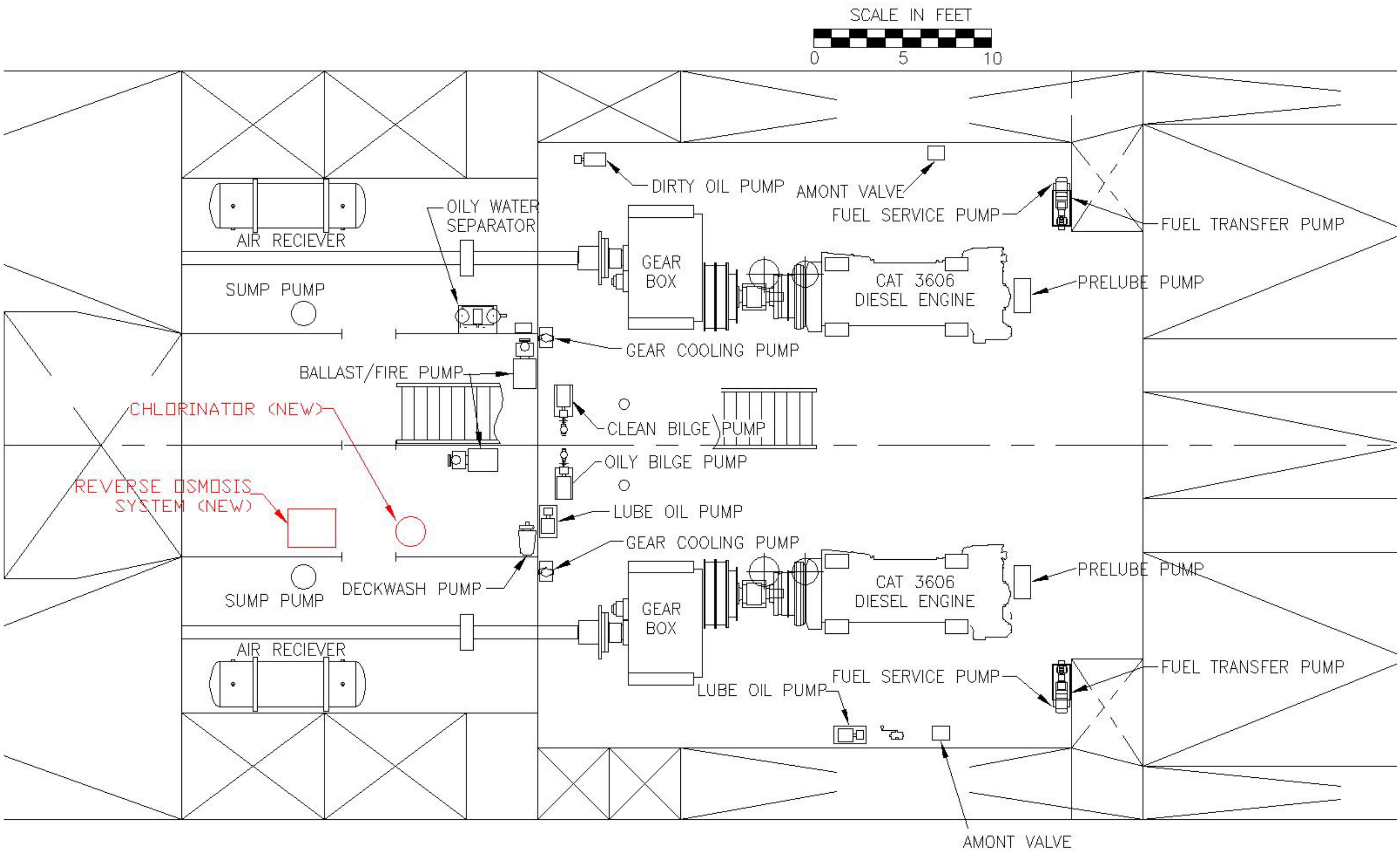


Figure 4-7. Machinery Arrangement after Retrofitting the USACE Vessel

Figure 4-7 shows where the new PWG would be located in the aft auxiliary machinery space near the existing ballast pumps. In addition to the PWG, a chlorinator is included in the study to ensure potable water quality. The chlorinator consists of a cylindrical, 30-gal tank with a peristaltic pump mounted on top of the tank. The tank has a 21-in diameter and a height of 36 in. The vendor recommends a clearance of two ft above the tank and two to three ft in front of the tank. No clearance is required on the sides or rear of the tank. The new chlorinator would be located between the new PWG and the ballast pumps.

Given the dimensions of the PWG and chlorinator systems, and the USACE vessel's arrangement, it appears as if there is sufficient clearance to install the new PWG and chlorinator unit. Access to the space would be through the ladder way providing access to the aft auxiliary machinery space.

Stability and Trim

The combined weight of both the PWG and the chlorinator is 1,020 lb. This is the sum of the PWG weight (650 lb (AXEON Water Technologies, 2013b)) and the chlorinator tank weight, including water (370 lb). The weight of the chlorinator tank is based on the assumption that the 30-gal tank is constructed of ¼-in steel (80 lb) and includes miscellaneous fittings (20 lb), a 20-lb pump, and 30 gal of water (250 lb; 30 gal x 8.3 lb/gal). The lightship weight of the USACE vessel is approximately 466 long tons, or 1,043,800 lb. The lightship weight was estimated by subtracting deadweight items (193 long tons of fuel, 47 long tons of fresh water, and 30 long tons for miscellaneous deadweight items) from the displacement of 736 long tons. Miscellaneous deadweight items include crew and effects, stores, spares, towing gear, and sewage. Therefore, the total weight addition from PWG retrofitting is only 0.1 percent of the total lightship weight [(1,020 lb)/1,043,800 lb)]. Such a change would have negligible impact on vessel stability and trim.

PWG Service Requirements

The new unit is located near the existing ballast pumps. Therefore, tying into the ballast system would be straightforward. Electrical, seawater, and brine connections would have to be provided. Seawater would be supplied from the vessel's main seawater suction, which is located in the same compartment as the new PWG. Brine would be piped to an overboard discharge. The new PWG draws 13.6 amps at 220 volts (normal operating amps, AXEON Water Technologies, 2013b), resulting in a connected load of just less under 3kW (13.6 amps x 220 volts = 2,992 watts). This load would account for approximately 1 percent of the vessel's current electrical capacity of 350 kW (ERG, personal communications, December 24, 2013).

Existing Potable Water System

The USACE vessel does not have an existing PWG. Potable water is supplied from a tank, which is filled from municipal water. The new PWG proposed in this analysis would be used exclusively for ballast and would not be connected to the existing potable water system.

4.2.3 Conclusion

Overall, this analysis demonstrates that it is feasible to retrofit the USACE vessel with a PWG capable of generating potable water at rates that would compensate for fuel consumption. The machinery space provides sufficient clearance for PWG installation and subsequent operation/maintenance. The impact on vessel stability and trim from the weight differential associated with the retrofit would be negligible since it would result in a change of well under 1 percent. Finally, the PWG electrical load is relatively small compared to the vessel's electrical capacity.

The total capital investment cost for retrofitting the USACE vessel, based on a linear interpolation of Table 3-9 cost data for 1.0- and 15-gpm PWG-chlorination systems, would be $66,400. The daily O&M cost would be approximately $12 per day, or approximately $4,400 per year (assuming 365 days per year). The O&M costs are similarly derived from linear interpolation of Table 3-10 cost data.

4.3 RESEARCH CLASS VESSEL

This section provides a brief characterization of the *Oscar Dyson* and its machinery arrangement, as well as an analysis of PWG retrofit requirements and impacts on space, stability, and PWG service connections.

4.3.1 Vessel Characteristics

The *Oscar Dyson* is a fisheries survey vessel owned and operated by the National Oceanic and Atmospheric Administration (NOAA). The primary mission of the vessel is to perform fisheries surveys. This vessel's homeport is in Kodiak, AK, and is a support platform to study and monitor Alaskan pollock and other fisheries, as well as oceanography in the Bering Sea and the Gulf of Alaska. The *Oscar Dyson* measures roughly 208 by 49 ft (length and beam, respectively) and has an internal volume of 2,139 GRT. The vessel is propelled by a single propeller driven by two electric motors and four diesel generators that power the electric motors. Table 4-3 summarizes relevant vessel characteristics and mechanical systems.

Table 4-3. Summary of *Oscar Dyson* Vessel Characteristics and Mechanical Systems

Vessel Characteristic	Dimension or Mechanical System Description
Length (overall)	206.7 ft
Beam	49.2 ft
Depth	28.4 ft
Draft (full load)	19.7 ft
Displacement	2,400 long tons
Gross registered tonnage	2,139
Total persons aboard	39
Fresh water tank volume	9,300 gal
Ballast tank volume	38,900 gal (147 m^3)

Table 4-3. Summary of *Oscar Dyson* Vessel Characteristics and Mechanical Systems

Vessel Characteristic	Dimension or Mechanical System Description
Fuel tank volume	113,100 gal
Propellers	One (single-screw propulsion)
Propulsion system	Single-screw diesel electric
Shaft Power	Two 1,125-kW electric motors on single shaft (2,250 kW total)
Generators	Two 1,360-kW generators and two 960-kW generators. Total electrical generating capability of 4,540 kW.

Sources: ABS, 2014b; NOAA, no date c

Machinery Space

As indicated in Figure 4-8, the *Oscar Dyson* has a main machinery room, an auxiliary machinery room, and a domestic equipment space. The main machinery room is located just aft of amidships. Vessel diagrams provided by NOAA indicate that this room is 45 ft long and spans the breadth of the boat. The auxiliary machinery room is located immediately forward of the main machinery space on a single level and has dimensions of 20 by 41 ft (length and breadth, respectively). The domestic equipment space is located immediately forward of the auxiliary machinery room and has dimensions of 20 ft by 28 ft (length and breadth, respectively).

The main machinery room has two levels. The lower level contains the following major items, as shown in Figure 4-9:

- Four diesel generators.
- Two electric propulsion motors.
- Two propulsion transformers.
- Two ship's service transformers.
- Main seawater system (including pumps and strainers).
- Bilge manifold.

The upper level contains the following major items as shown in Figure 4-10:

- Air conditioner chiller plant and pumps.
- Diesel generator expansion tanks and heat exchangers.
- Distilling units.
- Diesel generator exhaust system (not shown on drawing).

Each level also contains various electrical panels.

The auxiliary machinery room is located on a single level and contains the following major items:

- Fuel oil system (including purifier, pumps, and manifold).
- Engineer's workshop (with various pieces of workshop equipment).
- Ballast manifold.
- Storage area.

This space also contains various electrical panels.

The domestic equipment space contains the following major items:

- Potable water system components (ultraviolet purifiers, pressure tank, and hot water system).
- Marine sanitation device.
- Bow thruster drive transformers and controller.

The existing equipment in the auxiliary machinery room and domestic equipment space is shown in Figure 4-11.

Diesel electric propulsion systems for vessels of this size are common, with applications including offshore service vessels and small passenger vessels. However, overall machinery space on the *Oscar Dyson* is larger than that found on many similar sized vessels due to the low-noise features found on the vessel. These features include the large propulsion motors located in the main machinery space and the resilient mounting of much of the machinery. A more common arrangement would locate the propulsion motors outside the main machinery space using Z-drive units. The diesel generators are resiliently mounted on a large steel frame, which in turn is resiliently mounted to the ship. This intermediate frame results in a larger space requirement than a more common installation.

Since the additional space requirements are compensated for with a larger overall machinery space (which includes the auxiliary machinery room), EPA believes that the challenges of the PWG installation aboard the *Oscar Dyson* are typical of other vessels of its size.

Ballast System

The *Oscar Dyson* has four ballast tanks, which have a combined volume of 38,900 gal (147 cubic meters) (ABS, 2014b). The corresponding ballast capacity ranges from 144.7 long tons (147.1 metric tons) (fresh water) to 148.5 long tons (150.9 metric tons) (salt water) based on standard conversion factors.[7,8] All ballast piping is run to the ballast manifold located in the

[7] This document uses the following standard conversion factors provided by the Society of Naval Architects and Marine Engineers: 8.34 lb/gal for fresh water and 8.56 lb/gal for salt water. These densities are taken at 60°F and, for salt water, at a salinity of 3.5% (Comstock, 1967).

[8] Fresh water: (15,656 gal)(8.34 lb/gal)/(2,240 lb/long ton) = 58.3 long tons.
Salt water: (15,656 gal)(8.56 lb/gal)/(2,240 lb/long ton) = 59.8 long tons.

forward port corner of the auxiliary machinery room. Also located in this area is one of the vessel's bilge/ballast/fire pumps.

PWG System

The *Oscar Dyson* currently has two Alfa-Laval JWP-16-C-40 distillation units to generate fresh water. Each unit is rated at 1.3 gpm (NOAA, no date c). Heat for the units is supplied by the diesel engine jacket water cooling system supplemented with electric heaters. The units are located port and starboard on the upper level of the main machinery room. Fresh water is stored in two tanks with a total capacity of 9,300 gal and is disinfected by an ultraviolet purifier located in the domestic equipment space.

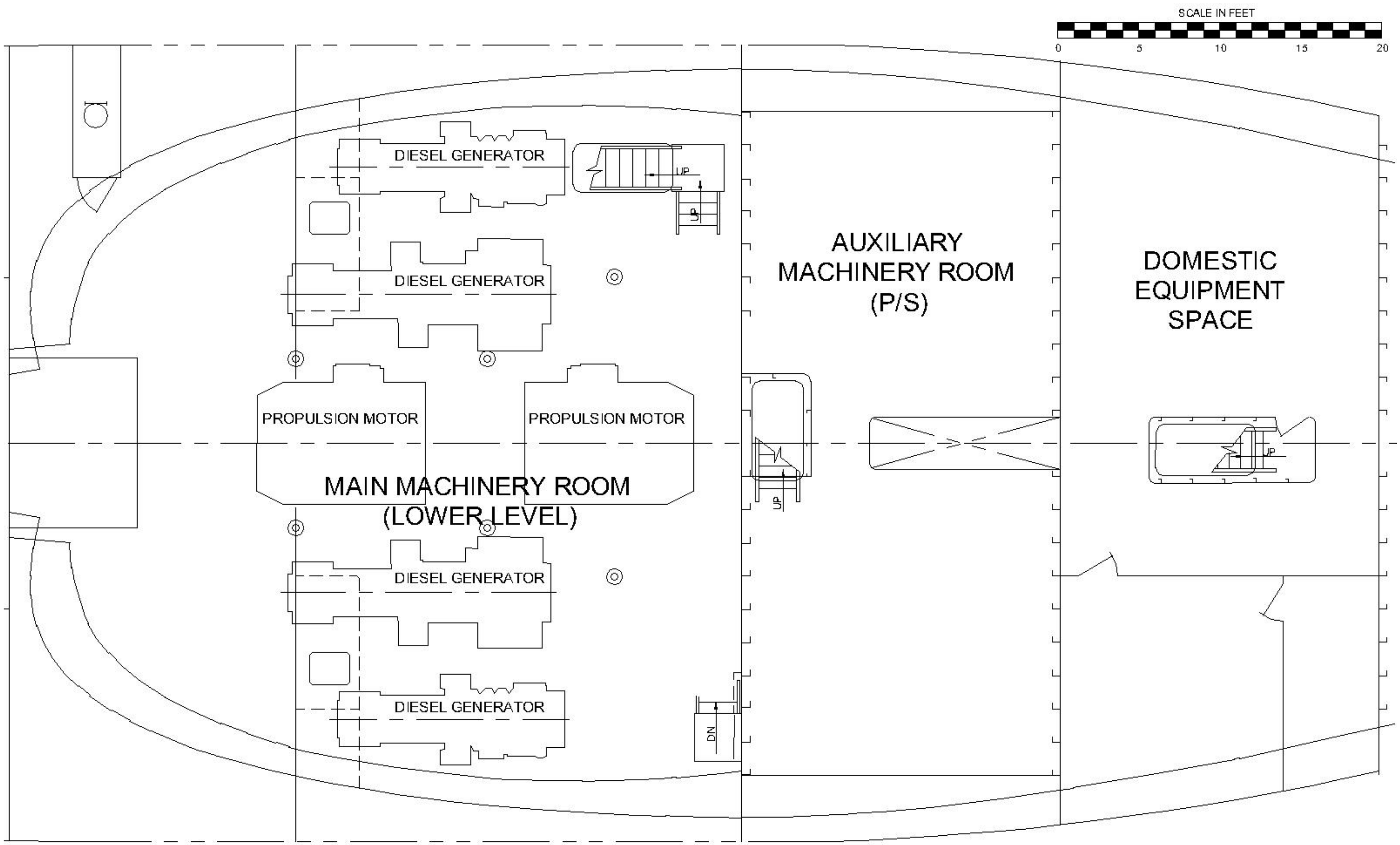


Figure 4-8. Machinery Space Locations for the *Oscar Dyson*

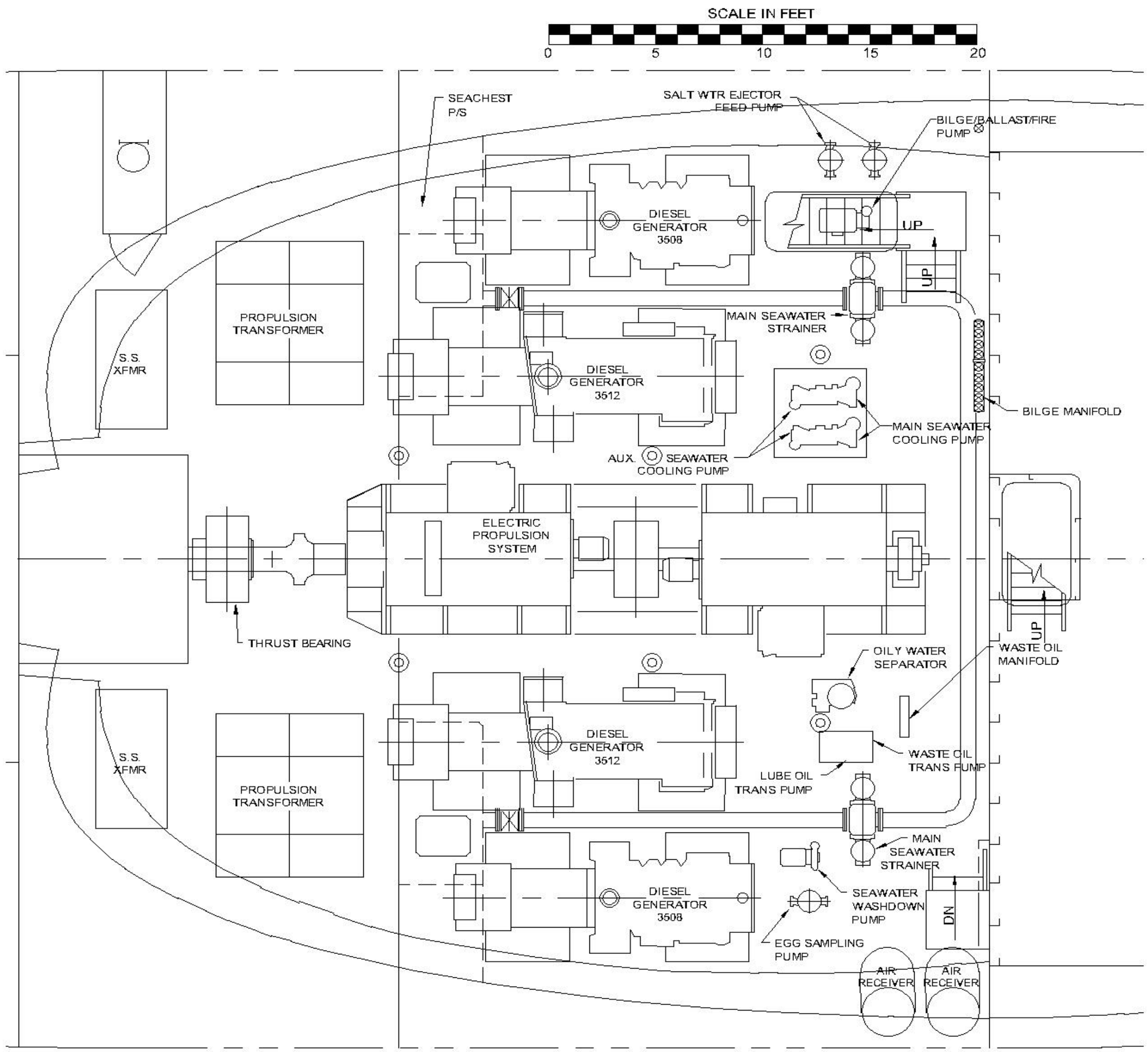


Figure 4-9. Main Machinery Room (Lower Level) for Existing Equipment on the *Oscar Dyson*

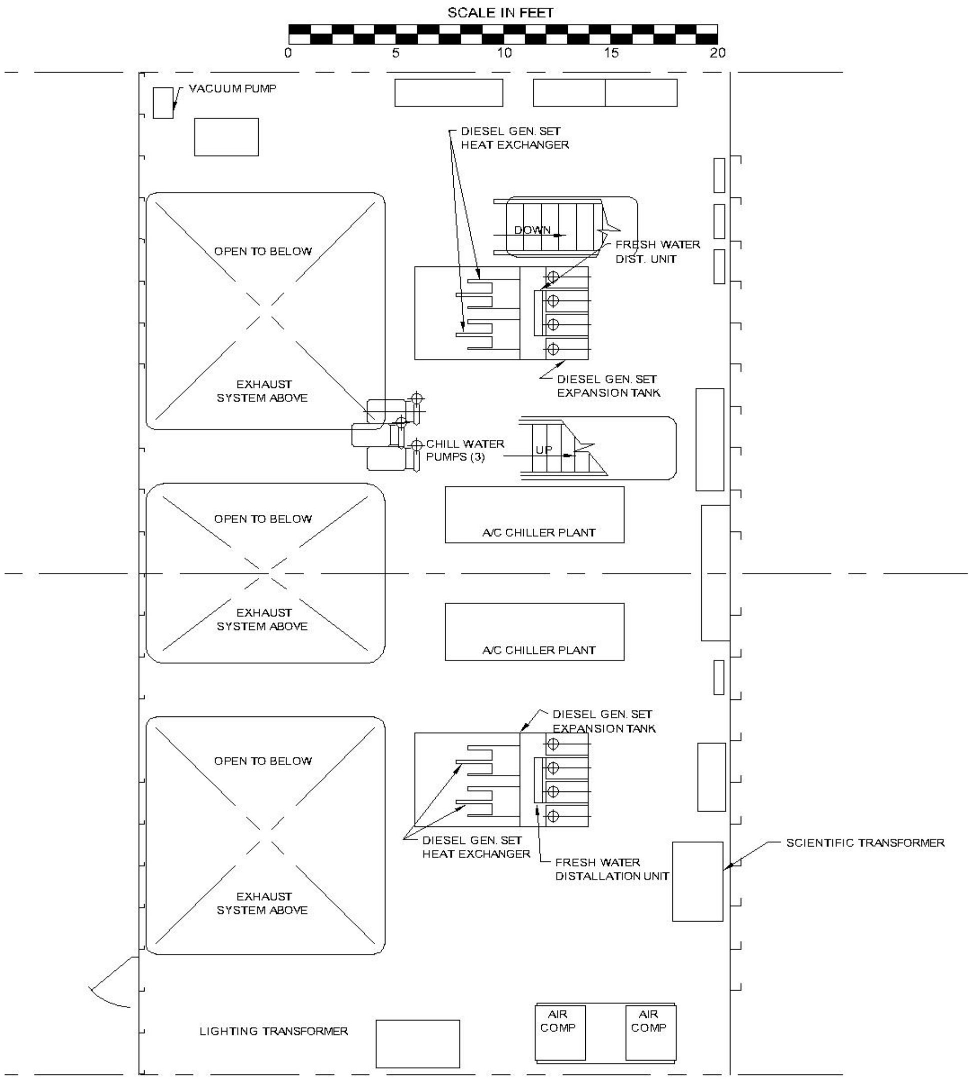


Figure 4-10. Main Machinery Room (Upper Level) for Existing Equipment on the *Oscar Dyson*

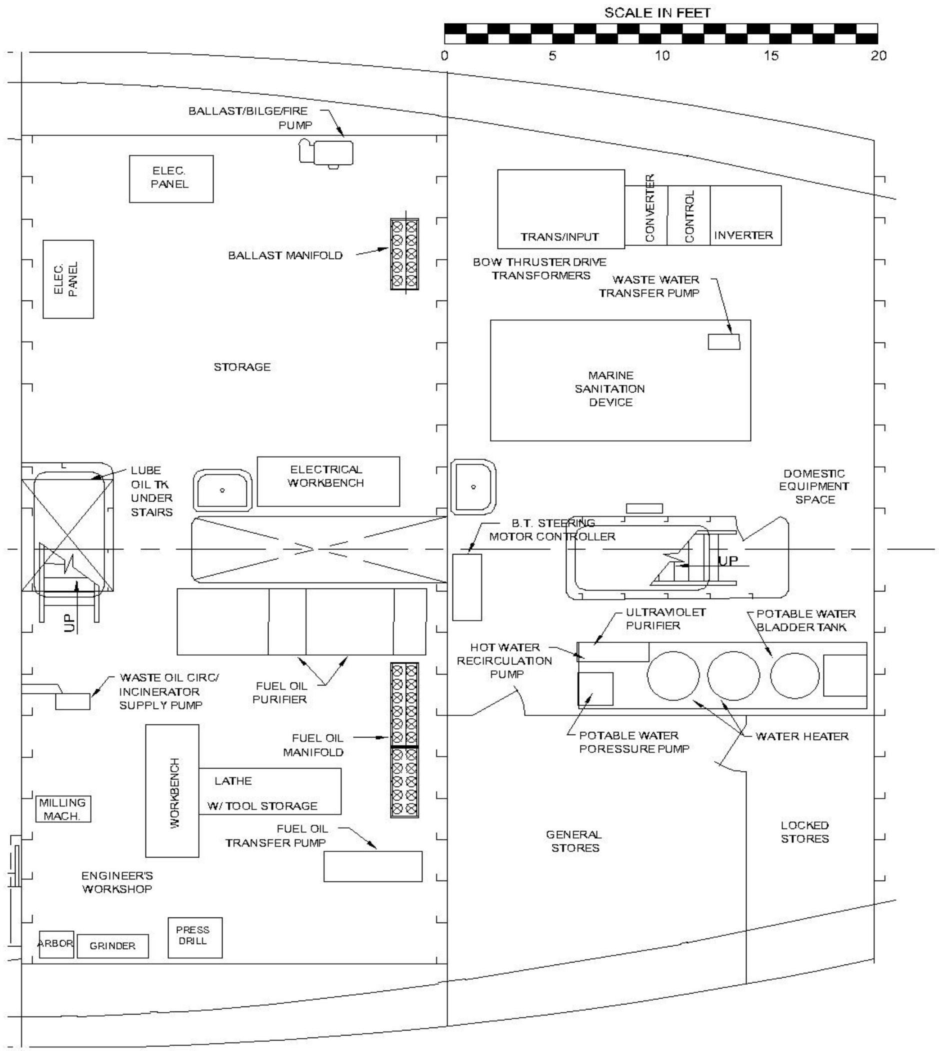


Figure 4-11. Auxiliary Machinery Room and Domestic Equipment Space for Existing Equipment on the *Oscar Dyson*

4.3.2 PWG Retrofit Analysis

The retrofit analysis for this vessel evaluated the following considerations:

- Machinery space – consideration of PWG space requirements, accessibility to the intended installation space, and PWG accessibility to any existing ballast and potable water systems.
- Stability and trim – consideration of PWG installation impacts on vessel weight and center of gravity.
- Service requirements – consideration of PWG accessibility to electrical power, seawater, and brine discharge connections.

To simplify installation and minimize costs, it is recommended that the existing distillers remain in place and in operation to service the vessel's domestic potable water requirements. Therefore, for the purpose of this study, the PWG must be sized to allow ballasting at a rate equal to that of the vessel's fuel consumption rate only. In this case, the reported fuel consumption rate for the *Oscar Dyson* is 1.7 gpm of diesel fuel (ERG, personal communications, August 1, 2013), which is equivalent to 12.6 lb/min, based on an assumed No. 2 diesel oil density of 7.2 lb/gal. The equivalent PWG rate necessary to offset 12.6 lb/min would be 1.5 gpm (12.6 lb/min/8.3 lb/gal).

The reported fuel consumption of 1.7 gpm represents a typical consumption rate. A more conservative estimate would consider the vessel's maximum fuel consumption rate. The maximum fuel consumption rate for the engines would be 66.9 gal/hr for each Cat 3508 unit and 90.9 gal/hr for each Cat 3512 unit (Caterpillar, no date). Based on an estimated overall generator load factor of 75 percent, the fuel consumption would be (66.9 gal/hr x 2 + 90.9 gal/hr x 2) x 0.75, or 236.7 gal/hr. The load factor represents the vessel's worst-case electrical load, from trawling in 13-ft seas. This is equal to 28.5 lb/min (236.7 gal/hr x 7.2 lb/gal/60 min/hr). The equivalent PWG rate necessary to offset 28.5 lb/min would be 3.4 gpm (28.5 lb/min/8.3 lb/gal).

Machinery Space

Based on the typical and conservative fuel consumption scenarios discussed above, the *Oscar Dyson* would require a PWG capable of producing 1.7 gpm to 3.4 gpm.

Two different representative PWG units were considered for this analysis:

- The Axeon R2 Series Reverse Osmosis System (AXEON Water Technologies, 2013b). This unit can be configured to provide from 1 to 6.3 gpm, depending on the number of membranes provided with the unit. All configurations have the same overall dimensions and approximately the same weight. This analysis considered the four-membrane, R2-4140 model configuration, which provides up to 4.2 gpm. The PWG has a length of 32 in, a depth of 26 in, and a height of 61 in.
- The Sea Recovery Coral Sea System (Sea Recovery, 2013). This unit can be configured to provide 1.9 to 4.7 gpm, depending on the membrane configuration. This system can accommodate up to six membrane filters. All configurations have

approximately the same dimensions and weight. This analysis considered the 5200/4V model, which provides 3.6 gpm. This PWG has a length of 30 in, a depth of 35 in, and a height of 53 in.

This feasibility analysis uses the Coral Sea system and assumes the system would have six membranes. The system has been designed to allow the system to operate below 100 percent capacity and would increase pump, seal, and membrane life.

It should be noted that the Coral Sea System is also available in a modular configuration. Though not selected in this analysis, the modular configuration allows the control unit, pumps, filters, and membrane vessels to be separately located, and would allow the system to be installed in locations without the space for an integrated unit.

There are three potential locations for the PWG installation:

- On the upper level of the main machinery room where the existing distiller units are located.
- In the auxiliary machinery room adjacent to the ballast manifold.
- In the domestic equipment space adjacent to components of the existing potable water system.

Locating the new PWG in place of the existing distiller units is not practical due to the way the existing distiller is located between the diesel generators' heat exchangers and expansion tanks. There is not sufficient space for the new PWG elsewhere in the main machinery room.

Locating the new PWG in the domestic equipment space is not practical due to lack of sufficient space in the area for additional equipment. Accordingly, the new PWG would be located on the port side of the auxiliary machinery room adjacent to the ballast manifold. This space also contains an electrical workbench, various electrical panels, and has an area designated as storage. It should be noted that the new PWG would take up some of the existing storage space, which may be limited on a vessel of this type and size.

In addition to the PWG, a chlorinator is included in the study to ensure potable water quality. The chlorinator consists of a cylindrical, 30-gal tank with a peristaltic pump mounted on top of the tank. The tank has a 21-in diameter and a height of 36 in. The vendor recommends a clearance of two ft above the tank and two to three ft in front of the tank. No clearance is required on the sides or rear of the tank. The new chlorinator would be located outboard of the ballast manifold near the existing ballast pump. Figure 4-12 shows the recommended locations for a new PWG and chlorinator.

Given the dimensions of the PWG and chlorinator systems, and the vessel's arrangement, it appears as if there is sufficient clearance to install the new PWG and chlorinator unit. Access to the space would be through the ladder way going into the auxiliary machinery room. Seawater piping from the chlorinator to the ballast system would be straightforward as the chlorinator is located within a few feet of the ballast manifold.

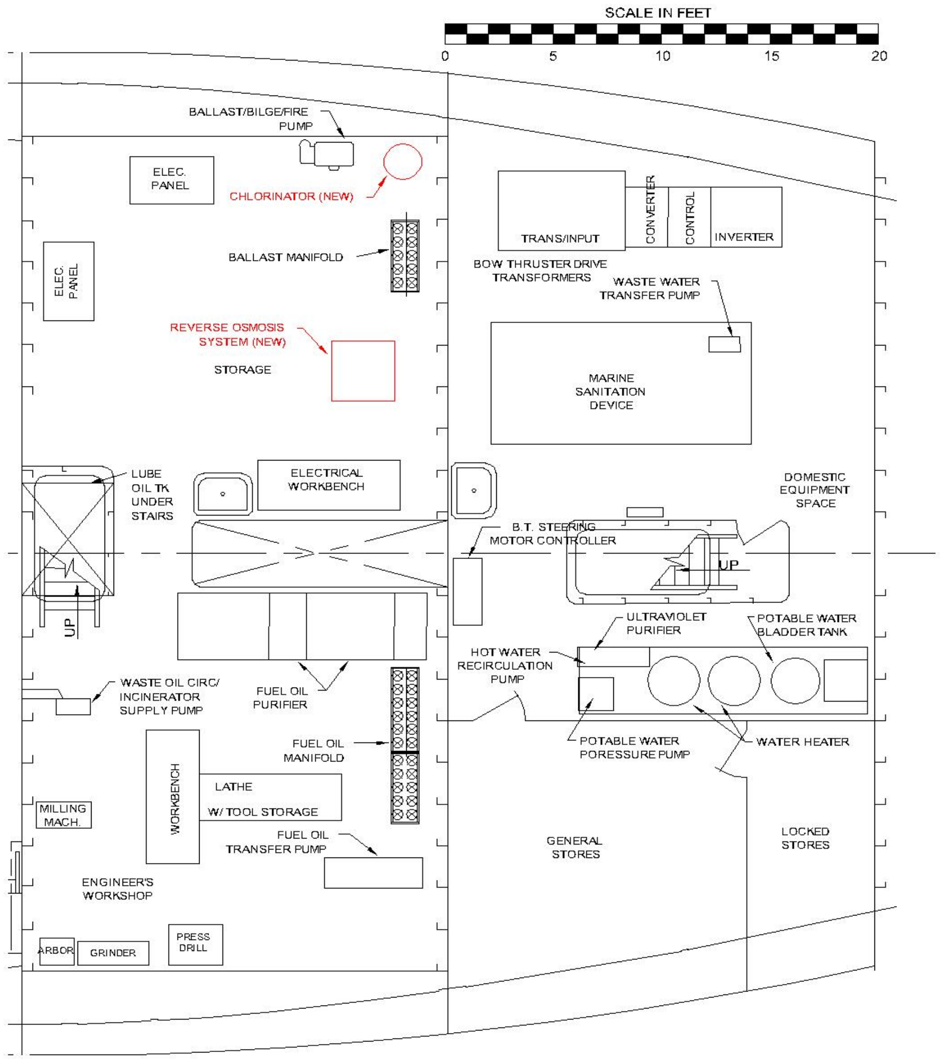


Figure 4-12. Auxiliary Machinery Room after Retrofitting the *Oscar Dyson*

Stability and Trim

The combined weight of both the PWG and the chlorinator is 1,120 lb. This is the sum of the PWG weight 750 lb (Sea Recovery, 2013) and the chlorinator tank weight, including water (370 lb). The weight of the chlorinator tank is based on the assumption that the 30-gal tank is constructed of ¼-in steel (80 lb) and includes miscellaneous fittings (20 lb), a 20-lb pump, and 30 gal of water (250 lb; 30 gal x 8.3 lb/gal). The lightship weight of the *Oscar Dyson* is approximately 1,750 long tons, or 3,920,000 lb, based upon data for similarly sized vessels. Therefore, the total weight addition from PWG retrofitting is only 0.03 percent of the total lightship weight [(1,120 lb)/(3,920,000 lb)]. Such a change would have negligible impact on vessel stability and trim.

PWG Service Requirements

The new unit would be located near the existing ballast manifold; therefore, tying into the ballast system would be straightforward. Electrical, seawater, and brine connections would have to be added. Seawater would be supplied from the vessel's main seawater system located in the main machinery room (lower level), with brine being discharged overboard by way of the auxiliary machinery room. The new PWG draws 36.6 amps at 220 volts (normal operating amps, Sea Recovery, 2013), resulting in a connected load of just over 5 kW (36.6 amps x 220 volts = 8,052 watts). This load would account for approximately 0.2 percent of the vessel's current electrical capacity of 4,540 kW (NOAA, no date c).

4.3.3 <u>Conclusion</u>

Overall, this analysis demonstrates it is feasible to retrofit the *Oscar Dyson* with a PWG capable of generating potable water at rates that would compensate for fuel consumption and that also would meet additional potable water demands met by the currently installed PWG. The machinery space provides sufficient clearance for PWG installation and subsequent operation/maintenance. The impact on vessel stability and trim from the weight differential associated with the retrofit would be negligible since it would result in a change of well under 1 percent. Finally, the PWG electrical load is relatively small compared to the vessel's electrical capacity.

The total capital investment cost for retrofitting the *Oscar Dyson*, based on a linear interpolation of Table 3-9 cost data for 1.0- and 15-gpm PWG-chlorination systems, would be $67,200. The daily O&M cost would be approximately $12 per day, or approximately $4,400 per year (assuming 365 days per year). The O&M costs are similarly derived from linear interpolation of Table 3-10 cost data.

4.4 PARAMETRIC ANALYSIS TO EXTRAPOLATE THE CASE-STUDY FINDINGS

Parametric design data are often used in the marine industry by naval architects and marine engineers in early stages of ship design. A parametric analysis uses vessel design characteristics, such as vessel length, beam, hull coefficients, required power, and weights, and presents these characteristics as a function of other vessel characteristics, either in a graphical form or by mathematical formulas. In this way, data from previously designed and built vessels or previously conducted design studies can be used for comparison to other vessel designs.

Parametric relationships defined by mathematical formulas are particularly useful for computer-assisted design studies.

EPA, in consultation with a naval architect, conducted a parametric analysis to determine whether the conclusions of the three case studies described in Sections 4.1 through 4.3 can be applied to other vessels. The analysis approach determines if the size of the machinery space of the vessels used for the case studies are representative of other vessels.

4.4.1 Meaningful Design Parameters

The most significant factor in determining if it is practical to install a particular piece of equipment within a machinery space is the required deck area that the piece of equipment requires. (The required deck area is the footprint of the equipment plus any clearances to meet operational or maintenance requirements.) A secondary factor is the volume requirement of the equipment.

As discussed in Sections 4.1.4, 4.2.3, and 4.3.3, EPA's PWG retrofit analyses indicated that weight and power requirements were not driving factors in determining whether a PWG could be installed in an existing vessel. Therefore, EPA did not address those characteristics as part of the parametric study.

4.4.2 Designs Used for EPA's Parametric Analysis

The data used for the parametric analysis were derived from vessel drawings. The drawings either were provided by vessel owners, specifically for this study, or were found in published sources. For a limited number of designs, EPA used proprietary drawings and masked the specific vessel names in these instances to allow for presentation of the data. In total, the parametric analysis used data from 23 vessel designs to determine suitable parametric relationships. This included data from research vessels, towboats, tugboats, passenger vessels, and offshore supply vessels. The sizes of the vessels included in this study ranged in length from 50 to 350 ft.

Data for certain vessel types, such as passenger and fishing vessels, were not readily available for this analysis. However, EPA believes that the parametric relationships developed based on other vessel types may be applicable to them as discussed in the following sections.

The data collected for each design were length (overall), length (between perpendiculars), beam, depth, draft, displacement, number of propellers, number of engines, propulsion horsepower, number of generators, and total installed generating capacity. Machinery space deck area and machinery space volume were determined from the available drawings.

Guidelines used to determine machinery space areas and volumes included:

- Excluded separate control rooms in the machinery space areas.
- Included auxiliary machinery spaces only if they were adjacent to the main machinery space.

- Based machinery space volumes on projected deck areas from the deck plates to the molded line of the deck above.

Table 4-4 lists the vessels used for the parametric analysis along with their principal characteristics and machinery space deck areas and volumes. The three vessels chosen for the case studies (the *R/V Pelican*, the USACE towboat, and the *Oscar Dyson*) appear in bold. The references section includes notes regarding the source of the vessel information used in the parametric study.

Table 4-4. Vessel Data Used in the Parametric Analysis

Vessel Type/Name	Length, Overall (ft)	Beam (ft)	Depth (ft)	Displacement (long tons)	Propulsion Horsepower (hp)	Cubic Number[1] (CN)	Machinery Space Deck Area (ft^2)	Machinery Space Volume (ft^3)
Research								
Pelican	**116.3**	**26.5**	**12.0**	**515**	**850**	**370**	**772**	**6,946**
Tagos	224.0	43.0	20.0	2,262	1,600	1,926	4,485	32,858
Oscar Dyson	**206.7**	**49.2**	**28.4**	**2,400**	**2,976**	**2,888**	**3,179**	**39,457**
Savannah	92.0	27.0	12.8	329	880	317	520	4,112
Sharp	150.0	32.0	14.0	N/A	1,283	672	1,384	12,692
Sikuliaq	242.0	52.0	27.5	3,394	6,000	3,461	3,794	41,726
Towboat								
Grand Tower	65.0	24.0	8.5	164	1,100	133	1,238	10,146
George C Grugett	114.0	35.0	10.3	510	3,000	409	1,390	13,409
Creve Coeur	77.4	32.0	10.0		1,280	248	838	8,032
USACE Vessel	**150.0**	**42.0**	**11.7**	**736**	**4,640**	**735**	**2,316**	**27,092**
Prairie du Rocher	51.0	19.0	8.5	88	880	82	384	3,489
Shorty Baird Replacement	95.0	39.0	10.0	N/A	2,600	371	1,492	13,100
Ted Cook	83.0	34.0	10.0	N/A	2,000	282	903	9,526
Passenger								
Unnamed Passenger Vessel	350.0	54.0	20.0	3,200	5,000	3,847	4,823	49,256
Tugboat								
Harbor Tug	78.0	34.0	12.3	N/A	5,080	327	820	8,405
Sause Brothers	135.4	46.0	21.3	N/A	8,000	1,324	1,280	17,920
China Tug	100.4	35.4	14.8	566	3,500	524	1,020	9,282
Great Lakes Tug	135.3	49.0	26.0	1,550	9,280	1,724	2,677	30,646

Table 4-4. Vessel Data Used in the Parametric Analysis

Vessel Type/Name	Length, Overall (ft)	Beam (ft)	Depth (ft)	Displace-ment (long tons)	Propulsion Horsepower (hp)	Cubic Number[1] (CN)	Machinery Space Deck Area (ft^2)	Machinery Space Volume (ft^3)
Offshore Support Vessel (OSV)								
Supply Boat	116.3	54.0	19.0	N/A	6,200	1,193	1,274	19,110
Dive Support Vessel	250.0	50.0	22.0	N/A	5,000	2,750	1,760	28,160
Trinity OSRV	208.5	44.0	17.0	2,514	2,560	1,560	1,152	15,600
Bender OSRV	210.0	45.0	17.0	2,570	3,000	1,607	1,300	15,600
Fishing Vessel								
Bay Islander	78.0	22.0	12.0	N/A	650	206	228	2,282

N/A – Not Available
[1] The cubic number is the product of the length, beam, and depth divided by 100.

4.4.3 Parametric Relationships

The primary variable of interest is machinery space deck area, with machinery space volume of secondary interest. Therefore, for this analysis they are the meaningful dependent variables, which are the function of some independent variable. The goal is to select an independent variable, a function of which will accurately predict the value of the dependent variables. The independent variable selected should not only result in a good fit of the available data, but should also make sense from an engineering standpoint.

Potential independent variables evaluated for this study included propulsion horsepower, length (overall), displacement, and cubic number (CN) (CN is defined as the product of the length, beam, and depth (in ft) divided by 100). For each potential independent variable, machinery space deck area and machinery space volume were evaluated using various curve fit types (i.e., linear, polynomial, exponential, etc.). It was concluded that a linear fit was most appropriate type to use for the data set evaluated. In each case, the coefficient of determination, R^2, was calculated.

Machinery-related parametric design data, particularly for machinery weight, is often presented as a function of installed horsepower. Therefore, that was the initial variable chosen for this study. However, as seen from the Figure 4-13, the relationship between propulsion horsepower and machinery space deck area is very poor, with a R^2 of around 0.1.

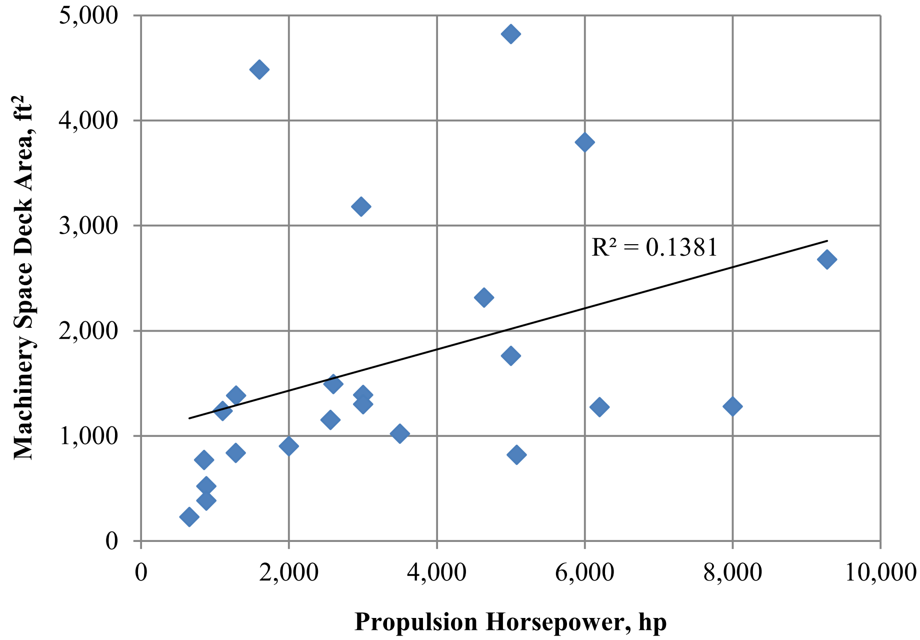


Figure 4-13. Machinery Space Deck Area vs. Propulsion Horsepower

Using the dimensional variables indicated in the following figures achieves a much better fit.

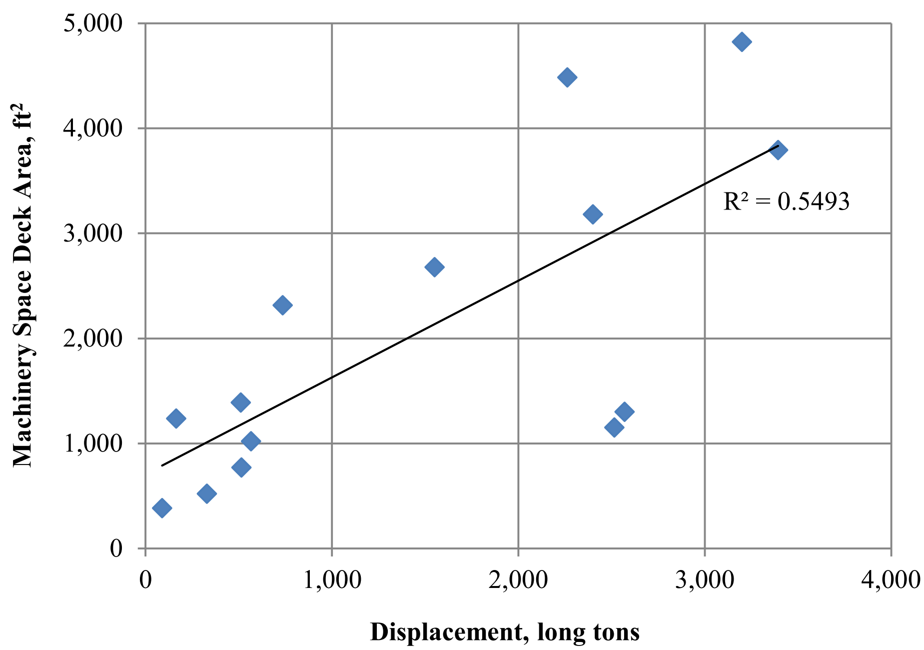


Figure 4-14. Machinery Space Deck Area vs. Displacement

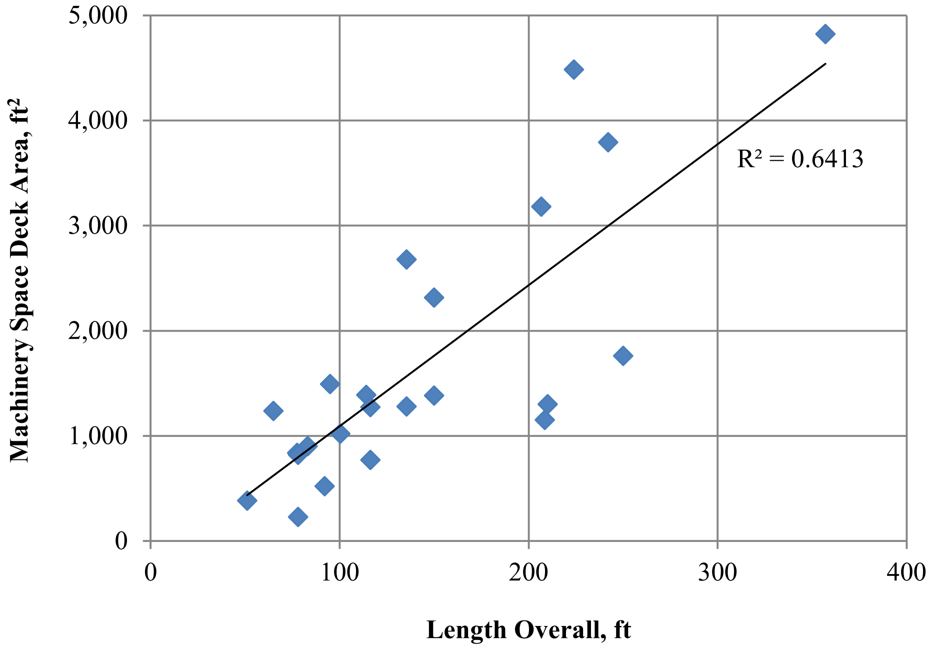


Figure 4-15. Machinery Space Deck Area vs. Length Overall

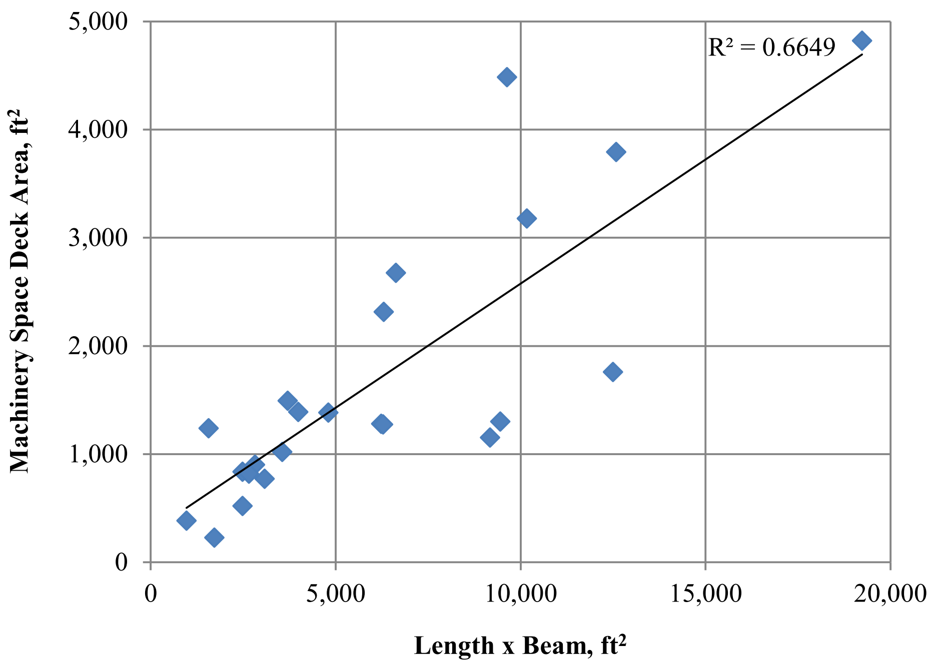


Figure 4-16. Machinery Space Deck Area vs. Length x Beam

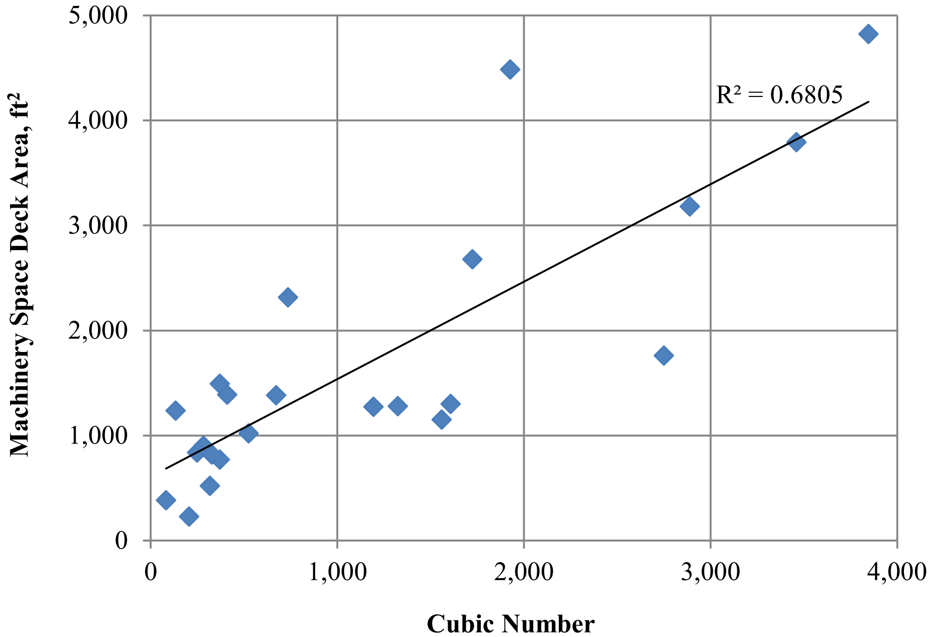


Figure 4-17. Machinery Space Deck Area vs. Cubic Number

With R^2 values of 0.66 and 0.68, respectively, length x beam and cubic number represent the best fits of the vessel data. This indicates that machinery space deck area is a function of overall vessel size. Although not presented here, the results for machinery space volume are similar to those for machinery space deck area. For machinery space volume, R^2 ranged from 0.25 based on horsepower to 0.85 based on cubic number.

