Ocean Water Desalination Water Quality Integration Bench-Scale Study

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THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

Metropolitan Water District of Southern California

Water Quality Section

Ocean Water Desalination

Water Quality Integration Bench-Scale Study

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EXECUTIVE SUMMARY

Introduction

The Ocean Water Desalination Water Quality Integration Bench-Scale Study was conducted by the Metropolitan Water District of Southern California (MWD) to support the effort by the West Basin Municipal Water District (WBMWD) to evaluate the feasibility of building ocean water desalination treatment facilities. This bench-scale study, in conjunction with pilot-scale studies conducted by Hazen and Sawyer on behalf of WBMWD, investigated potential water quality impacts of integrating desalinated ocean water into existing drinking water distribution systems in the WBMWD service area. The focus of this bench-scale study was chloramine residual stability and disinfectant byproduct (DBP) formation in the distribution system after integration of desalinated ocean water. The study objectives were to 1) develop methods to minimize chloramine decay in desalinated ocean water; 2) evaluate the impact of integrating desalinated ocean water in lieu of MWD water in various blends of source waters on chloramine stability and DBP formation and speciation; and 3) evaluate the effects of varying water quality parameters (temperature, pH, and bromide concentration in desalinated ocean water) on chloramine stability and DBP formation and speciation. The DBPs of interest in this study were trihalomethanes (THMs), haloacetic acids (HAAs), *N*-nitrosodimethylamine (NDMA), and iodinated DBPs: iodo-THMs and iodo-HAAs.

Study Approach

A simulated distribution system (SDS) test method was used in the bench-scale study to evaluate chloramine decay over time as well as DBP formation. Because the intent of WBMWD is to replace MWD water with disinfected corrosion-stabilized[1] desalinated ocean water (Desal) in parts of their distribution system, or potentially introduce Desal into MWD's distribution system, blends of Desal with groundwater (GW) from a WBMWD member agency and blends of Desal with MWD water were evaluated and compared to MWD/GW blends and MWD water only, respectively. In addition, because some agencies breakpoint chlorinate groundwater containing natural ammonia to free chlorine, both breakpoint chlorinated groundwater (GWbp) and non-breakpoint chlorinated groundwater blends were evaluated. Based on the current water supply operations of the WBMWD member agency selected for this study, the groundwater portion of both the Desal/groundwater blends and the MWD/groundwater blends comprised 75% of the blend. The Desal and MWD water blends were tested as 50/50 blends, as this is the projected highest potential Desal blend in an MWD pipeline.

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[1] All desalinated ocean water was passed through a calcite filter to add 65–80 mg/L alkalinity as $CaCO_3$.

The SDS tests were used to evaluate chloramine decay and to compare the relative chloramine decay and DBP formation in various source water blends at pH 8.2 and 25 °C with lower bromide Desal (0.23–0.28 mg/L). Additional tests were conducted to determine the effects of raising the pH to 8.6, dropping the temperature to 10 °C, or increasing the Desal bromide level to 0.49 mg/L. The temperature conditions represent the minimum and maximum temperature for MWD's plant effluents. The two pH conditions were selected because pH 8.2 is typical of that in the distribution system and pH 8.6 is the highest level in the MWD's distribution system, thus far. The bromide levels were selected based on current WBMWD desalination demonstration plant operation, which could maintain bromide levels under 0.3 mg/L during this study, and the assumption that as seawater reverse osmosis (SWRO) membranes age, salt rejection through the membranes will decrease.

The DBP formation tests evaluated the effect of varying the above-mentioned water quality parameters in the different blends of source waters on the formation and speciation of THMs, HAAs, NDMA (and other nitrosamines), iodo-THMs, and iodo-HAAs. Because a study conducted by the Long Beach Water Department showed that blends of desalinated ocean water and groundwater had lower DBPs than groundwater on the third day, but were higher in blends on the fifth day (Tseng et al, 2005), both 3- and 7-day SDS tests were conducted for the DBP analyses.

This study was conducted in two phases. In Phase I, a possible method for stabilizing the chloramine residual in corrosion-stabilized Desal water was developed and the chloramine decay in various blends and water quality conditions was evaluated. Phase II repeated the 25 °C test conditions from Phase I and DBP formation was evaluated. The test matrix is presented in Table ES-1.

Table ES-1. Phase I and Phase II Bench-Scale Test and Sampling Matrix

	Test Conditions				Sampling Matrix	
Test Number	***Target Desal Bromide (mg/L)***	***pH***	***Temp (°C)***	***Blend (%) Desal/MWD/GW/GWbp***	***Phase I Disinfectant Stability Test***	***Phase II DBP Test***
1a	0.3	8.2	25	100/0/0/0	pH (t_{initial} & t_{final} only)	THMs (3 & 7 days)
1b				0/100/0/0	Total Chlorine*	HAA9 (3 & 7 days)
1c				50/50/0/0	Total Ammonia*	Iodo-THMs (7 days)
1d				0/25/75/0	Free Ammonia	Iodo-HAAs (7 days)
1e				25/0/75/0	(t_{initial} & t_{final} only)	Nitrosamines (7 days)
1f				0/25/0/75	Nitrite	
1g				25/0/0/75	(t_{initial} & t_{final} only)	
1h				50/25/25/0†		
1i				50/25/0/25†		
1j				100/0/0/0†		
2a	0.3	8.6	25	100/0/0/0	pH (t_{initial} & t_{final} only)	THMs (3 & 7 days)
2b				0/100/0/0	Total Chlorine*	HAA9 (3 & 7 days)
2c				50/50/0/0	Total Ammonia*	
2d				25/0/75/0	Free Ammonia	
2e				25/0/0/75	(t_{initial} & t_{final} only)	
					Nitrite	
					(t_{initial} & t_{final} only)	
3a	0.3	8.2	10	100/0/0/0	pH (t_{initial} & t_{final} only)	
3b				0/100/0/0	Total Chlorine*	
3c				50/50/0/0	Total Ammonia*	
3d				25/0/75/0	Free Ammonia	
3e				25/0/0/75	(t_{initial} & t_{final} only)	
					Nitrite	
					(t_{initial} & t_{final} only)	
4a	0.3	8.6	10	100/0/0/0	pH (t_{initial} & t_{final} only)	
4b				0/100/0/0	Total Chlorine*	
4c				50/50/0/0	Total Ammonia*	
4d				25/0/75/0	Free Ammonia	
4e				25/0/0/75	(t_{initial} & t_{final} only)	
					Nitrite	
					(t_{initial} & t_{final} only)	
5a	0.5	8.2	25	100/0/0/0	pH (t_{initial} & t_{final} only)	THMs (3 & 7 days)
5b				0/100/0/0	Total Chlorine*	HAA9 (3 & 7 days)
5c				50/50/0/0	Total Ammonia*	Iodo-THMs (7 days)
5d				25/0/75/0	Free Ammonia	Iodo-HAAs (7 days)
5e				25/0/0/75	(t_{initial} & t_{final} only)	Nitrosamines (7 days)
					Nitrite	
					(t_{initial} & t_{final} only)	

*Total chlorine and total ammonia were analyzed at the following times: 0, 1†, 2†, and 4† hours, and 1, 2†, 3, 4†, and 7 days.

† Phase I only

Target chloramine was 2.5 mg/L except for MWD water and blends containing MWD water. MWD water was used as-is, without chlorine or ammonia adjustment prior to blending with other water sources.

Results

Stabilization of Desalinated Ocean Water Initial Chloramine Demand

The first objective of the Phase I tests was to determine the chlorine and ammonia dosages, and the detention time required to minimize chloramine decay in the desalinated ocean water. Figure ES-1 depicts the chloramine decay trend for the desalinated ocean water at pH 8.2 and 25 °C. The total chloramine decay of the desalinated ocean water became substantially reduced after 5 hours of incubation. The rate was reduced from 0.27 mg/L/hr in the first hour of incubation to 0.06 mg/L/hr after 4 hours, and 0.02 mg/L/hr after 5 hours of incubation. Although a 6-hour detention time was considered for the finished water reservoir in the WBMWD full-scale desalination plant preliminary master plan time constraints during the bench-scale testing limited the hold time to 4 hours. This was determined to be acceptable for the bench-scale tests based on the greatly reduced decay rate after 4 hours. For a full-scale ocean water desalination plant, corrosion-stabilized Desal should be pretreated with chlorine and ammonia, held for at least 5 hours, then the chloramine residuals should be boosted back up to target levels prior to blending with other source waters.

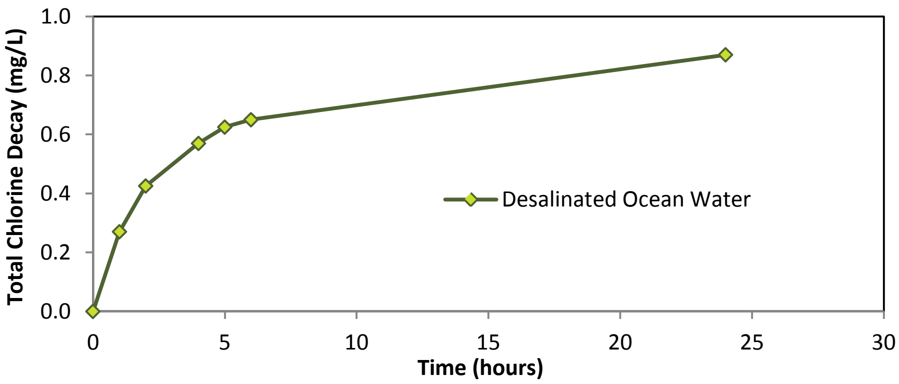


Figure ES-1. Chloramine Decay Curve for Corrosion Stabilized Desalinated Ocean Water (pH 8.2 and 25 °C) with initial target chloramine residual of 2.5 mg/L

Summary of Chloramine Stability Tests

The Phase I tests compared the chloramine decay rates of various source water blends, assessed the effects of pH (8.6 vs 8.2), temperature (10 °C vs 25 °C) and Desal bromide levels (0.49 mg/L vs 0.25 mg/L), resulting in the following findings:

1. In general, under the various test conditions evaluated in this study, the relative ranking of blend stability from most to least stable in the 7-day SDS tests were as follows:
    i. MWD (Test water had gone through decay in the distribution system)
    ii. 25% Desal/75% GW; 50% Desal/25% MWD/25% GW; 50% Desal/50% MWD; and 25% MWD/75% GW
    iii. 50% Desal/25% MWD/25% GWbp
    iv. 25% Desal/75% GWbp; Desal; and 25% MWD/75% GWbp

2. Raising the pH from 8.2 to 8.6 had mixed results on the chloramine decay rates in the various source water blends. Changes in the MWD water and in 50% Desal/50% MWD blend were not significant. Slight decreases in chloramine decay were achieved in the 25% Desal/75% GW blend, and in the Desal water at 10 °C. Increases in chloramine decay were obtained in the Desal at 25 °C and in the 25% Desal/75% GWbp samples at both temperatures.
3. Lowering the water temperature from 25 to 10 °C decreased the chloramine decay in all test conditions. Decay rates in the various blends dropped by 0.12–0.80 mg/L after 7 days, with the greatest decreases observed in the Desal tests.
4. Increasing the Desal bromide levels from 0.25 to 0.49 mg/L had little effect on the chloramine stability of the Desal/MWD or the Desal/GW blends, but did increase the chloramine decay in the Desal and the Desal/GWbp tests. Increases in decay after 7 days were 0.18 mg/L in the Desal and 0.33 mg/L in the Desal/GWbp blend.

Summary of DBP Formation Tests

The Phase II SDS tests compared DBP formation in various source water blends, assessed the effects of Desal bromide levels (0.22 vs 0.49 mg/L), and examined the effects of increasing pH from 8.2 to 8.6 on THM and HAA formation and speciation. The results are as follows:

1. Relative ranking of THM formation in the various source water blends from lowest to highest are:
    i. Desal
    ii. 25% Desal/75% GW
    iii. 25% MWD/75% GW
    iv. 50%Desal/50% MWD
    v. MWD
    vi. 25% Desal/75% GWbp
    vii. 25% MWD/75% GWbp
2. The THMs and HAAs for all of the blends on days 3 and 7 were well below their respective maximum contaminant levels (MCLs) of 80 and 60 µg/L.
3. Little difference was observed in the THM or HAA levels measured on day 3 versus day 7.
4. Substitution of MWD water with desalinated ocean water would likely decrease distribution system THMs, HAAs, iodo-THMs, and iodo-HAAs.
5. Raising the pH from 8.2 to 8.6 had little impact on THM and HAA formation.
6. Increases in Desal bromide levels from 0.22 to 0.49 mg/L had little impact on THM, HAA, NDMA, and iodo-THM formation and speciation. Increasing the bromide in the Desal water by 0.27 mg/L resulted in small bromide increases of 0.14 mg/L in the 50% Desal/50% MWD blend and only 0.07 mg/L bromide in the 25% Desal/75% GW and 25% Desal/75% GWbp blends.

7. Very low levels of NDMA were formed (< 5 ng/L), and the integration of desalinated ocean water in lieu of MWD would not increase NDMA levels in the water blends tested.
8. Iodo-THMs were not detected in the Desal water; the highest levels were found in the groundwater blends due to the relatively high iodide concentration (41 µg/L) in the groundwater.
9. Very low levels of iodo-HAAs were detected in the Desal water; the highest levels were found in the groundwater blends due to the relatively high iodide concentration (41 µg/L) in the groundwater.

Conclusions

This bench-scale study established a possible method for post-treatment stabilization of desalinated ocean water to maintain a stable chloramine residual; evaluated the impact of integrating desalinated ocean water in lieu of MWD water in various blends of source waters on chloramine stability and DBP formation and speciation; and evaluated the effects of varying temperature, pH, and bromide concentration on chloramine stability and DBP formation and speciation. The lessons learned from this SDS testing are summarized below.

1. <u>Post-Treatment Stabilization.</u> The strategy used in this study was to chloraminate corrosion-stabilized desalinated ocean water, provide an initial disinfectant decay period for 4 hours, and then boost the chlorine and ammonia back up to desired levels. This mitigated much of the rapid chloramine decay rates in the SDS tests. The recommendation is that the full-scale desalination facility design incorporates a chloramine contact time of at least 5 hours with subsequent chlorine and ammonia feed systems to stabilize chloramine residual prior to distribution of the desalinated ocean water.

2. <u>Chloramine Stability.</u> The chloramine residual decayed more quickly in the desalinated ocean water than in the MWD water because the MWD water had already undergone chloramine decay period prior to sampling. This made the MWD water inherently more stable than the other water blends in the chloramine stability tests. Despite this advantage, the chloramine stability tests indicated that there was very little difference in chloramine decay rates between blends with desalinated ocean water versus the same blends with MWD water. This same result was obtained with lower bromide (0.25 mg/L) and higher bromide (0.49 mg/L) desalinated ocean water. Thus, in the artificial environment of SDS testing, with clean glassware, no biofilms, and no corrosion scale, the integration of desalinated ocean water in lieu of MWD water when blended 50/50 with MWD water and 25/75 with non-breakpoint chlorinated or breakpoint chlorinated groundwater, had little impact on chloramine stability. However, changing source waters can have a dramatic impact on older corroded piping and biofilms, causing destabilization of metals, colored water, and loss of disinfectant

residual. Therefore, it is of critical importance to examine the results of the pipe loop study conducted with harvested distribution piping.

In all of the chloramine stability tests, the order of stability, ranked from most stable to least stable was generally: MWD > blends with non-breakpoint chlorinated groundwater > Desal > blends with breakpoint chlorinated groundwater. As previously mentioned, the MWD test water had already undergone chloramine decay in the distribution system when it was collected, affording it greater stability in these tests. High ammonia levels in the non-breakpoint chlorinated groundwater stabilized the chloramine residual in the GW blends. Once the GW was breakpoint chlorinated, there was no free ammonia to stabilize the residual and the relatively high organics and high bromide levels increased chloramine decay in the GWbp blends. It is important to note that even though these SDS tests showed that non-breakpoint chlorinated groundwater blends experienced low levels of chloramine decay, this may not be true in the distribution system. High levels of free ammonia in the distribution system can promote the growth of ammonia oxidizing bacteria and result in nitrification and subsequent rapid loss of disinfectant residual.

Overall chloramine decay for all conditions and blends ranged from 0.02–0.97 mg/L on day 1, 0.11–1.18 mg/L on day 3, and 0.22–1.47 mg/L after 7 days in the SDS tests. Higher decay rates are anticipated in the distribution system due to the chloramine demand exerted by piping and biofilms.

Temperature effects. Chloramine decay rates decreased at lower temperatures. A decrease in temperature from 25 to 10 °C reduced chloramine decay in the various blends by 0.06–0.54 mg/L on day 1, 0.07–0.67 on day 3, and 0.12–0.80 mg/L over the course of the 7-day SDS tests. Thus, the distribution system chloramine residuals can be expected to be significantly more stable in the cooler winter months than in the summer.

pH effects. Increasing pH from 8.2 to 8.6 after the addition of chlorine and ammonia had mixed results, but overall very little impact on chloramine decay. Chloramine decay was relatively unchanged in the MWD water and decreased slightly in the 50% Desal/50% MWD and in the 25% Desal/75% GW. In contrast, the decay increased slightly in the 25% Desal/75% GWbp and in the 25 °C Desal tests. This unexpected result indicates that a pH increase from 8.2 to 8.6 after the formation of chloramines may not be a good tool to increase chloramine stability – particularly in systems that breakpoint chlorinate.