The machinery space deck area vs. length x beam was chosen as the most appropriate parameter for the parametric analysis due to the linear fit and the match of units between the dependent and independent variables (i.e., machinery space deck area and length x beam both have units of ft^2). Figure 4-18 presents the same data set as Figure 4-16 but also identifies the various vessel types contained in the data set. It should be noted that the four OSV vessels used in the study are all below the linear fit trend line. Removing the OSV vessels from the data set would increase the value of R^2 to 0.86. This is discussed further in Section 4.4.5.

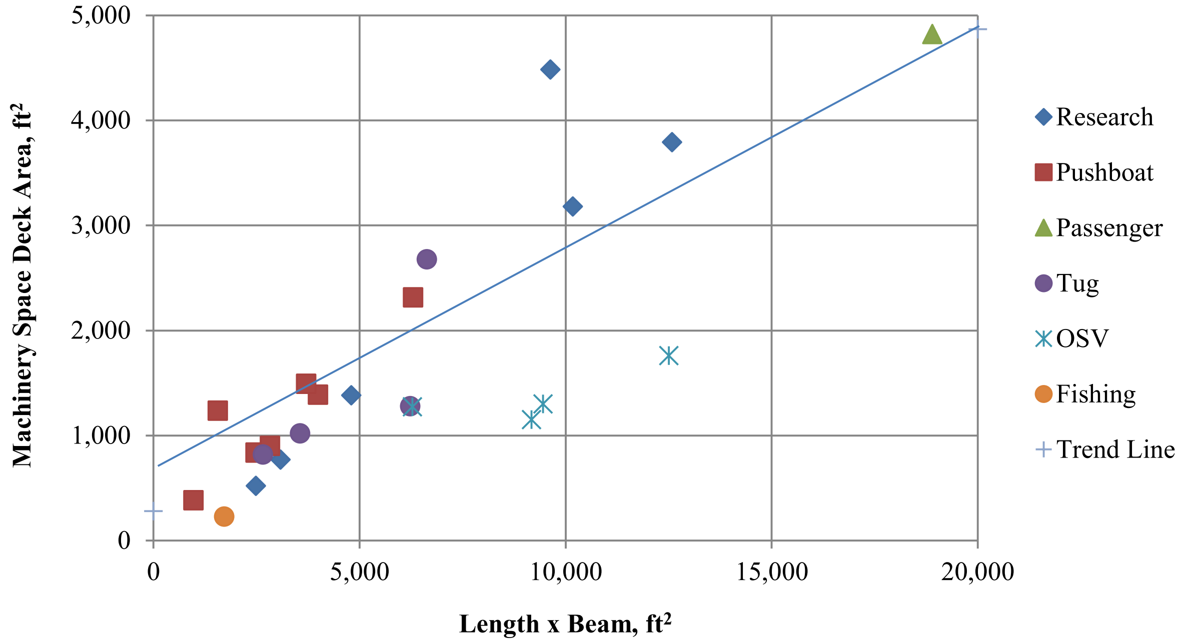


Figure 4-18. Machinery Space Deck Area vs. Cubic Number (Vessel Types Identified)

4.4.4 Case Studies vs. Parametric Data

The vessels used for the case studies were chosen to obtain a variety in vessel size and type, as permitted by the availability of suitable drawings. Figure 4-19 identifies the case study vessels compared to the other linear trend line and other vessels in the data set.

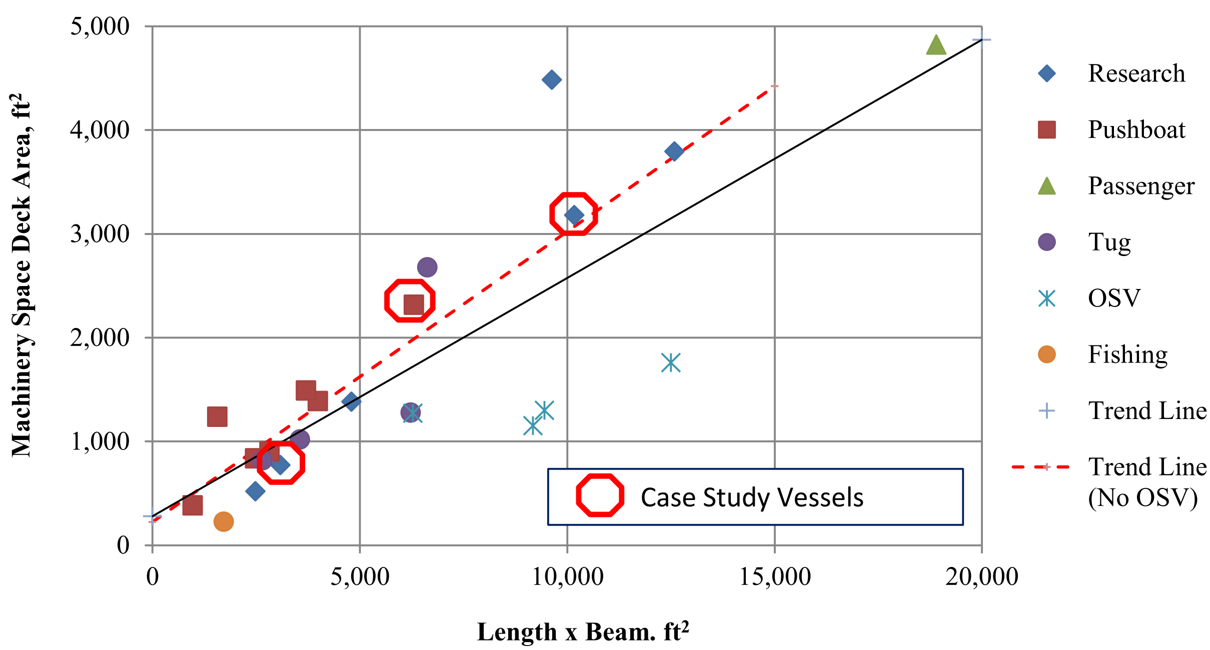


Figure 4-19. Machinery Space Deck Area vs. Length x Beam (Case Study Vessels Identified)

The two larger case study vessels (the USACE towboat and *Oscar Dyson*) are above the trend line while the smallest of the case study vessels (the *Pelican*) is below the trend line. Removing the four OSV vessels from the data set results in a different trend line with a better fit as previously discussed. All three case study vessels lie very close to this trend line. This indicates that, with the exception of OSV type vessels, the results of the case studies are likely representative of other vessels in this size range regarding machinery space size and indicate it is generally possible to retrofit vessels with suitable PWG units.

4.4.5 Application of Case Study Results to Retrofitting Various Vessel Types

Based on the results of the case studies and parametric data analysis, the different vessel types were analyzed to evaluate which ones could feasibly be retrofitted for PWG installation. Due to the varying designs of vessel types, it is not possible to make definitive vessel-specific conclusions; however, it is possible to draw general conclusions based upon the following:

- Machinery space deck area (the case studies indicate that deck areas equal to or above the data set trend line can accommodate PWG installation).
- Machinery space deck area demands for particular vessel types.
- Power density (as discussed below).

Power density is defined as propulsion horsepower divided by the cubic number, and represents the propulsion power compared to the overall size of the vessel. Since the parametric data suggest that length x beam is the most significant independent variable for machinery space deck area, the power density becomes a secondary factor in understanding machinery space size and, more importantly, the space that may be available for installation of additional equipment, such as PWG units. A high power density means that not only will the main engines be larger, but ancillary equipment, which supports the main engines such as fuel, cooling, and exhaust systems, will also be larger.

Below is a discussion of the application of the parametric analysis by vessel type.

Oceanographic Research Vessels

An oceanographic research vessel is defined as one used for instruction or research in the fields of limnology or oceanography. This includes marine geophysical or geological surveys, atmospheric research, and biological research. They are often fitted with a number of winches and lifting devices (such as cranes or A-frames) to enable scientific gear to be placed over the side. Vessels intended to conduct fisheries research are outfitted with trawling or other fishing gear. The number of persons aboard includes scientific personnel, often significantly increasing the number of persons over the vessel’s operating crew.

Research vessels generally do not carry any variable loads except for fuel, fresh water, and possibly wastewater. Ballast water, if required, is used to compensate for fuel burn.

Compared to other vessel types, the machinery spaces of research vessels may differ due to the following:

- Additional hydraulic power take-offs or power packs to service the winches and lifting devices.
- Additional seawater pumps to provide seawater for scientific purposes.
- Additional capacity to accommodate the larger number of persons aboard such as:
  - Increased generator capacity.
  - Increased fresh-water-making capacity.
  - Increased size of marine sanitation device.
- For vessels engaged in fisheries surveys or research, equipment to meet low radiated noise requirements:
  - Diesel electric propulsion.
  - Noise treatment for many pieces of machinery including the main engines and generators.
- Low power density; the six research vessels included in the data set average just 1.4 hp/CN.

The net effect of these differences means that research vessels typically contain smaller main engines but more, and/or larger, auxiliary equipment than other types of vessels of similar size.

EPA included several research vessels ranging in length from 92 to 242 ft in the data set used for this analysis, and used two for the case studies. Based on those case studies, it appears generally feasible to retrofit PWG units into research vessels for use in ballasting operations.

Towboats

A towboat is designed to push a barge or group of barges. They generally have a barge shape when viewed from above instead of the ship-shape found in most other vessel types. They are most often used in protected waters and are most common on the U.S. inland river system. Towboats are generally twin-screw, high powered for their size, and have rudders located both forward and aft of their propellers to assist in maneuvering while pushing a group of barges. The number of persons aboard consists solely of a small operating crew. Towboats typically do not have PWGs, but instead take potable water aboard from municipal water sources along their routes.

Towboats generally do not carry variable loads except for fuel, fresh water, and possibly wastewater. Ballast water, if required, is used to compensate for fuel burn and to provide acceptable trim.

Compared to other vessel types, the machinery spaces of towboats may differ due the following:

- Rectangular shape of machinery spaces.
- No competition for main deck space below other than for tankage.

- Machinery space extending to above the main deck with generators or other auxiliary equipment located above the main deck.
- Large propulsion hp compared to other types of vessels of comparable size; the seven towboats included in the data set had an average power density of 6.9 hp/CN.

The net effect of these differences means that towboats will typically have somewhat more available machinery space deck area than other types of vessels of similar size.

Several towboats ranging in length from 51 to 150 ft were included in the data set used for this analysis, with the largest used for one of the case studies. Based on this case study, and the machinery space deck areas typically found in this type of vessel, it is appears generally feasible to retrofit PWGs into towboats for use in ballasting operations.

Tugboats

A tugboat is designed to push, tow, or haul alongside another vessel. Unlike towboats, they are generally ship-shaped when viewed from above. There are several types of tugboats:

- Harbor tugs, which are used primarily to help dock large ships. They are designed to be highly maneuverable and have an exceptionally large amount of power for their size. Accommodations are minimal. They generally have a small operating area, such as within a particular port. They typically do not have a PWG aboard and instead fill their potable water tanks from available municipal water.
- Ocean-going tugs are larger than harbor tugs. They have a large amount of power for their size. Accommodations are provided for a crew suitable for an extended voyage.
- Integrated tug-barge tugs are similar to ocean-going tugs but are designed to push a barge using a notch built into the barge. They are most often used on coastal trades.

Propulsion type varies depending on the design and includes single or twin propellers, single or twin Z-drive propellers, or one or multiple vertical cycloidal drive (Voith Schneider) propulsion units.

Tugboats generally do not carry any variable loads except for fuel, fresh water, and possibly wastewater. Ballast water, if required, is used to compensate for fuel burn and to provide acceptable trim.

Compared to other vessel types, the machinery spaces of tugboats may differ due the following:

- Confined space due to typical tug hull shape.
- Large propulsion hp compared to other types of vessels of comparable size; the four tugboats included in the data set had an average power density of 6.6 hp/CN.

The net effect of these differences means that tugboats will typically have less available machinery space deck area than other types of vessels of similar size. For example, from Table 4-4, the towboat *George C. Grugett* is of similar dimensions and horsepower as the tugboat *China Tug*. However, the tugboat has a machinery space deck area 36 percent smaller than the similarly sized and powered towboat. The USACE towboat has installed power similar to Tug #1 in Table 4-4, but the towboat is much larger in overall dimensions and has a machinery space deck area 280 percent greater than the tugboat. Due to the typical tugboat hull shape and large power machinery installed, it may be challenging to retrofit PWGs into tugboats for ballasting operations.

Offshore Support Vessels (OSV)

Offshore support vessel is a term that includes a variety of vessel types supporting the offshore oil industry. Although designed for various missions as described below, these vessels tend to have commonalities in their configurations regarding overall arrangement and machinery space location and design. OSVs typically are designed with a forecastle, accommodations and pilothouse located forward, and a large open aft deck. The machinery is located in a confined space aft of amidships, with exhausts leading forward to avoid stacks interfering with the aft deck. OSVs have evolved from being fairly simple and low-cost designs to very sophisticated vessels with complicated dynamic positioning systems that include bow and stern thrusters and Z-drive propulsion.

Major types of OSVs include the following:

- Vessels that transport materials and equipment to offshore installations.
- Anchor handling and towing vessels, which handle anchors for offshore installations and also tow them from location to location.
- Diving and remote operating vehicle (ROV) support vessels, which provide support for diving systems and ROVs.
- Oil spill recovery vessels, which are equipped to respond to oil spills.

Although OSVs comprise a range of vessel types, some general observations can be made that apply to many of these vessels. Compared to other vessel types, the machinery spaces of OSVs may differ due to the following:

- Confined space due to other demands for below-deck space (particularly for offshore supply boats where the space is required for mud tanks and ballast tanks).
- Space demands for mud pumps for offshore supply vessels.
- Space demands for larger generators required for dynamic positioning systems.
- Modest propulsion hp compared to other types of vessels of comparable size; the four OSVs included in the data set have an average power density of 2.4 hp/CN.

OSVs, depending on their type, may carry significant variable loads in addition to fuel, fresh water, and possibly wastewater. Offshore supply vessels in particular carry drilling pipe, drilling mud, and other materials that are offloaded to the offshore platform. Ballast water, when required for stability, has to be added at a rate equal to the rate of the unloading of pipe and mud; in gpm, that amount of ballast water is outside the practical limits of what an onboard PWG could provide.

It is noted that each of the four OSVs included in the data set have machinery space deck areas significantly lower than the overall trend line, which is in some ways an aberration from the rest of the data. (Removing the four OSVs from the data set significantly increases the R^2 value from 0.66 to 0.86). This indicates the machinery spaces of the OSVs are more crowded than for the other vessel types. Based on the relatively small machinery space size and possible need for a large rate of ballasting, it may be challenging to retrofit PWGs into OSVs for ballasting operations.

Passenger Vessels

Passenger vessels in the data set vary widely in the type of service they provide and number of passengers aboard. In terms of ballasting practices, they can be divided into two general types: day service or overnight service.

Vessels in day service include ferries, dinner vessels, and tour and excursion boats. These boats generally operate in limited geographic areas and commonly return to their point of departure. Per Part 2.2.3.5.3 of the VGP, vessels are exempt from ballast water management requirements if they:

- Are engaged in short-distance voyages that operate or take on and discharge ballast water exclusively in one COTP zone or
- Do not travel more than 10 nautical miles and cross no physical barriers or obstructions (USEPA, 2013a).

Given the limited geographic area associated with their service, day-service passenger vessels are likely to be exempt from the VGP's ballast water management requirements.

Vessels in the size range of this study engaged in overnight service are typically small cruise ships with a passenger capacity ranging from fewer than 49 to several hundred. They include ships designed for either coastal service or inland river service. In almost all cases, the vessels have either geared diesel or diesel electric propulsion.

Compared to other vessel types, the machinery spaces of overnight passenger vessels may differ due to the following:

- Space demands for marine sanitation devices and wastewater holding tanks.
- Space demands for air conditioning and other HVAC equipment.
- Space demands for larger generators needed for passenger service electrical needs.

- Lower propulsion hp compared to other types of vessels of comparable size.
- Below-deck space demands for storage and service spaces.

The evaluation of six American small cruise ships indicates a power density ranging from 1.3 to 2.1 hp/CN, with an average of 1.8 hp/CN (Table 4-5). EPA identified the ships in Table 4-5 through the supplemental search and review of internet sources and industry publications. This is a low power density and is comparable to the power density for oceanographic research vessels of 1.4 hp/CN (discussed above), indicating that it should be feasible to install PWGs for use in ballasting operations in overnight passenger vessels.

Table 4-5. Vessel Characteristics for Various Small Cruise Ships

Vessel Name	Length (ft)	Beam (ft)	Depth (ft)	Propulsion Power (hp)	Cubic Number[1] (CN)	Power Density (hp/CN)	Source
Unnamed Passenger Vessel	350	54	20	5,000	3,780	1.3	OA, 2014
Queen of the Mississippi	230	50	12	2,600	1,323	2.0	SSC, no date
Kennicott	382	85	26	13,380	8,280	1.6	ABS, 2014c
Niagara Prince	177	39	9	1,142	625	1.8	Blount, no date
Grande Caribe	183	40	9	1,300	662	2.0	Blount, no date
Independence	223	50	8	2,842	1,331	2.1	Workboat, 2011
Average	*258*	*53*	*14*	*4,377*	*2,667*	*1.8*	

[1] The cubic number is the product of the length, beam, and depth divided by 100.

Fishing Vessels

Fishing vessels vary widely in size range and type of fishing operations. In almost all cases, the vessels have geared diesel propulsion with single screw configuration being the most common.

Although fishing vessels comprise a range of vessel types, some general observations can be made that apply to many of these vessels. Compared to other vessel types, the machinery spaces of fishing vessels may differ due to the following:

- Space demands for hydraulic power units required for fishing gear.
- Below-deck space demands for fish holds.
- Space demands for refrigeration equipment (for vessels with chilled fish holds).

The fishing vessel included in the parametric analysis has noticeably less machinery space deck area than the overall trend line for all vessels would suggest, and has a power density of 3.1 hp/CN. Analysis of 13 other recently built or modified fishing vessels (Table 4-6) indicate power densities ranging from 2.4 to 4.2 hp/CN, with an average of 3.0 hp/CN. EPA identified these ships through the supplemental review of industry publications. These power densities are comparable to that of the fishing vessel included in the parametric analysis. Due to the small deck area observed in both the parametric and supplemental analyses, it appears that it generally may be challenging to install a PWG in fishing vessels.

Table 4-6. Vessel Characteristics for Various Fishing Vessels

Vessel Name (Service)	Length (ft)	Beam (ft)	Depth (ft)	Propulsion Power (hp)	Cubic Number[1] (CN)	Power Density (hp/CN)	Source
Unnamed Vessel (Combination Scalloper and Trawler)	86	24	12	600	248	2.4	Chowning, 2013a
Arctic Prowler (Longliner)	136	40	15	2,000	816	2.5	Crowley, 2013a
Pursuit (Combination Scalloper and Trawler)	88	24	11	600	239	2.5	Chowning, 2014a
Unnamed Vessel (Shrimper)	105	27	13	1,000	369	2.7	Chowning, 2012
Raiders (Scalloper)	98	27	14	1,000	370	2.7	Chowning, 2013b
Rappahannock (Menhaden Steamer)	196	40	14	3,000	1,098	2.7	Crowley, 2013b
Norseman (Scalloper)	95	28	13	1,050	346	3.0	Chowning, 2014b
Araho (Trawler)	194	49	16	4,000	1,284	3.1	Chowning, 2013c
Bella Skye (Longliner)	75	20	8	500	120	4.2	QAS, no date
Fleeton (Menhaden Steamer)	184	38	14	3,000	979	3.1	Crowley, 2013b
Bay Islander (Trawler)	78	22	12	650	206	3.2	McKernan, 2006
Concordia (Scalloper)	95	28	15	1,000	386	2.6	Crowley, 2012
Miss Emily (Combination Shrimper, Crabber, and Tenderer)	72	28	13	660	262	2.5	Chowning, 2013d
Average	*116*	*30*	*13*	*1,466*	*517*	*3.0*	

[1] The cubic number is the product of the length, beam, and depth divided by 100.

4.4.6 Conclusions

A general conclusion from this parametric analysis is that machinery space deck area is best predicted as a function of the vessel's length x beam. In addition, the impact of incorporating a PWG capable of producing enough water ballast to compensate for fuel consumption is much more a function of vessel size than of vessel horsepower. Based on this parametric analysis, it generally appears feasible to retrofit PWG units into research vessels, towboats, and small overnight passenger vessels; it generally appears less feasible to retrofit PWG units into tugboats, offshore support vessels, and fishing vessels.

4.5 New Design vs. Retrofitting

The case studies described in Sections 4.1 through 4.3 were based on looking at existing machinery space arrangements and determining if there was sufficient space to install a suitably sized PWG for ballast water production within the existing machinery space. This section looks at the impact on a new vessel design if the PWG installation was one of the design requirements. For this assessment, EPA assumes that any additional PWG units would be sized to provide ballast water at a rate equal to the vessel's fuel burn.

In a new vessel design, particularly in the size range of EPA's analysis, space is often at a premium with machinery, fuel and ballast tankage, cargo, and possibly passenger and crew spaces all needing to fit in a limited amount of below-deck space. It is the job of the naval architect, in cooperation with the owner, to make trade-offs between these various demands in both determining the overall dimensions of the vessel and in allocating space for each function.

Based upon the parametric analysis and information regarding available PWG units, it can be determined, on an average basis, how much the vessel dimensions need to be increased to accommodate the PWG units. A basic assumption, verified by the case studies, is that machinery space deck area is the critical variable in determining whether a machinery space can accommodate a PWG unit.

4.5.1 Parametric Data for PWGs

The dimensions of six available PWG models were used to develop a relationship between PWG capacity and required deck area. Clearances of 2 ft on each side and 2 ft in front of each unit were included as part of the required area. In addition, the area required for a chlorinator consisting of a 21-in diameter tank with a 2-ft clearance in front of the unit was included. The required clearances were based on information from the respective vendors. No additional clearance is required at the rear of the PWG units. The chlorinator does not require clearances at the sides or rear.

Table 4-7 presents the PWG deck area requirements for the six available PWG models noted above. Figure 4-20 shows the relationship between the required PWG deck area and PWG capacity (in gpm).

Table 4-7. Deck Area Requirements by PWG Model

PWG Model	Model Configuration	PWG Max Rating (gpm)	PWG Dimensions						Deck Area (ft^2)		
			Length (ft)			Width (ft)					
			PWG	Clearance	Total	PWG	Clearance	Total	PWG	DS	Total
Axeon S3	Horizontal	1.5	4	4	8	2	2	4	32	8	40
Axeon M2	Horizontal	25	8.3	4	12.3	2.6	2	4.6	56.5	8	64.5
Coral Sea	Horizontal	4.7	5.1	4	9.1	2.9	2	4.9	44.2	8	52.2
Tasman Sea	Vertical	16.5	6.4	4	10.4	3.8	2	5.8	59.9	8	67.9
Axeon R2	Vertical	6.3	3.1	4	7.1	2.2	2	4.2	29.5	8	37.5
Coral Sea	Vertical	4.7	2.4	4	6.4	2.9	2	4.9	31.3	8	39.3

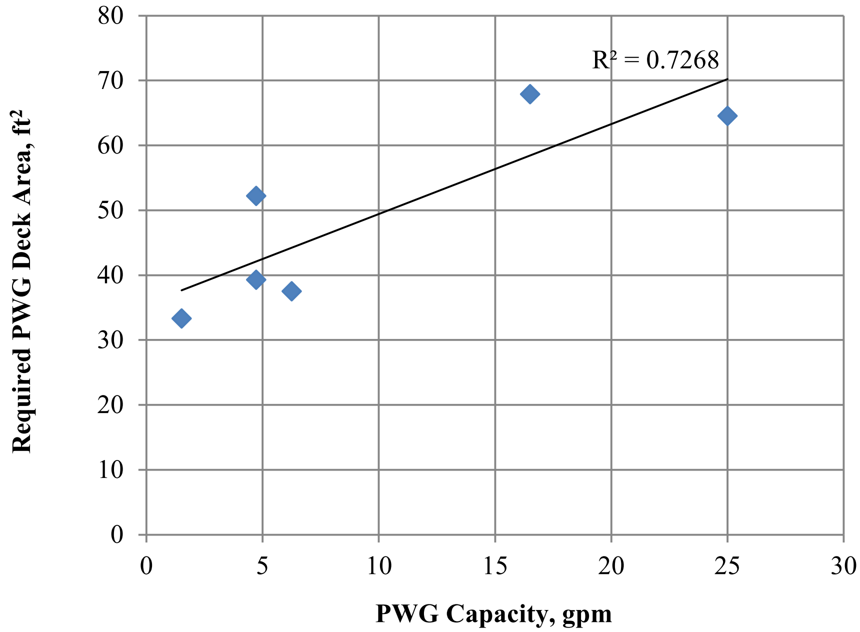


Figure 4-20. PWG Required Deck Area vs. PWG Capacity

A linear trend line was fit to the data with a R^2 factor of 0.73. The impact of the smaller deck footprint of the vertical configuration units is largely diluted by the additional requirements of clearance areas and the chlorinator area.

4.5.2 Impact on Vessel Characteristics

In theory, adding any additional piece of equipment to a design will result in a larger ship. In practice, a designer can often accommodate some amount of additional equipment by using a more efficient design or by making tradeoffs involving access, operational efficiency, or convenience to operating personnel.

The greatest impact on the vessel design occurs when vessel dimensions are increased to accommodate additional equipment without making additional design tradeoffs. This study looks at the impact on vessel design using this approach, as it demonstrates the most severe potential impact of the additional equipment, and as such "bounds the problem." In cases where the vessel design makes other tradeoffs to accommodate additional equipment, the impact on the overall vessel dimensions will be less than that indicated in this study.

Figure 4-16 gives the relationship, based on the data set available, between machinery space deck area and length x beam. This relationship indicates that each increase in the product of length x beam of 1,000 would increase the machinery space deck area by 280 ft^2. (This is derived from the linear trend line of Y = .2798X + 225.3, where Y is deck area and X is length x beam). Conversely, a desired increase in machinery space deck area of 100 ft^2 will require an increase of length x beam of 100/0.2798, or 357. (Note that the trend line discussed here excludes the four OSVs from the data set.)

The required additional PWG capacity is based on fuel consumption, which is a function of installed power (both for the propulsion engines and auxiliary engines such as diesel generators). As all vessels in the parametric data set use diesel engines, it is appropriate to select diesel engine fuel consumption values for this analysis. Modern medium speed diesel engines have published fuel-specific fuel consumption rates ranging from 0.33 to 0.37 lb/hp-hr (Caterpillar, 2008). This analysis uses a conservative fuel consumption rate of 0.4 lb/hp-hr. Table 4-8 presents a calculation of the impact on length x beam of adding a requirement to install a PWG with a capacity to generate water to compensate for fuel consumption.

Table 4-8. Required Increase in Length x Beam due to PWG Requirements

Total Installed Horsepower (hp)	Total Fuel Consumption (lb/hr)	Total Fuel Consumption (lb/min)	Required PWG Rate (gpm)	Required PWG Area (ft^2)[1]	Corresponding Length x Beam Increase (ft^2)
500	200	3.33	0.40	38.6	137.8
1,000	400	6.67	0.80	39.1	139.8
1,500	600	10.00	1.20	39.7	141.8
2,000	800	13.33	1.60	40.2	143.8
2,500	1,000	16.67	2.00	40.8	145.7
3,000	1,200	20.00	2.40	41.3	147.7
4,000	1,600	26.67	3.20	42.4	151.7
5,000	2,000	33.33	4.00	43.6	155.7
6,000	2,400	40.00	4.80	44.7	159.6
7,000	2,800	46.67	5.60	45.8	163.6
8,000	3,200	53.33	6.39	46.9	167.6
9,000	3,600	60.00	7.19	48.0	171.6
10,000	4,000	66.67	7.99	49.1	175.5

[1] Includes maintenance clearances and space for chlorinator.

The impact of the PWG on a vessel is much greater for smaller vessels than for larger ones for a given horsepower (see Table 4-8). For example, one of the smaller vessels in the data set, the *R/V Pelican*, has a length x beam of 3,082 ft^2. Even the lowest horsepower in the table (500) results in an increase in required length x beam of over 10 percent. In contrast, for the *Oscar Dyson*, one of the larger vessels in the data set with a length x beam of 10,170 ft^2, adding a PWG suitable to support a total installed horsepower of 10,000 would increase the length x beam requirement by less than 2 percent.

It is likely that naval architects faced with a 10 percent increase in vessel size would find other alternatives to deal with the issue of ballast water management. For instance, they might consider increasing the vessel's beam or lowering its center of gravity (perhaps by adding permanent solid ballast) to eliminate the need for ballast water altogether. Alternatively, as illustrated in previous case studies, existing free space on a vessel can sometimes be utilized to accommodate new equipment.

Another potential impact in incorporating PWGs into new vessel designs would be on the arrangement of ballast tanks. It is generally current practice (with the exception of peak tanks) to keep ballast tanks either full or empty. This approach minimizes the adverse effects on stability that are associated with partially full tanks. In a new design, where it is known that the practice would be to fill ballast tanks incrementally, the naval architect would likely maximize stability by using narrow or baffled tanks and wing tanks in lieu of double bottom tanks for water ballast.

Although the decision-making process will differ with each design, it is possible to make some general observations for various vessel types as discussed below.

Oceanographic Research Vessels

Oceanographic research vessels generally do not carry variable loads except for fuel, fresh water, and wastewater. Ballast, if required, is used to compensate for fuel consumption. Based on observations from the case studies and parametric analysis of existing vessels, it appears that using PWGs for ballast water for newly designed oceanographic research vessels may be feasible. These vessels typically have research-specific auxiliary systems that are located either in the main machinery space or, as needed, in a separate auxiliary machinery space. Adding a PWG makes it more likely that new vessel designs would further utilize and potentially expand the footprint of the auxiliary machinery space.

Towboats

Towboats generally do not carry variable loads except for fuel, fresh water, and wastewater. Ballast water, if required, is used to compensate for fuel burn and to provide acceptable trim. The hull geometry of towboats results in machinery spaces with large deck areas. Further, without other demands for below-deck spaces, suitably sized PWGs could be installed despite the large installed horsepower typical for these vessels. Based on observations from the case studies and parametric analysis of existing vessels, it appears that the using PWGs for ballast water for newly designed towboats may generally be feasible.

Tugboats

Tugboats generally do not carry variable loads except for fuel, fresh water, and wastewater. Ballast water, if required, is used to compensate for fuel burned and to provide acceptable trim. However, because of the hull shape and large propulsion horsepower that is typical of this vessel type, new vessel designs would require increasing the overall vessel size. Based on this and observations from the case studies and parametric analysis of existing vessels, it appears that using PWGs for ballast water for newly designed tugboats may be challenging without increasing vessel dimensions.

Offshore Support Vessels (OSVs)

OSVs, depending on their type, may carry significant variable loads in addition to fuel, fresh water, and wastewater. Offshore supply vessels in particular carry drilling pipe, drilling mud, and other materials that are offloaded at offshore platforms. When required for stability, the intake of ballast water must occur at a rate equal to that of the cargo unloading rate. The required ballast water intake rates would be significant and outside the practical limits of what a PWG could supply. Also, OSV machinery spaces are more limited than in other vessel types, posing further barriers to feasibility. Based on observations from the case studies and parametric analysis of existing vessels, it appears that using PWGs for ballast water for newly designed OSVs may not be feasible without increasing the overall vessel size by a significant amount.

Small Overnight Passenger Vessels

Small overnight passenger vessels generally have a low power density comparable to that of oceanographic research vessels (see discussion in Section 4.4.5). Therefore, it appears that using PWGs in newly designed vessels may generally be feasible. Small overnight passenger vessels typically have HVAC and waste management systems, which are located either in the main machinery space or, as needed, in a separate auxiliary machinery space. Adding a PWG makes it more likely that new vessel designs would further utilize and potentially expand the footprint of the auxiliary machinery space.

Fishing Vessels

Fishing vessels generally have small deck areas, as observed in Section 4.4.5. The limited deck area of this vessel type adversely impacts the overall feasibility of including PWGs in new vessels. However, their use may be feasible in some cases. Fish-hold volume and auxiliary equipment space requirements are vessel-specific and depend on the type of fishery involved. It would be more feasible to install PWGs on vessels that have less demand for fish-hold volumes and auxiliary equipment.

4.5.3 Economic Considerations

One unique aspect of newly designed vessels is that vessel designers can generally eliminate or reduce the need to ballast by designing wider vessels. The broader beam (i.e., width) will stabilize the vessel, thus reducing reliance on a PWG or eliminating its need altogether. The greater beam, however, would pose greater capital costs compared to that of a traditional vessel design, due to added construction and material costs. Also, the greater vessel size would likely result in increased operating costs, as the wider hull shape will increase hydrodynamic drag, thereby increasing fuel consumption, subsequent fuel costs, and greenhouse gas emissions.

Another unique aspect of PWG use in newly designed vessels is the costs savings generated over the life of the vessel from using potable water in the ballast tanks. Using sea or brackish water as ballast can cause deterioration of ballast tank protective coatings and corrosion of the ballast tank itself, ultimately requiring replacement of steel within the ballast tank. Using fresh water generated from the PWG would be expected to generally reduce corrosion in the ballast tank.

4.5.4 Extrapolation to Other Vessel Types and Sizes

Based on available data, EPA limited the parametric analysis to smaller vessel types. However, it is possible to project the results to larger vessel types. Clearly, it is not practical to produce potable water onboard at rates great enough to compensate for large, rapid changes in displacement as is seen in cargo operations of many ship types, such as bulk carriers or tankers. However, it may be technically feasible (although perhaps not economically feasible) for these ships to ballast with potable water provided shore-side (i.e., a municipal water supply) while discharging cargo, and then using PWGs to provide ballast water for fuel compensation purposes during their voyage.

In addition, using potable water generated onboard for ballast may be feasible for larger vessels that do not have rapidly changing loads. Vessel types fitting this category would include large passenger vessels (e.g., medium and large cruise ships) and some types of military vessels. One of the conclusions of this study is that the feasibility of retrofitting PWGs capable of producing enough water ballast to compensate for fuel consumption is much more a function of vessel size than of horsepower. Therefore, larger vessel types, particularly those with modest horsepower, may be candidates for this type of system.

One type of larger ship that might feasibly use PWGs for ballast water is large passenger ships such as cruise ships. These ships usually have large capacity distilling units to provide sufficient fresh water for hotel services (i.e., passengers, crew, wash water, etc.).

Table 4-9 provides data on three cruise ships for which published information concerning PWGs and installed power is publicly available. Large-capacity distilling units are installed in each ship. Based on installed horsepower and an assumed fuel consumption rate of 0.4 lb/hp-hr, EPA calculated the corresponding ballast rates required for fuel consumption compensation. The ballast rates range from 44 to 104 gpm. It should be noted that the assumed fuel consumption rate is conservative, given that the large diesel engines typically used in these vessels are more efficient than those used in smaller vessels. Therefore, the potable water production rates in Table 4-9 represent an upper bound for each vessel.

Table 4-9. Vessel and PWG Characteristics for Select Cruise Ships

Vessel Characteristics	*Oasis of the Seas*	*Queen Victoria*	*MSC Fantastica*
Installed PWGs	Hamworthy MSF 825/8	Wartsila Serk Como MSF	Hamworthy MSF 950-8 MSF
Production Capacity (gpm)	606	312	349
Passengers and Crew	7,700	2,900	4,874
Gallons per Person per Day	113	155	103
Installed Power (hp)	130,000	85,000	54,892
Specific Fuel Consumption (lb/hp-hr)	0.4	0.4	0.4
Fuel Consumption (lb/hr)	52,000	34,000	21,960
Required Ballast Water (gpm)	104	68	44
Required PWG Production Capacity Increase	17%	22%	13%

Sources: Kable, 2014; MP, 2010; Wartsila, 2014; Veristar, 2013

The calculation indicates that the overall water-making capacity for these large cruise ships would need to increase by 13 to 22 percent to provide sufficient fresh water for ballast to compensate for fuel use. In a new design, additional or larger distilling units would be installed to provide this additional potable water. Since these ships are already equipped with large capacity distilling units, the impact on both costs and overall ship operations of increasing their capacity will be less than for other types of vessels that do not have large, potable-water-generating capabilities. The additional cost of the larger distillers would be at least partially offset by eliminating the need for other ballast water management methods and by eliminating the corrosive effect of salt water in ballast tanks. Hence, using potable water generated onboard for ballasting may be feasible for medium and large cruise ships.

SECTION 5
EFFICACY OF PWG AND DISINFECTION SYSTEMS FOR BALLAST WATER GENERATION

A critical consideration in evaluating the utility of using a PWG ballast option is whether the resulting discharges would meet existing numeric discharge limits in EPA's 2013 VGP. These limits are the same as those finalized by the USCG in its 2012 ballast water rule. The standards are generally similar to those contained within the 2004 International Maritime Organization (IMO) Ballast Water convention. The 2013 VGP (76 FR 76716) and USCG ballast water discharge standards require:

- Organisms ≥50 micrometers (µm): <10 organisms/m^3.
- Organisms <50 µm, but ≥10 µm: <10 organisms/milliliter (ml).
- Organisms <10 µm:
  - Toxicogenic *Vibrio cholera*: <1 colony-forming units (CFU)/100 ml.
  - *Escherichia coli*: <250 CFU/100 ml.
  - Intestinal enterococci <100 CFU/100 ml.

The following sections describe tested PWG and disinfection system treatment efficacies, and whether they are capable of meeting numeric treatment limits at least as stringent as those in EPA's 2013 VGP. EPA's determination is based on a review of the scientific literature as well as a "proof of concept" field test conducted in partnership with MARAD and with technical support from the Maritime Environmental Resource Center (MERC) and Eastern Research Group, Inc. (ERG). The goal of the field test was to generate primary data on the organism treatment efficacy of such a system. The proof of concept testing occurred at MERC's ballast water testing facility in Baltimore, MD.

5.1 LITERATURE DATA ON TREATMENT EFFICACY OF PWG SYSTEMS

5.1.1 Literature Search Methodology

EPA conducted a literature search for existing information on PWG treatment efficacy data for organisms. EPA focused its literature search using the following methodology:

- Searched vendor websites and vendor system names identified through EPA's PWG research to look for existing efficacy data for these specific systems.
- Searched industry, government, and academic sources using Google Scholar to identify other articles, reports, or studies that might contain PWG and/or PWG with disinfection efficacy data.
- Searched the aforementioned sources using the following key words and combinations of key words: potable water, reverse osmosis, disinfection, treatment efficacy, treatment efficiency, CFU, and *E. coli*.

- Investigated the references noted in articles and reports found through the initial search to identify other potential sources of interest and looked for any type of pollutant removal data (not just organisms).

5.1.2 Overview of Literature Data on PWG Treatment Efficacy

PWG vendor websites and system information indicated that, while system specifications, including system treatment rates, are often publicly available, these materials do not include performance data for organisms. For the current design and marketing of PWGs, the user dictates the performance of the PWG and disinfection technology when they order the equipment from the system manufacturer. For example, when evaluating disinfection through chlorination, the vendor offers systems of various sizes that are able to treat ranges of water throughput (e.g., gpm), but the user would need to specify the level of performance required, which would then dictate the chemical addition rates.

Articles identified through technical journals (e.g., *Desalination, Water Resources,* and *Water Research)* spoke to the use of membrane technologies for potable water treatment. In *Desalination*, EPA identified several articles and studies focused on using membrane systems (e.g., RO) for potable water supplies. Most of the articles on treatment performance addressed the removal of arsenic and demonstrated removal rates of 40 to 99 percent (Kang et al., 2000; Ning, 2002; and Gholami et al., 2006). One article studied the effect of solution pH and generally observed that a higher pH correlated with greater removal rates (Kang et al., 2000). Another demonstrated organic matter removal rates of up to 85 percent (Pryor et al., 1998). Yet another observed the onset of membrane filter biofouling and scaling after approximately 6,000 hours of operation, with rapid biofouling and scaling occurring at approximately 11,000 hours (Kruithof et al., 1998).

Though EPA did not find specific treatment efficacy data for *Vibrio cholera*, *E. coli*, or intestinal enterococci, the Agency did identify a review paper providing the following efficacy data for other organisms:

- Siveka (1966) reported RO removal of coliform bacteria from feed water containing 1,500 to greater than 11,000 CFU per ml. The product water contained less than 3 CFU per 100 ml (as cited in Madaeni, 1999).
- Regunathan et al. (1983) reported RO removal of coliform bacteria from feed water containing 3.0×10^4 to 4.7×10^7 CFU per 100 ml. The product water contained less than 1 per 100 ml (as cited in Madaeni, 1999).
- Cooper and Straube (1979) studied RO removal efficacy of viruses from sewage. They observed complete removal of plaque-forming units (pfu) from feed water containing 105 to 107 pfu/gal. They also observed a 7- and 5-log removal of *poliovirus* and *coliphage*, respectively (as cited in Madaeni, 1999).
- Adham et al. (1998) conducted a bench-scale study to evaluate the removal effectiveness of the MS2 bacteriophage using five different RO membranes. They observed a virus reduction of 2.7 to more than 6.5 logs (as cited in WHO, 2004).

The World Health Organization (WHO) (2004) noted in its review of the literature that RO systems are seldom used to remove living organisms from water sources because other forms of filtration (e.g., microfiltration, ultrafiltration) are more cost effective and can achieve a similar degree of removal. WHO also noted a lack of literature on RO system efficacy, which is consistent with EPA's observations during the literature review.

5.1.3 Conclusion

EPA did not find PWG treatment efficacy data that was specific to zooplankton, phytoplankton, *Vibrio cholera*, *E. coli*, or intestinal enterococci. However, values reported for other organisms suggest that PWG systems may provide pathogen reductions in the broad range of 3 to 7 logs.

5.2 ENGINEERING ASSESSMENT OF PWG AND DISINFECTION SYSTEM TREATMENT EFFICACY

In light of the lack of literature data on PWG effectiveness for removing waterborne organisms, EPA conducted an engineering assessment to determine what removal or inactivation efficiencies can be reasonably expected from PWG-disinfection systems. The following sections summarize EPA's findings and conclusions for PWG systems that use RO or distillation, as well as for chemical and physical disinfection systems (i.e., chlorine, bromine, silver ion (chemical), or UV radiation (physical)).

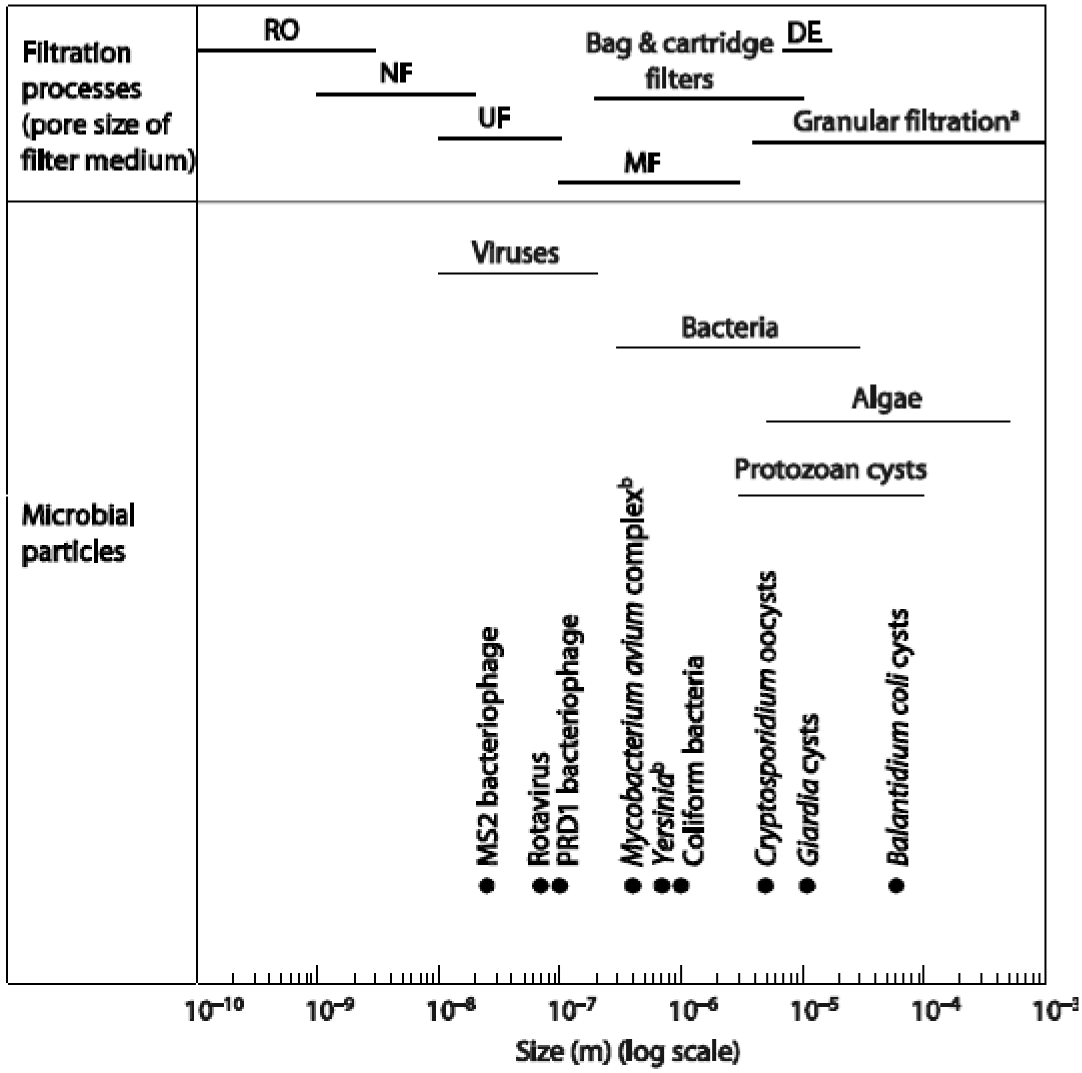
5.2.1 RO Treatment Mechanism and Expected Effect on Living Organisms

Unlike most other filtration methods, RO separation is not a size exclusion-based process. It is a pressure-driven process that reverses the chemical potential across a semipermeable membrane (i.e., RO systems operate by applying pressure across a semipermeable membrane). The pressure exerts a driving force that sends solvent molecules through the membrane. However, dissolved ions and suspended particles, which do not experience this driving force, are unable to permeate though the membrane.

Typically, RO systems utilize a prefiltration process to prevent fouling of the semipermeable membrane. Prefiltration processes include granular media and bag and cartridge filtration. The extent to which these pretreatment processes are used by an RO system depends on the quality of the water source. Granular media can include coal, sand, garnet, and activated carbon, and can remove organisms as small as 0.01 µm. Bag and cartridge filters remove contaminants and pathogens in the 0.2- to 10-µm range (WHO, 2004).

As discussed in Section 5.1, there is a lack of biological treatment efficacy data for RO systems; therefore, EPA is unable to quantify RO removal efficiencies based on existing literature alone for zooplankton, phytoplankton, *V. cholera*, *E. coli*, and intestinal enterococci. The reported RO removal efficiencies discussed in Section 5.1 suggest that RO systems could yield 3- to 7-log reductions of *V. cholera*, *E. coli*, or intestinal enterococci. Comparing organism sizes against typical RO system pore sizes (Figure 5-1) confirms that RO systems should be highly effective at removing living organisms in general, including bacteria, phytoplankton, and zooplankton, particularly when combined with pre-filtration. The figure shows that bacteria are, at a minimum, two orders of magnitude larger than even the largest RO membrane filter pores.

Therefore, it is reasonable to expect that RO systems can meet numeric treatment limits at least as stringent as those specified in EPA's 2013 VGP.



DE – diatomaceous earth; MF – microfiltration; NF – nanofiltration; UF – ultrafiltration
Source: WHO, 2004

Figure 5-1. Comparison of Organism Sizes against Filter Pore Sizes for Various Filtration Processes

Statistical data published by the American Water Works Association Research Foundation (AWWARF) (Nieminksi and Ballamy, 2000) indicates that *E. coli* concentrations in U.S. waters range from 30.4 to 173.9 CFU/100 ml at the 95 percent confidence interval. At the reduction minimum for this technology (i.e., 3 logs), it appears that it is likely to meet treatment limits at least as stringent as those specified in the 2013 VGP. At a concentration of 173.9 CFU/100 ml, a 3-log reduction would yield ballast water containing approximately 0.2 CFU/100 ml, well below the *E. coli* limit of 250 CFU/100 ml. EPA was unable to identify similar data for *V. cholera* and intestinal enterococci. Using the *E. coli* data as a surrogate, it is reasonable to conclude that RO systems could also meet the limits for both *V. cholera* (<1 CFU/100 ml) and intestinal enterococci (<100 CFU/100 ml).

In type-approved ballast water treatment systems, mechanical filtration is the most commonly used treatment technology component. These filters are typically fully automatic, self-cleaning screen or disk filters with a pore size of 50 μm to remove larger organisms and sediments (IHS Maritime, 2013; ABS, 2011; USEPA, 2011b; Albert et al., 2010). In comparison, the pore size of RO membrane filters is more than five orders of magnitude smaller than filters typical of ballast water treatment systems capable of removing organisms much smaller than 50 μm as discussed above. USEPA, 2011b discusses that media filters or membrane filters would need to be used to improve mechanical separation for ballast water treatment, but acknowledges that such devices have not yet been practically applied to ballast water treatment.

5.2.2 Distillation Treatment Mechanism and Expected Effect on Living Organisms

Distillation-based PWGs operate on the principle that seawater (or brackish or fresh water) can be evaporated under vacuum at temperatures as low as 40°C. Feed water starts evaporating immediately upon entry into the technology. The heat source used for this process is waste heat produced by the vessel's main engines. Approximately half of the seawater is evaporated to distillate water vapor, which is then condensed as potable water. The remaining half of the seawater (brine) is discharged upon generation. A demister removes entrained water droplets from the distillate water vapor and routes it to the brine discharge.

While the distillate water vapor is likely to be free of living organisms, fine entrained water droplets that are not completely removed by the demister have the potential to contain living organisms and other contaminants. Accordingly, water temperature and the time of treatment at that temperature are critical variables affecting organism mortality. Time-temperature studies and trials performed onboard vessels found 90 to 100 percent reduction of phytoplankton and zooplankton at 35 to 38°C for 20 hours (Rigby et al., 1999) and 100 percent zooplankton mortality at 38°C for 12 hours (Quilez-Badia et al., 2008; Mountfort et al., 2001). High-temperature treatment (55 to 80°C) for short periods (up to a few seconds) are also effective for phytoplankton and zooplankton (McCollin and Shanks, 2003; Quilez-Badia et al., 2003; Reavie et al., 2010). However, another study (Cao et al., 2014) indicates that a temperature of 80°C within 60 seconds of heating time is needed to kill bacteria such as *E. coli*.

Ballast water can be disinfected using waste heat provided by the ship's engines, or external sources such as steam or microwave heating (Gregg et al., 2009). Balaji et al. (2014) considers using heat treatment as part of a combination ballast water treatment system, citing a variety of studies of candidate combination technologies and their effectiveness, but acknowledges that issues remain. Review of available guides to ballast water treatment (IHS Maritime, 2013; ABS, 2011) did not identify any internationally type-approved ballast water treatment systems incorporating this technology.

A key consideration concerning the efficacy of distillation-based PWGs is that they apply a vacuum to permit distillation at lower temperatures. Such temperature reductions are likely to limit the overall efficacy of this technology. Based on the studies discussed above, distillation-based PWGs will likely treat zooplankton and phytoplankton, but may not have high removal efficiencies for some or many types of bacteria. This is particularly apparent when comparing distillation system operating temperatures, which can run as low as 40°C, to the 80°C kill temperature Cao et al (2014) reported for *E. coli*.

In addition to temperature, EPA also considered how operating pressures affect overall organism reductions. EPA's literature search did not identify any studies that exclusively investigated the relationship between pressure and achievable organism reductions. The literature describes temperature as the primary means of disinfection because it denatures organisms' enzymes (Csuros and Csuros, 1999). This principle appears to hold true even with autoclaves, an analogous technology where complete disinfection occurs under elevated pressures. The technology utilizes elevated pressures for the sole purpose of achieving higher disinfection temperatures than would otherwise be achievable at lower pressures; the elevated pressures in and of themselves do not directly translate to organism reductions (Csuros and Csuros, 1999). It is therefore reasonable to conclude that the lower pressures associated with distillation-based PWGs would provide negligible organism reductions.