3. <u>DBP formation.</u> With the exception of NDMA, the integration of desalinated ocean water with MWD water and both non-breakpoint chlorinated and breakpoint chlorinated groundwater had a beneficial impact on regulated and unregulated DBP formation in the SDS tests. Due to low levels of organic DBP precursors, very low levels of regulated THMs, HAAs, NDMA, and iodo-HAAs were formed and no detectable level of iodo-THMs

were formed in desalinated ocean water. Increasing the desalinated ocean water bromide from 0.22 to 0.49 mg/L had little impact on DBP formation, except for one suspect result where the 25% Desal/75% GWbp formed much greater iodo-HAAs at the higher bromide level. Blending desalinated ocean water with other water sources provided a dilution effect on all DBP concentrations with the exception of NDMA. The highest NDMA formation was in the 50% Desal/50% MWD blend. However, the NDMA concentration was below 4.5 ng/L in all blends of source waters, well below the CDPH notification level of 10 ng/L.

Overall, the levels of all DBPs were low, and all regulated DBPs were well below drinking water MCLs. Examination of THMs and HAAs demonstrated little DBP increase from day 3 to day 7 of the SDS test, as DBP formation was rapid. Blends with breakpoint chlorinated groundwater formed the highest THMs, HAAs, iodo-THMs, and iodo-HAAs due to the presence of organic precursors, bromide, and iodide. Finally, increasing pH from 8.2 to 8.6 had little impact on THM or HAA9 formation.

Section 1. INTRODUCTION

The West Basin Municipal Water District (WBMWD) is evaluating the feasibility of ocean water desalination to diversify their drinking water supply portfolio. As part of the evaluation, WBMWD, in partnership with the Metropolitan Water District of Southern California (MWD), conducted the Ocean Water Desalination Water Quality Integration Study to investigate the potential water quality impacts of integrating desalinated ocean water into existing drinking water distribution systems in the WBMWD service area. This report summarizes the findings for the subject bench-scale study.

Background

Distribution System Description and Operations

MWD is a consortium of 26 cities and water districts serving 19 million people in six counties in southern California. WBMWD is one of MWD's member agencies and provides drinking water to its 185-square mile service area in southwest Los Angeles County. WBMWD wholesales treated imported water purchased from MWD to California Water Service Company, city of Manhattan Beach, city of El Segundo, and Golden State Water Company Southwest District.

West Basin Municipal Water District Distribution System and Operations—The drinking water distribution systems in the WBMWD service area currently transport blends of MWD water and various local groundwater sources. The quality of the groundwater in this area varies. A brief water quality survey of groundwater shows some areas with high total dissolved solids (TDS) and bromide levels, possibly due to seawater intrusion. Additionally, the total ammonia level in the groundwater varies, ranging from 0.1 to 1.6 milligrams per liter (mg/L) of ammonia as nitrogen (NH_3-N) and the total organic carbon (TOC) ranges from 0.2 to 2.5 mg/L. Finally, the manganese level in the groundwater in some areas is relatively high, ranging from 10 to 200 micrograms per liter (µg/L).

WBMWD member agencies utilize different treatment strategies for disinfection. Some of the WBMWD member agencies breakpoint chlorinate their groundwater to free chlorine before adding ammonia to form chloramine and blending with MWD water. Others only dose chlorine to boost the total chlorine residual before or after blending with MWD water. WBMWD plans to replace some of the MWD water in its distribution system with desalinated ocean water upon the completion of an ocean water desalination facility. Initial injection locations are anticipated to be within WBMWD's distribution system. However, future expansion into MWD's distribution system has been discussed. The point(s) of introduction of the desalinated ocean water has not yet been determined.

Metropolitan Water District of Southern California Distribution System and Operations—MWD owns and operates five water treatment plants: the Robert B. Diemer (Diemer), Joseph Jensen (Jensen), Henry J. Mills (Mills), Robert A. Skinner (Skinner), and F. E. Weymouth (Weymouth) water treatment plants. The two primary raw water sources for the treatment plants are Colorado River water (CRW) and State Project water (SPW). The Jensen and Mills plants treat SPW exclusively, while the Diemer, Skinner, and Weymouth plants treat blends of SPW and CRW. Three of MWD's treatment plants currently serve the Central Pool service area: the Jensen plant in Granada Hills, the Weymouth plant in La Verne, and the Diemer plant in Yorba Linda. The Central Pool service area covers the major population centers of Los Angeles and Orange counties (including WBMWD service area), southern Ventura County, and southwestern San Bernardino County. The service connections in the Central Pool service area can receive water from any one of the three treatment plants or any combination of the three. However, WBMWD service connections typically receive water from the Jensen or Weymouth plants.

MWD uses chloramines to maintain disinfectant residual in the distribution. MWD's target chloramine residual leaving the treatment plants is 2.5 mg/L. In order to minimize chloramine decay in the distribution system due to nitrification, MWD's distribution system goals are to maintain a total chlorine residual of at least 1.8 mg/L and to keep nitrite levels under 0.010 mg/L at all service connections at all times.

Distribution System Integration Challenges

In addition to reviewing current published seawater desalination literature, MWD evaluated five case studies of seawater reverse osmosis plants (Gabelich & Scott, 2012). Based on these reviews, several potential water quality issues associated with the integration of desalinated seawater into existing potable water distribution systems were identified. These include: 1) increases in bromide, boron, and chloride concentrations; 2) decrease in disinfectant stability; and 3) increases in disinfection byproduct (DBP) formation, *N*-nitrosodimethylamine (NDMA) formation, and corrosion. This bench-scale study conducted by MWD specifically addressed the potential impact of the integration of desalinated seawater on the stability of distribution system chloramine residuals and the formation of DBPs, including NDMA. These issues are discussed below.

Chloramine Stability—In order to meet regulatory disinfection requirements, desalinated ocean water will require disinfection with free chlorine. Ammonia must then be added to form chloramine prior to pumping into the distribution system(s). The target chloramine residual and chlorine-to-ammonia ratios of the desalinated ocean water will match MWD's distribution system target levels of 2.5 mg/L of total chlorine and chlorine-to-ammonia as nitrogen ratio (Cl_2:NH_3-N) of five to one. Previous studies of desalinated ocean water have indicated that elevated bromide concentrations associated with seawater quickly react with free chlorine to form hypobromous acid, which represents a source of chlorine demand (Tseng et al., 2005 and Le Goulellec et al., 2006). Furthermore, when ammonia is subsequently added, bromamines will form in addition to chloramines. Because dibromamine is very reactive as compared to chloramines, it decomposes rapidly, resulting in an unstable disinfectant residual. To ensure distribution system water quality and regulatory compliance, the disinfectant residual must be stabilized such that it will not cause a rapid decay of disinfectant within the distribution system. Recent studies suggest that bromide concentrations of less than 0.3 mg/L in the desalinated ocean water may reduce the problems associated with disinfectant stability and DBP formation (Separation Processes, Inc. & CDM, 2009). If decay issues persist, provision of a stabilization period (3–8 hours) may be required to reduce disinfectant issues by ensuring near complete decay of the bromamines prior to pumping into the distribution system.

Disinfection Byproducts—The Stage 1 and Stage 2 Disinfectants/Disinfection Byproduct (D/DBP) rules established by the US Environmental Protection Agency (USEPA) currently regulate four trihalomethanes (THMs) (chloroform [$CHCl_3$], bromoform [$CHBr_3$], bromodichloromethane [$CHBrCl_2$], and dibromochloromethane [$CHClBr_2$]) and five haloacetic acids (HAA5) (monochloroacetic acid [MCAA], dichloroacetic acid [DCAA], trichloroacetic acid [TCAA], monobromoacetic acid [MBAA], and dibromoacetic acid [DBAA]). Because reverse osmosis (RO) membranes remove a substantial amount of the natural organic matter that reacts with chlorine to form these THMs and HAA5, seawater reverse osmosis (SWRO) treatment results in very low regulated DBP concentrations. However, waters high in bromide that are blended with water containing organics will continue to form DBPs with increasing water age in the distribution system. When desalinated ocean water is blended with surface water containing TOCs, dibromamine and hypobromous acid will react with the TOCs to form brominated DBP. Studies conducted at Long Beach Water District and Santa Cruz Water District have demonstrated that the blending of low DBP, higher bromide (more than 0.3 mg/L) desalinated ocean water with distribution system water increased the DBPs in the blended water above that of the original distribution system water after 5 days (Tseng et al., 2005 and CDM, 2010). Additionally, the presence of bromide and iodide typically found in SWRO permeate will shift the types of DBPs found in the water toward currently unregulated brominated and iodated compounds.