5.2.3 Biocide Disinfection Treatment Mechanism and Expected Effect on Living Organisms

Chemical disinfectants inactivate organisms by destroying or damaging cellular structures, interfering with metabolism, and hindering biosynthesis and growth (USEPA, 2006). Chlorine, bromine, and silver ions can be used as chemical disinfectants; however, bromine and silver ion disinfection have not gained widespread acceptance compared to chlorine (WHO, 2004).

Chemical disinfectants are delivered to potable water sources using a variety of chemical forms. Chlorine is added either as a pure gas or as tablets or solutions containing chloride salts (e.g., sodium hypochlorite or calcium hypochlorite). Once added to the water, chlorine reacts to form hypochlorous acid (HOCl) and hypochlorite anions (OCl^-). Bromine is added as a pure liquid or an aqueous solution, and, similar to chlorine, forms an acid (hypobromous acid (HOBR)) and an anion (hypobromite anions (OBr^-)) when added to water. Silver is added directly to a potable water source through the electrolysis of a silver anode. The electrolytic reaction liberates silver ions from the anode, which in turn dissolve into the water source.

It is important to note that water quality affects the chemistry of disinfection chemicals, particularly when using chlorine and bromine. For example, sodium hypochlorite is most effective at low pH values that favor formation of hypochlorous acid (MEPC, 2010). At a pH of 8, the concentration of hypochlorous acid is 20 percent, whereas at a pH of 7, the concentration increases to 70 percent (Daniels and Selby, 2007). Bromine is similarly affected by pH; however, the effect is not as dramatic as with chlorine (MDE, 2012). Temperature can also affect the efficacy. For example, higher temperatures increase hypochlorite toxicity, thus increasing the biocidal efficacy of sodium hypochlorite (MESB 2002; Sano et al. 2004). Large quantities of compact sediment can negate the efficacy of chemical biocides, as they can provide refuge for aquatic species and prohibit full permeation of biocides (Electrichlor, 2002; Gray et al., 2006).

Table 5-1 lists bacterial reductions reported in the literature for chlorine (as sodium hypochlorite), silver, and bromine. Reported biocide reductions are >85 percent for sodium hypochlorite, >99.99 percent for silver, and 100 percent for bromine. It is important to note that the reductions in Table 5-1 are a function not only of the biocide dose and contact time, but also the quality of the potable water source. As noted previously, pH, temperature, and sediment loading will impact treatment efficacy. Therefore, actual reductions achieved onboard vessels are expected to be highly variable and will require adjustments to biocide concentrations, contact times, or both depending on source water characteristics. For this reason, EPA's focus is to establish a rough order of magnitude for the treatment efficacy of chlorine, silver, and bromine by aggregating the values reported in Table 5-1. In this regard, 85 to 100 percent reductions are likely when using the types of biocides listed below. This is equivalent to an approximate reduction of 1 to 5 logs, excluding those sources reporting 100 percent (i.e., infinite log) reductions.

Table 5-1. Reported Organism Reductions for Sodium Hypochlorite, Silver, and Bromine Disinfection

Residual Biocide	Contact Time (Hours)	Reported Organism Reduction	Source
Sodium hypochlorite			
7 to 10 ppm	2	>90% (indigenous bacteria in seawater ballast)	BMT Fleet Technology, 2002
4 to 6 ppm	24	99.6% (zooplankton); 100% (phytoplankton); 99.9% (bacteria)	Reynolds et al., 2008
5 ppm	24	100% (*V. cholera*); 85% (*E. coli*)	Zhang et al., 2003
Silver ion			
0.05 to 0.2 ppm	1.5	>99.99 (*E. coli*)	Jung, et al., 2008
30 μg/L (also included 30 μg/L hydrogen peroxide)	1	99.999% (*E. coli*)	Pedahzur et al., 1995 (as cited in WHO, 2004)
38 μg/L (also included 100 μg/L chlorine and 380 μg/L copper)	0.03	99.999% (*E. coli*)	Thurman and Gerba, 1989 (as cited in WHO, 2004)
Bromine			
150 μg/L	0.5	100% (*E. coli*)	Tanner and Pitner, 1939 (as cited in NAS, 1980)

The reductions noted above occurred in addition to organism removal during prior RO or distillation steps. For RO, literature values suggest 3- to 7-log reductions (see Section 5.2.1); therefore, the net reduction achieved through RO and subsequent biocide disinfection is likely to range from 4 to 12 logs. As discussed in Section 5.2.2, vacuum distillation systems may not effectively treat bacteria. Therefore, EPA conservatively assumes reductions will only occur during the subsequent biocide disinfection step, yielding 1- to 5-log reductions.

Assuming an *E. coli* concentration of 173.9 CFU/100 ml for U.S. waters, (Nieminksi and Ballamy, 2000) and assuming a minimum net reduction of 4 logs, it appears that a combined RO/biocide disinfection technology would yield ballast water containing approximately 0.02 CFU/100 ml, which is well below VGP treatment limits. Even in cases where *E. coli* ambient concentrations may be much higher, such as where there are combined sewer overflow discharges adjacent to the port or in certain non-U.S. waters where wastewater treatment may not be as developed, RO/biocide disinfection technology should produce treated water below the VGP limits. However, for the distillation/biocide disinfection technology, the ability to meet treatment limits is likely to be case-specific. Additionally, these concentrations do not factor in issues such as regrowth or cross contamination, which might increase concentrations prior to discharge. The estimated minimum net reduction for biocide disinfection (1 log) would generate water containing approximately 17.4 CFU/100 ml. This would be sufficient to meet the *E. coli* limit. However, the system may be challenged to meet limits without disinfection in events where ambient *E.coli* concentrations could be orders of magnitude higher. EPA was unable to identify similar data for *V. cholera* and intestinal enterococci; however, it is reasonable to expect these systems would reduce their concentrations by the same order of magnitude. Therefore, these systems are likely to meet the limits for both *V. cholera* (<1 CFU/100 ml) and intestinal enterococci (<100 CFU/100 ml).

In type-approved ballast water treatment systems, ballast water is commonly disinfected using electrolysis and electrochlorination, whereby hypochlorite is generated by electrolytic processes using seawater as the source of ions (IHS Maritime, 2013; ABS, 2011; USEPA, 2011b; Albert et al., 2010). Hypochlorite concentrations are measured as total residual oxidant (TRO). Based on a review of applications for approval of more than 10 ballast water management systems that make use of Active Substances (G9), EPA observed a range of active substance dosages that were generally greater than 6 mg/L TRO but less than 12 mg/L TRO. Free active chlorine stays in the water, continuing disinfection for several hours to several days, depending on initial concentration and ballast water characteristics such as salinity, temperature, organic-matter content, motions of the vessel, and ballast tank and venting system configuration (USEPA, 2011b).

Chlorine residual management for onboard PWGs emphasizes maintaining adequate chlorine residual throughout the distribution system to prevent contamination. For example, the United States Navy (United Sates Navy, 2005) requires chlorination (or bromination) to provide at least 0.2 halogen residual after a 30-minute contact time. The Centers for Disease Control and Prevention, Vessel Sanitation Program (voluntarily applicable to cruise ships), requires continuous halogenation to maintain a free halogen of greater than 0.2 mg/L and less than 5 mg/L throughout the distribution system (CDC, 2011).

The biocide disinfection systems that EPA identified for use in potable water generation are typically configured by vessel operators because specific dosage requirements vary by water source and operating conditions. These systems, however, are capable of providing residual concentrations that meet or exceed that of currently marketed ballast water treatment systems. Therefore, it is likely that the treatment efficacy of these disinfection systems would be comparable or more effective than currently available ballast water treatment systems, and thus are likely to meet VGP effluent limits.

5.2.4 Physical Disinfection Treatment Mechanism and Expected Effect on Living Organisms

UV radiation inactivates organisms by destroying the nucleic acids that make up their genetic coding, thereby preventing them from replicating (USEPA, 2006). Nucleic acids absorb UV light at wavelengths ranging from 200 to 300 nm, with peak absorption at about 260 nm (USEPA, 2006; WHO, 2004).

The effectiveness of UV radiation can be impaired by poor water quality. Water sources with high turbidity and particulate matter concentrations absorb or shield UV radiation, thus reducing the UV intensity delivered directly to the organism. UV effectiveness is further affected by the type of organism, as some are more resistant than others. Generally, viruses are most resistant to UV radiation, followed by bacteria, cryptosporidium oocysts, and *Giardia* cysts (USEPA, 2006). Table 5-2 lists bacterial reductions reported in the literature for UV disinfection at a given intensity and suggests UV disinfection systems typically achieve 1- to 4-log reductions.

Table 5-2. Reported Organism Reductions for Disinfection by UV Radiation

UV Intensity (mJ/cm^2)	Organism Reduction	Source
20	99.99% (*E. coli*)	WHO, 2004
0.65	99.99% (*V. cholera*)	WHO, 2004
3.0 to 8.4	90 to 99.99% (*E. coli*)	USEPA, 2006
6.7 to 8.4	99.9 to 99.99% (*E. coli*)	USAPHC, 2011
2.2 to 2.9	99.9 to 99.99% (*V. cholera*)	USAPHC, 2011

mJ – millijoules

The reductions noted above occur in addition to what is achieved during RO or distillation. The net reduction from RO and subsequent UV radiation is likely to range from 4 to 11 logs. For distillation and subsequent UV disinfection, EPA conservatively assumes reductions will occur only during the disinfection step, yielding likely reductions of 1 to 4 logs.

Assuming an *E. coli* concentration of 173.9 CFU/100 ml for U.S. waters, (Nieminksi and Ballamy, 2000), using a combined RO-UV disinfection system would yield a minimum reduction of 4 logs. This would generate water with approximately 0.02 CFU/100 ml, thus meeting the VGP treatment limits. However, at its minimum, distillation/UV disinfection could provide only a 1-log reduction. These systems would produce water containing approximately 17.4 CFU/100 ml, which would be sufficient to meet the *E. coli* limit. EPA was unable to identify similar data for *V. cholera* and intestinal enterococci; however, it is reasonable to expect these systems would reduce their concentrations by the same order of magnitude. Therefore, these systems are likely to meet the limits for both *V. cholera* (<1 CFU/100 ml) and intestinal enterococci (<100 CFU/100 ml).

UV disinfection is the second most common disinfection technology used by type-approved ballast water treatment system (IHS Maritime, 2013; ABS, 2011; USEPA, 2011b;

Albert et al., 2010). The major advantage of UV disinfection is that the technology does not require using active substances and does not generate toxic byproducts. The major disadvantage of UV disinfection is that turbidity in ballast water scatters or absorbs light rays and reduces transmissivity, reducing the effectiveness of the treatment. Pretreatment, such as filtration to remove smaller particles, improves UV's performance; accordingly, all UV-based ballast water treatment systems to date use front-end separation processes to improve UV transmission (Albert et al., 2010).

Type-approved ballast water treatment systems use one of two types of UV lamps. Low-pressure UV lamps emit monochromatic UV radiation at 254 nm, which is close to the optimum germicidal wavelength of 260 nm. Medium-pressure UV lamps emit polychromatic UV radiation over a broad spectrum ranging from 200 to 400 nm, including wavelengths in the germicidal range. The systems differ in energy efficiency, power rating, size, lamp service life, etc.; however, both systems are highly effective for removing microorganisms and many larger organisms when properly designed and operated. Because UV radiation does not produce residual oxidant, UV treatment is performed at both ballast water intake and discharge to reduce problems associated with bacterial regrowth or contamination (IHS Maritime, 2013; ABS, 2011).

All of the UV disinfection systems EPA identified as being used for potable water generation utilize low-pressure UV lamps. These lamps can provide UV treatment at levels that are comparable to the UV lamps used in ballast water treatment systems. It is likely that the treatment efficacy of PWG UV disinfection lamps and ballast water treatment system lamps would be comparable.

5.2.5 <u>Conclusions</u>

Based on the literature, it appears RO systems are likely to be highly effective at removing living organisms, given that bacteria are, at a minimum, two orders of magnitude larger than even the largest RO membrane filter pores. RO removal efficiency data suggest that RO systems could yield 3- to 7-log reductions of *V. cholera, E. coli*, or intestinal enterococci. It also is reasonable to expect that these systems would be highly effective against larger organisms, such as zooplankton and phytoplankton.

The vacuum distillation technology found in PWG systems will likely treat zooplankton and phytoplankton, yielding 90 to 100 percent reductions, but they may not be as effective in removing bacteria given the lower operating temperatures generally associated with the technology. EPA's review of available guides to ballast water treatment did not identify any type-approved ballast water treatment systems that incorporate vacuum distillation.

Literature values for organism reductions from disinfection with biocides indicate that reductions of 85 to 100 percent, or approximately 1 to 5 logs, are likely. Reductions from physical disinfection (i.e., UV) treatments are likely to range from 1 to 4 logs for microbiological organisms. When coupled with reverse osmosis, the net reduction from PWG and subsequent disinfection is likely to reach 4 to 12 logs. However, for vacuum distillation systems, the net reductions for microbiological organisms are expected to be lower, likely 1 to 4 logs since treatment predominantly will occur during disinfection given the lower operating temperatures generally associated with vacuum distillation systems.

Applying these log values to the *E. coli* concentration reported by Nieminksi and Ballamy (2000) shows that the RO-disinfection technology is capable of meeting VGP treatment limits. EPA estimated a 4-log reduction minimum regardless of the disinfection system utilized (i.e., biocides or UV radiation). Therefore, this technology is likely to generate ballast water containing approximately 0.02 CFU/100 ml, which would meet the VGP treatment limit for *E. coli*. EPA was unable to identify similar data for *V. cholera* and intestinal enterococci; however, it is reasonable to expect these systems would reduce their concentrations by the same order of magnitude. Therefore, these systems would also meet the limits for both *V. cholera* (<1 CFU/100 ml) and intestinal enterococci (<100 CFU/100 ml).

The distillation-disinfection technology preliminarily appears capable of meeting VGP discharge limits. As discussed above, the minimum organism reduction achievable through biocides or UV radiation technologies is one log. Applying this minimum to the *E. coli* concentration reported by Nieminksi and Ballamy (2000) of 174 CFU/100 ml reveals that distillation-disinfection systems would produce ballast water containing approximately 17.4 CFU/100 ml. This would meet the VGP treatment limit for *E. coli*. EPA was unable to identify similar data for *V. cholera* and intestinal enterococci; however, it is reasonable to expect these systems would reduce their concentrations by the same order of magnitude. Therefore, these systems would be likely to meet the limits for both *V. cholera* (<1 CFU/100 ml) and intestinal enterococci (<100 CFU/100 ml).

5.3 "PROOF OF CONCEPT" EVALUATION OF PWG-DISINFECTION SYSTEM EFFICACY

5.3.1 Background

MERC is a state of Maryland initiative that provides test facilities, information, and decision tools to address environmental issues facing the maritime industry. The Center's primary focus is to evaluate ballast water treatment systems based on their mechanical and biological efficacy and associated costs, as well as the economic impacts of ballast water regulations and management approaches.

MERC, in partnership with MARAD and EPA, tested a PWG system using methodologies generally consistent with EPA's Experimental Technology Verification (ETV) Program ballast water protocols. The PWG used in the proof of concept evaluation was an RO system that generated approximately 12 gpm. The RO system also included a media prefiltration and chlorination system. The prefiltration system consisted 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 then passed through a 5-μ filter bag and, finally, a 10-μ cartridge filter. The filter sizes were intentionally configured in this manner to maximize particulate filtration prior to the cartridge filter, reducing the frequency of cartridge filter changes, which were labor intensive compared to bag filter changes. The water was then pumped through the RO membrane and disinfected with a 12.5 percent sodium hypochlorite solution (1 ppm dose). The pH of the water product was then neutralized by passing the water through two calcite tanks.

The PWG used a spiral-wound 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 percent. The manufacturer has not assigned pore size values for individual membranes, but indicates a general pore size range of 0.1 to 2.5 nm (Dow Chemical Company, 2013).

To evaluate the performance characteristics of the PWG-chlorination system, MERC conducted four biological efficacy trials at its mobile test platform in Baltimore Harbor, MD. The trials focused on all EPA- and USCG-regulated taxonomic categories, including live organisms ≥50 µm; live organisms <50 µm, but ≥10 µm; and culturable organisms <10 µm. MERC also conducted whole effluent toxicity testing, chlorinated byproducts analyses, and water quality analyses, including total suspended solids, particulate organic carbon, dissolved organic carbon, and chlorophyll. The following section summarizes MERC's results, which focus specifically on the taxonomic EPA- and USCG-regulated categories. Appendix C contains a complete copy of MERC's report.

Each of the four trials conducted by MERC occurred over five to six days. Over this period, the PWG-chlorination system filled a test tank with a minimum of 150 m^3 of potable water, which was held in the tank until the end of the trial period. At the end of the period, the potable water was discharged into Baltimore Harbor. During discharge, MERC collected samples of the potable water using methods generally consistent with the EPA ETV protocol. However, because the PWG provided significantly lower flow rates than a typical ballast water treatment system, it was necessary to slightly modify certain elements of the standard ETV testing protocols. Protocols and modifications are discussed in detail in Appendix C.

During the proof of concept evaluation, the PWG-disinfection system encountered an unexpected system failure that prevented MERC from conducting the fifth and final trial. The system failure was caused by ruptures in two of the three prefiltration media filtration vessels. The evaluation was subsequently concluded and the system returned to the vendor. Upon conducting a failure analysis, it was concluded that the ruptures were the result of a siphoning effect that occurred within the media prefiltration discharge line during backwashing. The siphon created an unintended vacuum leading upstream to the media prefiltration tanks and exerted sufficient vacuum pressure to rupture them (ERG, personal communications, July 1, 2014).

Typically, the vendor installs a vacuum breaker on the discharge line to prevent appreciable buildups in vacuum pressure. The vendor noted that most of their units include vacuum breakers; however, the specific older unit provided did not. Given that the system failure is specific to the unit, and that the vendor noted most other units include a vacuum breaker, EPA believes that the system failure is likely a case-specific occurrence that is not representative of performance expectations for PWG-disinfection systems in general. See MERC discussion in Appendix C for additional discussion.

5.3.2 Summary of Results

This section summarizes the key results for PWG treatment efficacy for living organisms. Appendix C provides a detailed summary and discussion of these, and other results. These results, reproduced in Table 5-3, indicate the PWG-chlorination system produced potable water containing almost no living organisms ≥50 µm; no detectable living organisms <50 µm, but ≥10 µm; and no culturable organisms <10 µm. *E. coli* and enterococci concentrations were below 1

CFU/100 ml, while no colonies of *V. cholera* were detected. The residual total chlorine measured during discharge sampling ranged from 0.09 to 0.14 mg/l ± 0.03 mg/l. Please see Appendix C for a complete background of the MERC facility, description of methods and results, and additional discussion regarding the proof of concept testing.

Table 5-3. MERC Evaluation Results for Key Parameters Related to PWG Treatment Efficacy for Living Organisms

Trial ID	LO, ≥50 µm (cells/m³)	LO, ≥10 to <50 µm (cells/ml)	THB (cells/10 ml)	*E. coli* (CFU/ 100 ml)	Enterococci (CFU/ 100 ml)	*V. cholera* (No. of colonies)	Total Chlorine (mg/l)
PW-1	0.14	BDL	0	ND	<1	0	0.10 ± 0.01
PW-2	0	BDL	0	<1	<1	0	ND
PW-3	0	BDL	0	<1	<1	0	0.14 ± 0.01
PW-4	0	BDL	0	<1	<1	0	0.09 ± 0.02

BDL – Below detection limit (0.04 cells/ml)
LO – Live organisms
ND – No data
THB – Total heterotrophic bacteria

5.3.3 Conclusions

The proof of concept evaluation demonstrated that PWG-chlorination systems are capable of meeting each of the VGP numeric discharge limits. The tested system reduced the presence of organism to levels well below that required by the VGP limitations. The potable water discharge, however, contained residual chlorine at or slightly above the maximum ballast water effluent limit for residual biocides (i.e., 0.1 mg/L for total residual chlorine (TRC)) contained in the VGP. However, these concentrations were below the IMO limit of 0.2 mg/L for TRC. This suggests that vessels would need to monitor TRC concentrations in their ballast water tanks and adjust chlorine dosing accordingly to ensure compliance with the limit when deballasting, or apply a neutralizing agent.

It is important to note that although the evaluation demonstrated the capability of PWGs to meet VGP numeric limits, subsequent contamination downstream of the PWG could cause vessel discharges to exceed those limits. For example, microorganisms could reside and grow within the ballast system, where, depending on water conditions and residence times, microorganism levels could increase and even exceed the numeric limits upon discharge. This suggests that vessel owners/operators may need to monitor discharges to ensure compliance with the limits or implement measures to avoid contamination, such as those required at Part 2.2.3.5.1.3 of the VGP for vessels using public supply water for ballast (i.e., clean ballast tanks and supply lines and never subsequently introduce them to ambient water).

5.4 COMPARISON OF PWG-DISINFECTION SYSTEM TREATMENT EFFICACIES AGAINST 2013 VGP NUMERIC TREATMENT LIMITS

EPA's literature search for existing information on PWG treatment efficacy data for organisms did not yield information specific to zooplankton, phytoplankton, *Vibrio cholera*, *E.*

coli, or intestinal enterococci. However, values reported in the literature for other organisms provide a preliminary indication that PWG systems may reduce pathogens and other organisms sufficient to meet the VGP numeric limitations for ballast water discharges.

Subsequent technology-specific engineering assessments indicated that PWG and disinfection systems can conceptually reduce organism concentrations to levels below those required by the VGP. The analysis indicated that RO systems are likely to be highly effective at removing *V. cholera*, *E. coli*, and intestinal enterococci. It also appears that these systems would be highly effective against larger organisms such as zooplankton and phytoplankton. Distillation-based PWG systems will likely treat zooplankton and phytoplankton; however, they may not treat bacteria. Subsequent disinfection will yield additional organism reductions. Combined, the net reduction achieved from PWGs and their subsequent disinfection systems is likely to be 4 to 12 logs.

The proof of concept evaluation demonstrated the capability of an RO-based PWG-chlorination system to meet and exceed the VGP numeric discharge limits. Table 5-4 compares the evaluation results to the EPA and USCG numeric limits. As the table shows, the system generated potable water with organism levels that were well below their respective limits. These evaluation results corroborate the conclusions drawn from the literature and engineering assessment, and further suggest that these systems are likely to be highly effective at reducing organism concentrations.

Table 5-4. Comparison of Numeric Ballast Water Discharge Limits against MERC Evaluation Results

Taxonomic Classification	EPA and USCG Numeric Limit	Evaluation Results (Range)
Organisms ≥50 µm	<10 organisms/m^3	0 to 0.14 cells/m3
Organisms <50 µm, but ≥10 µm	<10 organisms/ml	Below limit of detection (<0.04 cell/ml)
Organisms <10 µm		
Toxicogenic *V. cholera*	<1 CFU/100 ml	No colonies detected
E. coli	<200 CFU/100 ml	<1 CFU/100 ml
Intestinal enterococci	<100 CFU/100 ml	<1 CFU/100 ml

SECTION 6
CONCLUSIONS REGARDING THE FEASIBILITY OF USING PWGS FOR BALLAST OPERATIONS

The largest driver of PWG feasibility is a vessel's required ballasting rate. The vessels evaluated by EPA had ballast rates ranging from approximately 155 to 800 gpm. In contrast, the maximum PWG production rate identified by EPA did not exceed 400 gpm. Only 5 percent of the PWGs reviewed by EPA are capable of producing water within the range of vessel ballast rates. The remaining 95 percent can produce water only at or below 30 gpm. A direct comparison of vessel ballasting and PWG production rates indicates that using PWGs as an all-purpose ballast water management alternative is not likely to be feasible without also utilizing other ballasting management strategies (e.g., internal ballasting, public water supply water), particularly for vessels requiring ballasting at a rate of hundreds of gallons per minute.

Although PWGs cannot feasibly support the ballasting needs of all vessels, there appear to be several applications where using a PWG may be feasible. For example, it may be feasible for vessels to use PWGs to compensate for fuel burn off. EPA estimated fuel burn rates for various types of vessels ranging from 0.3 to 18.3 gpm, well within the water production range achievable with PWGs.

EPA considered whether other feasibility issues would arise, such as during PWG retrofitting into existing vessels or installation into new vessels. The retrofit case studies that EPA conducted on a research vessel, a towboat, and a fast support vessel demonstrated that it was feasible to retrofit PWGs and disinfection systems into all three vessels, and that the PWG could provide sufficient water to meet ballasting needs associated with fuel burn off compensation. The case studies also indicated that system weight and power requirements are feasible, as the weight and electrical load differentials were negligible (0.03 to 0.1 percent of total weight, and 0.2 to 1 percent of total electrical capacity). The costs associated with retrofits or installations do not appear to be prohibitive; total capital investment costs ranged from approximately $53,000 to $67,200, while annual O&M costs ranged from approximately $2,600 to $4,400 per year (assuming 365 days per year).

EPA's parametric design data analysis suggests that the case study results apply to other types of vessels beyond those immediately covered in the case studies. In general, it appears feasible to retrofit or install PWG units into research vessels, towboats, and small overnight passenger vessels. However, it may be more challenging to retrofit or install PWG units into tugboats, offshore support vessels, and many fishing vessels.

Finally, EPA, in partnership with MARAD and MERC, evaluated the ability of a PWG system to reduce the concentration of living organisms in the discharge, including whether the discharge would be at or below the numeric ballast water discharge limits in the 2013 VGP. EPA's review of existing literature and engineering assessment suggest that PWGs can reduce organism concentrations to the concentrations at or below those required by the VGP. The proof of concept evaluation led by MERC provided land-based testing results, generally consistent with the ETV protocols, which demonstrated the capability of an RO-based PWG-chlorination system to produce potable water that meets the VGP limits. The results of the evaluation indicated that resulting organism concentrations were below the numeric limits contained in EPA's 2013 VGP.

SECTION 7
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APPENDIX A:

TECHNICAL SPECIFICATIONS FOR PWG AND DISINFECTION SYSTEMS

Table A-1. PWG Weights and Physical Dimensions

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm) Min	Production Rate (gpm) Max	Weight (lb)	Dimensions (ft) Height	Dimensions (ft) Width	Dimensions (ft) Depth	Volume (ft^3)
Distillation	Vendor 1	System 1	2.9	7.3	1,808	4.5	2.8	5.8	73.4
Distillation	Vendor 1	System 2	4.6	11.0	2,006	4.5	2.8	7.1	90.0
Distillation	Vendor 1	System 3	0.6	1.1	1,543	4.5	2.8	3.8	48.3
Distillation	Vendor 1	System 4	1.3	4.6	1,676	4.5	2.8	4.5	56.7
Reverse Osmosis	Vendor 2	System 1	--	0.1	140	2.0	1.7	2.0	6.7
Reverse Osmosis	Vendor 2	System 2	--	0.1	140	2.0	1.7	2.0	6.7
Reverse Osmosis	Vendor 2	System 3	--	0.2	160	2.0	1.7	1.7	5.6
Reverse Osmosis	Vendor 2	System 4	--	0.3	160	2.0	1.7	1.7	5.6
Reverse Osmosis	Vendor 2	System 5	--	0.4	160	2.0	1.7	1.7	5.6
Reverse Osmosis	Vendor 2	System 6	--	0.6	200	2.0	1.7	1.7	5.6
Reverse Osmosis	Vendor 2	System 7	--	0.7	230	2.0	1.7	1.7	5.6
Reverse Osmosis	Vendor 2	System 8	--	1.0	240	4.3	2.0	2.0	17.3
Reverse Osmosis	Vendor 2	System 9	--	1.4	--	--	--	--	--
Reverse Osmosis	Vendor 2	System 10	--	2.1	--	--	--	--	--
Reverse Osmosis	Vendor 2	System 11	--	3.1	--	--	--	--	--
Distillation	Vendor 3	System 1	--	4.6	1,222	4.6	4.3	5.2	102.8
Distillation	Vendor 3	System 2	--	5.5	2,222	3.9	5.2	5.6	115.3
Distillation	Vendor 3	System 3	--	7.3	3,111	5.6	5.2	7.9	230.5
Distillation	Vendor 3	System 4	--	9.2	3,333	5.6	5.2	7.9	230.5
Distillation	Vendor 3	System 5	--	11.0	4,222	6.6	5.2	7.9	271.2
Distillation	Vendor 3	System 6	--	7.3	6,000	7.9	5.9	10.5	488.2
Distillation	Vendor 3	System 7	--	11.0	6,444	9.2	5.9	10.5	569.6
Distillation	Vendor 3	System 8	--	1.8	1,100	3.6	4.3	5.2	80.8
Distillation	Vendor 3	System 9	--	3.7	1,200	4.6	4.3	5.3	104.8
Distillation	Vendor 3	System 10	--	5.6	3,100	5.6	5.3	7.9	234.5
Distillation	Vendor 3	System 11	--	7.3	3,200	5.6	5.3	7.9	234.5
Distillation	Vendor 3	System 12	--	9.0	3,300	5.6	5.3	7.9	234.5

Table A-1. PWG Weights and Physical Dimensions

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Weight (lb)	Dimensions (ft)			Volume (ft^3)
			Min	Max		Height	Width	Depth	
Distillation	Vendor 3	System 13	--	11.1	3,700	6.6	5.3	7.9	276.3
Distillation	Vendor 3	System 14	--	5.0	10,000	9.6	9.7	7.3	671.6
Distillation	Vendor 3	System 15	--	8.3	15,000	9.6	9.7	7.3	671.6
Distillation	Vendor 3	System 16	--	11.7	18,000	9.6	9.7	7.3	671.6
Reverse Osmosis	Vendor 4	System 1	--	8.3	1,260	2.6	8.3	5.3	114.8
Reverse Osmosis	Vendor 4	System 2	--	12.5	1,350	2.6	8.3	5.3	114.8
Reverse Osmosis	Vendor 4	System 3	--	16.7	1,460	2.6	8.3	5.3	114.8
Reverse Osmosis	Vendor 4	System 4	--	20.8	1,550	2.6	8.3	5.3	114.8
Reverse Osmosis	Vendor 4	System 5	--	25.0	1,650	2.6	8.3	5.3	114.8
Reverse Osmosis	Vendor 4	System 6	--	1.0	560	2.3	2.2	5.1	24.8
Reverse Osmosis	Vendor 4	System 7	--	2.1	590	2.3	2.2	5.1	24.8
Reverse Osmosis	Vendor 4	System 8	--	3.1	620	2.3	2.2	5.1	24.8
Reverse Osmosis	Vendor 4	System 9	--	4.2	650	2.3	2.2	5.1	24.8
Reverse Osmosis	Vendor 4	System 10	--	5.2	680	2.3	2.2	5.1	24.8
Reverse Osmosis	Vendor 4	System 11	--	6.3	700	2.3	2.2	5.1	24.8
Reverse Osmosis	Vendor 4	System 12	--	2.0	250	5.0	2.2	4.0	43.3
Reverse Osmosis	Vendor 4	System 13	--	2.7	265	5.0	2.2	4.0	43.3
Reverse Osmosis	Vendor 4	System 14	--	0.4	145	4.0	2.0	1.5	12.3
Reverse Osmosis	Vendor 4	System 15	--	0.8	155	4.0	2.0	1.5	12.3
Reverse Osmosis	Vendor 4	System 16	--	1.3	165	4.0	2.0	1.5	12.3
Reverse Osmosis	Vendor 4	System 17	--	1.5	165	4.0	2.0	1.5	12.3
Reverse Osmosis	Vendor 5	System 1	--	5.5	1,650	6.1	4.0	3.5	85.2
Reverse Osmosis	Vendor 5	System 2	--	7.3	1,950	6.1	4.0	3.5	85.2
Reverse Osmosis	Vendor 5	System 3	--	9.2	6,544	6.1	4.0	3.5	85.2
Reverse Osmosis	Vendor 5	System 4	--	11.0	6,544	12.7	5.0	5.3	332.5
Reverse Osmosis	Vendor 5	System 5	--	13.8	5,420	13.0	5.3	7.7	531.6
Reverse Osmosis	Vendor 5	System 6	--	14.7	5,070	13.0	5.3	7.9	548.9

Table A-1. PWG Weights and Physical Dimensions

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Weight (lb)	Dimensions (ft)			Volume (ft^3)
			Min	Max		Height	Width	Depth	
Reverse Osmosis	Vendor 5	System 7	--	17.2	10,234	15.0	6.7	9.0	900.0
Reverse Osmosis	Vendor 5	System 8	--	22.0	6,520	19.3	7.5	7.0	1,015.0
Reverse Osmosis	Vendor 5	System 9	--	36.7	6,800	19.6	5.0	6.7	652.8
Reverse Osmosis	Vendor 5	System 10	--	55.0	7,160	19.6	5.0	6.7	652.8
Reverse Osmosis	Vendor 5	System 11	--	78.0	8,830	23.8	6.7	7.3	1,161.1
Reverse Osmosis	Vendor 5	System 12	--	128.8	11,298	26.7	8.3	7.5	1,666.7
Reverse Osmosis	Vendor 6	System 1	--	0.8	184	--	--	--	--
Reverse Osmosis	Vendor 6	System 2	--	1.3	199	--	--	--	--
Reverse Osmosis	Vendor 6	System 3	--	0.2	144	--	--	--	--
Reverse Osmosis	Vendor 6	System 4	--	0.3	150	--	--	--	--
Reverse Osmosis	Vendor 6	System 5	--	0.4	159	--	--	--	--
Reverse Osmosis	Vendor 6	System 6	--	0.6	174	--	--	--	--
Reverse Osmosis	Vendor 6	System 7	--	0.8	192	--	--	--	--
Reverse Osmosis	Vendor 6	System 8	--	1.3	207	--	--	--	--
Reverse Osmosis	Vendor 6	System 9	--	0.4	177	--	--	--	--
Reverse Osmosis	Vendor 6	System 10	--	1.3	398	--	--	--	--
Reverse Osmosis	Vendor 6	System 11	--	1.7	416	--	--	--	--
Reverse Osmosis	Vendor 6	System 12	--	2.2	421	--	--	--	--
Reverse Osmosis	Vendor 6	System 13	--	3.0	529	--	--	--	--
Reverse Osmosis	Vendor 6	System 14	--	3.8	572	--	--	--	--
Reverse Osmosis	Vendor 6	System 15	--	5.2	655	--	--	--	--
Reverse Osmosis	Vendor 6	System 16	--	6.6	724	--	--	--	--
Reverse Osmosis	Vendor 6	System 17	--	6.9	--	--	--	--	--
Reverse Osmosis	Vendor 6	System 18	--	8.7	--	--	--	--	--
Reverse Osmosis	Vendor 6	System 19	--	11.1	--	--	--	--	--
Reverse Osmosis	Vendor 6	System 20	--	13.2	--	--	--	--	--
Reverse Osmosis	Vendor 6	System 21	--	15.6	--	--	--	--	--

Table A-1. PWG Weights and Physical Dimensions

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Weight (lb)	Dimensions (ft)			Volume (ft^3)
			Min	Max		Height	Width	Depth	
Reverse Osmosis	Vendor 6	System 22	--	20.8	--	--	--	--	--
Reverse Osmosis	Vendor 6	System 23	--	24.0	--	--	--	--	--
Reverse Osmosis	Vendor 6	System 24	--	26.7	--	--	--	--	--
Reverse Osmosis	Vendor 6	System 25	--	29.9	--	--	--	--	--
Reverse Osmosis	Vendor 6	System 26	--	7.6	--	--	--	--	--
Reverse Osmosis	Vendor 6	System 27	--	13.2	--	--	--	--	--
Reverse Osmosis	Vendor 6	System 28	--	16.7	--	--	--	--	--
Distillation	Vendor 7	System 1	--	1.7	1,333	4.7	4.5	4.6	94.9
Distillation	Vendor 7	System 2	--	2.5	1,371	4.7	4.5	4.6	94.9
Distillation	Vendor 7	System 3	--	3.3	1,391	4.7	4.5	4.6	94.9
Distillation	Vendor 7	System 4	--	4.2	1,427	4.7	5.4	4.6	114.3
Distillation	Vendor 7	System 5	--	5.0	1,447	4.7	5.4	4.6	114.3
Reverse Osmosis	Vendor 8	System 1	--	2.1	1,200	1.3	3.9	2.1	10.9
Reverse Osmosis	Vendor 8	System 2	--	4.2	1,900	5.0	9.6	5.0	239.6
Reverse Osmosis	Vendor 8	System 3	--	5.6	2,500	5.0	9.6	5.0	239.6
Reverse Osmosis	Vendor 8	System 4	--	6.9	2,600	5.0	9.6	5.0	239.6
Reverse Osmosis	Vendor 8	System 5	--	10.4	3,000	5.5	11.0	5.0	302.5
Reverse Osmosis	Vendor 8	System 6	--	13.9	3,500	5.5	11.0	5.5	332.8
Reverse Osmosis	Vendor 8	System 7	--	18.3	4,700	5.5	11.0	5.5	332.8
Reverse Osmosis	Vendor 8	System 8	--	21.9	5,800	5.5	11.3	6.0	371.3
Reverse Osmosis	Vendor 8	System 9	--	185	5,900	7.4	25.8	6.0	1,149.6
Reverse Osmosis	Vendor 8	System 10	--	100	3,500	7.4	14.0	2.7	276.9
Reverse Osmosis	Vendor 8	System 11	--	75	3,200	7.4	14.0	2.7	276.9
Reverse Osmosis	Vendor 8	System 12	--	60	3,200	7.4	14.0	2.7	276.9
Reverse Osmosis	Vendor 8	System 13	--	45	2,400	6.0	14.0	2.7	224.0
Reverse Osmosis	Vendor 8	System 14	--	30	2,200	6.0	14.0	2.7	224.0
Reverse Osmosis	Vendor 8	System 15	--	19	1,800	5.7	10.0	2.7	151.1

Table A-1. PWG Weights and Physical Dimensions

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Weight (lb)	Dimensions (ft)			Volume (ft³)
			Min	Max		Height	Width	Depth	
Reverse Osmosis	Vendor 8	System 16	--	7	1,100	5.7	9.2	2.7	138.5
Reverse Osmosis	Vendor 9	System 1	--	0.3	170	1.8	4.0	1.8	12.7
Reverse Osmosis	Vendor 9	System 2	--	0.4	180	1.8	4.2	1.8	13.4
Reverse Osmosis	Vendor 9	System 3	--	0.6	200	1.8	4.2	1.8	13.3
Reverse Osmosis	Vendor 9	System 4	--	0.8	210	1.8	4.4	1.8	13.9
Reverse Osmosis	Vendor 9	System 5	--	0.4	295	1.5	4.3	2.8	18.2
Reverse Osmosis	Vendor 9	System 6	--	0.7	321	1.5	4.6	2.8	19.2
Reverse Osmosis	Vendor 9	System 7	--	1.0	321	1.5	4.6	2.8	18.6
Reverse Osmosis	Vendor 9	System 8	--	1.4	360	1.8	4.6	2.8	22.8
Reverse Osmosis	Vendor 9	System 9	--	1.8	520	1.9	5.0	2.5	23.9
Reverse Osmosis	Vendor 9	System 10	--	2.5	551	1.9	5.1	2.5	24.7
Reverse Osmosis	Vendor 9	System 11	--	3.1	580	2.4	5.1	2.5	30.9
Reverse Osmosis	Vendor 9	System 12	--	3.7	820	2.6	9.0	3.8	87.9
Reverse Osmosis	Vendor 9	System 13	--	4.7	900	2.6	9.0	3.8	89.5
Reverse Osmosis	Vendor 9	System 14	--	5.7	980	2.6	9.0	3.8	89.5
Reverse Osmosis	Vendor 9	System 15	--	6.9	1,060	--	--	--	--
Reverse Osmosis	Vendor 9	System 16	--	9.7	1,300	2.6	9.7	5.0	124.0
Reverse Osmosis	Vendor 9	System 17	--	18.1	3,200	--	10.2	10.3	--
Reverse Osmosis	Vendor 9	System 18	--	27.8	--	8.0	19.0	8.2	1,253.8
Reverse Osmosis	Vendor 9	System 19	--	55.6	--	7.7	18.6	9.5	1,361.7
Distillation	Vendor 10	System 1	--	0.1	125	1.9	0.9	1.7	2.9
Distillation	Vendor 10	System 2	--	0.4	250	2.2	1.7	3.0	10.8
Distillation	Vendor 10	System 3	--	0.8	410	2.6	1.8	3.6	17.0
Distillation	Vendor 10	System 4	--	1.4	625	2.6	2.0	4.5	23.3
Distillation	Vendor 10	System 5	--	2.1	970	3.7	2.4	4.3	38.4
Distillation	Vendor 10	System 6	--	2.6	2,100	5.4	3.3	4.6	80.7
Distillation	Vendor 10	System 7	--	3.5	2,250	5.4	3.5	4.6	86.9

Table A-1. PWG Weights and Physical Dimensions

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Weight (lb)	Dimensions (ft)			Volume (ft^3)
			Min	Max		Height	Width	Depth	
Distillation	Vendor 10	System 8	--	5.2	2,900	5.7	3.7	6.8	142.0
Distillation	Vendor 10	System 9	--	7.6	4,800	5.7	4.2	7.7	181.0
Distillation	Vendor 10	System 10	--	10.4	5,600	6.3	5.4	7.9	271.6
Reverse Osmosis	Vendor 10	System 11	--	0.7	340	5.5	2.3	2.2	26.8
Reverse Osmosis	Vendor 10	System 12	--	1.4	375	5.5	2.8	2.2	32.8
Reverse Osmosis	Vendor 10	System 13	--	2.1	435	5.5	2.8	2.8	42.9
Reverse Osmosis	Vendor 10	System 14	--	2.8	480	5.5	2.8	2.8	42.9
Reverse Osmosis	Vendor 10	System 15	--	3.5	525	5.5	2.8	2.8	42.9
Reverse Osmosis	Vendor 10	System 16	--	4.2	580	5.5	2.8	2.8	42.9
Reverse Osmosis	Vendor 11	System 1	--	1.9	--	4.9	2.4	2.4	28.7
Reverse Osmosis	Vendor 11	System 2	--	2.5	--	4.9	2.4	2.4	28.7
Reverse Osmosis	Vendor 11	System 3	--	2.9	--	4.9	2.4	2.4	28.7
Reverse Osmosis	Vendor 11	System 4	--	3.6	--	4.9	2.4	2.4	28.7
Reverse Osmosis	Vendor 11	System 5	--	4.3	--	4.9	2.4	2.4	28.7
Reverse Osmosis	Vendor 11	System 6	--	4.7	--	4.9	2.4	2.4	28.7
Reverse Osmosis	Vendor 11	System 7	--	1.9	--	2.7	4.6	2.4	29.5
Reverse Osmosis	Vendor 11	System 8	--	2.5	--	2.7	4.6	2.4	29.5
Reverse Osmosis	Vendor 11	System 9	--	2.9	--	2.7	4.6	2.4	29.5
Reverse Osmosis	Vendor 11	System 10	--	3.6	--	2.7	4.6	2.4	29.5
Reverse Osmosis	Vendor 11	System 11	--	4.3	--	2.7	4.6	2.4	29.5
Reverse Osmosis	Vendor 11	System 12	--	4.7	--	2.7	4.6	2.4	29.5
Reverse Osmosis	Vendor 11	System 13	--	4.5	1,900	4.1	6.4	3.8	98.3
Reverse Osmosis	Vendor 11	System 14	--	8.3	2,100	4.1	6.4	3.8	98.3
Reverse Osmosis	Vendor 11	System 15	--	11.1	2,200	4.1	6.4	3.8	98.3
Reverse Osmosis	Vendor 11	System 16	--	13.2	2,400	4.1	6.4	3.8	98.3
Reverse Osmosis	Vendor 11	System 17	--	16.0	2,400	4.1	6.4	3.8	98.3
Reverse Osmosis	Vendor 11	System 18	--	8.3	3,700	5.5	13.2	6.2	450.7

Table A-1. PWG Weights and Physical Dimensions

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Weight (lb)	Dimensions (ft)			Volume (ft^3)
			Min	Max		Height	Width	Depth	
Reverse Osmosis	Vendor 11	System 19	--	15.6	4,000	5.5	13.2	6.2	450.7
Reverse Osmosis	Vendor 11	System 20	--	19.5	4,300	5.5	13.2	6.2	450.7
Reverse Osmosis	Vendor 11	System 21	--	27.1	4,800	5.5	13.2	6.2	450.7
Reverse Osmosis	Vendor 11	System 22	--	32.5	5,400	5.5	13.2	6.2	450.7
Reverse Osmosis	Vendor 11	System 23	--	32.5	5,400	5.5	13.2	6.2	450.7
Reverse Osmosis	Vendor 11	System 24	--	36.0	6,300	5.5	13.2	6.2	450.7
Reverse Osmosis	Vendor 12	System 1	--	5.6	2,600	10.0	3.5	6.0	210.0
Reverse Osmosis	Vendor 12	System 2	--	8.3	2,600	13.3	3.5	6.0	280.0
Reverse Osmosis	Vendor 12	System 3	--	11.1	2,700	16.3	5.0	6.0	487.5
Reverse Osmosis	Vendor 12	System 4	--	16.7	3,200	13.3	5.0	6.0	400.0
Reverse Osmosis	Vendor 12	System 5	--	22.2	4,200	16.3	6.0	6.0	585.0
Reverse Osmosis	Vendor 12	System 6	--	33.3	5,600	23.3	6.0	6.0	840.0
Reverse Osmosis	Vendor 12	System 7	--	44.4	6,500	16.3	6.0	6.0	585.0
Reverse Osmosis	Vendor 12	System 8	--	50.0	12,000	23.3	6.0	6.7	933.3
Reverse Osmosis	Vendor 12	System 9	--	66.7	13,000	23.3	6.0	6.7	933.3
Reverse Osmosis	Vendor 12	System 10	--	77.8	14,000	29.2	6.0	6.7	1,166.7
Reverse Osmosis	Vendor 12	System 11	--	94.4	15,000	23.3	6.0	6.7	933.3
Reverse Osmosis	Vendor 12	System 12	--	116.7	17,500	29.2	6.0	6.7	1,166.7
Reverse Osmosis	Vendor 12	System 13	--	136.1	17,500	29.2	6.0	6.7	1,166.7
Reverse Osmosis	Vendor 12	System 14	--	155.6	17,200	29.2	6.0	6.6	1,152.1
Reverse Osmosis	Vendor 12	System 15	--	175.0	18,000	29.2	6.0	6.6	1,152.1
Reverse Osmosis	Vendor 12	System 16	--	194.4	19,000	29.2	6.0	6.6	1,152.1
Reverse Osmosis	Vendor 12	System 17	--	220.1	21,000	29.2	7.1	6.7	1,377.3
Reverse Osmosis	Vendor 12	System 18	--	291.7	21,000	29.2	7.1	6.7	1,377.3
Reverse Osmosis	Vendor 12	System 19	--	347.2	22,000	29.2	7.1	6.8	1,394.5
Reverse Osmosis	Vendor 12	System 20	--	0.3	220	4.3	1.8	2.5	18.6
Reverse Osmosis	Vendor 12	System 21	--	0.5	230	4.3	1.8	2.5	18.6

Table A-1. PWG Weights and Physical Dimensions

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Weight (lb)	Dimensions (ft)			Volume (ft^3)
			Min	Max		Height	Width	Depth	
Reverse Osmosis	Vendor 12	System 22	--	0.7	250	4.3	1.8	2.5	18.6
Reverse Osmosis	Vendor 12	System 23	--	0.9	290	4.3	1.8	2.5	18.6
Reverse Osmosis	Vendor 12	System 24	--	0.8	395	5.1	2.8	4.2	60.0
Reverse Osmosis	Vendor 12	System 25	--	1.5	500	5.1	2.8	4.2	60.0
Reverse Osmosis	Vendor 12	System 26	--	2.1	360	5.1	2.8	4.2	60.0
Reverse Osmosis	Vendor 12	System 27	--	2.6	500	5.1	2.8	4.2	60.0
Reverse Osmosis	Vendor 12	System 28	--	3.3	750	5.1	2.8	4.2	60.0
Reverse Osmosis	Vendor 12	System 29	--	3.9	850	5.1	2.8	4.2	60.0
Reverse Osmosis	Vendor 12	System 30	--	4.2	970	5.1	2.8	4.2	60.0
Reverse Osmosis	Vendor 12	System 31	--	5.3	1,050	5.1	2.8	4.2	60.0
Reverse Osmosis	Vendor 13	System 1	--	0.3	96	1.0	2.0	1.2	2.3
Reverse Osmosis	Vendor 13	System 2	--	0.4	103	1.0	2.0	1.2	2.3
Reverse Osmosis	Vendor 13	System 3	--	0.6	110	1.0	2.0	1.2	2.3
Reverse Osmosis	Vendor 13	System 4	--	0.8	121	1.0	2.0	1.2	2.3
Reverse Osmosis	Vendor 13	System 5	--	1.0	134	1.0	2.0	1.2	2.3
Reverse Osmosis	Vendor 13	System 6	--	3.5	500	1.8	3.5	2.7	17.1
Reverse Osmosis	Vendor 13	System 7	--	15.3	2,000	1.8	3.5	2.7	17.1
Reverse Osmosis	Vendor 13	System 8	--	0.3	80	--	--	--	--
Reverse Osmosis	Vendor 13	System 9	--	0.6	92	--	--	--	--
Reverse Osmosis	Vendor 13	System 10	--	0.8	103	--	--	--	--
Reverse Osmosis	Vendor 13	System 11	--	1.0	115	--	--	--	--
Reverse Osmosis	Vendor 13	System 12	0.3	2.8	250	1.2	2.2	1.5	3.9
Reverse Osmosis	Vendor 13	System 13	0.3	1.7	250	1.2	2.2	1.5	3.9
Reverse Osmosis	Vendor 13	System 14	--	--	250	1.2	2.2	1.5	3.9
Reverse Osmosis	Vendor 13	System 15	0.3	1.7	250	1.2	2.2	1.5	3.9

Table A-2. PWG Heat and Power Requirements

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Heat Input Requirement (kW)	Heat Input Requirement (BTU/hr)	Electrical Requirements		
			Min	Max			Voltage (V)	Amperage (A)	Power (kW)
Distillation	Vendor 1	System 1	2.9	7.3	--	--	--	--	--
Distillation	Vendor 1	System 2	4.6	11.0	--	--	--	--	--
Distillation	Vendor 1	System 3	0.6	1.1	--	--	--	--	--
Distillation	Vendor 1	System 4	1.3	4.6	--	--	--	--	--
Reverse Osmosis	Vendor 2	System 1	--	0.1	--	--	--	--	--
Reverse Osmosis	Vendor 2	System 2	--	0.1	--	--	--	--	--
Reverse Osmosis	Vendor 2	System 3	--	0.2	--	--	--	--	--
Reverse Osmosis	Vendor 2	System 4	--	0.3	--	--	--	--	--
Reverse Osmosis	Vendor 2	System 5	--	0.4	--	--	--	--	--
Reverse Osmosis	Vendor 2	System 6	--	0.6	--	--	--	--	--
Reverse Osmosis	Vendor 2	System 7	--	0.7	--	--	--	--	--
Reverse Osmosis	Vendor 2	System 8	--	1.0	--	--	--	--	--
Reverse Osmosis	Vendor 2	System 9	--	1.4	--	--	--	--	--
Reverse Osmosis	Vendor 2	System 10	--	2.1	--	--	--	--	--
Reverse Osmosis	Vendor 2	System 11	--	3.1	--	--	--	--	--
Distillation	Vendor 3	System 1	--	4.6	750	2,559,000	--	--	--
Distillation	Vendor 3	System 2	--	5.5	1,050	3,583,000	--	--	--
Distillation	Vendor 3	System 3	--	7.3	1,400	4,777,000	--	--	--
Distillation	Vendor 3	System 4	--	9.2	1,750	5,971,000	--	--	--
Distillation	Vendor 3	System 5	--	11.0	2,100	7,165,000	--	--	--
Distillation	Vendor 3	System 6	--	7.3	1,000	3,412,000	--	--	--
Distillation	Vendor 3	System 7	--	11.0	1,400	4,777,000	--	--	--
Distillation	Vendor 3	System 8	--	1.8	350	1,194,000	--	--	--
Distillation	Vendor 3	System 9	--	3.7	525	1,791,000	--	--	--
Distillation	Vendor 3	System 10	--	5.6	1,050	3,583,000	--	--	--
Distillation	Vendor 3	System 11	--	7.3	1,400	4,777,000	--	--	--
Distillation	Vendor 3	System 12	--	9.0	1,750	5,971,000	--	--	--

Table A-2. PWG Heat and Power Requirements

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Heat Input Requirement (kW)	Heat Input Requirement (BTU/hr)	Electrical Requirements		
			Min	Max			Voltage (V)	Amperage (A)	Power (kW)
Distillation	Vendor 3	System 13	--	11.1	2,100	7,165,000	--	--	--
Distillation	Vendor 3	System 14	--	5.0	--	--	--	--	--
Distillation	Vendor 3	System 15	--	8.3	--	--	--	--	--
Distillation	Vendor 3	System 16	--	11.7	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 1	--	8.3	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 2	--	12.5	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 3	--	16.7	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 4	--	20.8	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 5	--	25.0	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 6	--	1.0	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 7	--	2.1	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 8	--	3.1	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 9	--	4.2	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 10	--	5.2	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 11	--	6.3	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 12	--	2.0	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 13	--	2.7	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 14	--	0.4	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 15	--	0.8	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 16	--	1.3	--	--	--	--	--
Reverse Osmosis	Vendor 4	System 17	--	1.5	--	--	--	--	--
Reverse Osmosis	Vendor 5	System 1	--	5.5	--	--	--	--	11
Reverse Osmosis	Vendor 5	System 2	--	7.3	--	--	--	--	19
Reverse Osmosis	Vendor 5	System 3	--	9.2	--	--	--	--	19
Reverse Osmosis	Vendor 5	System 4	--	11.0	--	--	--	--	19
Reverse Osmosis	Vendor 5	System 5	--	13.8	--	--	--	--	21
Reverse Osmosis	Vendor 5	System 6	--	14.7	--	--	--	--	22

Table A-2. PWG Heat and Power Requirements

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Heat Input Requirement (kW)	Heat Input Requirement (BTU/hr)	Electrical Requirements		
			Min	Max			Voltage (V)	Amperage (A)	Power (kW)
Reverse Osmosis	Vendor 5	System 7	--	17.2	--	--	--	--	26
Reverse Osmosis	Vendor 5	System 8	--	22.0	--	--	--	--	28
Reverse Osmosis	Vendor 5	System 9	--	36.7	--	--	--	--	49
Reverse Osmosis	Vendor 5	System 10	--	55.0	--	--	--	--	100
Reverse Osmosis	Vendor 5	System 11	--	78.0	--	--	--	--	140
Reverse Osmosis	Vendor 5	System 12	--	128.8	--	--	--	--	180
Reverse Osmosis	Vendor 6	System 1	--	0.8	--	--	--	--	2.3
Reverse Osmosis	Vendor 6	System 2	--	1.3	--	--	--	--	2.3
Reverse Osmosis	Vendor 6	System 3	--	0.2	--	--	--	--	1.5
Reverse Osmosis	Vendor 6	System 4	--	0.3	--	--	--	--	1.5
Reverse Osmosis	Vendor 6	System 5	--	0.4	--	--	--	--	1.5
Reverse Osmosis	Vendor 6	System 6	--	0.6	--	--	--	--	1.5
Reverse Osmosis	Vendor 6	System 7	--	0.8	--	--	--	--	2.3
Reverse Osmosis	Vendor 6	System 8	--	1.3	--	--	--	--	2.3
Reverse Osmosis	Vendor 6	System 9	--	0.4	--	--	--	--	2.3
Reverse Osmosis	Vendor 6	System 10	--	1.3	--	--	--	--	3.1
Reverse Osmosis	Vendor 6	System 11	--	1.7	--	--	--	--	4.6
Reverse Osmosis	Vendor 6	System 12	--	2.2	--	--	--	--	6.5
Reverse Osmosis	Vendor 6	System 13	--	3.0	--	--	--	--	6.5
Reverse Osmosis	Vendor 6	System 14	--	3.8	--	--	--	--	6.5
Reverse Osmosis	Vendor 6	System 15	--	5.2	--	--	--	--	8.4
Reverse Osmosis	Vendor 6	System 16	--	6.6	--	--	--	--	8.4
Reverse Osmosis	Vendor 6	System 17	--	6.9	--	--	--	--	15.3
Reverse Osmosis	Vendor 6	System 18	--	8.7	--	--	--	--	15.3
Reverse Osmosis	Vendor 6	System 19	--	11.1	--	--	--	--	15.3
Reverse Osmosis	Vendor 6	System 20	--	13.2	--	--	--	--	15.3
Reverse Osmosis	Vendor 6	System 21	--	15.6	--	--	--	--	15.3

Table A-2. PWG Heat and Power Requirements

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Heat Input Requirement (kW)	Heat Input Requirement (BTU/hr)	Electrical Requirements		
			Min	Max			Voltage (V)	Amperage (A)	Power (kW)
Reverse Osmosis	Vendor 6	System 22	--	20.8	--	--	--	--	30.5
Reverse Osmosis	Vendor 6	System 23	--	24.0	--	--	--	--	30.5
Reverse Osmosis	Vendor 6	System 24	--	26.7	--	--	--	--	30.5
Reverse Osmosis	Vendor 6	System 25	--	29.9	--	--	--	--	30.5
Reverse Osmosis	Vendor 6	System 26	--	7.6	--	--	--	--	30.5
Reverse Osmosis	Vendor 6	System 27	--	13.2	--	--	--	--	30.5
Reverse Osmosis	Vendor 6	System 28	--	16.7	--	--	--	--	30.5
Distillation	Vendor 7	System 1	--	1.7	--	--	--	--	--
Distillation	Vendor 7	System 2	--	2.5	--	--	--	--	--
Distillation	Vendor 7	System 3	--	3.3	--	--	--	--	--
Distillation	Vendor 7	System 4	--	4.2	--	--	--	--	--
Distillation	Vendor 7	System 5	--	5.0	--	--	--	--	--
Reverse Osmosis	Vendor 8	System 1	--	2.1	--	--	--	--	7.5
Reverse Osmosis	Vendor 8	System 2	--	4.2	--	--	--	--	10
Reverse Osmosis	Vendor 8	System 3	--	5.6	--	--	--	--	16.5
Reverse Osmosis	Vendor 8	System 4	--	6.9	--	--	--	--	20
Reverse Osmosis	Vendor 8	System 5	--	10.4	--	--	--	--	22
Reverse Osmosis	Vendor 8	System 6	--	13.9	--	--	--	--	40
Reverse Osmosis	Vendor 8	System 7	--	18.3	--	--	--	--	40
Reverse Osmosis	Vendor 8	System 8	--	21.9	--	--	--	--	48
Reverse Osmosis	Vendor 8	System 9	--	185	--	--	--	--	--
Reverse Osmosis	Vendor 8	System 10	--	100	--	--	--	--	--
Reverse Osmosis	Vendor 8	System 11	--	75	--	--	--	--	--
Reverse Osmosis	Vendor 8	System 12	--	60	--	--	--	--	--
Reverse Osmosis	Vendor 8	System 13	--	45	--	--	--	--	--
Reverse Osmosis	Vendor 8	System 14	--	30	--	--	--	--	--
Reverse Osmosis	Vendor 8	System 15	--	19	--	--	--	--	--

Table A-2. PWG Heat and Power Requirements

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm) Min	Production Rate (gpm) Max	Heat Input Requirement (kW)	Heat Input Requirement (BTU/hr)	Electrical Requirements Voltage (V)	Electrical Requirements Amperage (A)	Electrical Requirements Power (kW)
Reverse Osmosis	Vendor 8	System 16	--	7	--	--	--	--	--
Reverse Osmosis	Vendor 9	System 1	--	0.3	--	--	110, 220	18.7, 9.3	2.1
Reverse Osmosis	Vendor 9	System 2	--	0.4	--	--	110, 220	18.7, 9.3	2.1
Reverse Osmosis	Vendor 9	System 3	--	0.6	--	--	110, 220	25.4, 12.7	2.8
Reverse Osmosis	Vendor 9	System 4	--	0.8	--	--	110, 220	25.4, 12.7	2.8
Reverse Osmosis	Vendor 9	System 5	--	0.4	--	--	110, 220, 230, 380, 460	13.6, 6.8, 6.8, 4.1, 3.4	1.5
Reverse Osmosis	Vendor 9	System 6	--	0.7	--	--	110, 220, 230, 380, 460	23.7, 11.9, 11.6, 7.0, 5.8	2.6
Reverse Osmosis	Vendor 9	System 7	--	1.0	--	--	110, 220, 230, 380, 460	23.7, 11.9, 11.6, 7.0, 5.8	2.6
Reverse Osmosis	Vendor 9	System 8	--	1.4	--	--	110, 220, 230, 380, 460	23.7, 11.9, 11.6, 7.0, 5.8	2.6
Reverse Osmosis	Vendor 9	System 9	--	1.8	--	--	230, 380, 460	27.2, 16.5, 13.6	6.3

Table A-2. PWG Heat and Power Requirements

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Heat Input Requirement (kW)	Heat Input Requirement (BTU/hr)	Electrical Requirements		
			Min	Max			Voltage (V)	Amperage (A)	Power (kW)
Reverse Osmosis	Vendor 9	System 10	--	2.5	--	--	230, 380, 460	27.2, 16.5, 13.6	6.3
Reverse Osmosis	Vendor 9	System 11	--	3.1	--	--	230, 380, 460	27.2, 16.5, 13.6	6.3
Reverse Osmosis	Vendor 9	System 12	--	3.7	--	--	230, 380, 460	47.2, 28.6, 23.6	10.9
Reverse Osmosis	Vendor 9	System 13	--	4.7	--	--	230, 380, 460	47.2, 28.6, 23.6	10.9
Reverse Osmosis	Vendor 9	System 14	--	5.7	--	--	230, 380, 460	74.8, 45.3, 37.4	17.2
Reverse Osmosis	Vendor 9	System 15	--	6.9	--	--	230, 380, 460	74.8, 45.3, 37.4	17.2
Reverse Osmosis	Vendor 9	System 16	--	9.7	--	--	230, 380, 460	74.8, 45.3, 37.4	17.2
Reverse Osmosis	Vendor 9	System 17	--	18.1	--	--	230, 380, 460	145.2, 87.9, 72.6	33.4
Reverse Osmosis	Vendor 9	System 18	--	27.8	--	--	--	--	--
Reverse Osmosis	Vendor 9	System 19	--	55.6	--	--	--	--	--
Distillation	Vendor 10	System 1	--	0.1		75,000	--	--	0.8
Distillation	Vendor 10	System 2	--	0.4		250,000	--	--	2.9
Distillation	Vendor 10	System 3	--	0.8		500,000	--	--	2.9
Distillation	Vendor 10	System 4	--	1.4		832,000	--	--	6.5
Distillation	Vendor 10	System 5	--	2.1		1,250,000	--	--	6.5
Distillation	Vendor 10	System 6	--	2.6		1,430,000	--	--	0.6

Table A-2. PWG Heat and Power Requirements

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Heat Input Requirement (kW)	Heat Input Requirement (BTU/hr)	Electrical Requirements		
			Min	Max			Voltage (V)	Amperage (A)	Power (kW)
Distillation	Vendor 10	System 7	--	3.5		1,950,000	--	--	0.6
Distillation	Vendor 10	System 8	--	5.2		2,900,000	--	--	1.6
Distillation	Vendor 10	System 9	--	7.6		4,250,000	--	--	1.6
Distillation	Vendor 10	System 10	--	10.4		5,800,000	--	--	1.6
Reverse Osmosis	Vendor 10	System 11	--	0.7	--	--	--	--	--
Reverse Osmosis	Vendor 10	System 12	--	1.4	--	--	--	--	--
Reverse Osmosis	Vendor 10	System 13	--	2.1	--	--	--	--	--
Reverse Osmosis	Vendor 10	System 14	--	2.8	--	--	--	--	--
Reverse Osmosis	Vendor 10	System 15	--	3.5	--	--	--	--	--
Reverse Osmosis	Vendor 10	System 16	--	4.2	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 1	--	1.9	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 2	--	2.5	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 3	--	2.9	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 4	--	3.6	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 5	--	4.3	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 6	--	4.7	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 7	--	1.9	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 8	--	2.5	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 9	--	2.9	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 10	--	3.6	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 11	--	4.3	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 12	--	4.7	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 13	--	4.5	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 14	--	8.3	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 15	--	11.1	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 16	--	13.2	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 17	--	16.0	--	--	--	--	--

Table A-2. PWG Heat and Power Requirements

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Heat Input Requirement (kW)	Heat Input Requirement (BTU/hr)	Electrical Requirements		
			Min	Max			Voltage (V)	Amperage (A)	Power (kW)
Reverse Osmosis	Vendor 11	System 18	--	8.3	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 19	--	15.6	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 20	--	19.5	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 21	--	27.1	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 22	--	32.5	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 23	--	32.5	--	--	--	--	--
Reverse Osmosis	Vendor 11	System 24	--	36.0	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 1	--	5.6	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 2	--	8.3	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 3	--	11.1	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 4	--	16.7	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 5	--	22.2	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 6	--	33.3	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 7	--	44.4	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 8	--	50.0	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 9	--	66.7	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 10	--	77.8	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 11	--	94.4	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 12	--	116.7	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 13	--	136.1	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 14	--	155.6	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 15	--	175.0	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 16	--	194.4	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 17	--	220.1	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 18	--	291.7	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 19	--	347.2	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 20	--	0.3	--	--	--	--	--

Table A-2. PWG Heat and Power Requirements

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Heat Input Requirement (kW)	Heat Input Requirement (BTU/hr)	Electrical Requirements		
			Min	Max			Voltage (V)	Amperage (A)	Power (kW)
Reverse Osmosis	Vendor 12	System 21	--	0.5	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 22	--	0.7	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 23	--	0.9	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 24	--	0.8	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 25	--	1.5	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 26	--	2.1	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 27	--	2.6	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 28	--	3.3	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 29	--	3.9	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 30	--	4.2	--	--	--	--	--
Reverse Osmosis	Vendor 12	System 31	--	5.3	--	--	--	--	--
Reverse Osmosis	Vendor 13	System 1	--	0.3	--	--	115, 230	14.0, 7.0	1.61
Reverse Osmosis	Vendor 13	System 2	--	0.4	--	--	115, 230	14.0, 7.0	1.61
Reverse Osmosis	Vendor 13	System 3	--	0.6	--	--	115, 230	14.0, 7.0	1.61
Reverse Osmosis	Vendor 13	System 4	--	0.8	--	--	115, 230	16.6, 8.3	1.91
Reverse Osmosis	Vendor 13	System 5	--	1.0	--	--	115, 230	20.8, 10.4	2.39
Reverse Osmosis	Vendor 13	System 6	--	3.5	--	--	208, 230, 460	--	--
Reverse Osmosis	Vendor 13	System 7	--	15.3	--	--	190, 380, 400	--	--
Reverse Osmosis	Vendor 13	System 8	--	0.3	--	--	115, 230	14.0, 7.0	1.6
Reverse Osmosis	Vendor 13	System 9	--	0.6	--	--	115, 230	14.0, 7.0	1.6

Table A-2. PWG Heat and Power Requirements

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Heat Input Requirement (kW)	Heat Input Requirement (BTU/hr)	Electrical Requirements		
			Min	Max			Voltage (V)	Amperage (A)	Power (kW)
Reverse Osmosis	Vendor 13	System 10	--	0.8	--	--	115, 230	16.6, 8.3	1.9
Reverse Osmosis	Vendor 13	System 11	--	1.0	--	--	115, 230	20.8, 10.4	2.4
Reverse Osmosis	Vendor 13	System 12	0.3	2.8	--	--	115, 230	12.8, 6.4	1.5
Reverse Osmosis	Vendor 13	System 13	0.3	1.7	--	--	230	13.2	3.0
Reverse Osmosis	Vendor 13	System 14	--	--	--	--	208, 230, 460	9, 8.6, 4.3	1.9
Reverse Osmosis	Vendor 13	System 15	0.3	1.7	--	--	208, 230, 460	15, 13.2, 6.6	3.1

Table A-3. PWG Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Equipment Cost	Installation Cost	Annual O&M Cost	Notes
			Min	Max				
Distillation	Vendor 1	System 1	2.9	7.3	--	--	--	
Distillation	Vendor 1	System 2	4.6	11.0	--	--	--	
Distillation	Vendor 1	System 3	0.6	1.1	--	--	--	
Distillation	Vendor 1	System 4	1.3	4.6	--	--	--	
Reverse Osmosis	Vendor 2	System 1	--	0.1	$4,975	--	--	
Reverse Osmosis	Vendor 2	System 2	--	0.1	$5,575	--	--	
Reverse Osmosis	Vendor 2	System 3	--	0.2	$6,350	--	--	
Reverse Osmosis	Vendor 2	System 4	--	0.3	$6,750	--	--	
Reverse Osmosis	Vendor 2	System 5	--	0.4	$7,450	--	--	
Reverse Osmosis	Vendor 2	System 6	--	0.6	--	--	--	
Reverse Osmosis	Vendor 2	System 7	--	0.7	--	--	--	
Reverse Osmosis	Vendor 2	System 8	--	1.0	--	--	--	
Reverse Osmosis	Vendor 2	System 9	--	1.4	--	--	--	
Reverse Osmosis	Vendor 2	System 10	--	2.1	--	--	--	
Reverse Osmosis	Vendor 2	System 11	--	3.1	--	--	--	
Distillation	Vendor 3	System 1	--	4.6	--	--	--	
Distillation	Vendor 3	System 2	--	5.5	--	--	--	
Distillation	Vendor 3	System 3	--	7.3	--	--	--	
Distillation	Vendor 3	System 4	--	9.2	--	--	--	
Distillation	Vendor 3	System 5	--	11.0	--	--	--	
Distillation	Vendor 3	System 6	--	7.3	--	--	--	
Distillation	Vendor 3	System 7	--	11.0	--	--	--	
Distillation	Vendor 3	System 8	--	1.8	--	--	--	
Distillation	Vendor 3	System 9	--	3.7	--	--	--	
Distillation	Vendor 3	System 10	--	5.6	--	--	--	
Distillation	Vendor 3	System 11	--	7.3	--	--	--	
Distillation	Vendor 3	System 12	--	9.0	--	--	--	

Table A-3. PWG Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Equipment Cost	Installation Cost	Annual O&M Cost	Notes
			Min	Max				
Distillation	Vendor 3	System 13	--	11.1	--	--	--	
Distillation	Vendor 3	System 14	--	5.0	--	--	--	
Distillation	Vendor 3	System 15	--	8.3	--	--	--	
Distillation	Vendor 3	System 16	--	11.7	--	--	--	
Reverse Osmosis	Vendor 4	System 1	--	8.3	--	--	--	
Reverse Osmosis	Vendor 4	System 2	--	12.5	--	--	--	
Reverse Osmosis	Vendor 4	System 3	--	16.7	--	--	--	
Reverse Osmosis	Vendor 4	System 4	--	20.8	--	--	--	
Reverse Osmosis	Vendor 4	System 5	--	25.0	--	--	--	
Reverse Osmosis	Vendor 4	System 6	--	1.0	--	--	--	
Reverse Osmosis	Vendor 4	System 7	--	2.1	--	--	--	
Reverse Osmosis	Vendor 4	System 8	--	3.1	--	--	--	
Reverse Osmosis	Vendor 4	System 9	--	4.2	--	--	--	
Reverse Osmosis	Vendor 4	System 10	--	5.2	--	--	--	
Reverse Osmosis	Vendor 4	System 11	--	6.3	--	--	--	
Reverse Osmosis	Vendor 4	System 12	--	2.0	--	--	--	
Reverse Osmosis	Vendor 4	System 13	--	2.7	--	--	--	
Reverse Osmosis	Vendor 4	System 14	--	0.4	--	--	--	
Reverse Osmosis	Vendor 4	System 15	--	0.8	--	--	--	
Reverse Osmosis	Vendor 4	System 16	--	1.3	--	--	--	
Reverse Osmosis	Vendor 4	System 17	--	1.5	--	--	--	
Reverse Osmosis	Vendor 5	System 1	--	5.5	--	--	--	
Reverse Osmosis	Vendor 5	System 2	--	7.3	--	--	--	
Reverse Osmosis	Vendor 5	System 3	--	9.2	--	--	--	
Reverse Osmosis	Vendor 5	System 4	--	11.0	--	--	--	
Reverse Osmosis	Vendor 5	System 5	--	13.8	--	--	--	
Reverse Osmosis	Vendor 5	System 6	--	14.7	--	--	--	

Table A-3. PWG Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Equipment Cost	Installation Cost	Annual O&M Cost	Notes
			Min	Max				
Reverse Osmosis	Vendor 5	System 7	--	17.2	--	--	--	
Reverse Osmosis	Vendor 5	System 8	--	22.0	--	--	--	
Reverse Osmosis	Vendor 5	System 9	--	36.7	--	--	--	
Reverse Osmosis	Vendor 5	System 10	--	55.0	--	--	--	
Reverse Osmosis	Vendor 5	System 11	--	78.0	--	--	--	
Reverse Osmosis	Vendor 5	System 12	--	128.8	--	--	--	
Reverse Osmosis	Vendor 6	System 1	--	0.8	--	--	--	
Reverse Osmosis	Vendor 6	System 2	--	1.3	--	--	--	
Reverse Osmosis	Vendor 6	System 3	--	0.2	--	--	--	
Reverse Osmosis	Vendor 6	System 4	--	0.3	--	--	--	
Reverse Osmosis	Vendor 6	System 5	--	0.4	--	--	--	
Reverse Osmosis	Vendor 6	System 6	--	0.6	--	--	--	
Reverse Osmosis	Vendor 6	System 7	--	0.8	--	--	--	
Reverse Osmosis	Vendor 6	System 8	--	1.3	--	--	--	
Reverse Osmosis	Vendor 6	System 9	--	0.4	--	--	--	
Reverse Osmosis	Vendor 6	System 10	--	1.3	--	--	--	
Reverse Osmosis	Vendor 6	System 11	--	1.7	--	--	--	
Reverse Osmosis	Vendor 6	System 12	--	2.2	--	--	--	
Reverse Osmosis	Vendor 6	System 13	--	3.0	--	--	--	
Reverse Osmosis	Vendor 6	System 14	--	3.8	--	--	--	
Reverse Osmosis	Vendor 6	System 15	--	5.2	--	--	--	
Reverse Osmosis	Vendor 6	System 16	--	6.6	--	--	--	
Reverse Osmosis	Vendor 6	System 17	--	6.9	--	--	--	
Reverse Osmosis	Vendor 6	System 18	--	8.7	$73,000		$2,190 to $7,300	Assumed to be 3 to 10% of equipment cost.
Reverse Osmosis	Vendor 6	System 19	--	11.1	--	--	--	
Reverse Osmosis	Vendor 6	System 20	--	13.2	--	--	--	

Table A-3. PWG Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Equipment Cost	Installation Cost	Annual O&M Cost	Notes
			Min	Max				
Reverse Osmosis	Vendor 6	System 21	--	15.6	$95,000	--	$2,850 to $9,500	Assumed to be 3 to 10% of equipment cost.
Reverse Osmosis	Vendor 6	System 22	--	20.8	--	--		
Reverse Osmosis	Vendor 6	System 23	--	24.0	--	--		
Reverse Osmosis	Vendor 6	System 24	--	26.7	--	--		
Reverse Osmosis	Vendor 6	System 25	--	29.9	$152,845	--	$4,585 to $15,285	Assumed to be 3 to 10% of equipment cost.
Reverse Osmosis	Vendor 6	System 26	--	7.6	--	--	--	
Reverse Osmosis	Vendor 6	System 27	--	13.2	--	--	--	
Reverse Osmosis	Vendor 6	System 28	--	16.7	--	--	--	
Distillation	Vendor 7	System 1	--	1.7	$30,000 to $50,000	$10,000 to $15,000	--	
Distillation	Vendor 7	System 2	--	2.5	--	--	--	
Distillation	Vendor 7	System 3	--	3.3	--	--	--	
Distillation	Vendor 7	System 4	--	4.2	--	--	--	
Distillation	Vendor 7	System 5	--	5.0	$45,000 to $50,000	$50,000 to $100,000	--	
Reverse Osmosis	Vendor 8	System 1	--	2.1	--	--	--	
Reverse Osmosis	Vendor 8	System 2	--	4.2	--	--	--	
Reverse Osmosis	Vendor 8	System 3	--	5.6	--	--	--	
Reverse Osmosis	Vendor 8	System 4	--	6.9	--	--	--	
Reverse Osmosis	Vendor 8	System 5	--	10.4	--	--	--	
Reverse Osmosis	Vendor 8	System 6	--	13.9	--	--	--	
Reverse Osmosis	Vendor 8	System 7	--	18.3	--	--	--	
Reverse Osmosis	Vendor 8	System 8	--	21.9	--	--	--	
Reverse Osmosis	Vendor 8	System 9	--	185	--	--	--	
Reverse Osmosis	Vendor 8	System 10	--	100	--	--	--	
Reverse Osmosis	Vendor 8	System 11	--	75	--	--	--	
Reverse Osmosis	Vendor 8	System 12	--	60	--	--	--	

Table A-3. PWG Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Equipment Cost	Installation Cost	Annual O&M Cost	Notes
			Min	Max				
Reverse Osmosis	Vendor 8	System 13	--	45	--	--	--	
Reverse Osmosis	Vendor 8	System 14	--	30	--	--	--	
Reverse Osmosis	Vendor 8	System 15	--	19	--	--	--	
Reverse Osmosis	Vendor 8	System 16	--	7	--	--	--	
Reverse Osmosis	Vendor 9	System 1	--	0.3	--	--	--	
Reverse Osmosis	Vendor 9	System 2	--	0.4	--	--	--	
Reverse Osmosis	Vendor 9	System 3	--	0.6	--	--	--	
Reverse Osmosis	Vendor 9	System 4	--	0.8	--	--	--	
Reverse Osmosis	Vendor 9	System 5	--	0.4	--	--	--	
Reverse Osmosis	Vendor 9	System 6	--	0.7	--	--	--	
Reverse Osmosis	Vendor 9	System 7	--	1.0	--	--	--	
Reverse Osmosis	Vendor 9	System 8	--	1.4	--	--	--	
Reverse Osmosis	Vendor 9	System 9	--	1.8	--	--	--	
Reverse Osmosis	Vendor 9	System 10	--	2.5	--	--	--	
Reverse Osmosis	Vendor 9	System 11	--	3.1	--	--	--	
Reverse Osmosis	Vendor 9	System 12	--	3.7	--	--	--	
Reverse Osmosis	Vendor 9	System 13	--	4.7	--	--	--	
Reverse Osmosis	Vendor 9	System 14	--	5.7	--	--	--	
Reverse Osmosis	Vendor 9	System 15	--	6.9	--	--	--	
Reverse Osmosis	Vendor 9	System 16	--	9.7	--	--	--	
Reverse Osmosis	Vendor 9	System 17	--	18.1	--	--	--	
Reverse Osmosis	Vendor 9	System 18	--	27.8	--	--	--	
Reverse Osmosis	Vendor 9	System 19	--	55.6	--	--	--	
Distillation	Vendor 10	System 1	--	0.1	$10,600	--	$212	Assumed to be 2% of equipment cost.
Distillation	Vendor 10	System 2	--	0.4	--	--	--	
Distillation	Vendor 10	System 3	--	0.8	--	--	--	
Distillation	Vendor 10	System 4	--	1.4	--	--	--	

Table A-3. PWG Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm) Min	Production Rate (gpm) Max	Equipment Cost	Installation Cost	Annual O&M Cost	Notes
Distillation	Vendor 10	System 5	--	2.1	--	--	--	
Distillation	Vendor 10	System 6	--	2.6	$100,000	--	$2,000	Assumed to be 2% of equipment cost.
Distillation	Vendor 10	System 7	--	3.5	--	--	--	
Distillation	Vendor 10	System 8	--	5.2	--	--	--	
Distillation	Vendor 10	System 9	--	7.6	--	--	--	
Distillation	Vendor 10	System 10	--	10.4	--	--	--	
Reverse Osmosis	Vendor 10	System 11	--	0.7	--	--	--	
Reverse Osmosis	Vendor 10	System 12	--	1.4	--	--	--	
Reverse Osmosis	Vendor 10	System 13	--	2.1	--	--	--	
Reverse Osmosis	Vendor 10	System 14	--	2.8	--	--	--	
Reverse Osmosis	Vendor 10	System 15	--	3.5	--	--	--	
Reverse Osmosis	Vendor 10	System 16	--	4.2	--	--	--	
Reverse Osmosis	Vendor 11	System 1	--	1.9	--	--	--	
Reverse Osmosis	Vendor 11	System 2	--	2.5	--	--	--	
Reverse Osmosis	Vendor 11	System 3	--	2.9	--	--	--	
Reverse Osmosis	Vendor 11	System 4	--	3.6	--	--	--	
Reverse Osmosis	Vendor 11	System 5	--	4.3	--	--	--	
Reverse Osmosis	Vendor 11	System 6	--	4.7	--	--	--	
Reverse Osmosis	Vendor 11	System 7	--	1.9	--	--	--	
Reverse Osmosis	Vendor 11	System 8	--	2.5	--	--	--	
Reverse Osmosis	Vendor 11	System 9	--	2.9	--	--	--	
Reverse Osmosis	Vendor 11	System 10	--	3.6	--	--	--	
Reverse Osmosis	Vendor 11	System 11	--	4.3	--	--	--	
Reverse Osmosis	Vendor 11	System 12	--	4.7	--	--	--	
Reverse Osmosis	Vendor 11	System 13	--	4.5	--	--	--	
Reverse Osmosis	Vendor 11	System 14	--	8.3	--	--	--	
Reverse Osmosis	Vendor 11	System 15	--	11.1	--	--	--	

Table A-3. PWG Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Equipment Cost	Installation Cost	Annual O&M Cost	Notes
			Min	Max				
Reverse Osmosis	Vendor 11	System 16	--	13.2	--	--	--	
Reverse Osmosis	Vendor 11	System 17	--	16.0	--	--	--	
Reverse Osmosis	Vendor 11	System 18	--	8.3	--	--	--	
Reverse Osmosis	Vendor 11	System 19	--	15.6	--	--	--	
Reverse Osmosis	Vendor 11	System 20	--	19.5	--	--	--	
Reverse Osmosis	Vendor 11	System 21	--	27.1	--	--	--	
Reverse Osmosis	Vendor 11	System 22	--	32.5	--	--	--	
Reverse Osmosis	Vendor 11	System 23	--	32.5	--	--	--	
Reverse Osmosis	Vendor 11	System 24	--	36.0	--	--	--	
Reverse Osmosis	Vendor 12	System 1	--	5.6	--	--	--	
Reverse Osmosis	Vendor 12	System 2	--	8.3	--	--	--	
Reverse Osmosis	Vendor 12	System 3	--	11.1	--	--	--	
Reverse Osmosis	Vendor 12	System 4	--	16.7	--	--	--	
Reverse Osmosis	Vendor 12	System 5	--	22.2	--	--	--	
Reverse Osmosis	Vendor 12	System 6	--	33.3	--	--	--	
Reverse Osmosis	Vendor 12	System 7	--	44.4	--	--	--	
Reverse Osmosis	Vendor 12	System 8	--	50.0	--	--	--	
Reverse Osmosis	Vendor 12	System 9	--	66.7	--	--	--	
Reverse Osmosis	Vendor 12	System 10	--	77.8	--	--	--	
Reverse Osmosis	Vendor 12	System 11	--	94.4	--	--	--	
Reverse Osmosis	Vendor 12	System 12	--	116.7	--	--	--	
Reverse Osmosis	Vendor 12	System 13	--	136.1	--	--	--	
Reverse Osmosis	Vendor 12	System 14	--	155.6	--	--	--	
Reverse Osmosis	Vendor 12	System 15	--	175.0	--	--	--	
Reverse Osmosis	Vendor 12	System 16	--	194.4	--	--	--	
Reverse Osmosis	Vendor 12	System 17	--	220.1	--	--	--	
Reverse Osmosis	Vendor 12	System 18	--	291.7	--	--	--	

Table A-3. PWG Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Equipment Cost	Installation Cost	Annual O&M Cost	Notes
			Min	Max				
Reverse Osmosis	Vendor 12	System 19	--	347.2	--	--	--	
Reverse Osmosis	Vendor 12	System 20	--	0.3	--	--	--	
Reverse Osmosis	Vendor 12	System 21	--	0.5	--	--	--	
Reverse Osmosis	Vendor 12	System 22	--	0.7	--	--	--	
Reverse Osmosis	Vendor 12	System 23	--	0.9	--	--	--	
Reverse Osmosis	Vendor 12	System 24	--	0.8	--	--	--	
Reverse Osmosis	Vendor 12	System 25	--	1.5	--	--	--	
Reverse Osmosis	Vendor 12	System 26	--	2.1	--	--	--	
Reverse Osmosis	Vendor 12	System 27	--	2.6	--	--	--	
Reverse Osmosis	Vendor 12	System 28	--	3.3	--	--	--	
Reverse Osmosis	Vendor 12	System 29	--	3.9	--	--	--	
Reverse Osmosis	Vendor 12	System 30	--	4.2	--	--	--	
Reverse Osmosis	Vendor 12	System 31	--	5.3	--	--	--	
Reverse Osmosis	Vendor 13	System 1	--	0.3	--	--	--	
Reverse Osmosis	Vendor 13	System 2	--	0.4	--	--	--	
Reverse Osmosis	Vendor 13	System 3	--	0.6	--	--	--	
Reverse Osmosis	Vendor 13	System 4	--	0.8	--	--	--	
Reverse Osmosis	Vendor 13	System 5	--	1.0	$11,000	$4,000 to $8,000	$450 to $570	Assumed to be 3% of equipment and installation costs.
Reverse Osmosis	Vendor 13	System 6	--	3.5	--	--	--	
Reverse Osmosis	Vendor 13	System 7	--	15.3	$37,000	$10,000	$1,410	Assumed to be 3% of equipment and installation costs.
Reverse Osmosis	Vendor 13	System 8	--	0.3	--	--	--	
Reverse Osmosis	Vendor 13	System 9	--	0.6	--	--	--	
Reverse Osmosis	Vendor 13	System 10	--	0.8	--	--	--	
Reverse Osmosis	Vendor 13	System 11	--	1.0	--	--	--	

Table A-3. PWG Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Production Rate (gpm)		Equipment Cost	Installation Cost	Annual O&M Cost	Notes
			Min	Max				
Reverse Osmosis	Vendor 13	System 12	0.3	2.8	--	--	--	
Reverse Osmosis	Vendor 13	System 13	0.3	1.7	--	--	--	
Reverse Osmosis	Vendor 13	System 14	--	--	--	--	--	
Reverse Osmosis	Vendor 13	System 15	0.3	1.7	--	--	--	

Table A-4. Disinfection System Power Requirements, Weights, and Physical Dimensions

System Technology	Vendor No.	Vendor System No.	Disinfection Rate (gpm)		Power (W)	Weight (lb)	Dimensions (ft)			Volume (ft^3)	Notes
			Min	Max			Height	Width	Depth		
Ultraviolet	Vendor 14	System 1	--	13.2	--	23.2	1.8	1.4	0.5	1.3	
Ultraviolet	Vendor 14	System 2	--	66.0	--	--	--	--	--	--	
Electro-Katadyn	Vendor 15	System 1	--	35.2	40	18.7	1.6	0.2	0.2	0.1	
Electro-Katadyn	Vendor 15	System 2	--	70.4	40	41.6	2.0	0.5	0.5	0.4	
Electro-Katadyn	Vendor 15	System 3	--	105.7	40	42.4	2.0	0.5	0.5	0.4	
Electro-Katadyn	Vendor 15	System 4	--	140.9	40	43.3	2.0	0.5	0.5	0.4	
Electro-Katadyn	Vendor 15	System 5	--	211.3	40	44.9	2.0	0.5	0.5	0.4	
Chlorination	Vendor 16	System 1	--	--	45	19.0	1.5	1.0	1.3	2.0	
Chlorination	Vendor 16	System 2	--	--	45	28.0	1.8	1.2	1.6	3.8	
Chlorination	Vendor 16	System 3	--	--	--	36.0	2.3	1.7	2.0	7.6	
Chlorination	Vendor 16	System 4	80.0	3,960	--	26.0	1.0	1.5	1.5	2.3	Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 16	System 5	80.0	3,960	--	34.0	1.4	1.7	1.7	4.0	Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 16	System 6	80.0	3,960	--	40.0	2.3	1.7	1.7	6.3	
Chlorination	Vendor 16	System 7	--	15,000	--	14.0	1.0	1.7	2.0	3.3	Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 16	System 8	--	15,000	--	22.0	1.4	1.7	2.0	4.8	Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 16	System 9	--	15,000	--	28.0	2.3	1.7	2.0	7.6	Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.

Table A-4. Disinfection System Power Requirements, Weights, and Physical Dimensions

System Technology	Vendor No.	Vendor System No.	Disinfection Rate (gpm) Min	Disinfection Rate (gpm) Max	Power (W)	Weight (lb)	Dimensions (ft) Height	Dimensions (ft) Width	Dimensions (ft) Depth	Volume (ft^3)	Notes
Chlorination	Vendor 16	System 10	70.0	42,000	--	70.0	2.9	3.3	2.0	19.3	Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 16	System 11	1.0	158,500	--	70.0	2.9	3.3	2.0	19.3	Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 17	System 1	528.3	2,641.7	37	22.1	--	--	--	--	Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Ultraviolet	Vendor 17	System 2	3.5	5.3	90	4.4	3.1	0.7	0.7	1.6	
Ultraviolet	Vendor 17	System 3	17.6	28.2	90	52.9	2.7	1.6	1.0	4.4	
Ultraviolet	Vendor 17	System 4	28.6	45.3	180	55.1	2.7	1.6	1.0	4.4	
Bromination	Vendor 18	System 1	16.0	35.0	--	44.0	2.3	3.1	1.3	8.7	
Bromination	Vendor 18	System 2	--	19.0	--	119.0	3.7	1.2	1.7	7.2	
Bromination	Vendor 18	System 3	--	19.0	--	133.0	3.7	1.2	1.7	7.2	
Bromination	Vendor 18	System 4	--	19.0	--	141.0	3.7	1.2	1.7	7.2	
Bromination	Vendor 18	System 5	15.0	25.0	--	45.0	2.3	2.0	0.7	3.1	
Bromination	Vendor 18	System 6	0.7	8.3	--	30.0	--	--	--	--	
Bromination	Vendor 18	System 7	8.4	16.0	--	37.0	--	--	--	--	
Bromination	Vendor 18	System 8	8.4	16.0	--	141.0	--	--	--	--	
Chlorination	Vendor 19	System 1	--	--	--	--	2.4	--	--	--	
Chlorination	Vendor 19	System 2	--	--	--	--	3.1	--	--	--	
Ultraviolet	Vendor 19	System 3	--	13.2	30	--	3.2	0.7	0.7	1.6	
Ultraviolet	Vendor 19	System 4	--	26.4	80	--	3.2	0.8	0.7	1.8	
Ultraviolet	Vendor 19	System 5	--	39.6	130	--	3.2	0.8	0.7	1.8	
Ultraviolet	Vendor 19	System 6	--	70.4	200	--	4.1	1.2	1.0	4.8	

Table A-4. Disinfection System Power Requirements, Weights, and Physical Dimensions

System Technology	Vendor No.	Vendor System No.	Disinfection Rate (gpm) Min	Disinfection Rate (gpm) Max	Power (W)	Weight (lb)	Dimensions (ft) Height	Dimensions (ft) Width	Dimensions (ft) Depth	Volume (ft^3)	Notes
Ultraviolet	Vendor 19	System 7	--	--	300	--	5.6	--	--	--	
Ultraviolet	Vendor 19	System 8	--	--	400	--	4.3	--	--	--	
Ultraviolet	Vendor 19	System 9	--	--	600	--	5.6	--	--	--	
Ultraviolet	Vendor 19	System 10	--	--	600	--	4.3	--	--	--	
Ultraviolet	Vendor 19	System 11	--	--	800	--	4.3	--	--	--	
Ultraviolet	Vendor 19	System 12	--	--	900	--	5.6	--	--	--	
Ultraviolet	Vendor 19	System 13	--	--	1,200	--	4.3	--	--	--	
Ultraviolet	Vendor 19	System 14	--	--	1,800	--	6.2	--	--	--	
Ultraviolet	Vendor 19	System 15	--	--	2,400	--	6.2	--	--	--	
Ultraviolet	Vendor 19	System 16	--	--	3,000	--	6.2	--	--	--	
Ultraviolet	Vendor 19	System 17	--	--	3,600	--	6.2	--	--	--	
Ultraviolet	Vendor 19	System 18	--	--	4,500	--	6.2	--	--	--	
Chlorination	Vendor 20	System 1	--	--	--	--	--	--	--	--	
Electro-Katadyn	Vendor 20	System 2	--	66.0	--	--	--	--	--	--	
Ultraviolet	Vendor 20	System 3	2.6	6.2	35	33.1	--	--	--	--	Vendor claims UV dosage of 36,000 W-s/cm^2.
Ultraviolet	Vendor 20	System 4	3.7	8.7	--	--	--	--	--	--	Vendor claims UV dosage of 36,000 W-s/cm^2.
Ultraviolet	Vendor 20	System 5	7.1	20.2	--	--	--	--	--	--	Vendor claims UV dosage of 36,000 W-s/cm^2.
Ultraviolet	Vendor 20	System 6	11.0	30.7	--	--	--	--	--	--	Vendor claims UV dosage of 36,000 W-s/cm^2.
Ultraviolet	Vendor 20	System 7	15.2	55.0	--	--	--	--	--	--	Vendor claims UV dosage of 36,000 W-s/cm^2.
Ultraviolet	Vendor 20	System 8	24.7	69.9	--	--	--	--	--	--	Vendor claims UV dosage of 36,000 W-s/cm^2.
Ultraviolet	Vendor 20	System 9	38.1	106.1	--	--	--	--	--	--	Vendor claims UV dosage of 36,000 W-s/cm^2.
Ultraviolet	Vendor 20	System 10	52.6	190.2	290	55.1	--	--	--	--	Vendor claims UV dosage of 36,000 W-s/cm^2.

Table A-4. Disinfection System Power Requirements, Weights, and Physical Dimensions

System Technology	Vendor No.	Vendor System No.	Disinfection Rate (gpm) Min	Disinfection Rate (gpm) Max	Power (W)	Weight (lb)	Dimensions (ft) Height	Dimensions (ft) Width	Dimensions (ft) Depth	Volume (ft^3)	Notes
Ultraviolet	Vendor 21	System 1	88.1	735.3	--	--	--	--	--	--	
Ultraviolet	Vendor 22	System 1	--	5.3	30	--	--	--	--	--	
Ultraviolet	Vendor 22	System 2	--	11.9	40	--	--	--	--	--	
Ultraviolet	Vendor 22	System 3	--	15.9	40	--	--	--	--	--	
Ultraviolet	Vendor 22	System 4	--	19.8	80	--	--	--	--	--	
Ultraviolet	Vendor 22	System 5	--	22.5	80	--	--	--	--	--	
Ultraviolet	Vendor 22	System 6	--	26.4	480	--	--	--	--	--	
Ultraviolet	Vendor 22	System 7	--	35.1	120	--	--	--	--	--	
Ultraviolet	Vendor 22	System 8	--	61.6	160	--	--	--	--	--	
Ultraviolet	Vendor 22	System 9	--	88.0	200	--	--	--	--	--	
Ultraviolet	Vendor 22	System 10	--	132.1	320	--	--	--	--	--	
Ultraviolet	Vendor 22	System 11	--	176.1	400	--	--	--	--	--	
Ultraviolet	Vendor 22	System 12	--	286.2	480	--	--	--	--	--	
Ultraviolet	Vendor 22	System 13	--	352.2	640	--	--	--	--	--	
Ultraviolet	Vendor 22	System 14	--	594.4	800	--	--	--	--	--	
Ultraviolet	Vendor 22	System 15	--	880.6	960	--	--	--	--	--	
Ultraviolet	Vendor 22	System 16	--	1,100.7	1,200	--	--	--	--	--	
Ultraviolet	Vendor 22	System 17	--	1,519.0	1,440	--	--	--	--	--	
Ultraviolet	Vendor 22	System 18	--	242.2	600	--	--	--	--	--	
Ultraviolet	Vendor 22	System 19	--	308.2	750	--	--	--	--	--	
Ultraviolet	Vendor 22	System 20	--	484.3	900	--	--	--	--	--	
Ultraviolet	Vendor 22	System 21	--	660.4	1,200	--	--	--	--	--	
Ultraviolet	Vendor 22	System 22	--	968.6	1,500	--	--	--	--	--	
Ultraviolet	Vendor 22	System 23	--	1,408.9	1,800	--	--	--	--	--	
Ultraviolet	Vendor 22	System 24	--	1,805.2	2,250	--	--	--	--	--	
Ultraviolet	Vendor 22	System 25	--	2,421.6	2,700	--	--	--	--	--	
Ultraviolet	Vendor 22	System 26	--	2,993.9	3,300	--	--	--	--	--	

Table A-4. Disinfection System Power Requirements, Weights, and Physical Dimensions

System Technology	Vendor No.	Vendor System No.	Disinfection Rate (gpm) Min	Disinfection Rate (gpm) Max	Power (W)	Weight (lb)	Dimensions (ft) Height	Dimensions (ft) Width	Dimensions (ft) Depth	Volume (ft^3)	Notes
Ultraviolet	Vendor 22	System 27	--	176.1	--	--	--	--	--	--	
Ultraviolet	Vendor 22	System 28	--	396.3	--	--	--	--	--	--	
Ultraviolet	Vendor 22	System 29	--	572.4	--	--	--	--	--	--	
Ultraviolet	Vendor 22	System 30	--	1,100.7	--	--	--	--	--	--	
Ultraviolet	Vendor 22	System 31	--	1,541.0	--	--	--	--	--	--	
Ultraviolet	Vendor 22	System 32	--	2,201.4	--	--	--	--	--	--	
Ultraviolet	Vendor 22	System 33	--	3,302.2	--	--	--	--	--	--	
Ultraviolet	Vendor 22	System 34	--	5,283.4	--	--	--	--	--	--	
Chlorination	Vendor 23	System 1	45.8	916.7	--	18.0	1.6	1.7	1.7	4.8	Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 23	System 2	137.5	2,775.0	--	18.0	1.6	1.7	1.7	4.8	Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 23	System 3	45.8	916.7	--	27.0	2.1	1.7	1.7	6.1	Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 23	System 4	137.5	2,775.0	--	27.0	2.1	1.7	1.7	6.1	Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 23	System 5	45.8	916.7	--	35.0	3.1	1.7	1.7	9.1	Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 23	System 6	137.5	2,775.0	--	35.0	3.1	1.7	1.7	9.1	Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.

Table A-5. Expected Life of Disinfection System Consumables and Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Disinfection Rate (gpm)		Expected Life of Consumables			Equipment Cost	Installation Cost	Annual O&M Cost	Notes
			Min	Max	Bromination (gal/cartridge)	Ultraviolet (hr/lamp)	Electro-Katadyn (gal/anode)				
Ultraviolet	Vendor 14	System 1	--	13.2	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 14	System 2	--	66.0	N/A	--	N/A	--	--	--	--
Electro-Katadyn	Vendor 15	System 1	--	35.2	N/A	N/A	1,056,690	--	--	--	Anode life: 4,000 m^3 at 0.05 ppm Ag^+; 2,0000 m^3 at 0.1 ppm Ag^+
Electro-Katadyn	Vendor 15	System 2	--	70.4	N/A	N/A	1,056,690	--	--	--	Anode life: 4,000 m^3 at 0.05 ppm Ag^+; 2,0000 m^3 at 0.1 ppm Ag^+
Electro-Katadyn	Vendor 15	System 3	--	105.7	N/A	N/A	1,056,690	--	--	--	Anode life: 4,000 m^3 at 0.05 ppm Ag^+; 2,0000 m^3 at 0.1 ppm Ag^+
Electro-Katadyn	Vendor 15	System 4	--	140.9	N/A	N/A	1,056,690	--	--	--	Anode life: 4,000 m^3 at 0.05 ppm Ag^+; 2,0000 m^3 at 0.1 ppm Ag^+
Electro-Katadyn	Vendor 15	System 5	--	211.3	N/A	N/A	1,056,690	--	--	--	Anode life: 4,000 m^3 at 0.05 ppm Ag^+; 2,0000 m^3 at 0.1 ppm Ag^+
Chlorination	Vendor 16	System 1	--	--	N/A	N/A	N/A	--	--	--	--
Chlorination	Vendor 16	System 2	--	--	N/A	N/A	N/A	--	--	--	--
Chlorination	Vendor 16	System 3	--	--	N/A	N/A	N/A	--	--	--	--
Chlorination	Vendor 16	System 4	80.0	3,960	N/A	N/A	N/A	--	--	--	O&M activities replace pump tube per year, clean out point of injection. Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.

Table A-5. Expected Life of Disinfection System Consumables and Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Disinfection Rate (gpm) Min	Disinfection Rate (gpm) Max	Expected Life of Consumables: Bromination (gal/cartridge)	Expected Life of Consumables: Ultraviolet (hr/lamp)	Expected Life of Consumables: Electro-Katadyn (gal/anode)	Equipment Cost	Installation Cost	Annual O&M Cost	Notes
Chlorination	Vendor 16	System 5	80.0	3,960	N/A	N/A	N/A	--	--	--	O&M activities replace pump tube per year, clean out point of injection. Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 16	System 6	80.0	3,960	N/A	N/A	N/A	--	--	--	O&M activities replace pump tube per year, clean out point of injection. Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 16	System 7	--	15,000	N/A	N/A	N/A	--	--	--	O&M activities replace pump tube per year, clean out point of injection. Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.

Table A-5. Expected Life of Disinfection System Consumables and Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Disinfection Rate (gpm) Min	Disinfection Rate (gpm) Max	Expected Life of Consumables: Bromination (gal/cartridge)	Expected Life of Consumables: Ultraviolet (hr/lamp)	Expected Life of Consumables: Electro-Katadyn (gal/anode)	Equipment Cost	Installation Cost	Annual O&M Cost	Notes
Chlorination	Vendor 16	System 8	--	15,000	N/A	N/A	N/A	--	--	--	O&M activities replace pump tube per year, clean out point of injection. Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 16	System 9	--	15,000	N/A	N/A	N/A	--	--	--	O&M activities replace pump tube per year, clean out point of injection. Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 16	System 10	70.0	42,000	N/A	N/A	N/A	--	--	--	O&M activities replace pump tube per year, clean out point of injection. Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.

Table A-5. Expected Life of Disinfection System Consumables and Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Disinfection Rate (gpm) Min	Max	Expected Life of Consumables: Bromination (gal/cartridge)	Ultraviolet (hr/lamp)	Electro-Katadyn (gal/anode)	Equipment Cost	Installation Cost	Annual O&M Cost	Notes
Chlorination	Vendor 16	System 11	1.0	158,500	N/A	N/A	N/A	--	--	--	O&M activities replace pump tube per year, clean out point of injection. Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 17	System 1	528.3	2,641.7	N/A	N/A	N/A	--	--	--	Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Ultraviolet	Vendor 17	System 2	3.5	5.3	N/A	9,000	N/A	--	--	--	--
Ultraviolet	Vendor 17	System 3	17.6	28.2	N/A	9,000	N/A	--	--	--	--
Ultraviolet	Vendor 17	System 4	28.6	45.3	N/A	9,000	N/A	--	--	--	--
Bromination	Vendor 18	System 1	16.0	35.0	55,000	N/A	N/A	$6,577	--	--	Cartridge life assumes Br dosing at 1 ppm. Equipment cost is $6,577 for 16- to 24-gpm and 25- to 35-gpm units. Vendor estimated installation cost is assumed to be 10 to 15% of equipment cost. Each cartridge costs $108.
Bromination	Vendor 18	System 2	--	19.0	55,000	N/A	N/A	$13,278	--	--	Cartridge life assumes Br dosing at 1 ppm; each cartridge costs $108.
Bromination	Vendor 18	System 3	--	19.0	55,000	N/A	N/A	--	--	--	Cartridge life assumes Br dosing at 1 ppm; each cartridge costs $108.

Table A-5. Expected Life of Disinfection System Consumables and Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Disinfection Rate (gpm)		Expected Life of Consumables			Equipment Cost	Installation Cost	Annual O&M Cost	Notes
			Min	Max	Bromination (gal/cartridge)	Ultraviolet (hr/lamp)	Electro-Katadyn (gal/anode)				
Bromination	Vendor 18	System 4	--	19.0	55,000	N/A	N/A	--	--	--	Cartridge life assumes Br dosing at 1 ppm; each cartridge costs $108.
Bromination	Vendor 18	System 5	15.0	25.0	55,000	N/A	N/A	--	--	--	Cartridge life assumes Br dosing at 1 ppm; each cartridge costs $108.
Bromination	Vendor 18	System 6	0.7	8.3	55,000	N/A	N/A	$5,392	--	--	Cartridge life assumes Br dosing at 1 ppm; each cartridge costs $108.
Bromination	Vendor 18	System 7	8.4	16.0	55,000	N/A	N/A	--	--	--	Cartridge life assumes Br dosing at 1 ppm; each cartridge costs $108.
Bromination	Vendor 18	System 8	8.4	16.0	55,000	N/A	N/A	$19,311	--	--	Cartridge life assumes Br dosing at 1 ppm; each cartridge costs $108.
Chlorination	Vendor 19	System 1	--	--	N/A	N/A	N/A	--	--	--	--
Chlorination	Vendor 19	System 2	--	--	N/A	N/A	N/A	--	--	--	--
Ultraviolet	Vendor 19	System 3	--	13.2	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 19	System 4	--	26.4	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 19	System 5	--	39.6	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 19	System 6	--	70.4	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 19	System 7	--	--	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 19	System 8	--	--	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 19	System 9	--	--	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 19	System 10	--	--	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 19	System 11	--	--	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 19	System 12	--	--	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 19	System 13	--	--	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 19	System 14	--	--	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 19	System 15	--	--	N/A	--	N/A	--	--	--	--

Table A-5. Expected Life of Disinfection System Consumables and Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Disinfection Rate (gpm) Min	Disinfection Rate (gpm) Max	Expected Life of Consumables: Bromination (gal/cartridge)	Expected Life of Consumables: Ultraviolet (hr/lamp)	Expected Life of Consumables: Electro-Katadyn (gal/anode)	Equipment Cost	Installation Cost	Annual O&M Cost	Notes
Ultraviolet	Vendor 19	System 16	--	--	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 19	System 17	--	--	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 19	System 18	--	--	N/A	--	N/A	--	--	--	--
Chlorination	Vendor 20	System 1	--	--	N/A	N/A	N/A	$13,560	$1,356	--	Installation cost is assumed to be 10% of equipment cost.
Electro-Katadyn	Vendor 20	System 2	--	66.0	N/A	N/A	--	$4,300	$430	--	Vendor estimated installation cost is assumed to be 10% of equipment cost. Each anode costs $980.
Ultraviolet	Vendor 20	System 3	2.6	6.2	N/A	--	N/A	$2,550	$225	--	Vendor estimated installation cost is assumed to be 10% of equipment cost.
Ultraviolet	Vendor 20	System 4	3.7	8.7	N/A	--	N/A	--	--	--	Vendor estimated installation cost is assumed to be 10% of equipment cost.
Ultraviolet	Vendor 20	System 5	7.1	20.2	N/A	--	N/A	--	--	--	Vendor estimated installation cost is assumed to be 10% of equipment cost.
Ultraviolet	Vendor 20	System 6	11.0	30.7	N/A	--	N/A	$3,550	$355	--	Vendor estimated installation cost is assumed to be 10% of equipment cost.
Ultraviolet	Vendor 20	System 7	15.2	55.0	N/A	--	N/A	--	--	--	Vendor estimated installation cost is assumed to be 10% of equipment cost.
Ultraviolet	Vendor 20	System 8	24.7	69.9	N/A	--	N/A	--	--	--	Vendor estimated installation cost is assumed to be 10% of equipment cost.