Unregulated DBPs—Approximately 600 to 700 DBPs have been reported in the literature (Richardson, 2002); however, at present, only nine such species are regulated. Many of the currently unregulated DBPs may become regulated in the future, and it is therefore prudent to understand the byproduct formation potential of unregulated compounds as well. Chloramines are less reactive than free chlorine, and are therefore less susceptible to decay and formation of THMs and HAA5. The exception to this rule is when moderate to high amounts of bromide and/or iodide are present in the water to be treated with chloramine. With chloramination, dihalogenated acetic acids become more prevalent relative to chlorination and the speciation tends towards brominated and iodinated compounds. In addition to the regulated DBPs, HAA9 (the sum of MCAA, DCAA, TCAA, MBAA, DBAA, tribromoacetic acid [TBAA], bromochloroacetic acid [BCAA], bromodichloroacetic acid [BDCAA], and dibromochloroacetic acid [CDBAA]), iodoacetic acid (iodo-HAAs), iodo-THMs, haloamide, haloaldehyde, and 3-chloro-4-

(dichloromethyl)-5-hydroxy-2(5H)-furanone (MX)/brominated MX (BMX) formation are potential issues for water high in bromide and iodide when disinfected with chloramines (Foellmi, 2007).

NDMA—Recent studies conducted at MWD indicate that increases in bromide from 0.1 to 0.3 mg/L result in increased formation of another unregulated chloramine disinfection byproduct: *N*-nitrosodimethylamine (NDMA) (Yates, 2010). NDMA has received increased scrutiny in the past few years as it is considered by both the USEPA and the California Department of Public Health (CDPH) to be a probable human carcinogen. Although there is currently no MCL, it is a likely candidate for future regulations. NDMA currently has a CDPH notification level of 10 nanograms per liter (ng/L) and a public health goal of 0.003 µg/L set by the California State Office for Environmental Health Hazard Assessment. Quarterly sampling of MWD's system from 2006–2008 shows that NDMA is present in the effluents of the treatment plants at levels ranging from < 2 to 8.3 ng/L, with median values for each plant ranging from < 2 to 2.50 ng/L (Liang et al, 2009). Therefore, any changes in the system that could potentially increase NDMA formation in the distribution system must be carefully evaluated prior to implementation.

Objectives

The objectives of this bench-scale study were to 1) develop methods for post-treatment stabilization of desalinated ocean water to maintain a stable chloramine residual; 2) evaluate the impact of integrating desalinated ocean water in lieu of MWD water in various blends of source waters on chloramine stability and DBP formation and speciation; and 3) evaluate the effects of varying water quality parameters (temperature, pH, and bromide concentration in desalinated ocean water) on chloramine stability and DBP formation and speciation.

Report Organization

Section 2 presents the study approach, bench-scale apparatus, and test plan. Section 3 discusses source water quality throughout the test period. Section 4 and Section 5 cover chloramine stability and disinfection byproducts results, respectively. Finally, a summary and conclusions of the study are provided in Section 6.

Section 2. METHODS AND MATERIALS

Study Approach

Because desalinated ocean water may replace the MWD water currently served to WBMWD's subagencies, it is important to understand the impact of this source water change on chloramine stability and DBP formation. Since some subagencies breakpoint chlorinate to free chlorine while others do not, it is also important to understand the impact of blending desalinated ocean water with breakpoint chlorinated groundwater and non-breakpoint chlorinated groundwater on chloramine stability and DBP formation. Finally, since desalinated ocean water may be introduced into MWD's distribution system, examination of a blend of 50% desalinated ocean water/50% MWD water for chloramine stability and DBP formation was also warranted.

A simulated distribution system (SDS) test method was used in this bench-scale evaluation to compare the relative chloramine decay and DBP formation in various source water blends. In addition, the effects of temperature, pH, and desalinated ocean water bromide concentration on chloramine stability and DBP formation were evaluated. The conditions selected for this study were temperatures of 10 and 25 °C; pH levels of 8.2 and 8.6, and target bromide concentrations in the desalinated ocean water of 0.3 and 0.5 mg/L. The temperature conditions represent the minimum and maximum temperature for MWD's plant effluents. The two pH conditions were selected because pH 8.2 is typical of that in the distribution system and pH 8.6 is the highest pH in the MWD's distribution system thus far. At Metropolitan, maintaining a higher pH is both a corrosion control method and a strategy to minimize chloramine decay in the distribution system. In order to provide effective corrosion control, the plant effluent pH and Langelier saturation index (LSI) have been maintained at a minimum of 8.0 and +0.1, respectively. The bromide concentrations evaluated were based on SWRO membrane performance. Under current operation, the WBMWD desalination demonstration plant can maintain bromide levels under 0.3 mg/L. However, as SWRO membranes age, salt rejection through the membranes decreases, resulting in elevated bromide concentrations. In addition, different percentages of second pass permeate can be used to tailor the desalination plant effluent water quality. For these reason, a higher bromide concentration (0.5 mg/L) was also tested.

The DBP formation tests evaluated the effect of varying the above-mentioned water quality parameters for the different blends of source waters on THMs, HAAs, NDMA (and other nitrosamines), iodo-THMs, and iodo-HAAs formation and speciation. Because a study conducted by the Long Beach Water Department showed that blends of desalinated ocean water and groundwater had lower DBP than groundwater after 3 days, but were higher in blends after 5 days (Tseng et al., 2005), both 3- and 7-day SDS tests were conducted for the DBP analyses.

This study was conducted in two phases, as information from the first phase was required to determine the conditions for further testing in the second phase. The first phase of testing was designed to compare the chloramine stability in various source waters. In the second phase, DBP formation was evaluated, repeating the 25 °C test conditions from Phase I, as these conditions were expected to produce the most DBPs. The detailed test plans for Phase I and Phase II are shown in Appendix A.

Source Waters

Corrosion Stabilized Desalinated Ocean Water

Corrosion stabilized desalinated ocean (Desal) water was obtained from the West Basin Ocean Water Desalination Demonstration Facility in Redondo Beach, California (Figure 2-1). The combined first and second pass RO permeate was treated with acid and calcite and collected in a 500-gallon stabilization tank as shown in Figure 2-2. The higher target bromide concentration of 0.5 mg/L was achieved by varying the volumetric proportion of the first pass RO permeate in the blend. The desalinated ocean water was sampled prior to chlorine and ammonia addition. The sample tap was flushed for several minutes until the temperature of the water was stable before samples were collected. Desalinated ocean water samples were collected in amber glass bottles and stored in the refrigerator until use (less than two weeks).

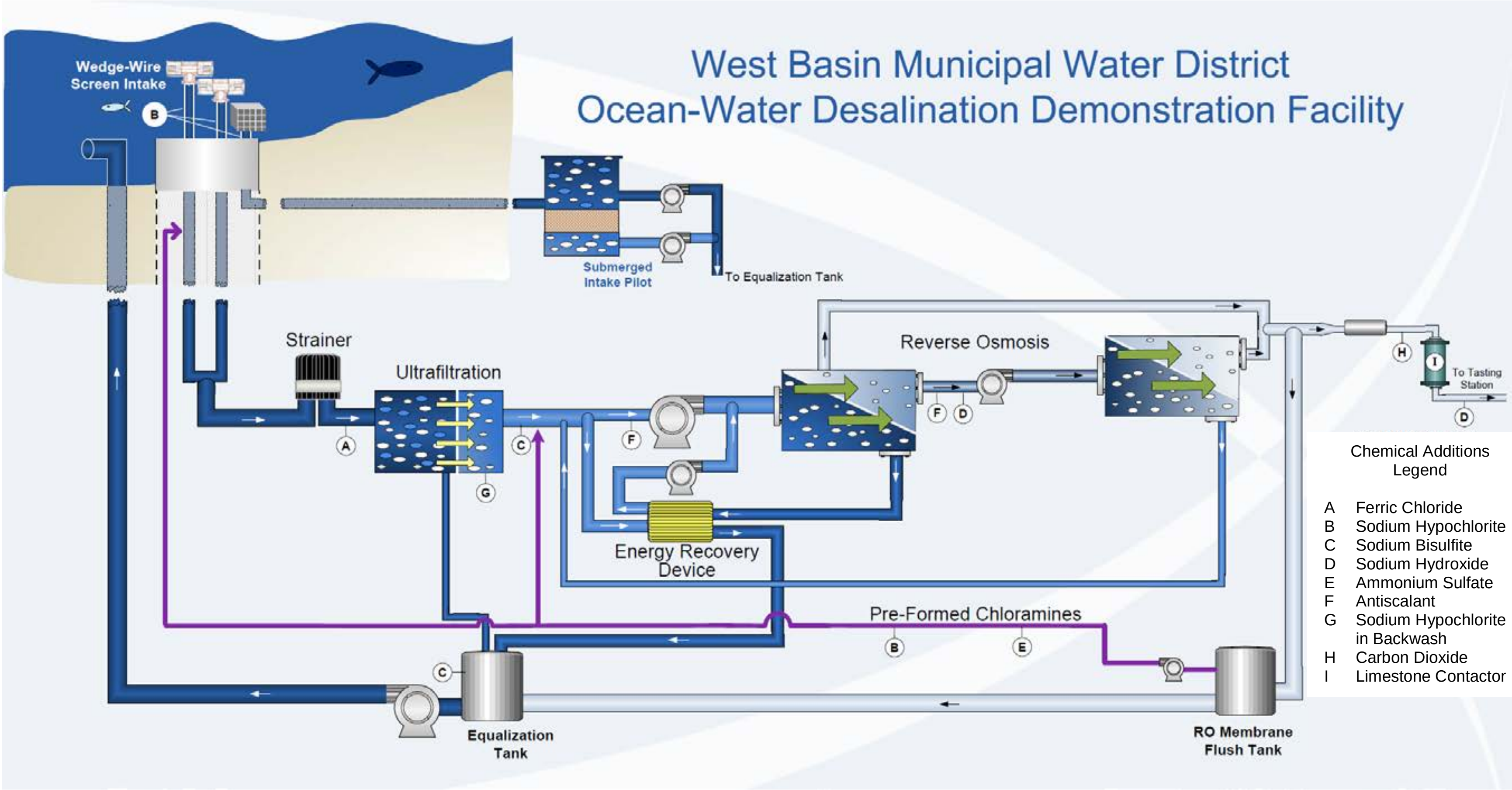


Figure 2-1. Process Flow Diagram for West Basin Ocean Water Desalination Demonstration Facility