Table A-5. Expected Life of Disinfection System Consumables and Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Disinfection Rate (gpm)		Expected Life of Consumables			Equipment Cost	Installation Cost	Annual O&M Cost	Notes
			Min	Max	Bromination (gal/cartridge)	Ultraviolet (hr/lamp)	Electro-Katadyn (gal/anode)				
Ultraviolet	Vendor 20	System 9	38.1	106.1	N/A	--	N/A	--	--	--	Vendor estimated installation cost is assumed to be 10% of equipment cost.
Ultraviolet	Vendor 20	System 10	52.6	190.2	N/A	--	N/A	$6,100	$610	--	Vendor estimated installation cost is assumed to be 10% of equipment cost.
Ultraviolet	Vendor 21	System 1	88.1	735.3	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 1	--	5.3	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 2	--	11.9	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 3	--	15.9	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 4	--	19.8	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 5	--	22.5	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 6	--	26.4	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 7	--	35.1	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 8	--	61.6	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 9	--	88.0	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 10	--	132.1	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 11	--	176.1	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 12	--	286.2	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 13	--	352.2	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 14	--	594.4	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 15	--	880.6	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 16	--	1,100.7	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 17	--	1,519.0	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 18	--	242.2	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 19	--	308.2	N/A	--	N/A	--	--	--	--

Table A-5. Expected Life of Disinfection System Consumables and Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Disinfection Rate (gpm) Min	Max	Expected Life of Consumables: Bromination (gal/cartridge)	Ultraviolet (hr/lamp)	Electro-Katadyn (gal/anode)	Equipment Cost	Installation Cost	Annual O&M Cost	Notes
Ultraviolet	Vendor 22	System 20	--	484.3	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 21	--	660.4	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 22	--	968.6	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 23	--	1,408.9	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 24	--	1,805.2	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 25	--	2,421.6	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 26	--	2,993.9	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 27	--	176.1	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 28	--	396.3	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 29	--	572.4	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 30	--	1,100.7	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 31	--	1,541.0	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 32	--	2,201.4	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 33	--	3,302.2	N/A	--	N/A	--	--	--	--
Ultraviolet	Vendor 22	System 34	--	5,283.4	N/A	--	N/A	--	--	--	--
Chlorination	Vendor 23	System 1	45.8	916.7	N/A	N/A	N/A	$674	--	--	O&M activities replace pump tube per year, clean out point of injection. Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.

Table A-5. Expected Life of Disinfection System Consumables and Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Disinfection Rate (gpm)		Expected Life of Consumables			Equipment Cost	Installation Cost	Annual O&M Cost	Notes
			Min	Max	Bromination (gal/cartridge)	Ultraviolet (hr/lamp)	Electro-Katadyn (gal/anode)				
Chlorination	Vendor 23	System 2	137.5	2,775.0	N/A	N/A	N/A	--	--	--	O&M activities replace pump tube per year, clean out point of injection. Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 23	System 3	45.8	916.7	N/A	N/A	N/A	$712	--	--	O&M activities replace pump tube per year, clean out point of injection. Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.

Table A-5. Expected Life of Disinfection System Consumables and Equipment, Installation, and Annual O&M Costs

System Technology	Vendor No.	Vendor System No.	Disinfection Rate (gpm) Min	Disinfection Rate (gpm) Max	Expected Life of Consumables: Bromination (gal/cartridge)	Expected Life of Consumables: Ultraviolet (hr/lamp)	Expected Life of Consumables: Electro-Katadyn (gal/anode)	Equipment Cost	Installation Cost	Annual O&M Cost	Notes
Chlorination	Vendor 23	System 4	137.5	2,775.0	N/A	N/A	N/A	--	--	--	O&M activities replace pump tube per year, clean out point of injection. Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 23	System 5	45.8	916.7	N/A	N/A	N/A	--	--	--	O&M activities replace pump tube per year, clean out point of injection. Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.
Chlorination	Vendor 23	System 6	137.5	2,775.0	N/A	N/A	N/A	$765	--	--	O&M activities replace pump tube per year, clean out point of injection. Disinfection capacity will depend on solution strength and chloride dosing. Estimate assumes use of 12% sodium hypochlorite solution dosed at 2 ppm.

N/A – Not Applicable

APPENDIX B:

SUMMARIES OF INFORMATION GATHERED IN TELEPHONE CONVERSATIONS WITH PWG VENDORS

INTRODUCTION

EPA contacted eight vendors for information about their potable water generation or disinfection systems. This included technical specifications, costs, and their overall perspective on the feasibility of using PWGs as a source of ballast water. The summaries are presented by interview date. EPA has not identified vendors by name, instead using their corresponding vendor numbers from Appendix A.

VENDOR 13 (APRIL 3, 2012)

The vendor believed that it could be feasible to use RO systems as a source of ballast water. As an example of this potential, the vendor indicated that seagoing tugs typically generate 1,500 gal/day of potable water and that factory ships generate 10,000 to 100,000 gal/day. However, the vendor also indicated that the generation rate of potable water would depend on the space available onboard the vessel. For example, while oil platforms can produce millions of gallons of potable water per day, the equipment used to generate that amount of water likely would not fit into small vessels. For vessels of about 300 GRT, the vendor believed that a realistic size for an RO system would be about 5,000 gal/day, while for larger commercial vessels the upper limit would be roughly 25,000 gal/day.

When asked if there were any specific features that would make RO systems technologically or economically infeasible, the vendor indicated that their systems could be retrofitted into tugs or fishing boats with relative ease. The vendor also pointed out that many of their systems are installed on vessels that do not already have preexisting RO systems installed onboard.

In terms of energy demand, the vendor commented that, as a general rule of thumb, RO systems require roughly 1 hp to generate 1,000 gal/day of potable water. The vendor also mentioned that RO systems draw their power directly from vessel generators powered by vessel engines.

The vendor provided cost information for RO systems (Table B-1). The vendor estimated annual O&M costs to be roughly 3 percent of equipment and installation costs. The vendor could not provide an estimate for energy-related costs, as the vendor believes there are too many factors to allow for accurate estimation. The vendor also indicated that systems generating more than 10,000 gal/day would need to be custom built. Systems producing more than 20,000-gal/day would require specialized equipment, such as multistage centrifugal units. Annual O&M costs for these systems could be as great as 10 percent of equipment and installation costs.

Table B-1. Summary of Vendor's Equipment, Installation, and Annual O&M Costs

Capacity (gal/day)	Equipment Cost	Installation Cost	Annual O&M Cost
1,500	$11,000	$4,000 to $8,000	$450 to $570
10,000	$37,000	$10,000	$1,410

Note: For each system, annual O&M cost is assumed to be 3% of equipment and installation costs.

If RO systems were used solely for ballasting purposes and not for potable water production, then filtration requirements could be reduced to allow for greater water production rates. The vendor noted that water temperature would affect generation rates. For example, a temperature drop from 70 to 30°F would reduce production rates by roughly half.

When asked about how RO and distillation systems compare, the vendor indicated that the overall size and maintenance requirements of distillation systems would make them a bigger commitment. The vendor also indicated that distillation system maintenance would be more expensive due to scaling and fouling.

The vendor commented that despite their potential drawbacks, the vendor believes distillation systems would be a great alternative for vessels that generate a lot of waste heat. However, the vendor also noted that vessels are becoming more energy-efficient, meaning less waste heat would be available to power distillation systems. Because of this trend, the vendor believes vessels are using RO systems to a greater extent than in the past.

For RO systems, the potable water recovery is roughly 10 to 40 percent of the total volume processed by the system. The remaining 60 to 90 percent is brine discharge containing a salt concentration of roughly 40,000 ppm.

VENDOR 7 (APRIL 3, 2012)

The vendor believes PWG feasibility would depend on the size of the vessel. Larger commercial vessels (e.g., cargo tankers and boat carriers) could use such a large volume of water that it would be difficult for distillation-based systems to keep up with ballasting demands. In such cases, vessels most likely would be incapable of supplying sufficient waste heat to the evaporator. The vendor estimated that vacuum distillation could produce 30 to 50 tons/day of potable water, although they only manufacture units capable of producing 10 to 30 tons/day.

The vendor noted that distillation systems use waste heat provided by vessel engines; they do not use dedicated heat sources such as boilers. The vendor also noted that the overall design of older vessels might not allow for efficient use of waste heat, making the potential for distillation systems less promising. Also, smaller and newer vessels are likely to generate insufficient waste heat, either because their engines operate more efficiently or because the evaporator must share the waste heat with other units (e.g., super or turbo chargers).

With regard to deck space requirements, the vendor indicated that distillation systems can be retrofitted into small vessels easily, and that their systems frequently are sold as retrofits. The vendor estimated that units capable of producing 1 to 5 tons/day of potable water could be retrofitted into smaller vessels such as tugs or fishing vessels. Units producing 100 or more tons/day could be retrofitted into larger commercial vessels.

The vendor provided cost information for distillation systems (Table B-2). Based on the vendor's estimates, the cost of purchasing and installing a distillation system would range from $40,000 to $150,000, depending on the overall production capacity of the system and the level of effort required to install the system. The vendor was unable to provide O&M cost estimates.

Table B-2. Summary of Vendor's Equipment and Installation Costs

Capacity (tons/day)	Equipment Cost	Installation Cost
10	\$30,000 to \$50,000	\$10,000 to \$15,000
30	\$45,000 to \$50,000	\$50,000 to \$100,000

According to the vendor, the U.S. market is favoring RO systems over distillation. To this extent, the vendor estimated that 70 percent of U.S. vessels use RO systems while the remaining 30 percent use distillation systems. The vendor also noted that distillation systems are becoming less common because vessels operate more efficiently, resulting in less available waste heat to supply to distillation systems.

VENDOR 9 (APRIL 3, 2012)

The vendor stated that RO systems could provide 400 to several hundreds of thousands of gallons per day. However, the production capacity would depend on what a vessel could accommodate. The vendor estimated that RO units producing 400 gal/day would be roughly the size of a microwave appliance, while the largest units would occupy a space equivalent to four automobiles parked side-by-side.

The vendor referred EPA to the company's website for literature specifying typical energy demands for RO systems. The vendor was unable to provide specific information on capital or O&M costs.

VENDOR 1 (APRIL 3 AND 5, 2012)

The vendor does not believe it would be feasible for vessels to ballast using onboard PWGs. For large vessels (i.e., tankers or cruises), the vendor estimated that they generate roughly 20 to 25 ton/day of potable water. Cruise ships would need to produce roughly 400 to 500 ton/day of potable water to replace spent fuel. Given the significant difference, the vendor believes that it would be difficult for large vessels to produce water at rates that would be adequate for ballasting.

The vendor also commented that compared to RO systems, distillation systems would not be feasible for small vessels. For a hypothetical ballasting rate of 20 gpm, the required distillation system would not fit into a small vessel. Furthermore, small vessels would not be able to provide sufficient waste heat to power the systems.

On large vessels, the vendor does not expect the size of the distillation system to be an issue because it would be smaller than the alternative (i.e., ballast water treatment systems). However, the vendor does not believe that distillation systems can produce potable water at rates adequate for meeting ballasting needs.

The vendor estimated that generating potable water at a rate of 10 ton/day would require 300 kW of waste heat. For a 300-GRT vessel, the vendor does not believe this would be an issue, as they generate roughly 2,000 kW, of which 1,000 kW is waste heat. The vendor expects that 1,600-GRT vessels would generate roughly 4 to 5 MW of power, of which 60 to 70 percent is waste heat (i.e., 2.4 to 3.5 MW).

The vendor was unable to provide information on capital or O&M costs.

VENDOR 10 (APRIL 4, 2012)

The vendor believes using distillation systems for ballasting could be feasible depending on the overall ballasting rates required. The vendor noted that their distillation systems only support a production capacity of 200 to 50,000 gal/day.

The vendor provided characteristic weights, dimensions, and energy requirements for the 200- and 7,500-gal/day distillation systems (Table B-3). The corresponding energy requirements range from 75,000 to 2,900,000 BTU/hr. The vendor noted that engine waste heat powers the distillation systems, rather than dedicated heat sources (i.e., boilers).

Table B-3. Summary of Vendor's Distillation System Specifications

Capacity (gal/day)	Weight (lb)	Dimensions, L x W x H (in)	Energy Requirement (BTU/hr)
200	125	20 x 11 x 23	75,000
7,500	2,900	82 x 44 x 68	2,900,000

The vendor also provided the equipment and O&M cost estimates in Table B-4. The cost of purchasing a distillation system would range from $10,600 to $100,000. The vendor estimated annual O&M costs would be roughly 2 percent of the equipment cost, yielding an annual O&M cost ranging from $212 and $2,000. The vendor could not provide cost estimates for system installation.

Table B-4. Summary of Vendor's Equipment and O&M Costs

Unit Capacity (gal/day)	Equipment Cost	Annual O&M Cost
200	$10,600	$212
7,500	$100,000	$2,000

Note: For each system, annual O&M cost is assumed to be 2% of equipment cost.

The vendor noted that the feasibility of retrofitting distillation systems into an existing vessel would depend on engine room accessibility. If a vessel's engine room were equipped with access doors, the system could be loaded into the vessel with relative ease. However, if engine room access is limited, it would be necessary to cut hole into the hull of the vessel to load the distillation system into the engine room.

The vendor also commented that RO systems typically are used in vessels that cannot generate sufficient waste heat to utilize a distillation system. The vendor believes that 60 percent of all vessels use RO systems and that the remaining 40 percent use distillation systems.

VENDOR 6 (APRIL 4, 2012)

The vendor believes it would be feasible to use RO systems for ballasting purposes, since they would provide a continuous supply of potable water. The vendor also noted that energy for powering these systems is coincidentally generated during vessel operation; therefore, power requirements would not adversely affect vessel operations. Overall, the power requirements, provided by the vendor, range from 3 to 30 kW, depending on the size of the system (Table B-5). The vendor also noted that power requirements will vary, depending on the number of filter membranes in the system, the feed water quality, and the types of pumps and motors used in the engine room.

Table B-5. Summary of Vendor's RO System Power Requirements

Unit Capacity (gal/hr)	Power Requirement (kW)
284	3
500	15
938	15
1,792	30

The vendor also provided information on equipment and annual O&M costs (Table B-6). The equipment costs range from $73,000 to $152,845, depending on the size of the system. The vendor was not able to estimate installation costs, stating that it is too case-specific to allow for accurate estimates. The vendor estimated O&M costs to range from 3 to 10 percent of the installation cost, depending on the degree to which the equipment is kept in good working condition.

Table B-6. Summary of Vendor's Equipment and O&M Costs

Capacity (gal/hr)	Equipment Cost	Annual O&M Cost
284	Not Provided	Not Provided
500	$73,000	$2,190 to $7,300
938	$95,000	$2,850 to $9,500
1,792	$152,845	$4,585 to $15,285

Note: For each system, annual O&M cost is assumed to be 3 to 10% of equipment cost.

The vendor also noted that for RO systems, water quality would affect production rates. Feedwater with a relatively high degree of salinity would reduce overall production rates. Therefore, a vessel's ability to generate potable water would vary by geography. Feedwater temperature also would affect production rates, in that colder water reduces overall production rates.

When asked about the degree to which RO systems can filter out organisms, the vendor indicated that it would depend on the membrane filter installed in the RO system, noting that the system could be adjusted as needed. The vendor also indicated that, to produce potable water, it would be necessary to install a disinfection system downstream from the RO system. Product water from the RO system typically is disinfected using chlorination or UV systems. UV systems can disinfect 5 to 6 gpm on smaller vessels (i.e., 50 to 60 ft in length). The vendor expects smaller vessels would use chlorination while larger vessels would use UV systems.

VENDOR 24 (APRIL 5, 2012)

Water disinfection on vessels generally utilizes chlorination, electro-katadyn, or UV technologies. The vendor, who specializes in UV systems, noted that they primarily sell their systems to yachts measuring 100 to 200 ft in length.

For chlorination and electro-katadyn technologies, the disinfection system would be installed between the PWG and the water storage tank. UV disinfection systems would be installed downstream from the storage tank.

The vendor commented that the vendor does not believe it is feasible to generate potable water at the rates required for ballasting. Furthermore, the quality of source water can impact the effectiveness of the disinfection system. For example, water with high turbidity would adversely impact the effectiveness of UV disinfection systems.

The vendor provided installation and O&M costs for UV sterilizers (Table B-7). The annual O&M cost assumes a typical UV lamp life of 2 years and a typical lamp cost of $600.

Table B-7. Summary of Vendor's Equipment and O&M Costs

Capacity (gal/hr)	Installation Cost	Annual O&M Cost
83	$3,000	$300

VENDOR 20 (APRIL 9, 2012)

The vendor provided the equipment specifications in Table B-8. The vendor believes it could be feasible for small vessels to generate potable water at a rate sufficient to meet ballasting needs. However, the vendor does not believe it would be feasible for large vessels.

Table B-8. Summary of Vendor's Equipment Specifications

System Type	Vendor System No.	Capacity (gal/day)	Dimensions (mm)	Power (W)
Chlorination	System 1	253,605	800 x 800 x 2,640	250
Electro-Katadyn	System 2	95,102	48 x 480 x 150	<30
Ultraviolet	System 3	6,732 to 9,588	200 x 471 x 80	35
Ultraviolet	System 6	28,356 to 44,880	300 x 471 x 120	80
Ultraviolet	System 10	148,920 to 271,320	300 x 927 x 200	290

The vendor also provided equipment and installation costs for some chlorination, electro-katadyn, and UV disinfection systems (Table B-9). The vendor assumed installation costs to be 10 percent of equipment costs. The vendor was unable to estimate annual O&M costs, stating it would depend on the volume of water disinfected by the vessel over the course of a year.

Table B-9. Summary of Vendor's Equipment and O&M Costs

System Technology	Vendor System No.	Capacity (gal/day)	Equipment Cost	Installation Cost
Chlorination	System 1	253,605	$13,560	$1,356
Electro-Katadyn	System 2	95,102	$3,995	$400
Ultraviolet	System 3	6,732 to 9,588	$2,550	$255
Ultraviolet	System 6	28,356 to 44,880	$3,550	$355
Ultraviolet	System 10	148,920 to 271,320	$6,100	$610

Note: For each system, the installation cost is assumed to be 10% of equipment costs.

The vendor noted that system consumables include chlorine, silver anodes, and UV lamps for chlorination, electro-katadyn, and UV disinfection systems, respectively. The vendor was not able to estimate how much chlorine would be required per gallon of disinfected water, as they do not sell chlorine to their customers. Silver anodes for electro-katadyn systems would require replacement after disinfecting roughly 1,850,000 gallons and each electrode costs approximately $850. Replacement lamps for UV disinfection systems would be necessary every 8,000 hrs of operation. The total cost for replacing the lamps would depend on how many are in the system. It would vary by model as follows:

- System 3: $195 (one lamp required);
- System 6: $195 (four lamps required); and
- System 10: $217 (five lamps required).

APPENDIX C:

PROOF OF CONCEPT EVALUATION OF PWGs AS OPTIONS FOR MANAGING BALLAST WATER FOR TARGET VESSELS

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

Maritime Environmental Resource Center

September 2014

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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 ≥ 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 3.49×10^6 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

Test Plan for a Proof of Concept Evaluation of A Potable Water Generator as an Option for Managing Ballast Water for Target Vessels

August 20, 2013

Questions and comments should be directed to:

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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 treatment systems 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 ballast water treatment systems to prevent the introduction of non-native species, MERC has developed as a partnership between the Maryland Port Administration (MPA), Chesapeake Biological Laboratory/ University of Maryland Center for Environmental Science (CBL/UMCES), U.S. Maritime Administration (MARAD), Smithsonian Environmental Research Center (SERC), University of Maryland (UMD), and Old Dominion University to provide independent performance testing and to help facilitate the transition of new treatment technologies to shipboard implementation and operations.

The following protocols describe how MERC will evaluate the performance characteristics of a Potable Water Generator (PWG) through objective and quality assured land-based testing. The goal of this specific evaluation is to provide Eastern Research Group (ERG) and U.S. Environmental Protection Agency (EPA) with information on the performance of a PWG under the conditions specified in the test plan. The data and information on performance characteristics will cover PWG performance information that users need and will 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 for ballast water discharge.

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. Treatment systems are not labeled or listed as acceptable or unacceptable but tests and results are in a format consistent with that requested by specific regulations (e.g., IMO D2, G8 and G9) so that can be used to determine compliance by Administrations and classification societies. Sampling and analytical procedures utilized by the MERC team are also consistent with the EPA Environmental Technology Verification (ETV) Protocols (2010). Draft and final reports on PWG performance will be provided to ERG and complete raw datasets will be made available upon request. All specific terms of a testing program associated with a particular technology, including management of test findings, are outlined in the contract executed between ERG and MERC/University of Maryland Center for Environmental Science (UMCES).

2. Background and Goals of the Proof of Concept Evaluation

Inland and Seagoing Vessels less than 1600 gross registered tons (3000 gross tons) are not required to meet the numeric treatment limits in Section 2.2.3.5 of the Final Vessel General Permit (VGP). EPA found that technologies to treat ballast water from this size class of vessels are not currently Best Available Technology (BAT) within the meaning of the Clean Water Act. An inland vessel means a vessel that operates exclusively on inland waters, typically in freshwater environments. This means that numeric ballast water limits are not currently applicable for the majority of vessels operating on the Great Lakes. EPA encouraged vessels in this size class to use alternate measures to reduce the number of living organisms in their ballast water discharges, including use of those measures found in Part 2.2.3.5 of the VGP and use of onboard potable water generators. However, EPA did not feel comfortable mandating these requirements because the Agency did not have sufficient information about the availability and efficacy of these management approaches for these vessels. EPA concluded that, although technologies are promising for future development, they did not support the conclusion that numeric ballast water discharge limits for small inland and seagoing vessels represents BAT at this time or over the life of the permit. For example, most ballast water treatment systems have been designed for larger vessels and/or vessels which only uptake or discharge ballast water on either end of longer voyages.

Some smaller vessels, because of their unique designs and operations, such as those crossing the Chicago Sanitary Canal connecting the Great Lakes to the Mississippi River Basin, might be able to use onboard potable water for ballasting. This is particularly true for vessels that use ballast to compensate for fuel burn off and sewage generation. Additionally, some larger vessels may be able to use onboard potable water for ballasting if they have smaller ballast tank volumes and/or flow rates, or their operations allow for such an approach. This task is designed to thoroughly evaluate whether such systems can be used as an effective form of ballast water management for these vessels, and if so, whether they are environmentally effective. If shown to be effective and their use is practicable, the potential use of the technologies could conceptually reduce the spread and dispersion of ANS within and into the Great Lakes and in other U.S. (and international waters).

EPA is seeking to test potable water generators as option for managing ballast water for small vessels. ERG has selected MERC to perform a proof of concept series of land-based tests of a potable water generator and disinfection system to evaluate its efficacy for preventing the discharge of living organisms from ballast water tanks. This proof of concept is part of a larger assessment of the feasibility of PWGs to produce ballast for vessels working in freshwater (particularly the Great Lakes), coastal, and open ocean environments. A final report will discuss the performance of a PWG for this new application in terms of (a) mechanical reliability, (b) reducing the number of living organisms, and (c) the production of toxic conditions of residual byproducts. Although the test shall generally follow the test protocols provided in ETV Generic Protocol for the Verification of Ballast Water Treatment Technology (EPA/600/R-10/146), the objectives are limited to a general evaluation of a PWG and some deviations from the ETV Protocols will be required because PWG produce potable water at much slower flow rates than typical ballast water management systems are able to treat water. It is also important to note that the PWG will not be identified and the data resulting from this proof of concept study can not used for the certification or approval of any specific technology. The test PWG system will be selected and provided by ERG.

3. 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).

4. Overview of Test Facilities

The following is a summary of the MERC land-based ballast water management system test facility. However, not all components described will be used as part of the PWG evaluation. To take advantage of the diverse physical, chemical and biological conditions found in the Chesapeake Bay, MERC has developed a Mobile Test Platform. With one installation, a test ballast water treatment system can be evaluated with the same protocols, by the same facility and staff, under varying natural salinities and associated ambient communities, by moving the barge-based test facility to different locations.

The barge is 155’ x 50’ with a draft of 2’ when tanks empty and 5’ when tanks full. The Mobile Test Platform has two identical steel 310 m^3 test tanks (with typical internal tank coating) and two identical 60 hp centrifugal pumps, with two eight-inch piping systems for versatility in moving ballast water and for tank filling and discharge. Test tanks serve as mimic ballast tanks. Testing flow rates can vary from a minimum of 100 m^3/hr and maximum of 350 m^3/hr for each pump and flow pressure of up to 60 psi can be achieved. Three power connections are provided for treatment systems: 1. 100 Amps 480V, 60 Hz, 3 phase, 2. 50 Amps, 480V, 60 Hz, 3 phase, and 3. 30 Amps, 120V, 60 Hz. The test facility is operated by an integrated monitoring and control system for remote control of variable speed drives, flow rates and pressure, plus data logging of valve positions, tank levels/volume, power quality, flow rate, pressure, sampling system operations, and treatment system status. The barge has an onboard office, dry and wet labs, plus sampling and storage containers.

5. Basic Evaluation Approach

Please note that this Test Plan describes the specifics for the MERC proof of concept evaluation of the Potable Water Generator (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) available on the MERC website (www.maritime-enviro.org). This Plan also refers to, and incorporates specifics guidelines and requirements found in:

- International Maritime Organization (2008) Resolution MEPC.174 (58) Guidelines for Approval of Ballast Water Management Systems (G8); and
- ETV Generic Protocols for the Verification of Ballast Water Treatment Technologies, (2010) EPA/600/R-10/146.

The fundamental approach of MERC is to conduct independent, scientifically-sound, rigorous, and quality assured evaluations of ballast water treatment systems using the framework provided in the G8 guidelines and specific methodologies found in ETV protocols. As a general rule, MERC relies on challenging ambient conditions found in the Chesapeake Bay, and typically does not artificially augment test waters organisms in most evaluations to avoid artifacts and the potential for overestimation of treatment system performance (see Table 1). For example, rapid changes in physical conditions (such as salinity or total suspended solids) as supplemental organisms are being added to influent ballast water may cause significant mortality, independent of treatment.

In cases where ambient challenge conditions fall substantially short of the G8 guidelines and/or ETV protocols, MERC has the ability to augment total suspended solids (TSS), particulate organic carbon (POC) and dissolved organic carbon (DOC), plus, phytoplankton, and zooplankton. However, while physical, chemical and biological conditions will be documented, no augmentation of challenge water will take place as part of this PWG proof of concept study.

Table 1. Comparison of USEPA-ETV and G8 Recommended Challenge Conditions to Ranges of Various Physical, Chemical and Biological Parameters in Ambient Water from the MERC Facility, Baltimore, MD during the BWMS testing season (March – December, 2008 - 2013).

Parameter	**USEPA ETV †**	**Recommended IMO G8‡**	**MERC Facility Baltimore Ambient Ranges**
Temperature (°C)	4 - 35	No Requirement	6.1 - 28.6
Salinity (psu)	0 - 36	Two salinities, >10 psu difference	1.5 - 14.9
Total Suspended Solids (mg/L)	Min. 24	> 50	3.3 - 38.3 Ave = 10
Mineral Matter (mg/L)	Min. 20	No Requirement	2.4 - 32.8
Particulate Organic Carbon (mg/L)	Min. 4	> 5	0.5 - 10.2 Ave = 1
Dissolved Organic Carbon (mg/L)	Min. 6	> 5	2.4 - 4.6 Ave = 3-4
Live Organisms > 50 μm/m^3	Min. 100,000	> 100,000	31,175* - 4,555,042
Live Organisms 10 - 50 μm/ml	Min. 1,000	> 1,000	258** - 36,497
Culturable Bacteria cfu/ml	Min 1,000	>1,000	E.coli: 0 - 162 Enterococci: 0 - 114 THB^: 146 - 31,833

†ETV Generic Protocol for the Verification of Ballast Water Treatment Technologies, 2010.
‡IMO Guidelines for the Approval of Ballast Water Management Systems (G8) 2008, MEPC.174 (58).
*Typically > 100,000/m^3, this one low value comes from one trial where an additional 90,000/m^3 zooplankton were present but just under 50 μm in size then grew to > 50 μm during the 5-day hold time.
** Typically > 1,000/ml, ambient concentrations below 900/ml have occurred during 0.08% of the trials.
^ Total heterotrophic bacteria based on cultured plate counts.

Prior to any formal testing, one mechanical commissioning run of the PWG system will be conducted with the system manufacturer, to assure appropriate treatment operations onboard the MERC Mobile Test Platform (see below). This run will identify and correct initial mechanical or operating issues. After the PWG system commissioning has been completed and accepted by the manufacturer, MERC and ERG, the manufacturer will submit a formal statement that the PWG is ready for evaluations reliability and efficacy.

MERC will conduct a series of three to five biological efficacy trials focused on all USCG, EPA and IMO regulated taxonomic categories, including live organisms > 50 µm, 10 - 50 µm, and culturable bacteria. See descriptions below and in the MERC QAPP and SOPs.

The uptake event of each trial will be modified from MERC's typical protocol to accommodate the unique design and slow fill rate of the PWG. Each uptake event will utilize ambient challenge water with no augmentation. One mimic ballast tank will be filled to at least 150 m^3 over a 4 to 5 day period using a 2-inch hose connected directly from the PWG to a bottom pipe on the tank. Fill rate and times will be determined by the specific PWG selected by EPA-ERG and the amount of downtime required to perform normal maintenance on the system (such as changing out pre filters). To characterize the challenge water and generated potable water during the fill time, discrete samples will be collected before (upstream) and after (downstream) the PWG once per day, on 3 different days (beginning, middle and end) of the tank filling period. The samples collected before and after the PWG during tank filling will follow the modified approach described below because the flow rates will not allow for the ETV Protocol recommenced time-integrated isokinetic sampling.

Sampling of the potable water upon discharge (after 4 to 5-day filling and hold time) will be through the MERC Mobile Test Platform piping system, set in the discharge configuration at 150 to 200 m^3/hr, and will be consistent with the ETV Protocol. The analyses of all samples (regardless of how collected) will follow the ETV Protocols and MERC SOPs.

6. Summary of Land-Based Testing and Sampling Design

The simulated ballast system of the MERC Mobile Test Platform has been designed to allow for water to be split equally, and delivered simultaneously, to a "control" (untreated) tank and a "treated" tank (passing first through the treatment system). However, for the PWG trials, only one piping system and one test tank (hereafter referred to as the potable tank) will be used. Detailed drawings of the MERC Mobile Test Platform and ballast system can be found in the MERC QAPP and QMP.

During uptake, discrete samples of both the challenge water (before the PWG) and the potable water (after the PWG) will be analyzed for concentrations of live organisms and water quality parameters. Upon discharge, statistically-validated (Miller et al., 2011), continuous, time-integrated samples will be 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 below.

Samples for biological examination will include the >50µm size fraction (nominally zooplankton), the 10-50 µm size fraction (organisms less the 10 µm will be noted), culturable bacteria, and water quality (total suspended solids (TSS), particulate organic carbon (POC), dissolved organic carbon (DOC) and Chlorophyll (Chl)). During the discharge events, if the PWG utilizes chlorine disinfection, samples will also be collected for whole effluent toxicity testing and the evaluation of chlorinated by-products. See Table 2 for the list of samples to be collected, with corresponding volumes and purpose.

At the completion of each trial, the MERC piping system is immediately flushed with fresh municipal water prior to conducting a subsequent trial. See SOPs for additional details on test operations and sampling.

Table 2. MERC will be collecting a variety of data on physical, chemical, biological, and toxicological parameters during this evaluation. Table 2 describes samples collected and analyzed.

Parameter	Sample ID	Purpose	MERC Sample Volume/Time points
Water Quality (temp, salinity, oxygen, turbidity, chlorophyll fluorescence)	During tank potable water filling and hold time	Quantify challenge and potable water	Direct measurements, every 15 minutes, using multi-parameter instruments.
Total Suspended Solids (TSS) mg/L	a. Uptake Challenge b. Uptake Potable c. Discharge Potable	Quantify challenge and potable water	Uptake: 1 - 4L subsamples from 20 L sample on each of the 3 day sampling events, Discharge: 3 time points.
Particulate Organic Matter (POC) mg/L	a. Uptake Challenge b. Uptake Potable c. Discharge Potable	Quantify challenge and potable water	Uptake: 2L subsample from 20 L sample on each of the 3 day sampling events. Discharge: 2L subsamples from the 75 L time-integrated sample.
Dissolved Organic Matter (DOC) mg/L	a. Uptake Challenge b. Uptake Potable c. Discharge Potable	Quantify challenge and potable water	Uptake: 2L subsample from 20 L sample on each of the 3 day sampling events. Discharge: 2L subsamples from the 75 L time-integrated sample.
Chlorophyll-a µg/L	a. Uptake Challenge b. Uptake Potable c. Discharge Potable	Quantify challenge and potable water	Uptake: 2L subsample from 20 L sample on each of the 3 day sampling events. Discharge: 2L subsamples from the 75 L time-integrated sample.
Viable Organisms > 50 µm / m^3	a. Uptake Challenge b. Uptake Potable c. Discharge Potable	Quantify live organisms > 50 µm	Uptake: 20 L sample on each of the 3 day sampling events. Discharge: 7 m^3 time-integrated samples
Viable Organisms 10-50 µm / ml	a. Uptake Challenge b. Uptake Potable c. Discharge Potable	Quantify live organisms 10 – 50 µm	Uptake: 250 ml subsamples from 20 L sample on each of the 3 day sampling events. Discharge: 250 ml subsamples from the 75 L time-integrated sample.
Culturable Bacteria cfu/ml	a. Uptake Challenge b. Uptake Potable c. Discharge Potable	Quantify regulated indicator pathogens and total heterotrophic bacteria	Uptake: 1L subsamples from 20 L sample on each of the 3 day sampling events. Discharge: 1L subsamples from the 75 L time-integrated sample.
Toxicity (if chlorinating)	Discharge Potable	Quantify whole effluent toxicity and chlorinated by-products	Discharge: 75 L time-integrated sample.

Uptake and challenge = the process of filling a mimic ballast tank.
Discharge potable = the process of emptying a mimic ballast tank.

Viable Organisms >50µm in size

Uptake Sampling

Since the uptake event is spread over several days, on each of three tank uptake (fill) days, MERC will collect a 20 L discrete sample (using MERC SOPs) of challenge water (before the PWG) and potable water (after the PWG). The sample will be processed using the nets and canisters mentioned below in the discharge paragraph.

Discharge Sampling

The MERC ETV sampling system consists of paired canisters, each designed to accommodate a 35 µm (50 µm diagonally) mesh plankton net used to collect the >50 µm size fraction. One pair handles water from the potable water ballast tank. The paired sampling canister/net arrangement allows for the residual from the cod-end of one net from each pair to be processed for examination while filtration continues via the other net, thereby avoiding clogging. In this way, unimpaired filtration back and forth between each pair of nets continues until a total of 7 m^3 has been processed from the discharge water stream. The sampling canisters are designed to allow complete immersion of each net during the filtration process, thereby minimizing trauma to filtered organisms.

Uptake and Discharge Analyses

The proportion and total concentration of live versus dead organisms > 50 µm will be determined using standard movement and response to stimuli techniques, and this live/dead analysis will take place within three hours of collecting the individual samples. A volume of 3 m^3 is collected for ambient water (high numbers of live organisms) and 7 m^3 is collected for filtered water (presumably very few live organisms). Depending upon concentrations, quantification of organisms > 50 µm in ambient samples may require analysis of sub-samples and extrapolation to the entire 3 m^3. The > 50 µm samples will then also be fixed with buffered, 10% formalin in 500ml Nalgene bottles and transported to the Smithsonian Environmental Research Center (SERC) for additional taxonomic evaluation. Total counts and general taxonomic classification will be conducted under a dissecting microscope at 25X, except for some taxa, which will be removed and identified using a compound microscope. Larval forms of invertebrates will be identified to higher taxonomic levels such as order (e.g., Decapoda) suborder (e.g., Balanomorpha) or class (e.g., Bivalvia). Adults will be identified to species in most cases. The counts will be separated into 3 size classes: total >50-µm (#/m3), >75 µm to <120µm, and around 1 mm.

Viable Organism 10 - 50 µm in size

Uptake Sampling

Since the uptake event is spread over several days, on each of three tank uptake (fill) days, MERC will take 20L discrete samples (using MERC SOPs) for both challenge and potable water. Two liters from these well-mixed, integrated samples will be subject to three distinct analyses and counts (described briefly below and in detail in SOPs)

Discharge Sampling

A 75 L time integrated sample will be collected as an unfiltered split sample in parallel with the > 50 µm fraction. This sample will be the source water for all other analyses including the 10-50 µm fraction. Two (2) liters from this well-mixed, integrated sample will be subject to three distinct analyses and counts (described briefly below and in detail in SOPs).

Uptake and Discharge Analyses

All live unfiltered samples will be processed or examined within three hours of collection on the MERC Mobile Test Platform or at nearby partner laboratories. All preserved samples are also transported to MERC partner laboratories, for further analyses and taxonomic identification.

One 250 ml sub-sample will be stained using a combination of CMFDA (5-chloromethylfluorescein diacetate) and FDA (fluorescein diacetate) as a selective live/viable indicator. Samples stained with CMFDA+FDA, are incubated and observed on a Sedgewick Rafter slide using a Olympus IX-51 inverted phase/fluorescent microscope . Cells are scored as live when showing strong fluorescence signature under excitation (some cells also show motility). This approach has been validated for use in the Chesapeake Bay (Steinberg et al., 2011) and provides the data for comparison to discharge standards. The counts will be separated into 2 size classes: total >10 µm - >50 µm (#/ml), and <10 µm.

As supporting information, two other sub-samples are analyzed. A second 250 ml is collected and fixed with standard Lugol's solution in amber Nalgene bottles to estimate total cell abundances (but not live versus dead) and for species identification under an inverted compound microscope using grid settlement columns and phase contrast lighting. A third sub-sample is filtered (Whatman GF/F 0.7 µm pore, 47 mm diameter membrane) and frozen (-20^{o}C) until analysis of total active chlorophyll-a by the CBL/UMCES Nutrient Analytical Services Laboratory using US EPA Methods 445.0 for extractive/fluorometric techniques.

<u>Viable Bacteria and Indicator Pathogens</u>

Uptake Sampling

Since the uptake event is spread over several days, on each of three tank uptake (fill) days, MERC will take 20L discrete samples (using MERC SOPs) for both challenge and potable water. An unfiltered 1 L sample will be analyzed to determine concentrations of total heterotrophic bacteria and three specific indicator pathogens, *E. coli*, intestinal *Enterococci*, and toxigenic *Vibrio cholera* (described briefly below and in detail in SOPs).

Discharge Sampling

An unfiltered 1 L sample of water sub-sampled from an integrated 75 L sample will be analyzed to determine concentrations of total heterotrophic bacteria and three specific indicator pathogens, *E. coli*, intestinal *Enterococci*, and toxigenic *Vibrio cholera* (described briefly below and in detail in SOPs).

Uptake and Discharge Analyses

Total heterotrophic bacteria will be enumerated by spread plate method using MA or R2A agar according to *Standard Methods for the Examination of Water and Wastewater* (21st edition, 2005). The presence and abundance of *E. coli* and intestinal *Enterococci* is determined using a commercially available chromogenic substrate method (IDEXX Laboratories, Inc.; Noble et al. 2003) and 10 ml and 100 ml water sample aliquots. Additionally, concentrations of culturable *E. coli* and intestinal *Enterococci* are determined using a standard US EPA 1603 method, namely, membrane filtration on mTEC agar (*E. coli*) (1 ml, 10 ml and 100 ml) and mEA agar (*Enterococcus*) (10 ml and 100 ml). Finally, the abundance of total and toxigenic *V. cholerae* will be determined by filtration and selection on TCBS agar and enumerated using species-specific RNA colony blot (500 µl to 1 ml) and *ctxA* DNA colony blot (1-10 ml). Viable toxigenic cells of *V. cholerae* are assayed with a commercial DFA kit specific for serogroup O1 (New Horizons Diagnostics) using monoclonal antibodies tagged with fluorescein isothiocyanate (FITC) (Hasan et al. 1994).

<u>Quantifying Physical Conditions</u>

During an uptake event, a muliparameter water quality instrument, deployed from the barge at a depth of one meter, will collect challenge water data every 15 minutes. Live data will include temperature, salinity, dissolved oxygen, turbidity (NTU), and chlorophyll fluorescence. A barge-mounted weather station records data from air temp, pressure, wind speed and other data. Continuous live water quality and weather data can also be viewed at the MERC Mobile Test Facility location in Baltimore can be viewed at www.maritime-enviro.org/Live.php.

In the potable tank, temperature, salinity, dissolved oxygen, chlorophyll fluorescence, and turbidity (NTU) will be measured every 15 minutes during the test trials using a multi-parameter instrument (calibrated before each trial according to manufacturer's specifications) deployed into the tank.

During the discharge events, a hand-held instrument will also be used to measure temperature, salinity, and dissolved oxygen of the filtered water in the zooplankton canisters 3 times during the event (beginning, mid and end points).

<u>Quantifying Water Quality Conditions</u>

Uptake Sampling

Since the uptake event is spread over several days, on each of three tank uptake (fill) days, MERC will take 20L discrete samples (using MERC SOPs) for both challenge and potable water. Water will be processed to determine concentrations of total suspended solids (TSS), particulate organic carbon (POC), and dissolved organic carbon (DOC). See MERC SOPs.

Discharge Sampling

Water sub-sampled from an integrated 75 L sample will be processed to determine concentrations of particulate organic carbon (POC), and dissolved organic carbon (DOC). Subsamples will be collected at three time points (beginning, mid, near-end) to be processed for concentrations of total suspended solids (TSS). See MERC SOPs.

Uptake and Discharge Analyses

Frozen samples are transported to UMCES-CBL. Water chemistry analyses are conducted by the UMCES-CBL Nutrient Analytical Services Laboratory (NASL) using EPA methods (see MERC SOPs).

Treatment Toxicity

Whole Effluent Toxicity Testing

If the PWG employs chlorine disinfection, MERC will conduct one set of toxicity tests for each discharge event. The testing is designed to meet IMO G9 requirements and uses test methods and species employed by the EPA for Whole Effluent Toxicity (WET) testing of effluents (EPA 2002 and ASTM 2006).

A fish, an invertebrate and a plant (algae) will be used in all ballast discharge tests. Because this study is evaluating the use of potable water generators, primarily as a mechanism to manage ballast water that will be discharged into the freshwaters of the Great Lakes and other inland waters, freshwater organisms will be used in these tests. The vertebrate species used in the test will be the fathead minnow (*Pimephelas promelas*); the invertebrate species will be a water flea (*Ceriodaphnia dubia)*; and the microalgal species will be *Pseudokirchneriella subcapitata (formerly Selenastrum capricornutum)*, all listed as freshwater test species in EPA's Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms, Fourth Edition (EPA, 2002).

Both acute and chronic data will be generated for each test. A dilution series, using deep well water, will be run for each species. A total of 38 L samples will be collected at the time of discharge from the potable tank. This includes enough water to do all of the test renewals. Test water will be stored in large HDPE containers and held at 4°C in the dark to retain as much of the initial toxicity as possible. All of the tests will be conducted at the University of Maryland Wye Research and Education Center toxicology laboratory and will be initiated within three to four hours of the completion of a specific trial.

Toxicity endpoints will include survival in acute fish and invertebrate tests, survival and growth in chronic fish and invertebrate tests, and population growth in chronic algal tests as required in Section 5.2.4 of the G9 document (IMO, 2008). Tests are designed with a dilution series to allow calculation of daily LC50 (concentration yielding 50% lethality) values from acute and chronic mortality data. In addition, chronic tests will include sufficient treatment replication to allow calculation of NOEC (no observable effect concentration), LOEC (lowest observable effect concentration) and EC25 (percent concentration yielding a 25% effect) values for all toxicity endpoints as required in Section 5.2.5 of the G9 (IMO, 2008). Statistical analyses will be performed using ToxCalc statistical software (TSS, 2006) according to methods from USEPA (2002) and ASTM (2006) guidance documents. A test trial will be considered a failure on the grounds of residual toxicity upon discharge if acute lethality (as indicated by determination of an LC50 of less than 100%) occurs in any test species.

Evaluation of Chlorinated By-Products

If the PWG employs chlorine disinfection, MERC will take samples for one set of analyses for chlorinate by-products for each discharge event. The analyses will be subcontracted to ALS Environmental.

7. Test Trials

MERC will conduct 3 to 5 replicate land-based testing trials of the PWG as a proof of concept evaluation. With the anticipated 4 to 5 days required to fill a mimic ballast tank to approximately 150 m3 of potable water, the individual trial weekly schedule will involve: (a) starting the PWG and first sample day on a Thursday, (b) followed by a second uptake sampling day on Friday, (c) the PWG system would then continue to produce potable water and fill the tank on Saturday and Sunday, (d) with a final uptake sampling day on Monday and the PWG shutdown, and (e) the discharge sampling would then take place on Tuesday. Required maintenance (TBD) will take place as needed throughout the trial period and individual test trials would be scheduled for every other week during the study period.

Table 3. A summary of the trials to be conducted.

Trial #	Treatment	Trial Type
Com1	Potable Water Generator	Commissioning
1	Potable Water Generator	Biological
2	Potable Water Generator	Biological
3	Potable Water Generator	Biological
4*	Potable Water Generator	Biological
5*	Potable Water Generator	Biological

*To be determined

8. Data Analysis

As noted above, continuous time-integrated samples will be taken. Consequently, please note that although certain assays employ replicates or sub-samples during analysis, to avoid pseudo-replication, the unit of replication for statistical analyses is each trial (n = 4 or 5. We assume that all measures for a single trial provide one estimate of treatment efficacy. Thus, treatment efficacy for any biological parameter is estimated as changes found before and after filtration (percent reduction), and as the difference in concentration between filtered water and discharge standards. This approach controls for variation due to temporal changes in environmental conditions.

Quality Assurance and Quality Control policies and procedures, data recording processing and storage, and detailed roles and responsibilities can be found in the MERC QMP, QAPP and SOPs.

9. Evaluation Schedule (planned dates based on current plan and may vary):

- MERC Test Plan for the PWG system finalized and approved by ERG **[DATE].**
- Delivery and installation of PWG system, **[DATE].**
- MERC evaluation of PWG system in Baltimore MD initiated by **[DATE]**.
- MERC will complete sample analysis and compile data from the evolution by **[DATE].**
- MERC will distribute a draft report on the performance of the PWG system for review ERG and EPA **[DATE].**
- MERC will submit a final summary report to ERG and EPA by **28 Feb 2014**.

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

Full analysis results are provided on the following pages.

ALS Environmental

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NELAP Certifications: NJ PA010 , NY 11759 , PA 22-293 DoD ELAP: A2LA 0818.01
State Certifications: DE ID 11 , MA PA0102 , MD 128 , VA 460157 , WV 343

August 26, 2014

Ms. Janet Barnes
University of MD-UMCES - Solomons, MD
P.O. Box 38
146 Williams Street
Solomons, MD 20688

Certificate of Analysis

Project Name:	**2014-MD BRACKISH WATER STUDY**	Workorder:	**2006708**
Purchase Order:		Workorder ID:	**2014-MD BRACKISH WATER STUDY**

Dear Ms. Barnes:

Enclosed are the analytical results for samples received by the laboratory on Wednesday, May 14, 2014.

The ALS Environmental laboratory in Middletown, Pennsylvania is a National Environmental Laboratory Accreditation Program (NELAP) accredited laboratory and as such, certifies that all applicable test results meet the requirements of NELAP.

If you have any questions regarding this certificate of analysis, please contact Ms. Debra J. Musser (Project Coordinator) at (717) 944-5541.

Analyses were performed according to our laboratory's NELAP-approved quality assurance program and any applicable state requirements. The test results meet requirements of the current NELAP standards or state requirements, where applicable. For a specific list of accredited analytes, refer to the certifications section of the ALS website at www.alsglobal.com/en/Our-Services/Life-Sciences/Environmental/Downloads.

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ALS Spring City: 10 Riverside Drive, Spring City, PA 19475 610-948-4903

This page is included as part of the Analytical Report and must be retained as a permanent record thereof.

Debra J Musser

Ms. Debra J. Musser
Project Coordinator

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NELAP Certifications: NJ PA010 , NY 11759 , PA 22-293 DoD ELAP: A2LA 0818.01
State Certifications: DE ID 11 , MA PA0102 , MD 128 , VA 460157 , WV 343

SAMPLE SUMMARY

Workorder: 2006708 2014-MD BRACKISH WATER STUDY

Lab ID	Sample ID	Matrix	Date Collected	Date Received	Collected By
2006708001	Distribution 714 4260 Evergreen Ave	Water	5/13/2014 11:09	5/14/2014 10:15	Collected by Client

Notes

-- Samples collected by ALS personnel are done so in accordance with the procedures set forth in the ALS Field Sampling Plan (20 - Field Services Sampling Plan).
-- All Waste Water analyses comply with methodology requirements of 40 CFR Part 136.
-- All Drinking Water analyses comply with methodology requirements of 40 CFR Part 141.
-- Unless otherwise noted, all quantitative results for soils are reported on a dry weight basis.
-- The Chain of Custody document is included as part of this report.
-- All Library Search analytes should be regarded as tentative identifications based on the presumptive evidence of the mass spectra. Concentrations reported are estimated values.
-- Parameters identified as "analyze immediately" require analysis within 15 minutes of collection. Any "analyze immediately" parameters not listed under the header "Field Parameters" are preformed in the laboratory and are therefore analyzed out of hold time.
-- Method references listed on this report beginning with the prefix "S" followed by a method number (such as S2310B-97) refer to methods from "Standard Methods for the Examination of Water and Wastewater".

Standard Acronyms/Flags

J	Indicates an estimated value between the Method Detection Limit (MDL) and the Practical Quantitation Limit (PQL) for the analyte
U	Indicates that the analyte was Not Detected (ND)
N	Indicates presumptive evidence of the presence of a compound
MDL	Method Detection Limit
PQL	Practical Quantitation Limit
RDL	Reporting Detection Limit
ND	Not Detected - indicates that the analyte was Not Detected at the RDL
Cntr	Analysis was performed using this container
RegLmt	Regulatory Limit
LCS	Laboratory Control Sample
MS	Matrix Spike
MSD	Matrix Spike Duplicate
DUP	Sample Duplicate
%Rec	Percent Recovery
RPD	Relative Percent Difference
LOD	DoD Limit of Detection
LOQ	DoD Limit of Quantitation
DL	DoD Detection Limit

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PROJECT SUMMARY

Workorder: 2006708 2014-MD BRACKISH WATER STUDY

Workorder Comments

Please see the attached EPA 551 results analyzed by Weck Laboratories, Inc. DJM

Please see the attached EPA 552 results analyzed by Eurofins. DJM

Sample Comments

Lab ID: 2006708001 **Sample ID:** Distribution 714 4260 Evergreen Ave **Sample Type:** SAMPLE

Assuming that all bromate present in the sample is in the form of sodium bromate, the sodium bromate concentration is <5.9 ug/L.

Assuming that all chlorate present in the sample is in the form of sodium chlorate, the sodium chlorate concentration is 43.6 ug/L.

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ANALYTICAL RESULTS

Workorder: 2006708 2014-MD BRACKISH WATER STUDY

Lab ID: **2006708001** Date Collected: 5/13/2014 11:09 Matrix: Water

Sample ID: **Distribution 714 4260 Evergreen Ave** Date Received: 5/14/2014 10:15

Parameters	Results	Flag	Units	RDL	Method	Prepared	By	Analyzed	By	*Cntr*
VOLATILE ORGANICS										
Bromodichloromethane	ND		ug/L	0.50	EPA 524.2	5/20/14	TMP	5/20/14 22:09	TMP	B
Bromoform	ND		ug/L	0.50	EPA 524.2	5/20/14	TMP	5/20/14 22:09	TMP	B
Chlorodibromomethane	ND		ug/L	0.50	EPA 524.2	5/20/14	TMP	5/20/14 22:09	TMP	B
Chloroform	ND		ug/L	0.50	EPA 524.2	5/20/14	TMP	5/20/14 22:09	TMP	B
1,2,3-Trichloropropane	ND		ug/L	0.50	EPA 524.2	5/20/14	TMP	5/20/14 22:09	TMP	B
Surrogate Recoveries	*Results*	*Flag*	*Units*	*Limits*	*Method*	*Prepared*	*By*	*Analyzed*	*By*	*Cntr*
1,2-Dichlorobenzene-d4 (S)	73.6		%	70 - 130	EPA 524.2	5/20/14	TMP	5/20/14 22:09	TMP	B
4-Bromofluorobenzene (S)	78.2		%	70 - 130	EPA 524.2	5/20/14	TMP	5/20/14 22:09	TMP	B
HERBICIDES										
Dalapon	ND		ug/L	4.0	EPA 515.3	5/15/14	JSH	5/16/14 18:48	EGO	I
Surrogate Recoveries	*Results*	*Flag*	*Units*	*Limits*	*Method*	*Prepared*	*By*	*Analyzed*	*By*	*Cntr*
2,4-Dichlorophenylacetic acid (S)	106		%	70 - 130	EPA 515.3	5/15/14	JSH	5/16/14 18:48	EGO	I
WET CHEMISTRY										
Bromate	ND		ug/L	5.0	EPA 300.1	5/20/14	SSL	5/20/14 13:48	SSL	H
Chlorate	34.2		ug/L	20.0	EPA 300.1	5/20/14	SSL	5/20/14 13:48	SSL	H
METALS										
Sodium, Total	4.4		mg/L	0.25	EPA 200.7	5/21/14	AAM	5/23/14 05:20	ZMC	G1
SUBCONTRACTED ANALYSIS										
Subcontracted Analysis	See Attached				Subcontract			7/31/14 00:00	SUB	D

Debra J Musser

Ms. Debra J. Musser
Project Coordinator

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QUALITY CONTROL DATA

Workorder: 2006708 2014-MD BRACKISH WATER STUDY

QC Batch: SVGC/34212 **Analysis Method:** EPA 515.3

QC Batch Method: EPA 515.3

Associated Lab Samples: 2006708001

METHOD BLANK: 2016997

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Dalapon	ND	ug/L	4.0	
2,4-Dichlorophenylacetic acid (S)	95	%	70 - 130	

LABORATORY CONTROL SAMPLE: 2016998

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Dalapon	5	ug/L	5.6	113	70 - 130	
2,4-Dichlorophenylacetic acid (S)		%		88	70 - 130	

MATRIX SPIKE SAMPLE: 2016999 ORIGINAL:

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MS % Rec	% Rec Limit	Qualifiers
Dalapon		ug/L	5	5.5	110	70 - 130	
2,4-Dichlorophenylacetic acid (S)		%				70 - 130	

MATRIX SPIKE SAMPLE: 2017000 ORIGINAL:

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MS % Rec	% Rec Limit	Qualifiers
Dalapon		ug/L	5	11.8	237	70 - 130	
2,4-Dichlorophenylacetic acid (S)		%				70 - 130	

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QUALITY CONTROL DATA

Workorder: 2006708 2014-MD BRACKISH WATER STUDY

SAMPLE DUPLICATE: 2017001 ORIGINAL:

Parameter	Original Result	Units	DUP Result	RPD	Max RPD	Qualifiers
Dalapon		ug/L	ND		30	
2,4-Dichlorophenylacetic acid (S)		%		100	130	
2,4-Dichlorophenylacetic acid (S)		%		2.6		

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QUALITY CONTROL DATA

Workorder: 2006708 2014-MD BRACKISH WATER STUDY

QC Batch: WETC/138176 **Analysis Method:** EPA 300.1

QC Batch Method: EPA 300.1

Associated Lab Samples: 2006708001

METHOD BLANK: 2018446

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Bromate	ND	ug/L	5.0	
Chlorate	ND	ug/L	20.0	

LABORATORY CONTROL SAMPLE: 2018447

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Bromate	25	ug/L	24.4	97.7	85 - 115	
Chlorate	250	ug/L	243	97.2	90 - 110	

MATRIX SPIKE: 2018449 DUPLICATE: 2018450 ORIGINAL: 2006965001

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MSD Result	MS % Rec	MSD % Rec	% Rec Limit	RPD	Max RPD	Qualifiers
Chlorate		ug/L	250	302	277	110	99.9	75 - 125	8.69	25	

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QUALITY CONTROL DATA

Workorder: 2006708 2014-MD BRACKISH WATER STUDY

QC Batch: VOMS/32695 **Analysis Method:** EPA 524.2

QC Batch Method: EPA 524.2

Associated Lab Samples: 2006708001

METHOD BLANK: 2018766

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Chloroform	ND	ug/L	0.50	
Bromodichloromethane	ND	ug/L	0.50	
Chlorodibromomethane	ND	ug/L	0.50	
Bromoform	ND	ug/L	0.50	
1,2,3-Trichloropropane	ND	ug/L	0.50	
1,2-Dichlorobenzene-d4 (S)	75.8	%	70 - 130	
4-Bromofluorobenzene (S)	75.7	%	70 - 130	

LABORATORY CONTROL SAMPLE: 2018767

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Chloroform	1	ug/L	1.0	102	50 - 150	
Bromodichloromethane	1	ug/L	1.2	120	50 - 150	
Chlorodibromomethane	1	ug/L	0.99	98.6	50 - 150	
Bromoform	1	ug/L	0.88	88.2	50 - 150	
1,2-Dichlorobenzene-d4 (S)		%		87.6	70 - 130	
4-Bromofluorobenzene (S)		%		88.7	70 - 130	

LABORATORY CONTROL SAMPLE: 2018768

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Chloroform	5	ug/L	4.8	96.1	70 - 130	
Bromodichloromethane	5	ug/L	5.1	102	70 - 130	
Chlorodibromomethane	5	ug/L	5.4	108	70 - 130	
Bromoform	5	ug/L	5.0	99.3	70 - 130	
1,2,3-Trichloropropane	5	ug/L	5.7	113	70 - 130	
1,2-Dichlorobenzene-d4 (S)		%		103	70 - 130	
4-Bromofluorobenzene (S)		%		95.6	70 - 130	

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QUALITY CONTROL DATA

Workorder: 2006708 2014-MD BRACKISH WATER STUDY

MATRIX SPIKE: 2019023 DUPLICATE: 2019024 ORIGINAL: 2006905001

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MSD Result	MS % Rec	MSD % Rec	% Rec Limit	RPD	Max RPD	Qualifiers
Chloroform		ug/L		4.2	4.0				5.26	40	
Bromodichloromethane		ug/L		5.1	5.3				2.53	40	
Chlorodibromomethane		ug/L		5.6	5.3				5.52	40	
Bromoform		ug/L		5.3	5.1				3.86	40	
1,2,3-Trichloropropane		ug/L	5	6.2	5.5	124	109	70 - 130	12.5	40	
4-Bromofluorobenzene (S)		%				106	99	70 - 130	6.79		
1,2-Dichlorobenzene-d4 (S)		%				110	101	70 - 130	8.94		

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QUALITY CONTROL DATA

Workorder: 2006708 2014-MD BRACKISH WATER STUDY

QC Batch: MDIG/45493 **Analysis Method:** EPA 200.7

QC Batch Method: EPA TRMD

Associated Lab Samples: 2006708001

METHOD BLANK: 2018853

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Sodium, Total	ND	mg/L	0.25	

LABORATORY CONTROL SAMPLE: 2018854

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Sodium, Total	10	mg/L	10.7	107	85 - 115	

MATRIX SPIKE: 2018855 DUPLICATE: 2018856 ORIGINAL: 2007347003

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MSD Result	MS % Rec	MSD % Rec	% Rec Limit	RPD	Max RPD	Qualifiers
Sodium, Total		mg/L		41.2	42.8				3.87	20	

MATRIX SPIKE SAMPLE: 2018857 ORIGINAL:

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MS % Rec	% Rec Limit	Qualifiers
Sodium, Total		mg/L		916			

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State Certifications: DE ID 11 , MA PA0102 , MD 128 , VA 460157 , WV 343

QUALITY CONTROL DATA CROSS REFERENCE TABLE

Workorder: 2006708 2014-MD BRACKISH WATER STUDY

Lab ID	Sample ID	Prep Method	Prep Batch	Analysis Method	Analysis Batch
2006708001	PW1-DC-P	EPA 515.3	SVGC/34212	EPA 515.3	SVGC/34214
2006708001	PW1-DC-P			EPA 300.1	WETC/138176
2006708001	PW1-DC-P			EPA 524.2	VOMS/32695
2006708001	PW1-DC-P	EPA TRMD	MDIG/45493	EPA 200.7	META/44389

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Middletown, PA 17057
P. 717-944-5541
F.717-944-1430

DJM

CHAIN OF CUSTODY/ REQUEST FOR ANALYSIS

ALL SHADED AREAS MUST BE COMPLETED BY THE CLIENT/ SAMPLER. INSTRUCTIONS ON THE BACK.

Page 1 of 1
Courier: UPS
Tracking #: 1Z W05WR901

2006708

Co. Name: University of Maryland - UMCES - CBL
Contact (Report to): Janet Barnes
Phone: 410-326-7428
Address: P.O. Box 38
146 Williams St.
Solomons, MD 20688

Bill to (if different than Report to):
PO#:

Project Name/#: PW1-DC
ALS Quote #: 454283

TAT: [✓] Normal-Standard TAT is 10-12 business days. [ ] Rush-Subject to ALS approval and surcharges.
Date Required:
Approved By: JMB

Email? ✓-Y barnes@umces.edu
Fax? -Y No.:

	***Container Type	CG	AG	CG	PL	AG	AG
	***Container Size	40 ml	250 ml	60 ml	250 ml	1L	1L
	***Preservative	ASC HCL	NH_4Cl	NH_4Cl	HNO3	EDA	$Na_2S_2O_3$
	ANALYSES/METHOD REQUESTED	VOC by 524.2	HAA by 552.5	Acetonitrile by 551	Sodium 200.7	Bromate and Chlorate 300.1	Herbicides by 515.3

	Sample Description/Location (as it will appear on the lab report)	COC Comments	Sample Date	Military Time	*G or C	**Matrix	VOC by 524.2	HAA by 552.5	Acetonitrile by 551	Sodium 200.7	Bromate and Chlorate 300.1	Herbicides by 515.3
1	PW1-DC-P		5/13/14	1109	C	DW	2	1	2	1	1	2
2												
3												
4												
5												
6		A 5/14/14 1852										
7												
8												

Enter Number of Containers Per Analysis

Sample Receipt Information (completed by Sample Receiving)
Performed by: [illegible]
Cooler Temp: 1°C
Therm. ID: TH-219
No. of Coolers: 1
Notes:

Correct containers?	Correct sample volume?	Correct preservation?	Headspace/Volatiles?	Circle appropriate Y or N.
Y	Y	Y	Y	

Custody seals Present?	(if present) Seals intact?	Received on ice?	COC/Labels complete/accurate?	Container in good condition?
N		Y	Y	Y

SAMPLED BY (Please Print): Eva Bailey

Project Comments: Sample time above is when sample taken from tank. Sample time on bottles when filled.

	Relinquished By / Company Name	Date	Time		Received By / Company Name	Date	Time
1	Janet Barnes / UMCES-CBL	5/13/14	1238	2	[signature] ALS	5/14/14	1015
3				4			
5				6			
7				8			
9				10			

Data Deliverables: [X] Standard [ ] CLP-like [ ] NJ-Reduced [ ] NJ-Full [ ]
EDDs Required? [✓] If yes, format type: MS Excel
DOD Criteria Required? No

SDWA Forms? yes [ ] yes [ ] yes [ ] yes [ ] Other

State Samples Collected In? MD [X] NJ [ ] NY [ ] PA [ ]

ALS FIELD SERVICES: [ ] Pickup [ ] Labor [ ] Composite Sampling [ ] Rental Equipment [ ] Other:

* G=Grab; C=Composite
**Matrix: AI=Air; DW=Drinking Water; GW=Groundwater; OI=Oil; OL=Other Liquid; SL=Sludge; SO=Soil; WP=Wipe; WW=Wastewater
***Container Type: AG-Amber Glass; CG-Clear Glass, PL-Plastic. Container Size: 250ml, 500ml, 1L, 8oz., etc. Preservative: HCl, HNO3, NaOH, etc.

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Rev 01-2013

Tuesday, August 26, 2014 2:04:25 PM
Page 12 of 26
ALS

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Analytical Laboratory Service - Since 1964

CERTIFICATE OF ANALYSIS

Client:	ALS Environmental - PA 34 Dogwood Lane Middletown PA, 17057	**Report Date:**	07/31/14 13:15
		Received Date:	05/16/14 10:30
		Turn Around:	Normal
Attention:	Debra Musser	**Client Project:**	2006708
Phone:	(800) 794-7709		
Fax:	(717) 944-1430		
Work Order(s):	4E16027		

NELAP #04229CA ELAP#1132 NEVADA #CA211 HAWAII LACSD #10143

The results in this report apply to the samples analyzed in accordance with the Chain of Custody document. Weck Laboratories, Inc. certifies that the test results meet all NELAC requirements unless noted in the case narrative. This analytical report is confidential and is only intended for the use of Weck Laboratories, Inc. and its client. This report contains the Chain of Custody document, which is an integral part of it, and can only be reproduced in full with the authorization of Weck Laboratories, Inc.

Dear Debra Musser :

Enclosed are the results of analyses for samples received 05/16/14 10:30 with the Chain of Custody document. The samples were received in good condition, at 8.4 °C and on ice. All analysis met the method criteria except as noted below or in the report with data qualifiers.

Case Narrative:
SUPP report generated to include mono compounds. BG 7/31/14

Reviewed by:

Brandon Gee
Project Manager

WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 05/16/14 10:30
Date Reported: 07/31/14 13:15

ANALYTICAL REPORT FOR SAMPLES

Sample ID	Sampled by:	Sample Comments	Lab ID	Matrix	Date Sampled
2006708	Client		4E16027-01	Water	05/13/14 00:00

ANALYSES

DBPs by EPA 551.1

WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 05/16/14 10:30
Date Reported: 07/31/14 13:15

4E16027-01 **2006708**

Sampled: 05/13/14 00:00 **Sampled By:** Client **Matrix:** Water

DBPs by EPA 551.1

Method: EPA 551.1 Batch: W4E1377 Prepared: 05/27/14 14:18 Analyst: Juliet Chootipanya

Analyte	Result		MRL	Units	Dil	Analyzed	Qualifier
1,1,1-trichloro-2-propanone	ND		0.50	ug/l	1	05/30/14 05:39	
1,1-Dichloro-2-propanone	ND		0.50	ug/l	1	05/30/14 05:39	
Bromochloroacetonitrile	ND		0.50	ug/l	1	05/30/14 05:39	
Chloral hydrate	ND		0.50	ug/l	1	05/30/14 05:39	
Chloropicrin	ND		0.50	ug/l	1	05/30/14 05:39	
Dibromoacetonitrile	ND		0.50	ug/l	1	05/30/14 05:39	
Dichloroacetonitrile	ND		0.50	ug/l	1	05/30/14 05:39	
Trichloroacetonitrile	ND		0.50	ug/l	1	05/30/14 05:39	
Surr: Decafluorobiphenyl	*89 %*	Conc:*8.88*	*80-120*	%			

WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 05/16/14 10:30
Date Reported: 07/31/14 13:15

Sampled: 05/13/14 00:00

4E16027-01RE1 **2006708**
Sampled By: Client

Matrix: Water

DBPs by EPA 551.1

Method: EPA 551.1 Batch: W4G0414 Prepared: 07/09/14 10:39 Analyst: Juliet Chootipanya

Analyte	Result		MRL	Units	Dil	Analyzed	Qualifier
Bromoacetonitrile	ND		0.50	ug/l	1	07/09/14 22:01	O-14
Chloroacetonitrile	ND		0.50	ug/l	1	07/09/14 22:01	O-14
Surr: Decafluorobiphenyl	*86 %*	Conc:*8.60*	*80-120*	%			*O-14*

WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 05/16/14 10:30
Date Reported: 07/31/14 13:15

QUALITY CONTROL SECTION

WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 05/16/14 10:30
Date Reported: 07/31/14 13:15

DBPs by EPA 551.1 - Quality Control

Batch W4E1377 - EPA 551.1

Analyte	Result	MRL	Units	Spike Level	Source Result	%REC	% REC Limits	RPD	RPD Limit	Data Qualifiers
Blank (W4E1377-BLK1)				Analyzed: 05/30/14 04:24						
1,1,1-trichloro-2-propanone	ND	0.50	ug/l							
1,1-Dichloro-2-propanone	ND	0.50	ug/l							
Bromochloroacetonitrile	ND	0.50	ug/l							
Chloral hydrate	ND	0.50	ug/l							
Chloropicrin	ND	0.50	ug/l							
Dibromoacetonitrile	ND	0.50	ug/l							
Dichloroacetonitrile	ND	0.50	ug/l							
Trichloroacetonitrile	ND	0.50	ug/l							
Surr: Decafluorobiphenyl	*9.16*		*ug/l*	*10.0*		*92*	*80-120*			
LCS (W4E1377-BS1)				Analyzed: 05/30/14 04:49						
1,1,1-trichloro-2-propanone	10.9	0.50	ug/l	10.0		109	75-125			
1,1-Dichloro-2-propanone	10.6	0.50	ug/l	10.0		106	75-125			
Bromochloroacetonitrile	8.95	0.50	ug/l	10.0		90	75-125			
Chloral hydrate	12.8	0.50	ug/l	10.0		128	75-125			Q-08
Chloropicrin	8.74	0.50	ug/l	10.0		87	75-125			
Dibromoacetonitrile	8.70	0.50	ug/l	10.0		87	75-125			
Dichloroacetonitrile	10.6	0.50	ug/l	10.0		106	75-125			
Trichloroacetonitrile	8.98	0.50	ug/l	10.0		90	75-125			
Surr: Decafluorobiphenyl	*9.11*		*ug/l*	*10.0*		*91*	*80-120*			
LCS Dup (W4E1377-BSD1)				Analyzed: 05/30/14 05:14						
1,1,1-trichloro-2-propanone	11.1	0.50	ug/l	10.0		111	75-125	1	25	
1,1-Dichloro-2-propanone	10.4	0.50	ug/l	10.0		104	75-125	2	25	
Bromochloroacetonitrile	10.0	0.50	ug/l	10.0		100	75-125	11	25	
Chloral hydrate	11.9	0.50	ug/l	10.0		119	75-125	7	25	
Chloropicrin	9.37	0.50	ug/l	10.0		94	75-125	7	25	
Dibromoacetonitrile	9.86	0.50	ug/l	10.0		99	75-125	12	25	
Dichloroacetonitrile	10.8	0.50	ug/l	10.0		108	75-125	1	25	
Trichloroacetonitrile	9.52	0.50	ug/l	10.0		95	75-125	6	25	
Surr: Decafluorobiphenyl	*10.4*		*ug/l*	*10.0*		*104*	*80-120*			

Batch W4G0414 - EPA 551.1

Analyte	Result	MRL	Units	Spike Level	Source Result	%REC	% REC Limits	RPD	RPD Limit	Data Qualifiers
Blank (W4G0414-BLK1)				Analyzed: 07/09/14 20:46						
Bromoacetonitrile	ND	0.50	ug/l							
Chloroacetonitrile	ND	0.50	ug/l							
Surr: Decafluorobiphenyl	*8.68*		*ug/l*	*10.0*		*87*	*80-120*			
LCS (W4G0414-BS1)				Analyzed: 07/09/14 21:11						
Bromoacetonitrile	9.06	0.50	ug/l	10.0		91	80-120			
Chloroacetonitrile	8.92	0.50	ug/l	10.0		89	80-120			
Surr: Decafluorobiphenyl	*9.47*		*ug/l*	*10.0*		*95*	*80-120*			

Weck Laboratories, Inc 14859 East Clark Avenue, City of Industry, California 91745-1396 (626) 336-2139 FAX (626) 336-2634

WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 05/16/14 10:30
Date Reported: 07/31/14 13:15

DBPs by EPA 551.1 - Quality Control

Batch W4G0414 - EPA 551.1

Analyte	Result	MRL	Units	Spike Level	Source Result	%REC	% REC Limits	RPD	RPD Limit	Data Qualifiers
LCS Dup (W4G0414-BSD1)				Analyzed: 07/10/14 12:44						
Bromoacetonitrile	10.7	0.50	ug/l	10.0		107	80-120	17	25	
Chloroacetonitrile	10.5	0.50	ug/l	10.0		105	80-120	16	25	
Surr: Decafluorobiphenyl	*10.2*		*ug/l*	*10.0*		*102*	*80-120*			

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34 Dogwood Lane
Middletown PA, 17057

Date Received: 05/16/14 10:30
Date Reported: 07/31/14 13:15

Notes and Definitions

Q-08	High bias in the QC sample does not affect sample result since analyte was not detected or below the reporting limit.
O-14	This analysis was requested by the client after the holding time was exceeded.
ND	NOT DETECTED at or above the Reporting Limit. If J-value reported, then NOT DETECTED at or above the Method Detection Limit (MDL)
NR	Not Reportable
Dil	Dilution
dry	Sample results reported on a dry weight basis
RPD	Relative Percent Difference
% Rec	Percent Recovery
Sub	Subcontracted analysis, original report available upon request
MDL	Method Detection Limit
MDA	Minimum Detectable Activity
MRL	Method Reporting Limit

Any remaining sample(s) will be disposed of one month from the final report date unless other arrangements are made in advance.

An Absence of Total Coliform meets the drinking water standards as established by the California Department of Health Services.

The Reporting Limit (RL) is referenced as the Laboratory's Practical Quantitation Limit (PQL) or the Detection Limit for Reporting Purposes (DLR).

All samples collected by Weck Laboratories have been sampled in accordance to laboratory SOP Number MIS002.

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110 South Hill Street
South Bend, IN 46617
Tel: (574) 233-4777
Fax: (574) 233-8207
1 800 332 4345

Laboratory Report

Client: ALS

Attn: Karen Elofsky
34 Dogwood Lane
Middletown, PA 17057

Copies to: None

Report: 317971
Priority: Standard Written
Status: Final
PWS ID: Not Supplied
PA Lab ID: 68466

Sample Information

EEA ID #	Client ID	Method	Collected Date / Time	Collected By:	Received Date / Time
3029940	2006708 001	552.2	05/13/14 11:09	Client	05/21/14 10:30

Report Summary

Note: Sample container was provided by the client.

Detailed quantitative results are presented on the following pages. The results presented relate only to the samples provided for analysis.

We appreciate the opportunity to provide you with this analysis. If you have any questions concerning this report, please do not hesitate to call Nathan Trowbridge at (574) 233-4777.

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Traci Chlebowski
Digitally signed by Traci Chlebowski
Date: 2014.06.10 15:14:23 -04'00'

Authorized Signature Title Date

Client Name: ALS
Report #: 317971

Client Name: ALS Report #: 317971

Sampling Point: 2006708 001 PWS ID: Not Supplied

Disinfection Byproducts

Analyte ID #	Analyte	Method	Reg Limit	MRL†	Result	Units	Preparation Date	Analyzed Date	EEA ID #
5589-96-8	Bromochloroacetic acid	552.2	---	1.0	< 1.0	ug/L	05/23/14 07:40	05/23/14 17:45	3029940
5278-95-5	Chlorodibromoacetic acid	552.2	---	2.0	< 2.0	ug/L	05/23/14 07:40	05/23/14 17:45	3029940
631-64-1	Dibromoacetic acid	552.2	---	1.0	< 1.0	ug/L	05/23/14 07:40	05/23/14 17:45	3029940
79-43-6	Dichloroacetic acid	552.2	---	1.0	< 1.0	ug/L	05/23/14 07:40	05/23/14 17:45	3029940
79-08-3	Monobromoacetic acid	552.2	---	1.0	< 1.0	ug/L	05/23/14 07:40	05/23/14 17:45	3029940
79-11-8	Monochloroacetic acid	552.2	---	2.0	< 2.0	ug/L	05/23/14 07:40	05/23/14 17:45	3029940
75-96-7	Tribromoacetic acid	552.2	---	4.0	< 4.0	ug/L	05/23/14 07:40	05/23/14 17:45	3029940
76-03-9	Trichloroacetic acid	552.2	---	1.0	< 1.0	ug/L	05/23/14 07:40	05/23/14 17:45	3029940
---	Total HAA5	552.2	60 *	2.0	< 2.0	ug/L	05/23/14 07:40	05/23/14 17:45	3029940

† EEA has demonstrated it can achieve these report limits in reagent water, but can not document them in all sample matrices.

Reg Limit Type:	MCL	SMCL	AL
Symbol:	*	^	!

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Tuesday, August 26, 2014 2:04:25 PM
Page 22 of 26 ALS

Client Name: ALS Report #: 317971

Lab Definitions

Continuing Calibration Check Standard (CCC) / Continuing Calibration Verification (CCV) / Initial Calibration Verification Standard (ICV) / Initial Performance Check (IPC) - is a standard containing one or more of the target analytes that is prepared from the same standards used to calibrate the instrument. This standard is used to verify the calibration curve at the beginning of each analytical sequence, and may also be analyzed throughout and at the end of the sequence. The concentration of continuing standards may be varied, when prescribed by the reference method, so that the range of the calibration curve is verified on a regular basis.

Internal Standards (IS) - are pure compounds with properties similar to the analytes of interest, which are added to field samples or extracts, calibration standards, and quality control standards at a known concentration. They are used to measure the relative responses of the analytes of interest and surrogates in the sample, calibration standard or quality control standard.

Laboratory Duplicate (LD) - is a field sample aliquot taken from the same sample container in the laboratory and analyzed separately using identical procedures. Analysis of laboratory duplicates provides a measure of the precision of the laboratory procedures.

Laboratory Fortified Blank (LFB) / Laboratory Control Sample (LCS) - is an aliquot of reagent water to which known concentrations of the analytes of interest are added. The LFB is analyzed exactly the same as the field samples. LFBs are used to determine whether the method is in control.

Laboratory Method Blank (LMB) / Laboratory Reagent Blank (LRB) - is a sample of reagent water included in the sample batch analyzed in the same way as the associated field samples. The LMB is used to determine if method analytes or other background contamination have been introduced during the preparation or analytical procedure. The LMB is analyzed exactly the same as the field samples.

Laboratory Trip Blank (LTB) / Field Reagent Blank (FRB) - is a sample of laboratory reagent water placed in a sample container in the laboratory and treated as a field sample, including storage, preservation, and all analytical procedures. The FRB/LTB container follows the collection bottles to and from the collection site, but the FRB/LTB is not opened at any time during the trip. The FRB/LTB is primarily a travel blank used to verify that the samples were not contaminated during shipment.

Matrix Spike Duplicate Sample (MSD) / Laboratory Fortified Sample Matrix Duplicate (LFSMD) - is a sample aliquot taken from the same field sample source as the Matrix Spike Sample to which known quantities of the analytes of interest are added in the laboratory. The MSD is analyzed exactly the same as the field samples. Analysis of the MSD provides a measure of the precision of the laboratory procedures in a specific matrix.

Matrix Spike Sample (MS) / Laboratory Fortified Sample Matrix (LFSM) - is a sample aliquot taken from field sample source to which known quantities of the analytes of interest are added in the laboratory. The MS is analyzed exactly the same as the field samples. The purpose is to demonstrate recovery of the analytes from a sample matrix to determine if the specific matrix contributes bias to the analytical results.

Quality Control Standard (QCS) / Second Source Calibration Verification (SSCV) - is a solution containing known concentrations of the analytes of interest prepared from a source different from the source of the calibration standards. The solution is obtained from a second manufacturer or lot if the lot can be demonstrated by the manufacturer as prepared independently from other lots. The QCS sample is analyzed using the same procedures as field samples. The QCS is used as a check on the calibration standards used in the method on a routine basis.

Reporting Limit Check (RLC) / Initial Calibration Check Standard (ICCS) - is a procedural standard that is analyzed each day to evaluate instrument performance at or below the minimum reporting limit (MRL).

Surrogate Standard (SS) / Surrogate Analyte (SUR) - is a pure compound with properties similar to the analytes of interest, which is highly unlikely to be found in any field sample, that is added to the field samples, calibration standards, blanks and quality control standards before sample preparation. The SS is used to evaluate the efficiency of the sample preparation process.

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Run Log

Run ID: **191203** Method: **552.2**

Type	Sample Id	Sample Site	Matrix	Instrument ID	Analysis Date	Calibration File
CCL	3032520		RW	BP	05/23/2014 16:34	552_2-052214BP
LMB	3032517		RW	BP	05/23/2014 17:09	552_2-052214BP
FS	3029940	2006708 001	DW	BP	05/23/2014 17:45	552_2-052214BP
CCC	3032518		RW	BP	05/24/2014 00:09	552_2-052214BP

QC Summary Report

Sample Type	Analyte	Method	MRL	Client ID	Result Flag	Amount	Target	Units	% Recovery	Recovery Limits	RPD	RPD Limit	Dil Factor	Extracted	Analyzed	EEA ID #
CCL	SS-2-Bromopropionic acid	552.2	N/A	---		4.6972	5.0	ug/L	94	70 - 130	---	---	1.0	05/23/2014 07:40	05/23/2014 16:34	3032520
CCL	Bromochloroacetic acid	552.2	1.0	---		0.7152	1.0	ug/L	72	71 - 154	---	---	1.0	05/23/2014 07:40	05/23/2014 16:34	3032520
CCL	Chlorodibromoacetic acid	552.2	2.0	---		0.8362	1.0	ug/L	84	43 - 185	---	---	1.0	05/23/2014 07:40	05/23/2014 16:34	3032520
CCL	Dibromoacetic acid	552.2	1.0	---		0.7730	1.0	ug/L	77	50 - 150	---	---	1.0	05/23/2014 07:40	05/23/2014 16:34	3032520
CCL	Dichloroacetic acid	552.2	1.0	---		0.6601	1.0	ug/L	66	50 - 150	---	---	1.0	05/23/2014 07:40	05/23/2014 16:34	3032520
CCL	Monobromoacetic acid	552.2	1.0	---		0.7076	1.0	ug/L	71	50 - 150	---	---	1.0	05/23/2014 07:40	05/23/2014 16:34	3032520
CCL	Monochloroacetic acid	552.2	2.0	---		1.6065	2.0	ug/L	80	50 - 150	---	---	1.0	05/23/2014 07:40	05/23/2014 16:34	3032520
CCL	Tribromoacetic acid	552.2	4.0	---		0.6905	1.0	ug/L	69	36 - 206	---	---	1.0	05/23/2014 07:40	05/23/2014 16:34	3032520
CCL	Trichloroacetic acid	552.2	1.0	---		0.6887	1.0	ug/L	69	50 - 150	---	---	1.0	05/23/2014 07:40	05/23/2014 16:34	3032520
CCL	IS-1,2,3-Trichloropropane	552.2	N/A	---		24996	23453	ug/L	107	70 - 130	---	---	1.0	05/23/2014 07:40	05/23/2014 16:34	3032520
LMB	SS-2-Bromopropionic acid	552.2	N/A	---		4.7464	5.0	ug/L	95	70 - 130	---	---	1.0	05/23/2014 07:40	05/23/2014 17:09	3032517
LMB	Bromochloroacetic acid	552.2	1.0	---	<	1.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:09	3032517
LMB	Chlorodibromoacetic acid	552.2	2.0	---	<	2.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:09	3032517
LMB	Dibromoacetic acid	552.2	1.0	---	<	1.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:09	3032517
LMB	Dichloroacetic acid	552.2	1.0	---	<	1.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:09	3032517
LMB	Monobromoacetic acid	552.2	1.0	---	<	1.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:09	3032517
LMB	Monochloroacetic acid	552.2	2.0	---	<	2.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:09	3032517
LMB	Tribromoacetic acid	552.2	4.0	---	<	4.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:09	3032517
LMB	Trichloroacetic acid	552.2	1.0	---	<	1.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:09	3032517
LMB	IS-1,2,3-Trichloropropane	552.2	N/A	---		23740	23453	ug/L	101	70 - 130	---	---	1.0	05/23/2014 07:40	05/23/2014 17:09	3032517
FS	SS-2-Bromopropionic acid	552.2	N/A	2006708 001		5.0776	5.0	ug/L	102	70 - 130	---	---	1.0	05/23/2014 07:40	05/23/2014 17:45	3029940
FS	Bromochloroacetic acid	552.2	1.0	2006708 001	<	1.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:45	3029940
FS	Chlorodibromoacetic acid	552.2	2.0	2006708 001	<	2.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:45	3029940
FS	Dibromoacetic acid	552.2	1.0	2006708 001	<	1.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:45	3029940
FS	Dichloroacetic acid	552.2	1.0	2006708 001	<	1.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:45	3029940
FS	Monobromoacetic acid	552.2	1.0	2006708 001	<	1.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:45	3029940
FS	Monochloroacetic acid	552.2	2.0	2006708 001	<	2.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:45	3029940
FS	Tribromoacetic acid	552.2	4.0	2006708 001	<	4.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:45	3029940
FS	Trichloroacetic acid	552.2	1.0	2006708 001	<	1.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:45	3029940
FS	IS-1,2,3-Trichloropropane	552.2	N/A	2006708 001		23119	23453	ug/L	99	70 - 130	---	---	1.0	05/23/2014 07:40	05/23/2014 17:45	3029940
FS	Total HAA5	552.2	2.0	2006708 001	<	2.0		ug/L	---	---	---	---	1.0	05/23/2014 07:40	05/23/2014 17:45	3029940
CCC	SS-2-Bromopropionic acid	552.2	N/A	---		5.0831	5.0	ug/L	102	70 - 130	---	---	1.0	05/23/2014 07:40	05/24/2014 00:09	3032518
CCC	Bromochloroacetic acid	552.2	1.0	---		22.5743	20.0	ug/L	113	70 - 130	---	---	1.0	05/23/2014 07:40	05/24/2014 00:09	3032518
CCC	Chlorodibromoacetic acid	552.2	2.0	---		20.9079	20.0	ug/L	105	70 - 130	---	---	1.0	05/23/2014 07:40	05/24/2014 00:09	3032518
CCC	Dibromoacetic acid	552.2	1.0	---		22.0686	20.0	ug/L	110	70 - 130	---	---	1.0	05/23/2014 07:40	05/24/2014 00:09	3032518
CCC	Dichloroacetic acid	552.2	1.0	---		23.0121	20.0	ug/L	115	70 - 130	---	---	1.0	05/23/2014 07:40	05/24/2014 00:09	3032518
CCC	Monobromoacetic acid	552.2	1.0	---		22.9116	20.0	ug/L	115	70 - 130	---	---	1.0	05/23/2014 07:40	05/24/2014 00:09	3032518
CCC	Monochloroacetic acid	552.2	2.0	---		43.6217	40.0	ug/L	109	70 - 130	---	---	1.0	05/23/2014 07:40	05/24/2014 00:09	3032518
CCC	Tribromoacetic acid	552.2	4.0	---		17.6013	20.0	ug/L	88	70 - 130	---	---	1.0	05/23/2014 07:40	05/24/2014 00:09	3032518
CCC	Trichloroacetic acid	552.2	1.0	---		23.0661	20.0	ug/L	115	70 - 130	---	---	1.0	05/23/2014 07:40	05/24/2014 00:09	3032518

EEA Run ID 191203 / EEA Report # 317971

ALS

QC Summary Report (cont.)

Sample Type	Analyte	Method	MRL	Client ID	Result Flag	Amount	Target	Units	% Recovery	Recovery Limits	RPD	RPD Limit	Dil Factor	Extracted	Analyzed	EEA ID #
CCC	IS-1,2,3-Trichloropropane	552.2	N/A	---		23684	23453	ug/L	101	70 - 130	---	---	1.0	05/23/2014 07:40	05/24/2014 00:09	3032518

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EEA Run ID 191203 / EEA Report # 317971

ALS Environmental
34 Dogwood Lane ▪ Middletown, PA 17057 ▪ Phone: 717-944-5541 ▪ Fax: 717-944-1430 ▪ www.alsglobal.com

NELAP Certifications: NJ PA010 , NY 11759 , PA 22-293 DoD ELAP: A2LA 0818.01
State Certifications: DE ID 11 , MA PA0102 , MD 128 , VA 460157 , WV 343

August 26, 2014

Ms. Janet Barnes
University of MD-UMCES - Solomons, MD
P.O. Box 38
146 Williams Street
Solomons, MD 20688

Certificate of Analysis

Project Name:	**2014-MD BRACKISH WATER STUDY**	Workorder:	**2009393**
Purchase Order:		Workorder ID:	**PW2-DC**

Dear Ms. Barnes:

Enclosed are the analytical results for samples received by the laboratory on Thursday, May 29, 2014.

The ALS Environmental laboratory in Middletown, Pennsylvania is a National Environmental Laboratory Accreditation Program (NELAP) accredited laboratory and as such, certifies that all applicable test results meet the requirements of NELAP.

If you have any questions regarding this certificate of analysis, please contact Ms. Debra J. Musser (Project Coordinator) at (717) 944-5541.

Analyses were performed according to our laboratory's NELAP-approved quality assurance program and any applicable state requirements. The test results meet requirements of the current NELAP standards or state requirements, where applicable. For a specific list of accredited analytes, refer to the certifications section of the ALS website at www.alsglobal.com/en/Our-Services/Life-Sciences/Environmental/Downloads.

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ALS Spring City: 10 Riverside Drive, Spring City, PA 19475 610-948-4903

This page is included as part of the Analytical Report and must be retained as a permanent record thereof.

Debra J Musser
Ms. Debra J. Musser
Project Coordinator

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ALS Environmental

34 Dogwood Lane ▪ Middletown, PA 17057 ▪ Phone: 717-944-5541 ▪ Fax: 717-944-1430 ▪ www.alsglobal.com

NELAP Certifications: NJ PA010 , NY 11759 , PA 22-293 DoD ELAP: A2LA 0818.01
State Certifications: DE ID 11 , MA PA0102 , MD 128 , VA 460157 , WV 343

SAMPLE SUMMARY

Workorder: 2009393 PW2-DC

Lab ID	Sample ID	Matrix	Date Collected	Date Received	Collected By
2009393001	PW2-DC-P/Merc Barge	Water	5/28/2014 10:50	5/29/2014 10:00	Ms. Janet Barnes
2009393002	Trip Blank	Water	5/29/2014 10:00	5/29/2014 10:00	Ms. Janet Barnes

Notes

-- Samples collected by ALS personnel are done so in accordance with the procedures set forth in the ALS Field Sampling Plan (20 - Field Services Sampling Plan).
-- All Waste Water analyses comply with methodology requirements of 40 CFR Part 136.
-- All Drinking Water analyses comply with methodology requirements of 40 CFR Part 141.
-- Unless otherwise noted, all quantitative results for soils are reported on a dry weight basis.
-- The Chain of Custody document is included as part of this report.
-- All Library Search analytes should be regarded as tentative identifications based on the presumptive evidence of the mass spectra. Concentrations reported are estimated values.
-- Parameters identified as "analyze immediately" require analysis within 15 minutes of collection. Any "analyze immediately" parameters not listed under the header "Field Parameters" are preformed in the laboratory and are therefore analyzed out of hold time.
-- Method references listed on this report beginning with the prefix “S” followed by a method number (such as S2310B-97) refer to methods from “Standard Methods for the Examination of Water and Wastewater”.

Standard Acronyms/Flags

J	Indicates an estimated value between the Method Detection Limit (MDL) and the Practical Quantitation Limit (PQL) for the analyte
U	Indicates that the analyte was Not Detected (ND)
N	Indicates presumptive evidence of the presence of a compound
MDL	Method Detection Limit
PQL	Practical Quantitation Limit
RDL	Reporting Detection Limit
ND	Not Detected - indicates that the analyte was Not Detected at the RDL
Cntr	Analysis was performed using this container
RegLmt	Regulatory Limit
LCS	Laboratory Control Sample
MS	Matrix Spike
MSD	Matrix Spike Duplicate
DUP	Sample Duplicate
%Rec	Percent Recovery
RPD	Relative Percent Difference
LOD	DoD Limit of Detection
LOQ	DoD Limit of Quantitation
DL	DoD Detection Limit

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PROJECT SUMMARY

Workorder: 2009393 PW2-DC

Workorder Comments

Please see the attached EPA 551 results analyzed by Weck Laboratories, Inc. DJM

Please see the attached EPA 552 results analyzed by Eurofins DJM

Sample Comments

Lab ID: 2009393001 **Sample ID:** PW2-DC-P/Merc Barge **Sample Type:** SAMPLE

Assuming that all bromate present in the sample is in the form of sodium bromate, the sodium bromate concentration is <5.9 ug/L.

Assuming that all chlorate present in the sample is in the form of sodium chlorate, the sodium chlorate concentration is 52.2 ug/L.

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ANALYTICAL RESULTS

Workorder: 2009393 PW2-DC

Lab ID: **2009393001** Date Collected: 5/28/2014 10:50 Matrix: Water
Sample ID: **PW2-DC-P/Merc Barge** Date Received: 5/29/2014 10:00

Parameters	Results	Flag	Units	RDL	Method	Prepared	By	Analyzed	By	*Cntr*
VOLATILE ORGANICS										
Bromodichloromethane	ND		ug/L	0.50	EPA 524.2	6/7/14	TMP	6/7/14 08:40	TMP	B
Bromoform	1.2		ug/L	0.50	EPA 524.2	6/7/14	TMP	6/7/14 08:40	TMP	B
Chlorodibromomethane	ND		ug/L	0.50	EPA 524.2	6/7/14	TMP	6/7/14 08:40	TMP	B
Chloroform	ND		ug/L	0.50	EPA 524.2	6/7/14	TMP	6/7/14 08:40	TMP	B
1,2,3-Trichloropropane	ND		ug/L	0.50	EPA 524.2	6/7/14	TMP	6/7/14 08:40	TMP	B
Surrogate Recoveries	*Results*	*Flag*	*Units*	*Limits*	*Method*	*Prepared*	*By*	*Analyzed*	*By*	*Cntr*
1,2-Dichlorobenzene-d4 (S)	92.4		%	70 - 130	EPA 524.2	6/7/14	TMP	6/7/14 08:40	TMP	B
4-Bromofluorobenzene (S)	75.2		%	70 - 130	EPA 524.2	6/7/14	TMP	6/7/14 08:40	TMP	B
HERBICIDES										
Dalapon	ND		ug/L	4.0	EPA 515.3	6/2/14	KMR	6/2/14 21:59	EGO	J1
Surrogate Recoveries	*Results*	*Flag*	*Units*	*Limits*	*Method*	*Prepared*	*By*	*Analyzed*	*By*	*Cntr*
2,4-Dichlorophenylacetic acid (S)	99		%	70 - 130	EPA 515.3	6/2/14	KMR	6/2/14 21:59	EGO	J1
WET CHEMISTRY										
Bromate	ND		ug/L	5.0	EPA 300.1	6/4/14	SSL	6/4/14 13:14	SSL	I
Chlorate	40.9		ug/L	20.0	EPA 300.1	6/4/14	SSL	6/4/14 13:14	SSL	I
METALS										
Sodium, Total	7.4		mg/L	0.25	EPA 200.7	6/4/14	AAM	6/5/14 13:49	ZMC	H1
SUBCONTRACTED ANALYSIS										
Subcontracted Analysis	See Attached				Subcontract			7/31/14 00:00	SUB	D

Debra J Musser
Ms. Debra J. Musser
Project Coordinator

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ANALYTICAL RESULTS

Workorder: 2009393 PW2-DC

Lab ID: **2009393002** Date Collected: 5/29/2014 10:00 Matrix: Water
Sample ID: **Trip Blank** Date Received: 5/29/2014 10:00

Parameters	Results	Flag	Units	RDL	Method	Prepared	By	Analyzed	By	*Cntr*
VOLATILE ORGANICS										
Bromodichloromethane	ND		ug/L	0.50	EPA 524.2	6/7/14	TMP	6/7/14 02:15	TMP	B
Bromoform	ND		ug/L	0.50	EPA 524.2	6/7/14	TMP	6/7/14 02:15	TMP	B
Chlorodibromomethane	ND		ug/L	0.50	EPA 524.2	6/7/14	TMP	6/7/14 02:15	TMP	B
Chloroform	ND		ug/L	0.50	EPA 524.2	6/7/14	TMP	6/7/14 02:15	TMP	B
1,2,3-Trichloropropane	ND		ug/L	0.50	EPA 524.2	6/7/14	TMP	6/7/14 02:15	TMP	B
Surrogate Recoveries	*Results*	*Flag*	*Units*	*Limits*	*Method*	*Prepared*	*By*	*Analyzed*	*By*	*Cntr*
1,2-Dichlorobenzene-d4 (S)	90.7		%	70 - 130	EPA 524.2	6/7/14	TMP	6/7/14 02:15	TMP	B
4-Bromofluorobenzene (S)	96.7		%	70 - 130	EPA 524.2	6/7/14	TMP	6/7/14 02:15	TMP	B

Debra J Musser

Ms. Debra J. Musser
Project Coordinator

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QUALITY CONTROL DATA

Workorder: 2009393 PW2-DC

QC Batch: SVGC/34405 **Analysis Method:** EPA 515.3

QC Batch Method: EPA 515.3

Associated Lab Samples: 2009393001

MATRIX SPIKE SAMPLE: 2024379 ORIGINAL:

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MS % Rec	% Rec Limit	Qualifiers
Dalapon		ug/L	5	6.5	129	70 - 130	
2,4-Dichlorophenylacetic acid (S)		%				70 - 130	

SAMPLE DUPLICATE: 2024380 ORIGINAL:

Parameter	Original Result	Units	DUP Result	RPD	Max RPD	Qualifiers
Dalapon		ug/L	ND		30	
2,4-Dichlorophenylacetic acid (S)		%		107	130	
2,4-Dichlorophenylacetic acid (S)		%		6.6		

MATRIX SPIKE SAMPLE: 2024381 ORIGINAL: 2009393001

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MS % Rec	% Rec Limit	Qualifiers
Dalapon	ND	ug/L	5	6.0	120	70 - 130	
2,4-Dichlorophenylacetic acid (S)	99	%				70 - 130	

METHOD BLANK: 2024382

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Dalapon	ND	ug/L	4.0	
2,4-Dichlorophenylacetic acid (S)	94	%	70 - 130	

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QUALITY CONTROL DATA

Workorder: 2009393 PW2-DC

LABORATORY CONTROL SAMPLE: 2024383

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Dalapon	5	ug/L	5.2	105	70 - 130	
2,4-Dichlorophenylacetic acid (S)		%		95	70 - 130	

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QUALITY CONTROL DATA

Workorder: 2009393 PW2-DC

QC Batch: WETC/138842 **Analysis Method:** EPA 300.1
QC Batch Method: EPA 300.1
Associated Lab Samples: 2009393001

METHOD BLANK: 2025381

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Bromate	ND	ug/L	5.0	
Chlorate	ND	ug/L	20.0	

LABORATORY CONTROL SAMPLE: 2025382

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Bromate	25	ug/L	23.0	92	85 - 115	
Chlorate	250	ug/L	248	99.1	90 - 110	

MATRIX SPIKE: 2025386 DUPLICATE: 2025387 ORIGINAL: 2009703001

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MSD Result	MS % Rec	MSD % Rec	% Rec Limit	RPD	Max RPD	Qualifiers
Chlorate		ug/L	250	336	351	101	108	75 - 125	4.51	25	

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QUALITY CONTROL DATA

Workorder: 2009393 PW2-DC

QC Batch: MDIG/45719 **Analysis Method:** EPA 200.7
QC Batch Method: EPA TRMD
Associated Lab Samples: 2009393001

METHOD BLANK: 2025583

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Sodium, Total	ND	mg/L	0.25	

LABORATORY CONTROL SAMPLE: 2025584

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Sodium, Total	10	mg/L	9.6	96.4	85 - 115	

MATRIX SPIKE: 2025585 DUPLICATE: 2025586 ORIGINAL: 2009247002

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MSD Result	MS % Rec	MSD % Rec	% Rec Limit	RPD	Max RPD	Qualifiers
Sodium, Total		mg/L	10	29.8	30.4	96.5	102	70 - 130	1.98	20	

MATRIX SPIKE SAMPLE: 2025587 ORIGINAL:

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MS % Rec	% Rec Limit	Qualifiers
Sodium, Total		mg/L		617			

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QUALITY CONTROL DATA

Workorder: 2009393 PW2-DC

QC Batch: VOMS/32864 **Analysis Method:** EPA 524.2

QC Batch Method: EPA 524.2

Associated Lab Samples: 2009393001, 2009393002

METHOD BLANK: 2027213

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Chloroform	ND	ug/L	0.50	
Bromodichloromethane	ND	ug/L	0.50	
Chlorodibromomethane	ND	ug/L	0.50	
Bromoform	ND	ug/L	0.50	
1,2,3-Trichloropropane	ND	ug/L	0.50	
1,2-Dichlorobenzene-d4 (S)	94.3	%	70 - 130	
4-Bromofluorobenzene (S)	81	%	70 - 130	

LABORATORY CONTROL SAMPLE: 2027214

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Chloroform	1	ug/L	0.98	98.4	50 - 150	
Bromodichloromethane	1	ug/L	1.0	103	50 - 150	
Chlorodibromomethane	1	ug/L	0.93	92.6	50 - 150	
Bromoform	1	ug/L	0.98	97.7	50 - 150	
1,2-Dichlorobenzene-d4 (S)		%		109	70 - 130	
4-Bromofluorobenzene (S)		%		84.6	70 - 130	

LABORATORY CONTROL SAMPLE: 2027215

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Chloroform	5	ug/L	5.7	115	70 - 130	
Bromodichloromethane	5	ug/L	5.1	103	70 - 130	
Chlorodibromomethane	5	ug/L	5.0	100	70 - 130	
Bromoform	5	ug/L	4.9	98.9	70 - 130	
1,2,3-Trichloropropane	5	ug/L	5.1	101	70 - 130	
1,2-Dichlorobenzene-d4 (S)		%		122	70 - 130	
4-Bromofluorobenzene (S)		%		98.1	70 - 130	

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State Certifications: DE ID 11 , MA PA0102 , MD 128 , VA 460157 , WV 343

QUALITY CONTROL DATA CROSS REFERENCE TABLE

Workorder: 2009393 PW2-DC

Lab ID	Sample ID	Prep Method	Prep Batch	Analysis Method	Analysis Batch
2009393001	PW2-DC-P/Merc Barge	EPA 515.3	SVGC/34405	EPA 515.3	SVGC/34413
2009393001	PW2-DC-P/Merc Barge			EPA 300.1	WETC/138842
2009393001	PW2-DC-P/Merc Barge	EPA TRMD	MDIG/45719	EPA 200.7	META/44526
2009393001	PW2-DC-P/Merc Barge			EPA 524.2	VOMS/32864
2009393002	Trip Blank			EPA 524.2	VOMS/32864

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CHAIN OF CUSTODY/ REQUEST FOR ANALYSIS

ALL SHADED AREAS MUST BE COMPLETED BY THE CLIENT / SAMPLER. INSTRUCTIONS ON THE BACK.

Page 1 of 1
Courier: UPS
Tracking #: 12WOSEF

2009393

Co. Name: UMCES-CBL-MERC
Contact (Report to): Janet Barnes
Phone: 410-326-7259
Address: P.O. Box 38, 146 Williams St. Solomons, MD 20688
Bill to (if different than Report to):
PO#:
Project Name/#: PWG-DC
ALS Quote #: 454283
TAT: [X] Normal-Standard TAT is 10-12 business days. [ ] Rush-Subject to ALS approval and surcharges.
Date Required:
Approved By: gmB
Email? [✓] Y barnes@umces.edu
Fax? [ ] Y No.:

	***Container Type	CG	AG	CG	PL	AG	AG	CG
	***Container Size	40ml	250ml	60	250	1L	1L	40ml
	***Preservative	ASC HCl	NH4Cl	NH4Cl	HNO3	EDA	Na2S2O3	NA
	ANALYSES/METHOD REQUESTED	VOC by 524.2	HAA by 552.5	Acetonitrile by 551	Sodium 200.7	Bromate Chlorate 300.1	Herbicide Dalapon 515.3	Trip Blanks

	Sample Description/Location (as it will appear on the lab report)	COC Comments	Sample Date	Military Time	*G or C	**Matrix	VOC by 524.2	HAA by 552.5	Acetonitrile by 551	Sodium 200.7	Bromate Chlorate 300.1	Herbicide Dalapon 515.3	Trip Blanks
1	PWG-DC-P	MERC Barge	5/28/14	1050	C	DW	2	1	4	1	1	2	2
2													
3													
4													
5													
6													
7	# 52914 1839												
8													

Enter Number of Containers Per Analysis

Performed by: [initials]
Cooler Temp: 3°C
Therm. ID: TH291
No. of Coolers:
Notes:

Circle appropriate Y or N.
Correct containers? Y N
Correct sample volume? Y N
Correct preservation? Y N
Headspace/Volatiles? Y N
Custody seals Present? Y N
(If present) Seals intact? Y N
Received on ice? Y N
COC/Labels complete/accurate? Y N
Container in good condition? Y N

SAMPLED BY (Please Print): Janet Barnes
Project Comments: sample time on bottles when filled

	Relinquished By / Company Name	Date	Time		Received By / Company Name	Date	Time
1	Janet Barnes	5/28/14	1230	2	[signature] ALS	5-29-14	1000
3				4			
5				6			
7				8			
9				10			

Data Deliverables: [X] Standard [ ] CLP-like [ ] NJ-Reduced [ ] NJ-Full
EDDs Required? [✓] If yes, format type: MS Excel
SDWA Forms? yes
State Samples Collected In? MD [X] NJ NY PA Other
DOD Criteria Required? No

ALS FIELD SERVICES
[ ] Pickup
[ ] Labor
[ ] Composite Sampling
[ ] Rental Equipment
[ ] Other:

* G=Grab; C=Composite
**Matrix: AI=Air; DW=Drinking Water; GW=Groundwater; OI=Oil; OL=Other Liquid; SL=Sludge; SO=Soil; WP=Wipe; WW=Wastewater
***Container Type: AG-Amber Glass; CG-Clear Glass, PL-Plastic. Container Size: 250ml, 500ml, 1L, 8oz., etc. Preservative: HCl, HNO3, NaOH, etc.
Copies: WHITE - ORIGINAL CANARY - CUSTOMER COPY
Rev 01-2013

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CERTIFICATE OF ANALYSIS

Client:	ALS Environmental - PA 34 Dogwood Lane Middletown PA, 17057	**Report Date:**	07/31/14 11:45
		Received Date:	06/03/14 09:10
		Turn Around:	Normal
Attention:	Debra Musser	**Client Project:**	2009393
Phone:	(800) 794-7709		
Fax:	(717) 944-1430		
Work Order(s):	4F03015		

NELAP #04229CA ELAP#1132 NEVADA #CA211 HAWAII LACSD #10143

The results in this report apply to the samples analyzed in accordance with the Chain of Custody document. Weck Laboratories, Inc. certifies that the test results meet all NELAC requirements unless noted in the case narrative. This analytical report is confidential and is only intended for the use of Weck Laboratories, Inc. and its client. This report contains the Chain of Custody document, which is an integral part of it, and can only be reproduced in full with the authorization of Weck Laboratories, Inc.