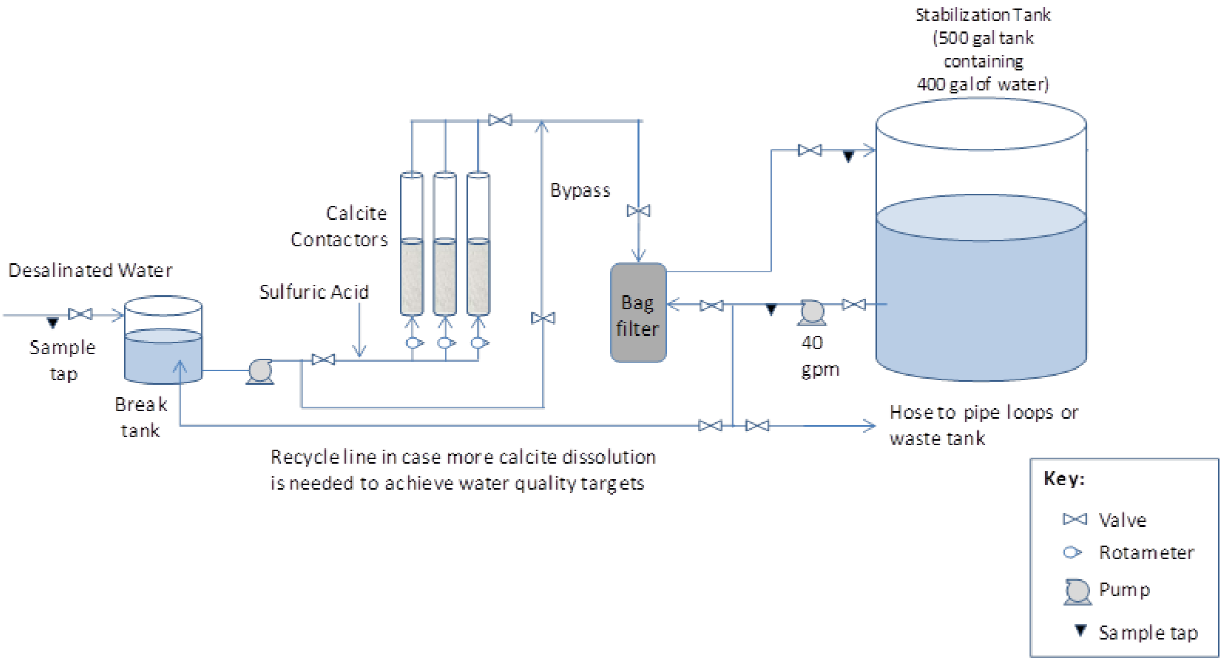


Figure 2-2. Process Flow Diagram for SWRO Permeate Stabilization Process

MWD Water

MWD water was collected from the distribution system at service connection WB-4 (Figure 2-3), located on the West Basin Feeder in the city of Manhattan Beach. This location was selected because it provided water samples that were representative of MWD's distribution system water quality in the WBMWD service area. MWD samples were collected on the day of testing in amber glass bottles and were used as-is, without chlorine or ammonia adjustment prior to blending with other source waters. This provided the best simulation of potential blend conditions. The sample tap was flushed until the temperature of the water was stable before samples were collected from the tap.

Since either Weymouth or Jensen plants may supply the WB-4 connection, the conductivity of the water from WB-4 was measured to determine which plant was supplying the service connection. Throughout the entire bench-scale study, water samples from WB-4 came from the Weymouth plant, which could either be direct Weymouth plant effluent or have passed through the Garvey Reservoir in Monterey Park where the total chlorine residual would have been boosted to 2.5 mg/L. Weymouth plant was treating 85% CRW and 15% SPW throughout the study period.

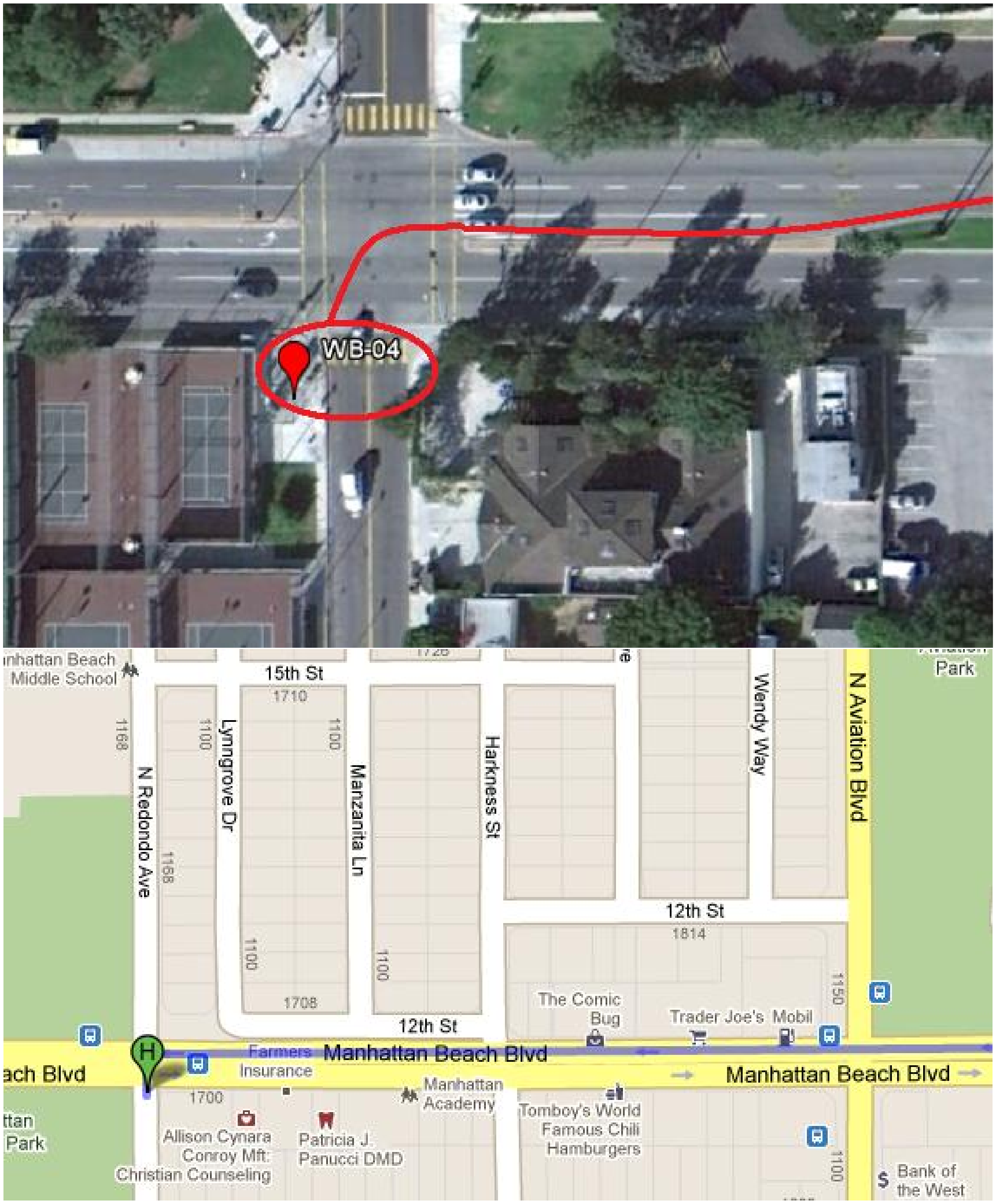


Figure 2-3. Service Connection WB-4 (Surface Map)