Dear Debra Musser :

Enclosed are the results of analyses for samples received 06/03/14 09:10 with the Chain of Custody document. The samples were received in good condition, at 6.3 °C and on ice. All analysis met the method criteria except as noted below or in the report with data qualifiers.

Case Narrative:
SUPP report generated to reprot Mono compounds. BG 7/31/14

Reviewed by:

Brandon Gee
Project Manager

Page 1 of 8

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Tuesday, August 26, 2014 2:04:32 PM
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ALS

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ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 06/03/14 09:10
Date Reported: 07/31/14 11:45

ANALYTICAL REPORT FOR SAMPLES

Sample ID	Sampled by:	Sample Comments	Lab ID	Matrix	Date Sampled
2009393 001	Client		4F03015-01	Water	05/28/14 00:00

ANALYSES

DBPs by EPA 551.1

WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 06/03/14 09:10
Date Reported: 07/31/14 11:45

4F03015-01 **2009393 001**

Sampled: 05/28/14 00:00 **Sampled By:** Client **Matrix:** Water

DBPs by EPA 551.1

Method: EPA 551.1 Batch: W4F0473 Prepared: 06/09/14 14:28 Analyst: Juliet Chootipanya

Analyte	Result		MRL	Units	Dil	Analyzed	Qualifier
Chloropicrin	ND		0.50	ug/l	1	06/12/14 23:02	
Dibromoacetonitrile	ND		0.50	ug/l	1	06/12/14 23:02	
Dichloroacetonitrile	ND		0.50	ug/l	1	06/12/14 23:02	
Surr: Decafluorobiphenyl	*108 %*	Conc: *10.8*	*80-120*	%			

WECK LABORATORIES, INC.
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ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 06/03/14 09:10
Date Reported: 07/31/14 11:45

4F03015-01RE1 **2009393 001**

Sampled: 05/28/14 00:00 **Sampled By:** Client **Matrix:** Water

DBPs by EPA 551.1

Method: EPA 551.1 Batch: W4G0414 Prepared: 07/09/14 10:39 Analyst: Juliet Chootipanya

Analyte	Result		MRL	Units	Dil	Analyzed	Qualifier
Bromoacetonitrile	ND		0.50	ug/l	1	07/09/14 22:26	O-14
Chloroacetonitrile	ND		0.50	ug/l	1	07/09/14 22:26	O-14
Surr: Decafluorobiphenyl	*84 %*	Conc:*8.43*	*80-120*	%			*O-14*

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Middletown PA, 17057

Date Received: 06/03/14 09:10
Date Reported: 07/31/14 11:45

QUALITY CONTROL SECTION

WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 06/03/14 09:10
Date Reported: 07/31/14 11:45

DBPs by EPA 551.1 - Quality Control

Batch W4F0473 - EPA 551.1

Analyte	Result	MRL	Units	Spike Level	Source Result	%REC	% REC Limits	RPD	RPD Limit	Data Qualifiers
Blank (W4F0473-BLK1)				Analyzed: 06/12/14 19:45						
1,1,1-trichloro-2-propanone	ND	0.50	ug/l							
1,1-Dichloro-2-propanone	ND	0.50	ug/l							
Bromochloroacetonitrile	ND	0.50	ug/l							
Chloral hydrate	ND	0.50	ug/l							
Chloropicrin	ND	0.50	ug/l							
Dibromoacetonitrile	ND	0.50	ug/l							
Dichloroacetonitrile	ND	0.50	ug/l							
Trichloroacetonitrile	ND	0.50	ug/l							
Surr: Decafluorobiphenyl	*10.9*		*ug/l*	*10.0*		*109*	*80-120*			
LCS (W4F0473-BS1)				Analyzed: 06/12/14 20:10						
1,1,1-trichloro-2-propanone	10.4	0.50	ug/l	10.0		104	75-125			
1,1-Dichloro-2-propanone	10.1	0.50	ug/l	10.0		101	75-125			
Bromochloroacetonitrile	10.5	0.50	ug/l	10.0		105	75-125			
Chloral hydrate	10.1	0.50	ug/l	10.0		101	75-125			
Chloropicrin	9.70	0.50	ug/l	10.0		97	75-125			
Dibromoacetonitrile	9.84	0.50	ug/l	10.0		98	75-125			
Dichloroacetonitrile	10.7	0.50	ug/l	10.0		107	75-125			
Trichloroacetonitrile	8.99	0.50	ug/l	10.0		90	75-125			
Surr: Decafluorobiphenyl	*10.9*		*ug/l*	*10.0*		*109*	*80-120*			
LCS Dup (W4F0473-BSD1)				Analyzed: 06/12/14 20:34						
1,1,1-trichloro-2-propanone	11.4	0.50	ug/l	10.0		114	75-125	9	25	
1,1-Dichloro-2-propanone	10.6	0.50	ug/l	10.0		106	75-125	5	25	
Bromochloroacetonitrile	11.1	0.50	ug/l	10.0		111	75-125	6	25	
Chloral hydrate	10.8	0.50	ug/l	10.0		108	75-125	6	25	
Chloropicrin	11.2	0.50	ug/l	10.0		112	75-125	14	25	
Dibromoacetonitrile	10.0	0.50	ug/l	10.0		100	75-125	2	25	
Dichloroacetonitrile	11.3	0.50	ug/l	10.0		113	75-125	5	25	
Trichloroacetonitrile	10.4	0.50	ug/l	10.0		104	75-125	14	25	
Surr: Decafluorobiphenyl	*10.9*		*ug/l*	*10.0*		*109*	*80-120*			

Batch W4G0414 - EPA 551.1

Analyte	Result	MRL	Units	Spike Level	Source Result	%REC	% REC Limits	RPD	RPD Limit	Data Qualifiers
Blank (W4G0414-BLK1)				Analyzed: 07/09/14 20:46						
Bromoacetonitrile	ND	0.50	ug/l							
Chloroacetonitrile	ND	0.50	ug/l							
Surr: Decafluorobiphenyl	*8.68*		*ug/l*	*10.0*		*87*	*80-120*			
LCS (W4G0414-BS1)				Analyzed: 07/09/14 21:11						
Bromoacetonitrile	9.06	0.50	ug/l	10.0		91	80-120			
Chloroacetonitrile	8.92	0.50	ug/l	10.0		89	80-120			
Surr: Decafluorobiphenyl	*9.47*		*ug/l*	*10.0*		*95*	*80-120*			

WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 06/03/14 09:10
Date Reported: 07/31/14 11:45

DBPs by EPA 551.1 - Quality Control

Batch W4G0414 - EPA 551.1

Analyte	Result	MRL	Units	Spike Level	Source Result	%REC	% REC Limits	RPD	RPD Limit	Data Qualifiers
LCS Dup (W4G0414-BSD1)				Analyzed: 07/10/14 12:44						
Bromoacetonitrile	10.7	0.50	ug/l	10.0		107	80-120	17	25	
Chloroacetonitrile	10.5	0.50	ug/l	10.0		105	80-120	16	25	
Surr: Decafluorobiphenyl	*10.2*		*ug/l*	*10.0*		*102*	*80-120*			

Weck Laboratories, Inc 14859 East Clark Avenue, City of Industry, California 91745-1396 (626) 336-2139 FAX (626) 336-2634

WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 06/03/14 09:10
Date Reported: 07/31/14 11:45

Notes and Definitions

O-14	This analysis was requested by the client after the holding time was exceeded.
ND	NOT DETECTED at or above the Reporting Limit. If J-value reported, then NOT DETECTED at or above the Method Detection Limit (MDL)
NR	Not Reportable
Dil	Dilution
dry	Sample results reported on a dry weight basis
RPD	Relative Percent Difference
% Rec	Percent Recovery
Sub	Subcontracted analysis, original report available upon request
MDL	Method Detection Limit
MDA	Minimum Detectable Activity
MRL	Method Reporting Limit

Any remaining sample(s) will be disposed of one month from the final report date unless other arrangements are made in advance.

An Absence of Total Coliform meets the drinking water standards as established by the California Department of Health Services.

The Reporting Limit (RL) is referenced as the Laboratory's Practical Quantitation Limit (PQL) or the Detection Limit for Reporting Purposes (DLR).

All samples collected by Weck Laboratories have been sampled in accordance to laboratory SOP Number MIS002.

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110 South Hill Street
South Bend, IN 46617
Tel: (574) 233-4777
Fax: (574) 233-8207
1 800 332 4345

Laboratory Report

Client: ALS

Attn: Karen Elofsky
34 Dogwood Lane
Middletown, PA 17057

Copies to: None

Report: 318604
Priority: Standard Written
Status: Final
PWS ID: Not Supplied
PA Lab ID: 68466

Sample Information

EEA ID #	Client ID	Method	Collected Date / Time	Collected By:	Received Date / Time
3036331	2009393 001	552.2	05/28/14 10:50	Client	06/03/14 09:00

Report Summary

Note: Sample container was provided by the client.

Detailed quantitative results are presented on the following pages. The results presented relate only to the samples provided for analysis.

We appreciate the opportunity to provide you with this analysis. If you have any questions concerning this report, please do not hesitate to call Nathan Trowbridge at (574) 233-4777.

Note: This report may not be reproduced, except in full, without written approval from EEA. EEA is accredited by the National Environmental Laboratory Accreditation Program (NELAP).

Traci Chlebowski
Digitally signed by Traci Chlebowski
Date: 2014.06.17 16:19:14 -04'00'

Authorized Signature Title Date

Client Name: ALS
Report #: 318604

Page 1 of 3

Client Name: ALS Report #: 318604

Sampling Point: 2009393 001 PWS ID: Not Supplied

Disinfection Byproducts

Analyte ID #	Analyte	Method	Reg Limit	MRL†	Result	Units	Preparation Date	Analyzed Date	EEA ID #
5589-96-8	Bromochloroacetic acid	552.2	---	1.0	< 1.0	ug/L	06/09/14 09:20	06/10/14 15:25	3036331
5278-95-5	Chlorodibromoacetic acid	552.2	---	2.0	< 2.0	ug/L	06/09/14 09:20	06/10/14 15:25	3036331
631-64-1	Dibromoacetic acid	552.2	---	1.0	< 1.0	ug/L	06/09/14 09:20	06/10/14 15:25	3036331
79-43-6	Dichloroacetic acid	552.2	---	1.0	< 1.0	ug/L	06/09/14 09:20	06/10/14 15:25	3036331
79-08-3	Monobromoacetic acid	552.2	---	1.0	< 1.0	ug/L	06/09/14 09:20	06/10/14 15:25	3036331
79-11-8	Monochloroacetic acid	552.2	---	2.0	< 2.0	ug/L	06/09/14 09:20	06/10/14 15:25	3036331
75-96-7	Tribromoacetic acid	552.2	---	4.0	< 4.0	ug/L	06/09/14 09:20	06/10/14 15:25	3036331
76-03-9	Trichloroacetic acid	552.2	---	1.0	< 1.0	ug/L	06/09/14 09:20	06/10/14 15:25	3036331
---	Total HAA5	552.2	60 *	2.0	< 2.0	ug/L	06/09/14 09:20	06/10/14 15:25	3036331

† EEA has demonstrated it can achieve these report limits in reagent water, but can not document them in all sample matrices.

Reg Limit Type:	MCL	SMCL	AL
Symbol:	*	^	!

Page 2 of 3

Client Name: ALS Report #: 318604

Lab Definitions

Continuing Calibration Check Standard (CCC) / Continuing Calibration Verification (CCV) / Initial Calibration Verification Standard (ICV) / Initial Performance Check (IPC) - is a standard containing one or more of the target analytes that is prepared from the same standards used to calibrate the instrument. This standard is used to verify the calibration curve at the beginning of each analytical sequence, and may also be analyzed throughout and at the end of the sequence. The concentration of continuing standards may be varied, when prescribed by the reference method, so that the range of the calibration curve is verified on a regular basis.

Internal Standards (IS) - are pure compounds with properties similar to the analytes of interest, which are added to field samples or extracts, calibration standards, and quality control standards at a known concentration. They are used to measure the relative responses of the analytes of interest and surrogates in the sample, calibration standard or quality control standard.

Laboratory Duplicate (LD) - is a field sample aliquot taken from the same sample container in the laboratory and analyzed separately using identical procedures. Analysis of laboratory duplicates provides a measure of the precision of the laboratory procedures.

Laboratory Fortified Blank (LFB) / Laboratory Control Sample (LCS) - is an aliquot of reagent water to which known concentrations of the analytes of interest are added. The LFB is analyzed exactly the same as the field samples. LFBs are used to determine whether the method is in control.

Laboratory Method Blank (LMB) / Laboratory Reagent Blank (LRB) - is a sample of reagent water included in the sample batch analyzed in the same way as the associated field samples. The LMB is used to determine if method analytes or other background contamination have been introduced during the preparation or analytical procedure. The LMB is analyzed exactly the same as the field samples.

Laboratory Trip Blank (LTB) / Field Reagent Blank (FRB) - is a sample of laboratory reagent water placed in a sample container in the laboratory and treated as a field sample, including storage, preservation, and all analytical procedures. The FRB/LTB container follows the collection bottles to and from the collection site, but the FRB/LTB is not opened at any time during the trip. The FRB/LTB is primarily a travel blank used to verify that the samples were not contaminated during shipment.

Matrix Spike Duplicate Sample (MSD) / Laboratory Fortified Sample Matrix Duplicate (LFSMD) - is a sample aliquot taken from the same field sample source as the Matrix Spike Sample to which known quantities of the analytes of interest are added in the laboratory. The MSD is analyzed exactly the same as the field samples. Analysis of the MSD provides a measure of the precision of the laboratory procedures in a specific matrix.

Matrix Spike Sample (MS) / Laboratory Fortified Sample Matrix (LFSM) - is a sample aliquot taken from field sample source to which known quantities of the analytes of interest are added in the laboratory. The MS is analyzed exactly the same as the field samples. The purpose is to demonstrate recovery of the analytes from a sample matrix to determine if the specific matrix contributes bias to the analytical results.

Quality Control Standard (QCS) / Second Source Calibration Verification (SSCV) - is a solution containing known concentrations of the analytes of interest prepared from a source different from the source of the calibration standards. The solution is obtained from a second manufacturer or lot if the lot can be demonstrated by the manufacturer as prepared independently from other lots. The QCS sample is analyzed using the same procedures as field samples. The QCS is used as a check on the calibration standards used in the method on a routine basis.

Reporting Limit Check (RLC) / Initial Calibration Check Standard (ICCS) - is a procedural standard that is analyzed each day to evaluate instrument performance at or below the minimum reporting limit (MRL).

Surrogate Standard (SS) / Surrogate Analyte (SUR) - is a pure compound with properties similar to the analytes of interest, which is highly unlikely to be found in any field sample, that is added to the field samples, calibration standards, blanks and quality control standards before sample preparation. The SS is used to evaluate the efficiency of the sample preparation process.

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Run Log

Run ID: **191677** Method: **552.2**

Type	Sample Id	Sample Site	Matrix	Instrument ID	Analysis Date	Calibration File
CCL	3039925		RW	PW3	06/10/2014 14:12	552_2-061014PW3
LMB	3039924		RW	PW3	06/10/2014 14:49	552_2-061014PW3
FS	3036331	2009393 001	DW	PW3	06/10/2014 15:25	552_2-061014PW3
MS	3039928	2009393 001	DW	PW3	06/10/2014 16:02	552_2-061014PW3
CCC	3039926		RW	PW3	06/10/2014 22:08	552_2-061014PW3

QC Summary Report

Sample Type	Analyte	Method	MRL	Client ID	Result Flag	Amount	Target	Units	% Recovery	Recovery Limits	RPD	RPD Limit	Dil Factor	Extracted	Analyzed	EEA ID #
CCL	SS-2-Bromopropionic acid	552.2	N/A	—		4.8792	5.0	ug/L	98	70 - 130	—	—	1.0	06/09/2014 09:20	06/10/2014 14:12	3039925
CCL	Bromochloroacetic acid	552.2	1.0	—		0.9904	1.0	ug/L	99	71 - 154	—	—	1.0	06/09/2014 09:20	06/10/2014 14:12	3039925
CCL	Chlorodibromoacetic acid	552.2	2.0	—		1.2740	1.0	ug/L	127	43 - 185	—	—	1.0	06/09/2014 09:20	06/10/2014 14:12	3039925
CCL	Dibromoacetic acid	552.2	1.0	—		1.0512	1.0	ug/L	105	50 - 150	—	—	1.0	06/09/2014 09:20	06/10/2014 14:12	3039925
CCL	Dichloroacetic acid	552.2	1.0	—		1.0746	1.0	ug/L	107	50 - 150	—	—	1.0	06/09/2014 09:20	06/10/2014 14:12	3039925
CCL	Monobromoacetic acid	552.2	1.0	—		1.1535	1.0	ug/L	115	50 - 150	—	—	1.0	06/09/2014 09:20	06/10/2014 14:12	3039925
CCL	Monochloroacetic acid	552.2	2.0	—		2.0069	2.0	ug/L	100	50 - 150	—	—	1.0	06/09/2014 09:20	06/10/2014 14:12	3039925
CCL	Tribromoacetic acid	552.2	4.0	—		1.3589	1.0	ug/L	136	36 - 206	—	—	1.0	06/09/2014 09:20	06/10/2014 14:12	3039925
CCL	Trichloroacetic acid	552.2	1.0	—		1.0067	1.0	ug/L	101	50 - 150	—	—	1.0	06/09/2014 09:20	06/10/2014 14:12	3039925
CCL	IS-1,2,3-Trichloropropane	552.2	N/A	—		62358	59698	ug/L	104	70 - 130	—	—	1.0	06/09/2014 09:20	06/10/2014 14:12	3039925
LMB	SS-2-Bromopropionic acid	552.2	N/A	—		4.7980	5.0	ug/L	96	70 - 130	—	—	1.0	06/09/2014 09:20	06/10/2014 14:49	3039924
LMB	Bromochloroacetic acid	552.2	1.0	—	<	1.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 14:49	3039924
LMB	Chlorodibromoacetic acid	552.2	2.0	—	<	2.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 14:49	3039924
LMB	Dibromoacetic acid	552.2	1.0	—	<	1.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 14:49	3039924
LMB	Dichloroacetic acid	552.2	1.0	—	<	1.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 14:49	3039924
LMB	Monobromoacetic acid	552.2	1.0	—	<	1.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 14:49	3039924
LMB	Monochloroacetic acid	552.2	2.0	—	<	2.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 14:49	3039924
LMB	Tribromoacetic acid	552.2	4.0	—	<	4.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 14:49	3039924
LMB	Trichloroacetic acid	552.2	1.0	—	<	1.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 14:49	3039924
LMB	IS-1,2,3-Trichloropropane	552.2	N/A	—		57244	59698	ug/L	96	70 - 130	—	—	1.0	06/09/2014 09:20	06/10/2014 14:49	3039924
FS	SS-2-Bromopropionic acid	552.2	N/A	2009393 001		5.1152	5.0	ug/L	102	70 - 130	—	—	1.0	06/09/2014 09:20	06/10/2014 15:25	3036331
FS	Bromochloroacetic acid	552.2	1.0	2009393 001	<	1.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 15:25	3036331
FS	Chlorodibromoacetic acid	552.2	2.0	2009393 001	<	2.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 15:25	3036331
FS	Dibromoacetic acid	552.2	1.0	2009393 001	<	1.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 15:25	3036331
FS	Dichloroacetic acid	552.2	1.0	2009393 001	<	1.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 15:25	3036331
FS	Monobromoacetic acid	552.2	1.0	2009393 001	<	1.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 15:25	3036331
FS	Monochloroacetic acid	552.2	2.0	2009393 001	<	2.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 15:25	3036331
FS	Tribromoacetic acid	552.2	4.0	2009393 001	<	4.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 15:25	3036331
FS	Trichloroacetic acid	552.2	1.0	2009393 001	<	1.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 15:25	3036331
FS	IS-1,2,3-Trichloropropane	552.2	N/A	2009393 001		52976	59698	ug/L	89	70 - 130	—	—	1.0	06/09/2014 09:20	06/10/2014 15:25	3036331
FS	Total HAA5	552.2	2.0	2009393 001	<	2.0		ug/L	—	—	—	—	1.0	06/09/2014 09:20	06/10/2014 15:25	3036331
MS	SS-2-Bromopropionic acid	552.2	N/A	2009393 001		4.4229	5.0	ug/L	88	70 - 130	—	—	1.0	06/09/2014 09:20	06/10/2014 16:02	3039928
MS	Bromochloroacetic acid	552.2	1.0	2009393 001		17.4756	20.0	ug/L	87	70 - 130	—	—	1.0	06/09/2014 09:20	06/10/2014 16:02	3039928
MS	Chlorodibromoacetic acid	552.2	2.0	2009393 001		18.5378	20.0	ug/L	93	70 - 130	—	—	1.0	06/09/2014 09:20	06/10/2014 16:02	3039928
MS	Dibromoacetic acid	552.2	1.0	2009393 001		20.1804	20.0	ug/L	101	70 - 130	—	—	1.0	06/09/2014 09:20	06/10/2014 16:02	3039928
MS	Dichloroacetic acid	552.2	1.0	2009393 001		16.4693	20.0	ug/L	82	70 - 130	—	—	1.0	06/09/2014 09:20	06/10/2014 16:02	3039928
MS	Monobromoacetic acid	552.2	1.0	2009393 001		16.1564	20.0	ug/L	81	70 - 130	—	—	1.0	06/09/2014 09:20	06/10/2014 16:02	3039928
MS	Monochloroacetic acid	552.2	2.0	2009393 001		38.5857	40.0	ug/L	96	70 - 130	—	—	1.0	06/09/2014 09:20	06/10/2014 16:02	3039928
MS	Tribromoacetic acid	552.2	4.0	2009393 001		17.1267	20.0	ug/L	86	70 - 130	—	—	1.0	06/09/2014 09:20	06/10/2014 16:02	3039928
MS	Trichloroacetic acid	552.2	1.0	2009393 001		18.2356	20.0	ug/L	91	70 - 130	—	—	1.0	06/09/2014 09:20	06/10/2014 16:02	3039928

QC Summary Report (cont.)

Sample Type	Analyte	Method	MRL	Client ID	Result Flag	Amount	Target	Units	% Recovery	Recovery Limits	RPD	RPD Limit	Dil Factor	Extracted	Analyzed	EEA ID #
MS	IS-1,2,3-Trichloropropane	552.2	N/A	2009393 001		53381	59698	ug/L	89	70 - 130	---	---	1.0	06/09/2014 09:20	06/10/2014 16:02	3039928
CCC	SS-2-Bromopropionic acid	552.2	N/A	---		4.9317	5.0	ug/L	99	70 - 130	---	---	1.0	06/09/2014 09:20	06/10/2014 22:08	3039926
CCC	Bromochloroacetic acid	552.2	1.0	---		19.4043	20.0	ug/L	97	70 - 130	---	---	1.0	06/09/2014 09:20	06/10/2014 22:08	3039926
CCC	Chlorodibromoacetic acid	552.2	2.0	---		20.1271	20.0	ug/L	101	70 - 130	---	---	1.0	06/09/2014 09:20	06/10/2014 22:08	3039926
CCC	Dibromoacetic acid	552.2	1.0	---		21.3994	20.0	ug/L	107	70 - 130	---	---	1.0	06/09/2014 09:20	06/10/2014 22:08	3039926
CCC	Dichloroacetic acid	552.2	1.0	---		17.7551	20.0	ug/L	89	70 - 130	---	---	1.0	06/09/2014 09:20	06/10/2014 22:08	3039926
CCC	Monobromoacetic acid	552.2	1.0	---		17.5069	20.0	ug/L	88	70 - 130	---	---	1.0	06/09/2014 09:20	06/10/2014 22:08	3039926
CCC	Monochloroacetic acid	552.2	2.0	---		39.6240	40.0	ug/L	99	70 - 130	---	---	1.0	06/09/2014 09:20	06/10/2014 22:08	3039926
CCC	Tribromoacetic acid	552.2	4.0	---		18.3925	20.0	ug/L	92	70 - 130	---	---	1.0	06/09/2014 09:20	06/10/2014 22:08	3039926
CCC	Trichloroacetic acid	552.2	1.0	---		20.0519	20.0	ug/L	100	70 - 130	---	---	1.0	06/09/2014 09:20	06/10/2014 22:08	3039926
CCC	IS-1,2,3-Trichloropropane	552.2	N/A	---		58325	59698	ug/L	98	70 - 130	---	---	1.0	06/09/2014 09:20	06/10/2014 22:08	3039926

Sample Type Key

Type (Abbr.)	Sample Type	Type (Abbr.)	Sample Type
CCC	Continuing Calibration Check		
CCL	Continuing Calibration Low		
FS	Field Sample		
LMB	Laboratory Method Blank		
MS	Matrix Spike		

ALS Environmental
34 Dogwood Lane ■ Middletown, PA 17057 ■ Phone: 717-944-5541 ■ Fax: 717-944-1430 ■ www.alsglobal.com

NELAP Certifications: NJ PA010 , NY 11759 , PA 22-293 DoD ELAP: A2LA 0818.01
State Certifications: DE ID 11 , MA PA0102 , MD 128 , VA 460157 , WV 343

August 26, 2014

Ms. Janet Barnes
University of MD-UMCES - Solomons, MD
P.O. Box 38
146 Williams Street
Solomons, MD 20688

Certificate of Analysis

Project Name:	**2014-MD BRACKISH WATER STUDY**	Workorder:	**2010351**
Purchase Order:		Workorder ID:	**PW3-DC**

Dear Ms. Barnes:

Enclosed are the analytical results for samples received by the laboratory on Wednesday, June 4, 2014.

The ALS Environmental laboratory in Middletown, Pennsylvania is a National Environmental Laboratory Accreditation Program (NELAP) accredited laboratory and as such, certifies that all applicable test results meet the requirements of NELAP.

If you have any questions regarding this certificate of analysis, please contact Ms. Debra J. Musser (Project Coordinator) at (717) 944-5541.

Analyses were performed according to our laboratory's NELAP-approved quality assurance program and any applicable state requirements. The test results meet requirements of the current NELAP standards or state requirements, where applicable. For a specific list of accredited analytes, refer to the certifications section of the ALS website at www.alsglobal.com/en/Our-Services/Life-Sciences/Environmental/Downloads.

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ALS Spring City: 10 Riverside Drive, Spring City, PA 19475 610-948-4903

Debra J Musser

This page is included as part of the Analytical Report and must be retained as a permanent record thereof.

Ms. Debra J. Musser
Project Coordinator

ALS Environmental

34 Dogwood Lane ■ Middletown, PA 17057 ■ Phone: 717-944-5541 ■ Fax: 717-944-1430 ■ www.alsglobal.com

NELAP Certifications: NJ PA010 , NY 11759 , PA 22-293 DoD ELAP: A2LA 0818.01
State Certifications: DE ID 11 , MA PA0102 , MD 128 , VA 460157 , WV 343

SAMPLE SUMMARY

Workorder: 2010351 PW3-DC

Lab ID	Sample ID	Matrix	Date Collected	Date Received	Collected By
2010351001	PW3-DC-P/MERC BARGE	Water	6/3/2014 10:30	6/4/2014 10:30	Collected by Client
2010351002	TRIP BLANK	Water	6/4/2014 10:30	6/4/2014 10:30	Collected by Client

Notes

- -- Samples collected by ALS personnel are done so in accordance with the procedures set forth in the ALS Field Sampling Plan (20 - Field Services Sampling Plan).
- -- All Waste Water analyses comply with methodology requirements of 40 CFR Part 136.
- -- All Drinking Water analyses comply with methodology requirements of 40 CFR Part 141.
- -- Unless otherwise noted, all quantitative results for soils are reported on a dry weight basis.
- -- The Chain of Custody document is included as part of this report.
- -- All Library Search analytes should be regarded as tentative identifications based on the presumptive evidence of the mass spectra. Concentrations reported are estimated values.
- -- Parameters identified as "analyze immediately" require analysis within 15 minutes of collection. Any "analyze immediately" parameters not listed under the header "Field Parameters" are preformed in the laboratory and are therefore analyzed out of hold time.
- -- Method references listed on this report beginning with the prefix “S” followed by a method number (such as S2310B-97) refer to methods from “Standard Methods for the Examination of Water and Wastewater”.

Standard Acronyms/Flags

J	Indicates an estimated value between the Method Detection Limit (MDL) and the Practical Quantitation Limit (PQL) for the analyte
U	Indicates that the analyte was Not Detected (ND)
N	Indicates presumptive evidence of the presence of a compound
MDL	Method Detection Limit
PQL	Practical Quantitation Limit
RDL	Reporting Detection Limit
ND	Not Detected - indicates that the analyte was Not Detected at the RDL
Cntr	Analysis was performed using this container
RegLmt	Regulatory Limit
LCS	Laboratory Control Sample
MS	Matrix Spike
MSD	Matrix Spike Duplicate
DUP	Sample Duplicate
%Rec	Percent Recovery
RPD	Relative Percent Difference
LOD	DoD Limit of Detection
LOQ	DoD Limit of Quantitation
DL	DoD Detection Limit

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PROJECT SUMMARY

Workorder: 2010351 PW3-DC

Workorder Comments

Please see the attached EPA 551 results analyzed by Weck Laboratories, Inc. DJM

Please see the attached EPA 552 results analyzed by Eurofins. DJM

Sample Comments

Lab ID: 2010351001 **Sample ID:** PW3-DC-P/MERC BARGE **Sample Type:** SAMPLE

The method 524.2 internal standard was recovered outside of the control limits.

Assuming that all bromate present in the sample is in the form of sodium bromate, the sodium bromate concentration is <5.9 ug/L.

Assuming that all chlorate present in the sample is in the form of sodium chlorate, the sodium chlorate concentration is 63.3 ug/L.

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ANALYTICAL RESULTS

Workorder: 2010351 PW3-DC

Lab ID: **2010351001** Date Collected: 6/3/2014 10:30 Matrix: Water
Sample ID: **PW3-DC-P/MERC BARGE** Date Received: 6/4/2014 10:30

Parameters	Results	Flag	Units	RDL	Method	Prepared	By	Analyzed	By	Cntr
VOLATILE ORGANICS										
Bromodichloromethane	ND		ug/L	0.50	EPA 524.2	6/10/14	TMP	6/10/14 20:04	TMP	I
Bromoform	0.57		ug/L	0.50	EPA 524.2	6/10/14	TMP	6/10/14 20:04	TMP	I
Chlorodibromomethane	ND		ug/L	0.50	EPA 524.2	6/10/14	TMP	6/10/14 20:04	TMP	I
Chloroform	ND		ug/L	0.50	EPA 524.2	6/10/14	TMP	6/10/14 20:04	TMP	I
1,2,3-Trichloropropane	ND		ug/L	0.50	EPA 524.2	6/10/14	TMP	6/10/14 20:04	TMP	I
Surrogate Recoveries	*Results*	*Flag*	*Units*	*Limits*	*Method*	*Prepared*	*By*	*Analyzed*	*By*	*Cntr*
1,2-Dichlorobenzene-d4 (S)	87.4		%	70 - 130	EPA 524.2	6/10/14	TMP	6/10/14 20:04	TMP	I
4-Bromofluorobenzene (S)	78.4		%	70 - 130	EPA 524.2	6/10/14	TMP	6/10/14 20:04	TMP	I
HERBICIDES										
Dalapon	ND		ug/L	4.0	EPA 515.3	6/11/14	KMR	6/11/14 23:30	EGO	G1
Surrogate Recoveries	*Results*	*Flag*	*Units*	*Limits*	*Method*	*Prepared*	*By*	*Analyzed*	*By*	*Cntr*
2,4-Dichlorophenylacetic acid (S)	103		%	70 - 130	EPA 515.3	6/11/14	KMR	6/11/14 23:30	EGO	G1
WET CHEMISTRY										
Bromate	ND		ug/L	5.0	EPA 300.1	6/10/14	SSL	6/10/14 07:09	SSL	F
Chlorate	49.6		ug/L	20.0	EPA 300.1	6/10/14	SSL	6/10/14 07:09	SSL	F
METALS										
Sodium, Total	5.6		mg/L	0.25	EPA 200.7	6/9/14	AAM	6/13/14 02:53	ZMC	E1
SUBCONTRACTED ANALYSIS										
Subcontracted Analysis	See attached				Subcontract			6/19/14 22:25	SUB	C

Debra J Musser
Ms. Debra J. Musser
Project Coordinator

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ANALYTICAL RESULTS

Workorder: 2010351 PW3-DC

Lab ID: **2010351002** Date Collected: 6/4/2014 10:30 Matrix: Water
Sample ID: **TRIP BLANK** Date Received: 6/4/2014 10:30

Parameters	Results	Flag	Units	RDL	Method	Prepared	By	Analyzed	By	*Cntr*
VOLATILE ORGANICS										
Bromodichloromethane	ND		ug/L	0.50	EPA 524.2	6/10/14	TMP	6/10/14 01:59	TMP	B
Bromoform	ND		ug/L	0.50	EPA 524.2	6/10/14	TMP	6/10/14 01:59	TMP	B
Chlorodibromomethane	ND		ug/L	0.50	EPA 524.2	6/10/14	TMP	6/10/14 01:59	TMP	B
Chloroform	ND		ug/L	0.50	EPA 524.2	6/10/14	TMP	6/10/14 01:59	TMP	B
1,2,3-Trichloropropane	ND		ug/L	0.50	EPA 524.2	6/10/14	TMP	6/10/14 01:59	TMP	B
Surrogate Recoveries	*Results*	*Flag*	*Units*	*Limits*	*Method*	*Prepared*	*By*	*Analyzed*	*By*	*Cntr*
1,2-Dichlorobenzene-d4 (S)	92.5		%	70 - 130	EPA 524.2	6/10/14	TMP	6/10/14 01:59	TMP	B
4-Bromofluorobenzene (S)	120		%	70 - 130	EPA 524.2	6/10/14	TMP	6/10/14 01:59	TMP	B

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QUALITY CONTROL DATA

Workorder: 2010351 PW3-DC

QC Batch: MDIG/45783 **Analysis Method:** EPA 200.7
QC Batch Method: EPA TRMD
Associated Lab Samples: 2010351001

METHOD BLANK: 2027722

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Sodium, Total	ND	mg/L	0.25	

LABORATORY CONTROL SAMPLE: 2027723

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Sodium, Total	10	mg/L	9.9	99.2	85 - 115	

MATRIX SPIKE: 2027724 DUPLICATE: 2027725 ORIGINAL: 2010181001

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MSD Result	MS % Rec	MSD % Rec	% Rec Limit	RPD	Max RPD	Qualifiers
Sodium, Total		mg/L		15.2	15.4				1.01	20	

MATRIX SPIKE SAMPLE: 2027726 ORIGINAL:

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MS % Rec	% Rec Limit	Qualifiers
Sodium, Total		mg/L		13.5			

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QUALITY CONTROL DATA

Workorder: 2010351 PW3-DC

QC Batch: VOMS/32878 **Analysis Method:** EPA 524.2

QC Batch Method: EPA 524.2

Associated Lab Samples: 2010351001, 2010351002

METHOD BLANK: 2028011

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Chloroform	ND	ug/L	0.50	
Bromodichloromethane	ND	ug/L	0.50	
Chlorodibromomethane	ND	ug/L	0.50	
Bromoform	ND	ug/L	0.50	
1,2,3-Trichloropropane	ND	ug/L	0.50	
1,2-Dichlorobenzene-d4 (S)	97.7	%	70 - 130	
4-Bromofluorobenzene (S)	85.9	%	70 - 130	

LABORATORY CONTROL SAMPLE: 2028012

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Chloroform	1	ug/L	0.60	60.2	50 - 150	
Bromodichloromethane	1	ug/L	1.0	100	50 - 150	
Chlorodibromomethane	1	ug/L	1.1	113	50 - 150	
Bromoform	1	ug/L	0.99	99	50 - 150	
4-Bromofluorobenzene (S)		%		80.2	70 - 130	
1,2-Dichlorobenzene-d4 (S)		%		98.8	70 - 130	

LABORATORY CONTROL SAMPLE: 2028013

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Chloroform	5	ug/L	5.5	111	70 - 130	
Bromodichloromethane	5	ug/L	5.0	99.6	70 - 130	
Chlorodibromomethane	5	ug/L	5.4	109	70 - 130	
Bromoform	5	ug/L	4.9	98.7	70 - 130	
1,2,3-Trichloropropane	5	ug/L	5.0	99.7	70 - 130	
1,2-Dichlorobenzene-d4 (S)		%		110	70 - 130	
4-Bromofluorobenzene (S)		%		95.1	70 - 130	

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QUALITY CONTROL DATA

Workorder: 2010351 PW3-DC

MATRIX SPIKE: 2028317 DUPLICATE: 2028318 ORIGINAL: 2010692014

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MSD Result	MS % Rec	MSD % Rec	% Rec Limit	RPD	Max RPD	Qualifiers
Chloroform		ug/L	5	4.6	5.0	92.6	100	70 - 130	8.01	40	
Bromodichloromethane		ug/L	5	5.2	5.1	104	102	70 - 130	2.03	40	
Chlorodibromomethane		ug/L	5	5.4	5.0	107	100	70 - 130	6.55	40	
Bromoform		ug/L	5	4.5	4.9	90.4	97.2	70 - 130	7.25	40	
1,2,3-Trichloropropane		ug/L	5	4.9	4.9	98.2	98.1	70 - 130	.08	40	
1,2-Dichlorobenzene-d4 (S)		%				114	109	70 - 130	4.85		
4-Bromofluorobenzene (S)		%				96.7	90.3	70 - 130	6.9		

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QUALITY CONTROL DATA

Workorder: 2010351 PW3-DC

QC Batch: WETC/139120 **Analysis Method:** EPA 300.1

QC Batch Method: EPA 300.1

Associated Lab Samples: 2010351001

METHOD BLANK: 2028028

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Bromate	ND	ug/L	5.0	
Chlorate	ND	ug/L	20.0	

LABORATORY CONTROL SAMPLE: 2028029

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Bromate	25	ug/L	23.8	95.3	85 - 115	
Chlorate	250	ug/L	246	98.3	90 - 110	

MATRIX SPIKE: 2028031 DUPLICATE: 2028032 ORIGINAL: 2010344001

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MSD Result	MS % Rec	MSD % Rec	% Rec Limit	RPD	Max RPD	Qualifiers
Bromate		ug/L	25	20.6	22.3	82.4	89.3	75 - 125	8.01	20	

MATRIX SPIKE: 2028033 DUPLICATE: 2028034 ORIGINAL: 2010353003

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MSD Result	MS % Rec	MSD % Rec	% Rec Limit	RPD	Max RPD	Qualifiers
Chlorate		ug/L	250	225	226	89.8	90.3	75 - 125	.53	25	

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QUALITY CONTROL DATA

Workorder: 2010351 PW3-DC

QC Batch: VOMS/32885 **Analysis Method:** EPA 524.2

QC Batch Method: EPA 524.2

Associated Lab Samples: 2010351001

METHOD BLANK: 2028366

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Chloroform	ND	ug/L	0.50	
Bromodichloromethane	ND	ug/L	0.50	
Chlorodibromomethane	ND	ug/L	0.50	
Bromoform	ND	ug/L	0.50	
1,2,3-Trichloropropane	ND	ug/L	0.50	
1,2-Dichlorobenzene-d4 (S)	93	%	70 - 130	
4-Bromofluorobenzene (S)	77.8	%	70 - 130	

LABORATORY CONTROL SAMPLE: 2028367

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Chloroform	1	ug/L	1.2	116	50 - 150	
Bromodichloromethane	1	ug/L	0.99	99.4	50 - 150	
Chlorodibromomethane	1	ug/L	0.91	90.9	50 - 150	
Bromoform	1	ug/L	1.0	100	50 - 150	
1,2-Dichlorobenzene-d4 (S)		%		106	70 - 130	
4-Bromofluorobenzene (S)		%		83.4	70 - 130	

LABORATORY CONTROL SAMPLE: 2028368

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Chloroform	5	ug/L	5.5	110	70 - 130	
Bromodichloromethane	5	ug/L	4.9	97.3	70 - 130	
Chlorodibromomethane	5	ug/L	5.4	108	70 - 130	
Bromoform	5	ug/L	4.9	97.9	70 - 130	
1,2,3-Trichloropropane	5	ug/L	4.9	97	70 - 130	
1,2-Dichlorobenzene-d4 (S)		%		113	70 - 130	
4-Bromofluorobenzene (S)		%		94	70 - 130	

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QUALITY CONTROL DATA

Workorder: 2010351 PW3-DC

QC Batch: SVGC/34522 **Analysis Method:** EPA 515.3

QC Batch Method: EPA 515.3

Associated Lab Samples: 2010351001

MATRIX SPIKE SAMPLE: 2028726 ORIGINAL:

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MS % Rec	% Rec Limit	Qualifiers
Dalapon		ug/L	5	6.2	125	70 - 130	
2,4-Dichlorophenylacetic acid (S)		%				70 - 130	

SAMPLE DUPLICATE: 2028727 ORIGINAL:

Parameter	Original Result	Units	DUP Result	RPD	Max RPD	Qualifiers
Dalapon		ug/L	ND		30	
2,4-Dichlorophenylacetic acid (S)		%		2.7		
2,4-Dichlorophenylacetic acid (S)		%		97	130	

MATRIX SPIKE SAMPLE: 2028728 ORIGINAL:

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MS % Rec	% Rec Limit	Qualifiers
Dalapon		ug/L	5	8.6	172	70 - 130	
2,4-Dichlorophenylacetic acid (S)		%				70 - 130	

METHOD BLANK: 2028729

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Dalapon	ND	ug/L	4.0	
2,4-Dichlorophenylacetic acid (S)	98	%	70 - 130	

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QUALITY CONTROL DATA

Workorder: 2010351 PW3-DC

LABORATORY CONTROL SAMPLE: 2028730

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Dalapon	5	ug/L	6.4	128	70 - 130	
2,4-Dichlorophenylacetic acid (S)		%		99	70 - 130	

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QUALITY CONTROL DATA CROSS REFERENCE TABLE

Workorder: 2010351 PW3-DC

Lab ID	Sample ID	Prep Method	Prep Batch	Analysis Method	Analysis Batch
2010351001	PW3-DC-P/MERC BARGE	EPA TRMD	MDIG/45783	EPA 200.7	META/44624
2010351002	TRIP BLANK			EPA 524.2	VOMS/32878
2010351001	PW3-DC-P/MERC BARGE			EPA 300.1	WETC/139120
2010351001	PW3-DC-P/MERC BARGE			EPA 524.2	VOMS/32885
2010351001	PW3-DC-P/MERC BARGE	EPA 515.3	SVGC/34522	EPA 515.3	SVGC/34542

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CHAIN OF CUSTODY/ REQUEST FOR ANALYSIS

ALL SHADED AREAS MUST BE COMPLETED BY THE CLIENT/SAMPLER. INSTRUCTIONS ON THE BACK.

Page 1 of 1
Courier: DAJ
Tracking #: 1Z W05 6R9 01 7371

* 2 0 1 0 3 5 1 *

Co. Name: UMCES-CBL-MERC
Contact (Report to): Janet Barnes
Phone: 410-326-7259
Address: P.O. Box 38, 146 Williams St., Solomons, MD 20688

Bill to (if different than Report to):
PO#:

Project Name/#: PW3-DC
ALS Quote #: 454283

TAT: [X] Normal-Standard TAT is 10-12 business days. [ ] Rush-Subject to ALS approval and surcharges.
Date Required:
Approved By:

Email? [X] -Y barnes@umces.edu
Fax? -Y No.:

***Container Type	CG	AG	CG	PL	AG	AG	CG
***Container Size	40ml	250 ml	60 ml	250 ml	1L	1L	40 ml
***Preservative	ASC HCL	NH4 Cl	NH4 Cl	HNO3	EDA	Na2S2O3	NA
ANALYSES/METHOD REQUESTED	VOC by 524.2 (pH<2) ✓	HAA by 552.5 ✓	Aceonitrile by 551 ✓	Sodium by 200.7 ✓	Bromate Chlorate by 300.1 ✓	Hebicides Dalapon by 515.3 ✓	Trip Blanks ✓

Enter Number of Containers Per Analysis

	Sample Description/Location (as it will appear on the lab report)	COC Comments	Sample Date	Military Time	*G or C	**Matrix	VOC by 524.2	HAA by 552.5	Aceonitrile by 551	Sodium by 200.7	Bromate Chlorate by 300.1	Hebicides Dalapon by 515.3	Trip Blanks
1	PW3-DC-P / MERC Barge		6/3/14	1030	C	DW	2	1	4	1	1	2	2
2		* Note: air bubble											
3		present in one trip											
4		blank vial											
5		* 3 drops HCl for VOC											
6													
7													
8													

MW 6/4/14 - DOS

Receipt Information (completed by Sample Receiving)
Performed by: MG
Cooler Temp: 4°C
Therm. ID: TH291
No. of Coolers:
Notes:

Circle appropriate Y or N.

Correct containers?	Correct sample volume?	Correct preservation?	Headspace/Volatiles?
Y / N	Y / N	Y / N	Y / N

Custody seals Present?	(if present) Seals Intact?	Received on ice?	COC/Labels complete/accurate?	Container in good condition?
Y / N	Y / N	Y / N	Y / N	Y / N

SAMPLED BY (Please Print): Eva Bailey
Project Comments: Sample time on bottles when filled

	Relinquished By / Company Name	Date	Time		Received By / Company Name	Date	Time
1	Janet Barnes	6/3/14	1120	2	M. Gory Tanley ALS	6-4-14	1030
3				4			
5				6			
7				8			
9				10			

Data Deliverables: [X] Standard [ ] CLP-like [ ] NJ-Reduced [ ] NJ-Full [ ] (other)
EDDs Required? [X] If yes, format type: MS Excel
DOD Criteria Required? NO

SDWA Forms?: yes [ ] yes [ ] yes [ ] yes [ ]
State Samples Collected In?: MD [X] NJ [ ] NY [ ] PA [ ]
Other

ALS FIELD SERVICES
[ ] Pickup
[ ] Labor
[ ] Composite Sampling
[ ] Rental Equipment
[ ] Other:

* G=Grab; C=Composite
**Matrix: AI=Air; DW=Drinking Water; GW=Groundwater; OI=Oil; OL=Other Liquid; SL=Sludge; SO=Soil; WP=Wipe; WW=Wastewater
***Container Type: AG-Amber Glass; CG-Clear Glass, PL-Plastic. Container Size: 250ml, 500ml, 1L, 8oz., etc. Preservative: HCl, HNO3, NaOH, etc.

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CERTIFICATE OF ANALYSIS

Client:	ALS Environmental - PA 34 Dogwood Lane Middletown PA, 17057	**Report Date:**	07/03/14 13:34
		Received Date:	06/10/14 09:05
		Turn Around:	Normal
Attention:	Debra Musser	**Client Project:**	2010351
Phone:	(800) 794-7709		
Fax:	(717) 944-1430		
Work Order(s):	4F10081		

NELAP #04229CA ELAP#1132 NEVADA #CA211 HAWAII LACSD #10143

The results in this report apply to the samples analyzed in accordance with the Chain of Custody document. Weck Laboratories, Inc. certifies that the test results meet all NELAC requirements unless noted in the case narrative. This analytical report is confidential and is only intended for the use of Weck Laboratories, Inc. and its client. This report contains the Chain of Custody document, which is an integral part of it, and can only be reproduced in full with the authorization of Weck Laboratories, Inc.

Dear Debra Musser :

Enclosed are the results of analyses for samples received 06/10/14 09:05 with the Chain of Custody document. The samples were received in good condition, at 5.0 °C and on ice. All analysis met the method criteria except as noted below or in the report with data qualifiers.

Case Narrative:

Reviewed by:

Brandon Gee
Project Manager

Weck Laboratories, Inc 14859 East Clark Avenue, City of Industry, California 91745-1396 (626) 336-2139 FAX (626) 336-2634

WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 06/10/14 09:05
Date Reported: 07/03/14 13:34

ANALYTICAL REPORT FOR SAMPLES

Sample ID	Sampled by:	Sample Comments	Lab ID	Matrix	Date Sampled
2010351 001	Client		4F10081-01	Water	06/03/14 00:00

ANALYSES

DBPs by EPA 551.1

WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 06/10/14 09:05
Date Reported: 07/03/14 13:34

4F10081-01 **2010351 001**

Sampled: 06/03/14 00:00 **Sampled By:** Client **Matrix:** Water

DBPs by EPA 551.1

Method: EPA 551.1 Batch: W4F0944 Prepared: 06/17/14 14:19 Analyst: Juliet Chootipanya

Analyte	Result		MRL	Units	Dil	Analyzed	Qualifier
1,1,1-trichloro-2-propanone	ND		0.50	ug/l	1	06/19/14 22:25	
1,1-Dichloro-2-propanone	ND		0.50	ug/l	1	06/19/14 22:25	
Bromoacetonitrile	ND		0.50	ug/l	1	06/19/14 22:25	
Bromochloroacetonitrile	ND		0.50	ug/l	1	06/19/14 22:25	
Chloral hydrate	ND		0.50	ug/l	1	06/19/14 22:25	
Chloroacetonitrile	ND		0.50	ug/l	1	06/19/14 22:25	
Chloropicrin	ND		0.50	ug/l	1	06/19/14 22:25	
Dibromoacetonitrile	ND		0.50	ug/l	1	06/19/14 22:25	
Dichloroacetonitrile	ND		0.50	ug/l	1	06/19/14 22:25	
Trichloroacetonitrile	ND		0.50	ug/l	1	06/19/14 22:25	
Surr: Decafluorobiphenyl	*98 %*	Conc:*9.77*	*80-120*	%			

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QUALITY CONTROL SECTION

WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 06/10/14 09:05
Date Reported: 07/03/14 13:34

DBPs by EPA 551.1 - Quality Control

Batch W4F0944 - EPA 551.1

Analyte	Result	MRL	Units	Spike Level	Source Result	%REC	% REC Limits	RPD	RPD Limit	Data Qualifiers
Blank (W4F0944-BLK1)				Analyzed: 06/19/14 21:10						
1,1,1-trichloro-2-propanone	ND	0.50	ug/l							
1,1-Dichloro-2-propanone	ND	0.50	ug/l							
Bromoacetonitrile	ND	0.50	ug/l							
Bromochloroacetonitrile	ND	0.50	ug/l							
Chloral hydrate	ND	0.50	ug/l							
Chloroacetonitrile	ND	0.50	ug/l							
Chloropicrin	ND	0.50	ug/l							
Dibromoacetonitrile	ND	0.50	ug/l							
Dichloroacetonitrile	ND	0.50	ug/l							
Trichloroacetonitrile	ND	0.50	ug/l							
Surr: Decafluorobiphenyl	*10.4*		*ug/l*	*10.0*		*104*	*80-120*			
LCS (W4F0944-BS1)				Analyzed: 06/19/14 21:35						
1,1,1-trichloro-2-propanone	10.2	0.50	ug/l	10.0		102	75-125			
1,1-Dichloro-2-propanone	9.65	0.50	ug/l	10.0		96	75-125			
Bromoacetonitrile	10.1	0.50	ug/l	10.0		101	75-125			
Bromochloroacetonitrile	9.12	0.50	ug/l	10.0		91	75-125			
Chloral hydrate	9.79	0.50	ug/l	10.0		98	75-125			
Chloroacetonitrile	11.6	0.50	ug/l	10.0		116	75-125			
Chloropicrin	8.57	0.50	ug/l	10.0		86	75-125			
Dibromoacetonitrile	8.93	0.50	ug/l	10.0		89	75-125			
Dichloroacetonitrile	8.90	0.50	ug/l	10.0		89	75-125			
Trichloroacetonitrile	8.92	0.50	ug/l	10.0		89	75-125			
Surr: Decafluorobiphenyl	*10.3*		*ug/l*	*10.0*		*103*	*80-120*			
LCS Dup (W4F0944-BSD1)				Analyzed: 06/20/14 10:45						
1,1,1-trichloro-2-propanone	10.9	0.50	ug/l	10.0		109	75-125	6	25	
1,1-Dichloro-2-propanone	9.78	0.50	ug/l	10.0		98	75-125	1	25	
Bromoacetonitrile	9.70	0.50	ug/l	10.0		97	75-125	5	25	
Bromochloroacetonitrile	9.74	0.50	ug/l	10.0		97	75-125	7	25	
Chloral hydrate	8.50	0.50	ug/l	10.0		85	75-125	14	25	
Chloroacetonitrile	11.5	0.50	ug/l	10.0		115	75-125	0.9	25	
Chloropicrin	9.33	0.50	ug/l	10.0		93	75-125	8	25	
Dibromoacetonitrile	9.41	0.50	ug/l	10.0		94	75-125	5	25	
Dichloroacetonitrile	9.27	0.50	ug/l	10.0		93	75-125	4	25	
Trichloroacetonitrile	10.0	0.50	ug/l	10.0		100	75-125	12	25	
Surr: Decafluorobiphenyl	*10.3*		*ug/l*	*10.0*		*103*	*80-120*			

WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 06/10/14 09:05
Date Reported: 07/03/14 13:34

Notes and Definitions

ND	NOT DETECTED at or above the Reporting Limit. If J-value reported, then NOT DETECTED at or above the Method Detection Limit (MDL)
NR	Not Reportable
Dil	Dilution
dry	Sample results reported on a dry weight basis
RPD	Relative Percent Difference
% Rec	Percent Recovery
Sub	Subcontracted analysis, original report available upon request
MDL	Method Detection Limit
MDA	Minimum Detectable Activity
MRL	Method Reporting Limit

Any remaining sample(s) will be disposed of one month from the final report date unless other arrangements are made in advance.