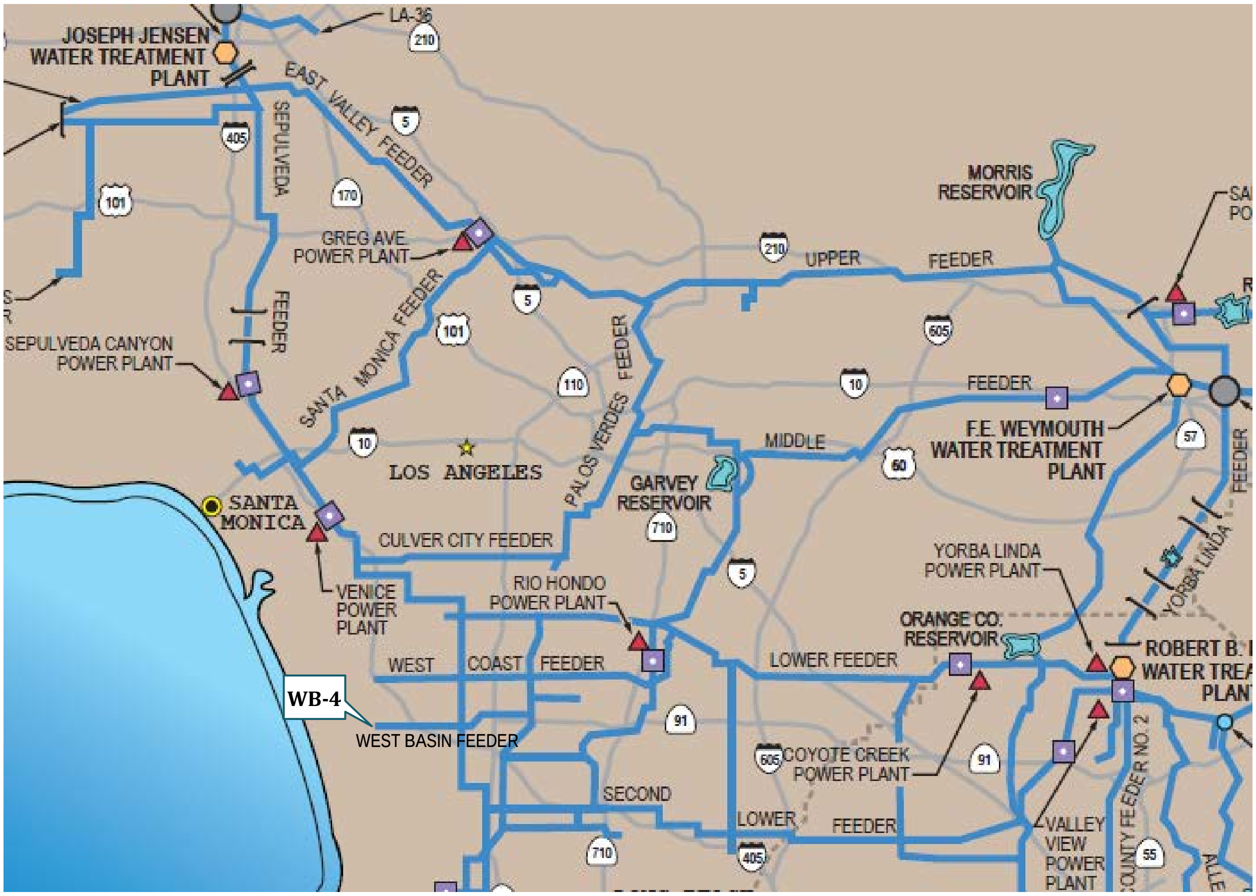


Figure 2-4. Service Connection WB-4 (Satellite Map)

Groundwater

Groundwater (GW) samples were collected from a WBMWD member agency well that is operated intermittently. This well was selected because the groundwater here has a higher range of bromide, TDS, ammonia, and relatively high TOC, which represents a worst-case condition. This WBMWD member agency generally blends MWD water with a maximum of 75% groundwater, mainly to dilute the high groundwater manganese concentrations to below the secondary MCL of 0.05 mg/L. After blending, chlorine is dosed to boost the total chlorine residual. They do not practice breakpoint chlorination. Due to presence of high ammonia concentration in the groundwater, free ammonia is present even after the addition of chlorine.

Groundwater samples were collected directly from the well prior to disinfection. The groundwater sample was collected in amber glass bottles on the day of the testing. Before the sample was collected, the sample line was flushed until the water temperature was stable.

Test Matrix

Table 2-1 provides the test conditions and sampling matrix for Phase I and Phase II. The blends represent various potential combinations that may exist in the distribution system when a full-scale desalination plant is operational. Throughout this report, MWD water is referred to as MWD, desalinated ocean water is referred to as Desal, non-breakpoint chlorinated groundwater is referred to as GW, and breakpoint chlorinated groundwater is referred to as GWbp.

Table 2-1. Phase I and Phase II Bench-Scale Test and Sampling Matrix

	Test Conditions				Sampling Matrix	
Test Number	***Target Desal Bromide (mg/L)***	***pH***	***Temp (°C)***	***Blend (%) Desal/MWD/GW/GWbp***	***Phase I Disinfectant Stability Test***	***Phase II DBP Test***
1a	0.3	8.2	25	100/0/0/0	pH ($t_{initial}$ & t_{final} only)	THMs (3 & 7 days)
1b				0/100/0/0	Total Chlorine*	HAA9 (3 & 7 days)
1c				50/50/0/0	Total Ammonia*	Iodo-THMs (7 days)
1d				0/25/75/0	Free Ammonia	Iodo-HAAs (7 days)
1e				25/0/75/0	($t_{initial}$ & t_{final} only)	Nitrosamines (7 days)
1f				0/25/0/75	Nitrite	
1g				25/0/0/75	($t_{initial}$ & t_{final} only)	
1h				50/25/25/0†		
1i				50/25/0/25†		
1j				100/0/0/0†		
2a	0.3	8.6	25	100/0/0/0	pH ($t_{initial}$ & t_{final} only)	THMs (3 & 7 days)
2b				0/100/0/0	Total Chlorine*	HAA9 (3 & 7 days)
2c				50/50/0/0	Total Ammonia*	
2d				25/0/75/0	Free Ammonia	
2e				25/0/0/75	($t_{initial}$ & t_{final} only)	
					Nitrite	
					($t_{initial}$ & t_{final} only)	
3a	0.3	8.2	10	100/0/0/0	pH ($t_{initial}$ & t_{final} only)	
3b				0/100/0/0	Total Chlorine*	
3c				50/50/0/0	Total Ammonia*	
3d				25/0/75/0	Free Ammonia	
3e				25/0/0/75	($t_{initial}$ & t_{final} only)	
					Nitrite	
					($t_{initial}$ & t_{final} only)	
4a	0.3	8.6	10	100/0/0/0	pH ($t_{initial}$ & t_{final} only)	
4b				0/100/0/0	Total Chlorine*	
4c				50/50/0/0	Total Ammonia*	
4d				25/0/75/0	Free Ammonia	
4e				25/0/0/75	($t_{initial}$ & t_{final} only)	
					Nitrite	
					($t_{initial}$ & t_{final} only)	
5a	0.5	8.2	25	100/0/0/0	pH ($t_{initial}$ & t_{final} only)	THMs (3 & 7 days)
5b				0/100/0/0	Total Chlorine*	HAA9 (3 & 7 days)
5c				50/50/0/0	Total Ammonia*	Iodo-THMs (7 days)
5d				25/0/75/0	Free Ammonia	Iodo-HAAs (7 days)
5e				25/0/0/75	($t_{initial}$ & t_{final} only)	Nitrosamines (7 days)
					Nitrite	
					($t_{initial}$ & t_{final} only)	

*Total chlorine and total ammonia were analyzed at the following times: 0, 1†, 2†, and 4† hours, and 1, 2†, 3, 4†, and 7 days.

† Phase I only

Target chloramine was 2.5 mg/L except for MWD water and blends containing MWD water. MWD water was used as-is, without chlorine or ammonia adjustment prior to blending with other water sources.

Bench-Scale Test Apparatus and Reagents

SDS Apparatus

Chlorine demand tests were conducted in 60-mL biochemical oxygen demand (BOD) bottles (Wheaton). Microliter syringes (Hamilton) and graduated pipettes (Kimax) of various sizes were used to dose ammonium chloride and sodium hypochlorite solutions. Source waters and blends of source waters were prepared in 4-L glass beakers (Pyrex) or glass bottles of various sizes. The SDS reaction vessels used in the tests were 300-mL BOD bottles (Wheaton or Kimble). The insulated water bath (Figure 2-5) was connected to a circulating water heater/chiller (VWR) and was covered with a lid to minimize chloramine decay caused by light.