An Absence of Total Coliform meets the drinking water standards as established by the California Department of Health Services.

The Reporting Limit (RL) is referenced as the Laboratory's Practical Quantitation Limit (PQL) or the Detection Limit for Reporting Purposes (DLR).

All samples collected by Weck Laboratories have been sampled in accordance to laboratory SOP Number MIS002.

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LABORATORY REPORT

This report contains 10 pages.
(including the cover page)

If you have any questions concerning this report, please do not hesitate to call us at (800) 332-4345 or (574) 233-4777.

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NELAC NARRATIVE PAGE

Client: ALS Report #: 319046NP

Eurofins Eaton Analytical, Inc. is a NELAP accredited laboratory. All reported results meet the requirements of the NELAC standards, unless otherwise noted.

EEA contact person: Nathan Trowbridge

NELAP requires complete reporting of deviations from method requirements, regardless of the suspected impact on the data. Quality control failures not reported within the report summary are noted here.

There were no quality control failures.

Note: This report may not be reproduced, except in full, without written approval from EEA. EEA is accredited by the National Environmental Laboratory Accreditation Program (NELAP).

Jim Vernon P.M. Digitally signed by James Vernon Date: 2014.06.18 09:13:32 -04'00'

Authorized Signature	Title	Date

Page 1 of 1

Page 2 of 10

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110 South Hill Street
South Bend, IN 46617
Tel: (574) 233-4777
Fax: (574) 233-8207
1 800 332 4345

Laboratory Report

Client:	ALS	Report:	319046
Attn:	Karen Elofsky 34 Dogwood Lane Middletown, PA 17057	Priority:	Standard Written
		Status:	Final
		PWS ID:	Not Supplied
		PA Lab ID:	68466
Copies to:	None		

Sample Information

EEA ID #	Client ID	Method	Collected Date / Time	Collected By:	Received Date / Time
3040772	2010351 001	552.2	06/03/14 10:30	Client	06/10/14 09:00

Report Summary

Note: See attached page for additional comments.

Note: Sample container was provided by the client.

Detailed quantitative results are presented on the following pages. The results presented relate only to the samples provided for analysis.

We appreciate the opportunity to provide you with this analysis. If you have any questions concerning this report, please do not hesitate to call Nathan Trowbridge at (574) 233-4777.

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Jim Vernon P.M. Digitally signed by James Vernon
Date: 2014.06.18 09:13:47 -04'00'

Authorized Signature Title Date

Client Name: ALS
Report #: 319046

Page 1 of 3

Page 3 of 10

Client Name: ALS Report #: 319046

Sampling Point: 2010351 001 PWS ID: Not Supplied

Disinfection Byproducts

Analyte ID #	Analyte	Method	Reg Limit	MRL†	Result	Units	Preparation Date	Analyzed Date	EEA ID #
5589-96-8	Bromochloroacetic acid	552.2	—	1.0	< 1.0	ug/L	06/13/14 08:40	06/13/14 18:45	3040772
5278-95-5	Chlorodibromoacetic acid	552.2	—	2.0	< 2.0	ug/L	06/13/14 08:40	06/13/14 18:45	3040772
631-64-1	Dibromoacetic acid	552.2	—	1.0	< 1.0	ug/L	06/13/14 08:40	06/13/14 18:45	3040772
79-43-6	Dichloroacetic acid	552.2	—	1.0	< 1.0	ug/L	06/13/14 08:40	06/13/14 18:45	3040772
79-08-3	Monobromoacetic acid	552.2	—	1.0	< 1.0	ug/L	06/13/14 08:40	06/13/14 18:45	3040772
79-11-8	Monochloroacetic acid	552.2	—	2.0	< 2.0	ug/L	06/13/14 08:40	06/13/14 18:45	3040772
75-96-7	Tribromoacetic acid	552.2	—	4.0	< 4.0	ug/L	06/13/14 08:40	06/13/14 18:45	3040772
76-03-9	Trichloroacetic acid	552.2	—	1.0	< 1.0	ug/L	06/13/14 08:40	06/13/14 18:45	3040772
—	Total HAA5	552.2	60 *	2.0	< 2.0	ug/L	06/13/14 08:40	06/13/14 18:45	3040772

† EEA has demonstrated it can achieve these report limits in reagent water, but can not document them in all sample matrices.

Reg Limit Type:	MCL	SMCL	AL
Symbol:	*	^	!

Client Name: ALS Report #: 319046

Lab Definitions

Continuing Calibration Check Standard (CCC) / Continuing Calibration Verification (CCV) / Initial Calibration Verification Standard (ICV) / Initial Performance Check (IPC) - is a standard containing one or more of the target analytes that is prepared from the same standards used to calibrate the instrument. This standard is used to verify the calibration curve at the beginning of each analytical sequence, and may also be analyzed throughout and at the end of the sequence. The concentration of continuing standards may be varied, when prescribed by the reference method, so that the range of the calibration curve is verified on a regular basis.

Internal Standards (IS) - are pure compounds with properties similar to the analytes of interest, which are added to field samples or extracts, calibration standards, and quality control standards at a known concentration. They are used to measure the relative responses of the analytes of interest and surrogates in the sample, calibration standard or quality control standard.

Laboratory Duplicate (LD) - is a field sample aliquot taken from the same sample container in the laboratory and analyzed separately using identical procedures. Analysis of laboratory duplicates provides a measure of the precision of the laboratory procedures.

Laboratory Fortified Blank (LFB) / Laboratory Control Sample (LCS) - is an aliquot of reagent water to which known concentrations of the analytes of interest are added. The LFB is analyzed exactly the same as the field samples. LFBs are used to determine whether the method is in control.

Laboratory Method Blank (LMB) / Laboratory Reagent Blank (LRB) - is a sample of reagent water included in the sample batch analyzed in the same way as the associated field samples. The LMB is used to determine if method analytes or other background contamination have been introduced during the preparation or analytical procedure. The LMB is analyzed exactly the same as the field samples.

Laboratory Trip Blank (LTB) / Field Reagent Blank (FRB) - is a sample of laboratory reagent water placed in a sample container in the laboratory and treated as a field sample, including storage, preservation, and all analytical procedures. The FRB/LTB container follows the collection bottles to and from the collection site, but the FRB/LTB is not opened at any time during the trip. The FRB/LTB is primarily a travel blank used to verify that the samples were not contaminated during shipment.

Matrix Spike Duplicate Sample (MSD) / Laboratory Fortified Sample Matrix Duplicate (LFSMD) - is a sample aliquot taken from the same field sample source as the Matrix Spike Sample to which known quantities of the analytes of interest are added in the laboratory. The MSD is analyzed exactly the same as the field samples. Analysis of the MSD provides a measure of the precision of the laboratory procedures in a specific matrix.

Matrix Spike Sample (MS) / Laboratory Fortified Sample Matrix (LFSM) - is a sample aliquot taken from field sample source to which known quantities of the analytes of interest are added in the laboratory. The MS is analyzed exactly the same as the field samples. The purpose is to demonstrate recovery of the analytes from a sample matrix to determine if the specific matrix contributes bias to the analytical results.

Quality Control Standard (QCS) / Second Source Calibration Verification (SSCV) - is a solution containing known concentrations of the analytes of interest prepared from a source different from the source of the calibration standards. The solution is obtained from a second manufacturer or lot if the lot can be demonstrated by the manufacturer as prepared independently from other lots. The QCS sample is analyzed using the same procedures as field samples. The QCS is used as a check on the calibration standards used in the method on a routine basis.

Reporting Limit Check (RLC) / Initial Calibration Check Standard (ICCS) - is a procedural standard that is analyzed each day to evaluate instrument performance at or below the minimum reporting limit (MRL).

Surrogate Standard (SS) / Surrogate Analyte (SUR) - is a pure compound with properties similar to the analytes of interest, which is highly unlikely to be found in any field sample, that is added to the field samples, calibration standards, blanks and quality control standards before sample preparation. The SS is used to evaluate the efficiency of the sample preparation process.

319046 256323

ALS Environmental
34 Dogwood Lane
Middletown, PA 17057
P. 717-944-5541
F. 717-944-1430

CHAIN OF CUSTODY/ REQUEST FOR ANALYSIS

ALL SHADED AREAS MUST BE COMPLETED BY THE CLIENT / SAMPLER. INSTRUCTIONS ON THE BACK.

COC #:
ALS Quote #:
1of1

Client Name: ALS Environmental
Address: 34 Dogwood Lane, Middletown, PA 17057
Contact: Customer Service
Phone#: (717) 944-5541
Project Name/#:
Bill To: ALS Environmental
TAT: [x] Normal-Standard TAT is 10-12 business days. [ ] Rush-Subject to ALSI approval and surcharges.
Date Required: Approved By:
Email? [x] Y ALMDT.Subcontract@ALSGlobal.com
Fax? [ ] Y No.:

Container Type: G
Container Size: 250
Preservative: NH4Cl

ANALYSES/METHOD REQUESTED: HAA (all 8 compounds are needed)

Enter Number of Containers Per Sample or Field Results Below.

Sample Description/Location (as it will appear on the lab report)	Sample Date	Time	*G or C	**Matrix	HAA (all 8 compounds are needed)
2010351 001 3040772	6/3/14	1030	DW	GW	1

Receipt Information (completed by Receiving Lab)
Cooler Temp: 4.2 Therm ID:
No. of Coolers: Y N Initial
Custody Seals Present?
(if present) Seals Intact?
Received on Ice?
COC/Labels Complete/Accurate?
Cont. in Good Cond.?
Correct Containers?
Correct Sample Volumes?
Correct Preservation?
Headspace/Volatiles?
Courier/Tracking #:

Sample/COC Comments
Sub to UL LLC
110 South Hill St
South Bend, IN 46617

Client Provided Sample Container

ALS Field Services: __Pickup __Labor __Composite Sampling __Rental Equipment __Other:

Project Comments:
LOGGED BY(signature): DATE TIME
REVIEWED BY(signature): DATE TIME

	Relinquished By / Company Name	Date	Time		Received By / Company Name	Date	Time
1	[signature]	6/9	1615	2	K Depuis	6-10-14	0900
3				4			
5				6			
7				8			
9				10			

Data Deliverables: [ ] Standard [ ] CLP-like [ ] USACE [ ]
Special Processing: USACE [ ] Navy [ ] [ ]
State Samples Collected In: [ ] NY [ ] NJ [ ] PA [ ] NC [ ]
Reportable to PADEP? Yes [ ]
PWSID #
Sample Disposal: Lab [ ] Special [ ]
EDDS: Format Type-

* G=Grab; C=Composite **Matrix - AI=Air; DW=Drinking Water; GW=Groundwater; OI=Oil; OL=Other Liquid; SL=Sludge; SO=Soil; WP=Wipe; WW=Wastewater

ALS ENVIRONMENTAL SHIPPING ADDRESS: 34 DOGWOOD LANE, MIDDLETOWN, PA 17057

Rev 10/11

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Eurofins Eaton Analytical
Run Log
Run ID: **191830** Method: **552.2**

Type	Sample Id	Sample Site	Matrix	Instrument ID	Analysis Date	Calibration File
CCL	3044248		RW	PW3	06/13/2014 16:56	552_2-061014PW3
LMB	3044247		RW	PW3	06/13/2014 17:32	552_2-061014PW3
FS	3040772	2010351 001	DW	PW3	06/13/2014 18:45	552_2-061014PW3
CCC	3044249		RW	PW3	06/14/2014 00:50	552_2-061014PW3

QC Summary Report

Sample Type	Analyte	Method	MRL	Client ID	Result Flag	Amount	Target	Units	% Recovery	Recovery Limits	RPD	RPD Limit	Dil Factor	Extracted	Analyzed	EEA ID #
CCL	SS-2-Bromopropionic acid	552.2	N/A	---		5.4155	5.0	ug/L	108	70 - 130	---	---	1.0	06/13/2014 08:40	06/13/2014 16:56	3044248
CCL	Bromochloroacetic acid	552.2	1.0	---		1.2507	1.0	ug/L	125	71 - 154	---	---	1.0	06/13/2014 08:40	06/13/2014 16:56	3044248
CCL	Chlorodibromoacetic acid	552.2	2.0	---		1.4036	1.0	ug/L	140	43 - 185	---	---	1.0	06/13/2014 08:40	06/13/2014 16:56	3044248
CCL	Dibromoacetic acid	552.2	1.0	---		1.2640	1.0	ug/L	126	50 - 150	---	---	1.0	06/13/2014 08:40	06/13/2014 16:56	3044248
CCL	Dichloroacetic acid	552.2	1.0	---		1.3181	1.0	ug/L	132	50 - 150	---	---	1.0	06/13/2014 08:40	06/13/2014 16:56	3044248
CCL	Monobromoacetic acid	552.2	1.0	---		1.4146	1.0	ug/L	141	50 - 150	---	---	1.0	06/13/2014 08:40	06/13/2014 16:56	3044248
CCL	Monochloroacetic acid	552.2	2.0	---		2.7752	2.0	ug/L	139	50 - 150	---	---	1.0	06/13/2014 08:40	06/13/2014 16:56	3044248
CCL	Tribromoacetic acid	552.2	4.0	---		1.3867	1.0	ug/L	139	36 - 206	---	---	1.0	06/13/2014 08:40	06/13/2014 16:56	3044248
CCL	Trichloroacetic acid	552.2	1.0	---		1.2132	1.0	ug/L	121	50 - 150	---	---	1.0	06/13/2014 08:40	06/13/2014 16:56	3044248
CCL	IS-1,2,3-Trichloropropane	552.2	N/A	---		58521	59698	ug/L	98	70 - 130	---	---	1.0	06/13/2014 08:40	06/13/2014 16:56	3044248
LMB	SS-2-Bromopropionic acid	552.2	N/A	---		5.1974	5.0	ug/L	104	70 - 130	---	---	1.0	06/13/2014 08:40	06/13/2014 17:32	3044247
LMB	Bromochloroacetic acid	552.2	1.0	---	<	1.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 17:32	3044247
LMB	Chlorodibromoacetic acid	552.2	2.0	---	<	2.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 17:32	3044247
LMB	Dibromoacetic acid	552.2	1.0	---	<	1.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 17:32	3044247
LMB	Dichloroacetic acid	552.2	1.0	---	<	1.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 17:32	3044247
LMB	Monobromoacetic acid	552.2	1.0	---	<	1.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 17:32	3044247
LMB	Monochloroacetic acid	552.2	2.0	---	<	2.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 17:32	3044247
LMB	Tribromoacetic acid	552.2	4.0	---	<	4.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 17:32	3044247
LMB	Trichloroacetic acid	552.2	1.0	---	<	1.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 17:32	3044247
LMB	IS-1,2,3-Trichloropropane	552.2	N/A	---		57955	59698	ug/L	97	70 - 130	---	---	1.0	06/13/2014 08:40	06/13/2014 17:32	3044247
FS	SS-2-Bromopropionic acid	552.2	N/A	2010351 001		5.3773	5.0	ug/L	108	70 - 130	---	---	1.0	06/13/2014 08:40	06/13/2014 18:45	3040772
FS	Bromochloroacetic acid	552.2	1.0	2010351 001	<	1.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 18:45	3040772
FS	Chlorodibromoacetic acid	552.2	2.0	2010351 001	<	2.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 18:45	3040772
FS	Dibromoacetic acid	552.2	1.0	2010351 001	<	1.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 18:45	3040772
FS	Dichloroacetic acid	552.2	1.0	2010351 001	<	1.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 18:45	3040772
FS	Monobromoacetic acid	552.2	1.0	2010351 001	<	1.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 18:45	3040772
FS	Monochloroacetic acid	552.2	2.0	2010351 001	<	2.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 18:45	3040772
FS	Tribromoacetic acid	552.2	4.0	2010351 001	<	4.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 18:45	3040772
FS	Trichloroacetic acid	552.2	1.0	2010351 001	<	1.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 18:45	3040772
FS	IS-1,2,3-Trichloropropane	552.2	N/A	2010351 001		59563	59698	ug/L	100	70 - 130	---	---	1.0	06/13/2014 08:40	06/13/2014 18:45	3040772
FS	Total HAA5	552.2	2.0	2010351 001	<	2.0		ug/L	---	---	---	---	1.0	06/13/2014 08:40	06/13/2014 18:45	3040772
CCC	SS-2-Bromopropionic acid	552.2	N/A	---		5.4325	5.0	ug/L	109	70 - 130	---	---	1.0	06/13/2014 08:40	06/14/2014 00:50	3044249
CCC	Bromochloroacetic acid	552.2	1.0	---		22.2866	20.0	ug/L	111	70 - 130	---	---	1.0	06/13/2014 08:40	06/14/2014 00:50	3044249
CCC	Chlorodibromoacetic acid	552.2	2.0	---		23.8258	20.0	ug/L	119	70 - 130	---	---	1.0	06/13/2014 08:40	06/14/2014 00:50	3044249
CCC	Dibromoacetic acid	552.2	1.0	---		24.5236	20.0	ug/L	123	70 - 130	---	---	1.0	06/13/2014 08:40	06/14/2014 00:50	3044249
CCC	Dichloroacetic acid	552.2	1.0	---		19.7954	20.0	ug/L	99	70 - 130	---	---	1.0	06/13/2014 08:40	06/14/2014 00:50	3044249
CCC	Monobromoacetic acid	552.2	1.0	---		19.7347	20.0	ug/L	99	70 - 130	---	---	1.0	06/13/2014 08:40	06/14/2014 00:50	3044249
CCC	Monochloroacetic acid	552.2	2.0	---		47.1615	40.0	ug/L	118	70 - 130	---	---	1.0	06/13/2014 08:40	06/14/2014 00:50	3044249
CCC	Tribromoacetic acid	552.2	4.0	---		17.1800	20.0	ug/L	86	70 - 130	---	---	1.0	06/13/2014 08:40	06/14/2014 00:50	3044249
CCC	Trichloroacetic acid	552.2	1.0	---		22.5605	20.0	ug/L	113	70 - 130	---	---	1.0	06/13/2014 08:40	06/14/2014 00:50	3044249

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QC Summary Report (cont.)

Sample Type	Analyte	Method	MRL	Client ID	Result Flag	Amount	Target	Units	% Recovery	Recovery Limits	RPD	RPD Limit	Dil Factor	Extracted	Analyzed	EEA ID #
CCC	IS-1,2,3-Trichloropropane	552.2	N/A	---		56858	59698	ug/L	95	70 - 130	---	---	1.0	06/13/2014 08:40	06/14/2014 00:50	3044249

Sample Type Key

Type (Abbr.)	Sample Type	Type (Abbr.)	Sample Type
CCC	Continuing Calibration Check		
CCL	Continuing Calibration Low		
FS	Field Sample		
LMB	Laboratory Method Blank		

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August 26, 2014

Ms. Janet Barnes
University of MD-UMCES - Solomons, MD
P.O. Box 38
146 Williams Street
Solomons, MD 20688

Certificate of Analysis

Project Name:	**2014-MD BRACKISH WATER STUDY**	Workorder:	**2011706**
Purchase Order:		Workorder ID:	**2014-MD BRACKISH WATER STUDY**

Dear Ms. Barnes:

Enclosed are the analytical results for samples received by the laboratory on Wednesday, June 11, 2014.

The ALS Environmental laboratory in Middletown, Pennsylvania is a National Environmental Laboratory Accreditation Program (NELAP) accredited laboratory and as such, certifies that all applicable test results meet the requirements of NELAP.

If you have any questions regarding this certificate of analysis, please contact Ms. Debra J. Musser (Project Coordinator) at (717) 944-5541.

Analyses were performed according to our laboratory's NELAP-approved quality assurance program and any applicable state requirements. The test results meet requirements of the current NELAP standards or state requirements, where applicable. For a specific list of accredited analytes, refer to the certifications section of the ALS website at www.alsglobal.com/en/Our-Services/Life-Sciences/Environmental/Downloads.

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ALS Spring City: 10 Riverside Drive, Spring City, PA 19475 610-948-4903

This page is included as part of the Analytical Report and must be retained as a permanent record thereof.

Debra J Musser
Ms. Debra J. Musser
Project Coordinator

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SAMPLE SUMMARY

Workorder: 2011706 2014-MD BRACKISH WATER STUDY

Lab ID	Sample ID	Matrix	Date Collected	Date Received	Collected By
2011706001	PW4-DC-P/MERC Barge	Water	6/10/2014 10:45	6/11/2014 10:20	Ms. Janet Barnes
2011706002	Trip Blank	Water	6/11/2014 10:20	6/11/2014 10:20	Ms. Janet Barnes

Notes

-- Samples collected by ALS personnel are done so in accordance with the procedures set forth in the ALS Field Sampling Plan (20 - Field Services Sampling Plan).
-- All Waste Water analyses comply with methodology requirements of 40 CFR Part 136.
-- All Drinking Water analyses comply with methodology requirements of 40 CFR Part 141.
-- Unless otherwise noted, all quantitative results for soils are reported on a dry weight basis.
-- The Chain of Custody document is included as part of this report.
-- All Library Search analytes should be regarded as tentative identifications based on the presumptive evidence of the mass spectra. Concentrations reported are estimated values.
-- Parameters identified as "analyze immediately" require analysis within 15 minutes of collection. Any "analyze immediately" parameters not listed under the header "Field Parameters" are preformed in the laboratory and are therefore analyzed out of hold time.
-- Method references listed on this report beginning with the prefix “S” followed by a method number (such as S2310B-97) refer to methods from “Standard Methods for the Examination of Water and Wastewater”.

Standard Acronyms/Flags

J	Indicates an estimated value between the Method Detection Limit (MDL) and the Practical Quantitation Limit (PQL) for the analyte
U	Indicates that the analyte was Not Detected (ND)
N	Indicates presumptive evidence of the presence of a compound
MDL	Method Detection Limit
PQL	Practical Quantitation Limit
RDL	Reporting Detection Limit
ND	Not Detected - indicates that the analyte was Not Detected at the RDL
Cntr	Analysis was performed using this container
RegLmt	Regulatory Limit
LCS	Laboratory Control Sample
MS	Matrix Spike
MSD	Matrix Spike Duplicate
DUP	Sample Duplicate
%Rec	Percent Recovery
RPD	Relative Percent Difference
LOD	DoD Limit of Detection
LOQ	DoD Limit of Quantitation
DL	DoD Detection Limit

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PROJECT SUMMARY

Workorder: 2011706 2014-MD BRACKISH WATER STUDY

Workorder Comments

Eurofins was unable to report the HAA data due to QC failure. DJM

See attached subcontracted acetonitriles results from Weck Labs. LDN

Sample Comments

Lab ID: 2011706001 **Sample ID:** PW4-DC-P/MERC Barge **Sample Type:** SAMPLE

Assuming that all bromate present in the sample is in the form of sodium bromate, the sodium bromate concentration is <5.9 ug/L.

Assuming that all chlorate present in the sample is in the form of sodium chlorate, the sodium chlorate concentration is 60.8 ug/L.

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ANALYTICAL RESULTS

Workorder: 2011706 2014-MD BRACKISH WATER STUDY

Lab ID: **2011706001** Date Collected: 6/10/2014 10:45 Matrix: Water
Sample ID: **PW4-DC-P/MERC Barge** Date Received: 6/11/2014 10:20

Parameters	Results	Flag	Units	RDL	Method	Prepared	By	Analyzed	By	Cntr
VOLATILE ORGANICS										
Bromodichloromethane	ND		ug/L	0.50	EPA 524.2	6/12/14	TMP	6/12/14 20:44	TMP	B
Bromoform	1.4		ug/L	0.50	EPA 524.2	6/12/14	TMP	6/12/14 20:44	TMP	B
Chlorodibromomethane	ND		ug/L	0.50	EPA 524.2	6/12/14	TMP	6/12/14 20:44	TMP	B
Chloroform	ND		ug/L	0.50	EPA 524.2	6/12/14	TMP	6/12/14 20:44	TMP	B
1,2,3-Trichloropropane	ND		ug/L	0.50	EPA 524.2	6/12/14	TMP	6/12/14 20:44	TMP	B
Surrogate Recoveries	*Results*	*Flag*	*Units*	*Limits*	*Method*	*Prepared*	*By*	*Analyzed*	*By*	*Cntr*
1,2-Dichlorobenzene-d4 (S)	102		%	70 - 130	EPA 524.2	6/12/14	TMP	6/12/14 20:44	TMP	B
4-Bromofluorobenzene (S)	85.5		%	70 - 130	EPA 524.2	6/12/14	TMP	6/12/14 20:44	TMP	B
HERBICIDES										
Dalapon	ND		ug/L	4.0	EPA 515.3	6/19/14	JEK	6/20/14 01:06	EGO	E
Surrogate Recoveries	*Results*	*Flag*	*Units*	*Limits*	*Method*	*Prepared*	*By*	*Analyzed*	*By*	*Cntr*
2,4-Dichlorophenylacetic acid (S)	100		%	70 - 130	EPA 515.3	6/19/14	JEK	6/20/14 01:06	EGO	E
WET CHEMISTRY										
Bromate	ND		ug/L	5.0	EPA 300.1	6/17/14	SSL	6/17/14 08:39	SSL	H
Chlorate	47.7		ug/L	20.0	EPA 300.1	6/17/14	SSL	6/17/14 08:39	SSL	H
METALS										
Sodium, Total	7.4		mg/L	0.25	EPA 200.7	6/12/14	AAM	6/17/14 05:07	ZMC	G1
SUBCONTRACTED ANALYSIS										
Subcontracted Analysis	See attached				Subcontract			6/19/14 22:50	SUB	D

Debra J Musser
Ms. Debra J. Musser
Project Coordinator

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ANALYTICAL RESULTS

Workorder: 2011706 2014-MD BRACKISH WATER STUDY

Lab ID: **2011706002** Date Collected: 6/11/2014 10:20 Matrix: Water
Sample ID: **Trip Blank** Date Received: 6/11/2014 10:20

Parameters	Results	Flag	Units	RDL	Method	Prepared	By	Analyzed	By	*Cntr*
VOLATILE ORGANICS										
Bromodichloromethane	ND		ug/L	0.50	EPA 524.2	6/12/14	TMP	6/12/14 15:11	TMP	B
Bromoform	ND		ug/L	0.50	EPA 524.2	6/12/14	TMP	6/12/14 15:11	TMP	B
Chlorodibromomethane	ND		ug/L	0.50	EPA 524.2	6/12/14	TMP	6/12/14 15:11	TMP	B
Chloroform	ND		ug/L	0.50	EPA 524.2	6/12/14	TMP	6/12/14 15:11	TMP	B
1,2,3-Trichloropropane	ND		ug/L	0.50	EPA 524.2	6/12/14	TMP	6/12/14 15:11	TMP	B
Surrogate Recoveries	*Results*	*Flag*	*Units*	*Limits*	*Method*	*Prepared*	*By*	*Analyzed*	*By*	*Cntr*
1,2-Dichlorobenzene-d4 (S)	107		%	70 - 130	EPA 524.2	6/12/14	TMP	6/12/14 15:11	TMP	B
4-Bromofluorobenzene (S)	115		%	70 - 130	EPA 524.2	6/12/14	TMP	6/12/14 15:11	TMP	B

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QUALITY CONTROL DATA

Workorder: 2011706 2014-MD BRACKISH WATER STUDY

QC Batch: MDIG/45866 **Analysis Method:** EPA 200.7

QC Batch Method: EPA TRMD

Associated Lab Samples: 2011706001

METHOD BLANK: 2029517

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Sodium, Total	ND	mg/L	0.25	

LABORATORY CONTROL SAMPLE: 2029518

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Sodium, Total	10	mg/L	9.6	95.9	85 - 115	

MATRIX SPIKE: 2029519 DUPLICATE: 2029520 ORIGINAL: 2011632001

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MSD Result	MS % Rec	MSD % Rec	% Rec Limit	RPD	Max RPD	Qualifiers
Sodium, Total		mg/L		341	316				7.68	20	

MATRIX SPIKE SAMPLE: 2029521 ORIGINAL:

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MS % Rec	% Rec Limit	Qualifiers
Sodium, Total		mg/L		14.9			

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QUALITY CONTROL DATA

Workorder: 2011706 2014-MD BRACKISH WATER STUDY

QC Batch: VOMS/32913 **Analysis Method:** EPA 524.2

QC Batch Method: EPA 524.2

Associated Lab Samples: 2011706001, 2011706002

METHOD BLANK: 2029737

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Chloroform	ND	ug/L	0.50	
Bromodichloromethane	ND	ug/L	0.50	
Chlorodibromomethane	ND	ug/L	0.50	
Bromoform	ND	ug/L	0.50	
1,2,3-Trichloropropane	ND	ug/L	0.50	
1,2-Dichlorobenzene-d4 (S)	92.4	%	70 - 130	
4-Bromofluorobenzene (S)	81.3	%	70 - 130	

LABORATORY CONTROL SAMPLE: 2029738

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Chloroform	1	ug/L	1.2	123	50 - 150	
Bromodichloromethane	1	ug/L	1.0	104	50 - 150	
Chlorodibromomethane	1	ug/L	1.1	109	50 - 150	
Bromoform	1	ug/L	1.0	102	50 - 150	
1,2-Dichlorobenzene-d4 (S)		%		110	70 - 130	
4-Bromofluorobenzene (S)		%		89.7	70 - 130	

LABORATORY CONTROL SAMPLE: 2029739

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Chloroform	5	ug/L	5.2	105	70 - 130	
Bromodichloromethane	5	ug/L	4.9	98.5	70 - 130	
Chlorodibromomethane	5	ug/L	4.9	97.4	70 - 130	
Bromoform	5	ug/L	4.2	84.1	70 - 130	
1,2,3-Trichloropropane	5	ug/L	4.2	84.6	70 - 130	
1,2-Dichlorobenzene-d4 (S)		%		107	70 - 130	
4-Bromofluorobenzene (S)		%		90.2	70 - 130	

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QUALITY CONTROL DATA

Workorder: 2011706 2014-MD BRACKISH WATER STUDY

MATRIX SPIKE: 2029858 DUPLICATE: 2029859 ORIGINAL: 2011704001

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MSD Result	MS % Rec	MSD % Rec	% Rec Limit	RPD	Max RPD	Qualifiers
Chloroform		ug/L	5	5.8	5.7	117	114	70 - 130	2.65	40	
Bromodichloromethane		ug/L	5	5.4	5.2	108	104	70 - 130	2.97	40	
Chlorodibromomethane		ug/L	5	5.8	5.6	116	112	70 - 130	3.21	40	
Bromoform		ug/L	5	6.2	5.7	123	114	70 - 130	7.73	40	
1,2,3-Trichloropropane		ug/L	5	5.4	5.5	107	110	70 - 130	2.42	40	
4-Bromofluorobenzene (S)		%				100	94	70 - 130	6.32		
1,2-Dichlorobenzene-d4 (S)		%				125	118	70 - 130	5.42		

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QUALITY CONTROL DATA

Workorder: 2011706 2014-MD BRACKISH WATER STUDY

QC Batch: WETC/139431 **Analysis Method:** EPA 300.1
QC Batch Method: EPA 300.1
Associated Lab Samples: 2011706001

METHOD BLANK: 2031421

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Bromate	ND	ug/L	5.0	
Chlorate	ND	ug/L	20.0	

LABORATORY CONTROL SAMPLE: 2031422

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Bromate	25	ug/L	24.0	96.1	85 - 115	
Chlorate	250	ug/L	243	97.2	90 - 110	

MATRIX SPIKE: 2031424 DUPLICATE: 2031425 ORIGINAL: 2011689006

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MSD Result	MS % Rec	MSD % Rec	% Rec Limit	RPD	Max RPD	Qualifiers
Chlorate		ug/L	250	226	230	90.4	92.2	75 - 125	1.95	25	

MATRIX SPIKE: 2031426 DUPLICATE: 2031427 ORIGINAL: 2012000001

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MSD Result	MS % Rec	MSD % Rec	% Rec Limit	RPD	Max RPD	Qualifiers
Chlorate		ug/L	250	233	233	92.6	92.4	75 - 125	.16	25	

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QUALITY CONTROL DATA

Workorder: 2011706 2014-MD BRACKISH WATER STUDY

QC Batch: SVGC/34633 **Analysis Method:** EPA 515.3

QC Batch Method: EPA 515.3

Associated Lab Samples: 2011706001

METHOD BLANK: 2033186

Parameter	Blank Result	Units	Reporting Limit	Qualifiers
Dalapon	ND	ug/L	4.0	
2,4-Dichlorophenylacetic acid (S)	87	%	70 - 130	

LABORATORY CONTROL SAMPLE: 2033187

Parameter	Spike Conc.	Units	LCS Result	LCS % Rec	% Rec Limit	Qualifiers
Dalapon	5	ug/L	6.3	126	70 - 130	
2,4-Dichlorophenylacetic acid (S)		%		97	70 - 130	

SAMPLE DUPLICATE: 2033188 ORIGINAL:

Parameter	Original Result	Units	DUP Result	RPD	Max RPD	Qualifiers
Dalapon		ug/L	ND		30	
2,4-Dichlorophenylacetic acid (S)		%		1.9		
2,4-Dichlorophenylacetic acid (S)		%		93	130	

MATRIX SPIKE SAMPLE: 2033189 ORIGINAL:

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MS % Rec	% Rec Limit	Qualifiers
Dalapon		ug/L	5	5.9	119	70 - 130	
2,4-Dichlorophenylacetic acid (S)		%				70 - 130	

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QUALITY CONTROL DATA

Workorder: 2011706 2014-MD BRACKISH WATER STUDY

MATRIX SPIKE SAMPLE: 2033190 ORIGINAL:

****NOTE - The Original Result shown below is a raw result and is only used for the purpose of calculating Matrix Spike percent recoveries. This result is not a final value and cannot be used as such.

Parameter	Original Result	Units	Spike Conc.	MS Result	MS % Rec	% Rec Limit	Qualifiers
Dalapon		ug/L	5	6.5	130	70 - 130	
2,4-Dichlorophenylacetic acid (S)		%				70 - 130	

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QUALITY CONTROL DATA CROSS REFERENCE TABLE

Workorder: 2011706 2014-MD BRACKISH WATER STUDY

Lab ID	Sample ID	Prep Method	Prep Batch	Analysis Method	Analysis Batch
2011706001	PW4-DC-P/MERC Barge	EPA TRMD	MDIG/45866	EPA 200.7	META/44660
2011706001	PW4-DC-P/MERC Barge			EPA 524.2	VOMS/32913
2011706002	Trip Blank			EPA 524.2	VOMS/32913
2011706001	PW4-DC-P/MERC Barge			EPA 300.1	WETC/139431
2011706001	PW4-DC-P/MERC Barge	EPA 515.3	SVGC/34633	EPA 515.3	SVGC/34642

ALS Environmental DJM

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Middletown, PA 17057
P. 717-944-5541
F. 717-944-1430

CHAIN OF CUSTODY/ REQUEST FOR ANALYSIS

ALL SHADED AREAS MUST BE COMPLETED BY THE CLIENT / SAMPLER. INSTRUCTIONS ON THE BACK.

Page 1 of 1

Courier:

Tracking #:

* 2 0 1 1 7 0 6 *

Co. Name: UMCES-CBL-MERC

Contact (Report to): Janet Barnes

Phone: 410-326-7259

Address: P.O. Box 38, 146 Williams Street, Solomons, MD 20688

Bill to (if different than Report to):

PO#:

Project Name/#: PW4-DC-[illegible]

ALS Quote #: 454283

TAT: ☒ Normal-Standard TAT is 10-12 business days. ☐ Rush-Subject to ALS approval and surcharges.

Date Required:

Approved By: JMB

Email? ☒ -Y barnes@umces.edu

Fax? -Y No.:

				***Container Type		CG	AG	CG	PL	AG	AG	CG			
				***Container Size		40 ml	250 ml	60 ml	250 ml	1L	1L	40 ml			
				***Preservative		Asc HCl	NH4 Cl	NH4 Cl	HNO3	EDA	Na2S2O3	NA			
				ANALYSES/METHOD REQUESTED		VOC by 524.2 ✓	HAA by 552.5 ✓	Acetonitrile by 551 ✓	Sodium by 200.7	Bromate Chlorate by 300.1	Dalapon Herbicides by 515.3	Trip Blanks ✓			
Sample Description/Location (as it will appear on the lab report)	COC Comments	Sample Date	Military Time	*G or C	**Matrix	Enter Number of Containers Per Analysis									
1 ~~[illegible] / MERC Barge~~		~~[illegible]~~		~~G~~	~~[illegible]~~	~~2~~	~~1~~	~~4~~	~~1~~	~~1~~	~~2~~	~~2~~			
2 [illegible]															
3 PW4-DC-P/ MERC Barge		6/10/14	1045	C	[illegible]	2	1	4	1	1	2	2			
4															
5															
6	ENTERED														
7															
8	6/11/14 MM														

(completed by Sample Receiving)

Performed by: MM

Cooler Temp: 3°C

Therm. ID: TH291

No. of Coolers:

Notes:

Circle appropriate Y or N.

Correct containers?	Y	N
Correct sample volume?	Y	N
Correct preservation?	Y	N
Headspace/Volatiles?	Y	N
Custody seals Present?	Y	N
(if present) Seals intact?	Y	N
Received on ice?	Y	N
COC/Labels complete/accurate?	Y	N
Container in good condition?	Y	N

SAMPLED BY (Please Print): Janet Barnes/Eva Bailey

Project Comments: Sample time on bottle when filled.

Relinquished By / Company Name	Date	Time	Received By / Company Name	Date	Time
1 [illegible]	[illegible]		2 [illegible] ALS	6-11-14	1020
3 Janet Barnes	6/10/14		4		
5			6		
7			8		
9			10		

Data Deliverables: ☒ Standard ☐ CLP-like ☐ NJ-Reduced ☐ NJ-Full ☐ (other)

SDWA Forms? yes ☐ yes ☐ yes ☐ yes ☐

State Samples Collected In? MD ☒ NJ ☐ NY ☐ PA ☐ Other

EDDs Required? ☒ If yes, format type: MS Excel

Other: Enter PWSID No.

DOD Criteria Required? NO

ALS FIELD SERVICES: ☐ Pickup ☐ Labor ☐ Composite Sampling ☐ Rental Equipment ☐ Other:

* G=Grab; C=Composite

**Matrix: AI=Air; DW=Drinking Water; GW=Groundwater; OI=Oil; OL=Other Liquid; SL=Sludge; SO=Soil; WP=Wipe; WW=Wastewater

***Container Type: AG-Amber Glass; CG-Clear Glass, PL-Plastic. Container Size: 250ml, 500ml, 1L, 8oz., etc. Preservative: HCl, HNO3, NaOH, etc.

Copies: WHITE - ORIGINAL CANARY - CUSTOMER COPY

Rev 01-2013

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ALS Environmental

34 Dogwood Lane
Middletown, PA 17057
P. 717-944-5541
F.717-944-1430

CHAIN OF CUSTODY/ REQUEST FOR ANALYSIS

ALL SHADED AREAS MUST BE COMPLETED BY THE CLIENT / SAMPLER. INSTRUCTIONS ON THE BACK.

COC #:

ALS Quote #:

1of1

Client Name: ALS Environmental
Address: 34 Dogwood Lane
Middletown, PA 17057
Contact: Customer Service
Phone#: (717) 944-5541
Project Name/#:
Bill To: ALS Environmental
TAT [ ] Normal-Standard TAT is 10-12 business days.
[ ] Rush-Subject to ALS approval and surcharges.
Date Required: Approved By:
Email? [x] -Y ALMDT.Subcontract@ALSGlobal.com
Fax? [ ] -Y No:

Container Type	G
Container Size	60ml
Preservative	NH4Cl+

ANALYSES/METHOD REQUESTED: Acetonitriles

Sample Description/Location (as it will appear on the lab report)	Sample Date	Time	*G or C	**Matrix	Acetonitriles
2011706 001	6/10/2014	0:00	C	W	4

Enter Number of Containers Per Sample or Field Results Below.

Receipt Information (completed by Receiving Lab)
Cooler Temp: ____ Therm ID:
No. of Coolers: ____ Y N Initial
Custody Seals Present?
(if present) Seals Intact?
Received on Ice?
COC/Labels Complete/Accurate?
Cont. in Good Cond.?
Correct Containers?
Correct Sample Volumes?
Correct Preservation?
Headspace/Volatiles?
Courier/Tracking #:

Sample/COC Comments

Sub to Weck

**Report Dichloroacetonitrile, Dibromoacetonitrile and Chloropicrin

Client also wants the 2 additional Mono's added when possible.

ALS Field Services: __Pickup __Labor __Composite Sampling __Rental Equipment __Other:

Project Comments:

LOGGED BY(signature): DATE TIME
REVIEWED BY(signature): DATE TIME

Relinquished By / Company Name	Date	Time	Received By / Company Name	Date	Time
1 [signature] ALS	6/12/14	7:00	2		
3			4		
5			6		
7			8		
9			10		

Data Deliverables: [ ] Standard [ ] CLP-like [ ] USACE [ ]
Reportable to PADEP? Yes [ ]
PWSID #
EDDS: Format Type-
Special Processing: USACE [ ] Navy [ ]
Sample Disposal: Lab [ ] Special [ ]
State Samples Collected In: [ ] NY [ ] NJ [ ] PA [ ] NC [ ]

* G=Grab; C=Composite **Matrix - AI=Air; DW=Drinking Water; GW=Groundwater; OI=Oil; OL=Other Liquid; SL=Sludge; SO=Soil; WP=Wipe; WW=Wastewater

ALS ENVIRONMENTAL SHIPPING ADDRESS: 34 DOGWOOD LANE, MIDDLETOWN, PA 17057

Rev 10/11

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ALS Environmental
34 Dogwood Lane
Middletown, PA 17057
P. 717-944-5541
F.717-944-1430

CHAIN OF CUSTODY/ REQUEST FOR ANALYSIS

ALL SHADED AREAS MUST BE COMPLETED BY THE CLIENT / SAMPLER. INSTRUCTIONS ON THE BACK.

COC #:
ALS Quote #:
1of1

Client Name: ALS Environmental
Address: 34 Dogwood Lane
Middletown, PA 17057
Contact: Customer Service
Phone#: (717) 944-5541
Project Name/#:
Bill To: ALS Environmental
TAT: [x] Normal-Standard TAT is 10-12 business days. [ ] Rush-Subject to ALSI approval and surcharges.
Date Required: Approved By:
Email? [x] Y ALMDT.Subcontract@ALSGlobal.com
Fax? [ ] Y No:

Container Type: G
Container Size: 250
Preservative: NH4Cl

ANALYSES/METHOD REQUESTED: HAA (all 8 compounds are needed)

Sample Description/Location (as it will appear on the lab report)	Sample Date	Time	*G or C	**Matrix	HAA (all 8 compounds are needed)
2011706.001	6/10/14	1045	C	DW	1

Enter Number of Containers Per Sample or Field Results Below.

Receipt Information (completed by Receiving Lab)
Cooler Temp: ____ Therm ID: ____
No. of Coolers: ____ Y N Initial
Custody Seals Present?
(if present) Seals Intact?
Received on Ice?
COC/Labels Complete/Accurate?
Cont. In Good Cond.?
Correct Containers?
Correct Sample Volumes?
Correct Preservation?
Headspace/Volatiles?
Courier/Tracking #:

Sample/COC Comments
Sub to UL LLC
110 South Hill St
South Bend, IN 46617

ALS Field Services: __Pickup __Labor __Composite Sampling __Rental Equipment __Other:

Project Comments:
LOGGED BY(signature): DATE TIME
REVIEWED BY(signature): DATE TIME

Relinquished By / Company Name	Date	Time	Received By / Company Name	Date	Time
1 [signature] ALS	6/24	1710	2		
3			4		
5			6		
7			8		
9			10		

Data Deliverables: Standard, CLP-like, USACE
Special Processing: USACE, Navy
State Samples Collected In: NY, NJ, PA, NC
Reportable to PADEP? Yes
PWSID #:
Sample Disposal: Lab, Special
EDDS: Format Type-

* G=Grab; C=Composite **Matrix - AI=Air; DW=Drinking Water; GW=Groundwater; OI=Oil; OL=Other Liquid; SL=Sludge; SO=Soil; WP=Wipe; WW=Wastewater

ALS ENVIRONMENTAL SHIPPING ADDRESS: 34 DOGWOOD LANE, MIDDLETOWN, PA 17057

Rev 10/11

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Analytical Laboratory Service - Since 1964

CERTIFICATE OF ANALYSIS

Client:	ALS Environmental - PA 34 Dogwood Lane Middletown PA, 17057	**Report Date:**	07/06/14 12:50
		Received Date:	06/13/14 10:00
		Turn Around:	Normal
Attention:	Debra Musser	**Client Project:**	2011706
Phone:	(800) 794-7709		
Fax:	(717) 944-1430		
Work Order(s):	4F13012		

NELAP #04229CA ELAP#1132 NEVADA #CA211 HAWAII LACSD #10143

The results in this report apply to the samples analyzed in accordance with the Chain of Custody document. Weck Laboratories, Inc. certifies that the test results meet all NELAC requirements unless noted in the case narrative. This analytical report is confidential and is only intended for the use of Weck Laboratories, Inc. and its client. This report contains the Chain of Custody document, which is an integral part of it, and can only be reproduced in full with the authorization of Weck Laboratories, Inc.

Dear Debra Musser :

Enclosed are the results of analyses for samples received 06/13/14 10:00 with the Chain of Custody document. The samples were received in good condition, at 5.7 °C and on ice. All analysis met the method criteria except as noted below or in the report with data qualifiers.

Case Narrative:

Reviewed by:

Brandon Gee
Project Manager

Weck Laboratories, Inc 14859 East Clark Avenue. City of Industry, California 91745-1396 (626) 336-2139 FAX (626) 336-2634

WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 06/13/14 10:00
Date Reported: 07/06/14 12:50

ANALYTICAL REPORT FOR SAMPLES

Sample ID	Sampled by:	Sample Comments	Lab ID	Matrix	Date Sampled
2011706 001	Client		4F13012-01	Water	06/10/14 00:00

ANALYSES

DBPs by EPA 551.1

WECK LABORATORIES, INC.
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ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 06/13/14 10:00
Date Reported: 07/06/14 12:50

4F13012-01 **2011706 001**

Sampled: 06/10/14 00:00 **Sampled By:** Client **Matrix:** Water

DBPs by EPA 551.1

Method: EPA 551.1 Batch: W4F0944 Prepared: 06/17/14 14:19 Analyst: Juliet Chootipanya

Analyte	Result		MRL	Units	Dil	Analyzed	Qualifier
1,1,1-trichloro-2-propanone	ND		0.50	ug/l	1	06/19/14 22:50	
1,1-Dichloro-2-propanone	ND		0.50	ug/l	1	06/19/14 22:50	
Bromoacetonitrile	ND		0.50	ug/l	1	06/19/14 22:50	
Bromochloroacetonitrile	ND		0.50	ug/l	1	06/19/14 22:50	
Chloral hydrate	ND		0.50	ug/l	1	06/19/14 22:50	
Chloroacetonitrile	ND		0.50	ug/l	1	06/19/14 22:50	
Chloropicrin	ND		0.50	ug/l	1	06/19/14 22:50	
Dibromoacetonitrile	ND		0.50	ug/l	1	06/19/14 22:50	
Dichloroacetonitrile	ND		0.50	ug/l	1	06/19/14 22:50	
Trichloroacetonitrile	ND		0.50	ug/l	1	06/19/14 22:50	
Surr: Decafluorobiphenyl	*126 %*	Conc: *12.6*	*80-120*	%			*S-03*

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34 Dogwood Lane
Middletown PA, 17057

Date Received: 06/13/14 10:00
Date Reported: 07/06/14 12:50

QUALITY CONTROL SECTION

WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 06/13/14 10:00
Date Reported: 07/06/14 12:50

DBPs by EPA 551.1 - Quality Control

Batch W4F0944 - EPA 551.1

Analyte	Result	MRL	Units	Spike Level	Source Result	%REC	% REC Limits	RPD	RPD Limit	Data Qualifiers
Blank (W4F0944-BLK1)				Analyzed: 06/19/14 21:10						
1,1,1-trichloro-2-propanone	ND	0.50	ug/l							
1,1-Dichloro-2-propanone	ND	0.50	ug/l							
Bromoacetonitrile	ND	0.50	ug/l							
Bromochloroacetonitrile	ND	0.50	ug/l							
Chloral hydrate	ND	0.50	ug/l							
Chloroacetonitrile	ND	0.50	ug/l							
Chloropicrin	ND	0.50	ug/l							
Dibromoacetonitrile	ND	0.50	ug/l							
Dichloroacetonitrile	ND	0.50	ug/l							
Trichloroacetonitrile	ND	0.50	ug/l							
Surr: Decafluorobiphenyl	*10.4*		*ug/l*	*10.0*		*104*	*80-120*			
LCS (W4F0944-BS1)				Analyzed: 06/19/14 21:35						
1,1,1-trichloro-2-propanone	10.2	0.50	ug/l	10.0		102	75-125			
1,1-Dichloro-2-propanone	9.65	0.50	ug/l	10.0		96	75-125			
Bromoacetonitrile	10.1	0.50	ug/l	10.0		101	75-125			
Bromochloroacetonitrile	9.12	0.50	ug/l	10.0		91	75-125			
Chloral hydrate	9.79	0.50	ug/l	10.0		98	75-125			
Chloroacetonitrile	11.6	0.50	ug/l	10.0		116	75-125			
Chloropicrin	8.57	0.50	ug/l	10.0		86	75-125			
Dibromoacetonitrile	8.93	0.50	ug/l	10.0		89	75-125			
Dichloroacetonitrile	8.90	0.50	ug/l	10.0		89	75-125			
Trichloroacetonitrile	8.92	0.50	ug/l	10.0		89	75-125			
Surr: Decafluorobiphenyl	*10.3*		*ug/l*	*10.0*		*103*	*80-120*			
LCS Dup (W4F0944-BSD1)				Analyzed: 06/20/14 10:45						
1,1,1-trichloro-2-propanone	10.9	0.50	ug/l	10.0		109	75-125	6	25	
1,1-Dichloro-2-propanone	9.78	0.50	ug/l	10.0		98	75-125	1	25	
Bromoacetonitrile	9.70	0.50	ug/l	10.0		97	75-125	5	25	
Bromochloroacetonitrile	9.74	0.50	ug/l	10.0		97	75-125	7	25	
Chloral hydrate	8.50	0.50	ug/l	10.0		85	75-125	14	25	
Chloroacetonitrile	11.5	0.50	ug/l	10.0		115	75-125	0.9	25	
Chloropicrin	9.33	0.50	ug/l	10.0		93	75-125	8	25	
Dibromoacetonitrile	9.41	0.50	ug/l	10.0		94	75-125	5	25	
Dichloroacetonitrile	9.27	0.50	ug/l	10.0		93	75-125	4	25	
Trichloroacetonitrile	10.0	0.50	ug/l	10.0		100	75-125	12	25	
Surr: Decafluorobiphenyl	*10.3*		*ug/l*	*10.0*		*103*	*80-120*			

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WECK LABORATORIES, INC.
Analytical Laboratory Service - Since 1964

ALS Environmental - PA
34 Dogwood Lane
Middletown PA, 17057

Date Received: 06/13/14 10:00
Date Reported: 07/06/14 12:50

Notes and Definitions

S-03	High surrogate recovery for this sample is possibly due to a sample matrix effect . The data was accepted since all target analytes were not detected.
ND	NOT DETECTED at or above the Reporting Limit. If J-value reported, then NOT DETECTED at or above the Method Detection Limit (MDL)
NR	Not Reportable
Dil	Dilution
dry	Sample results reported on a dry weight basis
RPD	Relative Percent Difference
% Rec	Percent Recovery
Sub	Subcontracted analysis, original report available upon request
MDL	Method Detection Limit
MDA	Minimum Detectable Activity
MRL	Method Reporting Limit

Any remaining sample(s) will be disposed of one month from the final report date unless other arrangements are made in advance.

An Absence of Total Coliform meets the drinking water standards as established by the California Department of Health Services.

The Reporting Limit (RL) is referenced as the Laboratory's Practical Quantitation Limit (PQL) or the Detection Limit for Reporting Purposes (DLR).

All samples collected by Weck Laboratories have been sampled in accordance to laboratory SOP Number MIS002.