Figure 2-5. Insulated Water Bath

Reagents

All solutions were prepared using Millipore Milli-Q water. Ammonium chloride solution was prepared by dissolving granular ammonium chloride (JT Baker, CAS #12125-02-9) in Milli-Q water to make 812 mg/L NH_3-N. Sodium hypochlorite solution was prepared by diluting the stock solution with 5% available chlorine (JT Baker, CAS #7681-52-9) to 1,000 mg/L available chlorine. Sodium hydroxide, used for pH adjustment, was prepared by dissolving sodium hydroxide pellets (Mallinckrodt, CAS #1310-73-2) in Milli-Q water to make 2 equivalence/L (Eq/L or Normal) solution. Sulfuric acid, also used for pH adjustment, was prepared by diluting 16.7% (v/v) stock solution (Ricca Chemical Company, catalog #8162-16) to a 2.5% solution.

Source Water and Blend Preparations

All source waters were prepared in the laboratory to mimic potential practical scenarios. The detailed procedures to prepare the source waters and the various blends are described below.

MWD Water—No additional chloramine was added to MWD water. Total chlorine levels were measured at the Water Quality Laboratory for the initial chloramine levels.

Desal—The desalinated ocean water was pre-warmed in the water bath until it reached the desired temperature (10 °C or 25 °C). A chlorine demand test was performed to determine the amount of chlorine solution needed to achieve 2.5 mg/L free chlorine residual after 15 minutes of contact time at the target temperature. The 15-minute contact time was selected to satisfy regulatory disinfection requirements. The chlorine demand test was conducted by spiking several 60-mL aliquots with varying chlorine dosages and measuring the residual after 15 minutes of incubation at the target temperature. The chlorine demand from each aliquot was averaged to obtain the final chlorine demand of the sample. Using this information, the desalinated ocean water was dosed with a chlorine stock solution to achieve 2.5 mg/L free chlorine residual at the end of 15 minutes of incubation at the target temperature. Ammonium chloride solution was then dosed to achieve 4.75:1 Cl_2:NH_3-N ratio. The pH of the sample was adjusted to the target (pH 8.2 or 8.6) and incubated for 4 hours at the target temperature. Based on initial chloramine stability results (see *Section 4 Chloramine Stability Results*), chloramine decay in the desalinated ocean water was substantially reduced after 4 hours of incubation. Although a greater reduction in decay rate would have been obtained after a 5-hour stabilization period (0.02 mg/L-h after 5-hour stabilization period versus 0.06 mg/L-h after 4-hour stabilization period), the 4-hour incubation duration was selected due to time constraints during the bench-scale testing. After the 4-hour incubation period, the total chlorine residual and total ammonia concentration of the desalinated ocean water sample was measured. Ammonium chloride and chlorine were added to the sample to boost the total ammonia to 0.53 mg/L as N and the total chlorine residual to 2.5 mg/L. The pH of the sample was then readjusted to the target as necessary before the desalinated ocean water sample was poured into BOD bottles for the SDS test or blended with other water sources.

GWbp—The groundwater was placed in the water bath until it reached the desired temperature (10 °C or 25 °C). Chlorine demand tests as described above were performed to determine the amount of chlorine solution needed to achieve 2.5 mg/L free chlorine residual after 15 minutes of contact time. Total ammonia in the groundwater was very high, ranging from 1.33 to 1.54 mg/L NH_3-N. Therefore, high chlorine dosages of at least 10 mg/L were needed just to break over to free chlorine. After the sample was dosed with chlorine solution and incubated for 15 minutes at target temperature, ammonium chloride solution was dosed to achieve 0.53 mg/L total ammonia (4.75:1 Cl_2:NH_3-N ratio). The pH of the sample was then adjusted to the target (pH 8.2 or 8.6) before the breakpoint chlorinated groundwater was blended with other water sources.

Blends—Blends with groundwater that was not breakpoint-chlorinated were chloraminated after blending. For all blend conditions, the conductivity of each blend was measured right after the source waters were blended, but before any chemical addition. The conductivity of the blend was then compared with the source waters' conductivities to confirm that the source waters were blended in the correct proportion.

> *Non-Breakpoint Chlorinated GW Blends (25% Desal/75% GW, 25% MWD/75% GW, 50% Desal/25% MWD/25% GW)*—For blends with non-breakpoint chlorinated groundwater, a 15-minute chlorine demand test was performed on the groundwater sample without breakpoint chlorinating the ammonia in the sample. After the source waters were blended, the total chlorine residual of the blended sample was measured. Sodium hypochlorite stock solution was added to the blended sample to achieve a 2.5 mg/L total chlorine residual. Ammonia was not added due to the high background ammonia levels of the groundwater.
>
> *Triple Blends (50% Desal/25% MWD/25% GW or GWbp Blends)*—For blends with three different source waters, MWD water and desalinated ocean water were blended prior to adding the groundwater. This method was selected because it represented the most likely future blending scenario. After blending, total chlorine residual and total ammonia of the blend was measured. Ammonium chloride and sodium hypochlorite were dosed, as necessary, to adjust the blend to 2.5 mg/L total chlorine residual and 0.53 mg/L total ammonia.
>
> *50% Desal/50% MWD Blend*—For this blend, after the two source waters were blended, no additional chemical adjustment, other than pH adjustment, was made to the sample. This method was selected because potential future integration projects of desalinated ocean water into MWD's pipelines would be unlikely to provide additional chlorination.

Simulated Distribution System Tests

After the test waters were prepared as described above, the pH was adjusted to target levels and aliquots were poured into BOD bottles without headspace and then placed into a water bath pre-set to the target temperature. For the chloramine stability tests, eight incubation times were selected (1, 2, and 4 hours and 1, 2, 3, 4, and 7 days). At each interval, two BOD bottles per blend were pulled from the water bath and analyzed for total chlorine, total ammonia, free ammonia, nitrite, and pH.

For the DBP formation SDS tests, the regulated THMs and HAA9 evaluations were sampled on day 3 and day 7; iodo-THM and iodo-HAA analyses were sampled on day 7. Samples from the BOD bottles were transferred to THM, HAA9, iodo-THM, and iodo-HAA vials containing appropriate quenching agents. Nitrosamines were sampled on day 7. For the nitrosamines SDS test, 500-mL amber glass bottles were filled with the sample with no headspace and incubated at 25 °C. The samples were removed from the water bath on day 7 and sodium sulfite was added to quench the chlorine. At each interval, total chlorine, total ammonia, free ammonia, nitrite, and pH were measured.

Analytical Methods

Free and Total Chlorine Residual—Free and total chlorine residuals were measured with a Hach analyzer (Model DR850; Hach Company, Loveland, CO). Free chlorine residual and total chlorine residual were measured using Hach Method number 10245 and 10250, respectively. The *N*,*N*-Diethyl-*p*-phenylenediamine (DPD) reagent used in this method did not just react with free and combined chlorine, but also with other oxidants. Due to the presence of bromide in desalinated ocean water and in groundwater, hypobromite and bromamines were formed, which contributed to the chlorine residual readings. The minimum reporting level (MRL) for free and total chlorine residual is 0.05 mg/L.

Because the groundwater tested contained a high level of manganese, tests were conducted to ensure that this constituent did not interfere with total chlorine residual measurements in the groundwater blends. Potassium iodide and sodium arsenite were used to treat the samples to correct for any interference caused by oxidized manganese. The results of the manganese interference tests in the different blends at various pH and temperature conditions can be found in Appendix B (Tables B-6-1 through B-6-3). Based on the results, 25% Desal/75% GWbp blend generally experienced the highest interference in the measurement of total chlorine residuals. However, at less than 0.11 mg/L, the interference for this blend was not significant.

Total Ammonia—A Hach DR850 analyzer was used to measure total ammonia by the ammonia salicylate method (Hach Method number 8155). Total ammonia was measured as mg/L NH_3-N; the MRL for total ammonia is 0.03 mg/L.

Free Ammonia—Free ammonia was measured using the selective electrode method with Orion probe model number 9512, Method 4500 (Standard Methods, 2012). The MRL for free ammonia is 0.03 mg/L.

Nitrite—A Hach DR850 analyzer was used to measure nitrite. Nitrite was measured as mg/L of nitrite as nitrogen (NO_2-N) using Hach Method number 8507. The MRL for nitrite is 0.005 mg/L NO_2-N.

Nephelometric Turbidity—Turbidity was measured using a Hach turbidity meter (Model 2100Q; Hach Company, Loveland, CO) per Method 2130B (Standard Methods, 2012).

Bromide—Bromide analyses were performed per EPA Method 300.0. The MRL for bromide is 0.02 mg/L. Since bromide must not be measured in chlorinated water, bromide analysis for MWD water was performed on Weymouth plant influent water.

Iodide—Total iodide samples were sent to Weck Laboratories and were analyzed per EPA Method 9056. Since iodide must not be measured in chlorinated water, iodide analysis for MWD water was performed on Weymouth plant influent water. The MRL for iodide is 10 µg/L.

NDMA—Nitrosamine compounds were extracted using solids phase extraction methods (SPE) with Ambersorb 572 per Method 6450B (Standard Methods, 2012) and then analyzed using gas chromatography/mass spectrometry. This method detected NDMA, *N*-nitrosodi-*n*-butylamine (NDBA), *N*-nitrosodiethylamine (NDEA), *N*-nitrosodi-*n*-propylamine (NDPA), *N*-nitrosomethyl-ethylamine (NMEA), *N*-nitrosomorpholine (NMOR), *N*-nitrosopyrrolidine (NPYR), and *N*-nitrosopiperidine (NPIP). The MRL for each of the nitrosamine compounds listed above is 2 ng/L.

THMs—MWD's Water Quality Laboratory utilized EPA method 551.1 for regulated THMs. The MRL for each THM species is 0.5 µg/L.

HAAs—MWD's Water Quality Laboratory utilized EPA methods 552.2 and 552.3 for HAA9. The MRL for MCAA and TCAA is 2.0 µg/L and for all other HAA species is 1.0 µg/L.

Iodo-THMs and Iodo-HAAs—Iodo-THMs and iodo-HAAs were analyzed by Underwriters Laboratory. Iodo-THM analyses were based on EPA method 524.2 (Underwriters Laboratory, 2013); the MRL for each of the iodo-THM species is 0.1 µg/L. Iodo-HAA analyses were conducted according to the method referenced by Li et al (2012). The MRL is 2.5 ng/L for chloroiodoacetic acid and bromoiodoacetic acid, and 5 ng/L for monoiodoacetic acid and diiodoacetic acid.

Sulfide—Sulfide was measured with a Hach DR850 analyzer using the methylene blue method (Hach Method number 8131). The estimated detection limit for sulfide is 0.01 mg/L S^{2-}.

All Other Analytical Methods—All other analytical methods were outlined in the current revision of Standard Methods (2012). Table 2-2 summarizes the method number and the MRL for each analysis.

Table 2-2. Summary of Analytical Methods

Parameter	Standard Method No.	MRL
Total Alkalinity	2320B	1 mg/L
Calcium	3111B	0.1 mg/L
Conductivity	2510B	1 µmho/cm
pH	4500H+ B	N/A*
TOC	5310C	0.2 mg/L
UV_{254}	5910B	0.004 abs/cm

*N/A = Not Applicable

Section 3. SOURCE WATER QUALITY

Table 3-1 and Table 3-2 summarize the median and range of water quality parameters for the source water used in the chloramine stability evaluation (Phase I) and the DBP formation evaluation (Phase II), respectively. Total chlorine residual for MWD water was analyzed in the field and in MWD's Water Quality Laboratory. Nitrite analysis for groundwater was initially performed both in the field and in the laboratory. After it was verified that there was no difference between field and laboratory readings, nitrite analyses were only performed in the laboratory along with the rest of the analyses listed in Table 3-1 and Table 3-2. The water quality of all source waters in Phase II was very similar to Phase I.

SWRO permeate contains low calcium, alkalinity, and TDS. The calcite filters increased the alkalinity of the desalinated ocean water to levels that were slightly lower than MWD water, and the calcium concentration to levels similar to MWD water. Compared to desalinated ocean water and MWD water, groundwater contained higher calcium and alkalinity, and had higher conductivity.

Since desalinated ocean water was collected prior to ammonia and chlorine addition, it contained no ammonia. MWD water had total ammonia levels that were consistently around 0.5 mg/L NH_3-N and had relatively low levels of free ammonia, ranging from 0.07 to 0.13 mg/L NH_3-N. In contrast, groundwater contained high levels of total ammonia, ranging from 1.33 to 1.54 mg/L NH_3-N and free ammonia, ranging from 0.75 to 1.35 mg/L NH_3-N (Table 3-1 and Table 3-2). The discrepancy between the total ammonia and free ammonia readings could be attributed to the different methods used in measuring the total ammonia and free ammonia. Total ammonia was measured using the ammonia salicylate method while free ammonia was measured using the selective electrode method.

The "higher bromide" (0.49 mg/L) desalinated ocean water was similar in alkalinity and had similar calcium concentrations as the "lower bromide" (~0.2 mg/L) desalinated ocean water. The TOC concentrations were also similar; the TOC levels in the "lower" and "higher" bromide desalinated ocean water were non-detect and 0.22 mg/L, respectively (reporting level is 0.2 mg/L). As expected, the "higher bromide" desalinated ocean water had higher conductivity than the "lower bromide" desalinated ocean water. Due to the low SPW blend, the bromide in Weymouth plant influent was low, ranging from 0.04 to 0.06 mg/L (Table 3-1 and Table 3-2). Groundwater had the highest bromide level of the three source waters tested, ranging from 0.89 to 1.0 mg/L and the highest conductivity, ranging from 1,507 to 1,590 µS/cm .

MWD water and desalinated ocean water iodide levels were less than the reporting level of 10 µg/L (Table 3-2). Groundwater contained a relatively high iodide concentration at 41 µg/L. Although no groundwater iodide sample was collected for the DBP formation test conducted at pH 8.2 and 25 °C, it was assumed to be unchanged from the previous week since all other water quality parameters were similar to the previous week's samples.

The specific ultraviolet absorbance (SUVA) is obtained by dividing UV absorbance at 254 nm by the TOC concentration. SUVA is an indicator of the relative humic content of the water. The desalinated ocean water contained a non-detectable level to a very low level of TOC. Even though the groundwater contains lower TOC than MWD water, it has a higher SUVA value in comparison. This indicates that the TOC in the groundwater has higher humic content and potentially more DBP precursors than MWD water. THMs and HAAs in the desalinated ocean water and the groundwater were not analyzed since these source waters did not contain any disinfectant, and thus assumed to have no THMs and HAAs.

Table 3-1. Phase I Bench Scale Study Source Water Quality

Water Quality Parameter	Corrosion Stabilized Desalinated Ocean Water		MWD Water**	Groundwater**
	Lower Bromide Tests**	Higher Bromide Tests		
Bromide (mg/L)	0.25 (0.23–0.28)	0.49	0.05 (0.04–0.06)	0.94 (0.89–1.00)
Total Chlorine (mg/L)	ND (< 0.05)	ND (< 0.05)	1.95 (1.84–2.10)	ND (< 0.05)
Total Ammonia (mg/L NH_3-N)	ND (< 0.03)	ND (< 0.03)	0.55* (0.46–0.61)	1.40 (1.33–1.54)
Free Ammonia (mg/L NH_3-N)	NA	NA	0.08* (0.07–0.12)	1.13 (0.75–1.23)
Nitrite (mg/L NO_2-N)	ND (< 0.005)	ND (< 0.005)	ND* (< 0.005)	ND (ND–0.005)
pH	7.96 (7.67–8.04)	7.93	8.10 (7.96–8.34)	7.82 (7.76–7.95)
Conductivity (µS/cm)	515* (501–551)	702*	897 (883–915)	1552 (1507–1590)
Turbidity (NTU)	0.29 (0.11–0.33)	0.11	0.08 (0.05–0.12)	0.49 (0.17–0.59)
Total Alkalinity (mg/L as $CaCO_3$)	74 (69–76)	78	122 (112–127)	226 (192–229)
Total Organic Carbon (mg/L)	ND (< 0.2)	0.22	2.61 (2.44–2.69)	1.89 (1.42–1.94)
Calcium (mg/L as Ca)	59 (57–62)	63	64 (62-64)	106 (103–114)
Sulfide (mg/L)	ND (< 0.01)	NA	ND (< 0.01)	ND (< 0.01)
Manganese (µg/L)	10	NA	ND (< 5)	63
Iron (µg/L)	ND (< 50)	NA	ND (< 50)	100

ND = Not Detected
NA = Not Analyzed

* Parameters analyzed after chemical adjustments (i.e., pH adjustment and/or chlorine addition, ammonia addition)
** Median (and range) values shown

Table 3-2. Phase II Bench Scale Study Source Water Quality

	Corrosion Stabilized Desalinated Ocean Water			
Water Quality Parameter	**Lower Bromide Tests**	**Higher Bromide Tests**	**MWD Water****	**Groundwater****
Bromide (mg/L)	0.22	0.49	0.05 (0.04–0.05)	0.95 (0.95–0.96)
Total Chlorine (mg/L)	ND (< 0.05)	ND (< 0.05)	1.94 (1.90–2.00)	ND (< 0.05)
Total Ammonia (mg/L NH_3-N)	ND (< 0.03)	ND (< 0.03)	0.58* (0.51–0.58)	1.46 (1.43–1.51)
Free Ammonia (mg/L NH_3-N)	NA	NA	0.11* (0.09–0.13)	1.18 (1.16–1.35)
Nitrite (mg/L NO_2-N)	ND (< 0.005)	ND (< 0.005)	ND* (< 0.005)	ND (< 0.005)
pH	7.88	7.93	8.19 (8.15–8.22)	7.99 (7.86–8.07)
Conductivity (µS/cm)	540*	704*	913 (897–925)	1571 (1562–1610)
Turbidity (NTU)	0.22	0.11	0.08 (0.07–0.08)	0.37 (0.31–0.54)
Total Alkalinity (mg/L as $CaCO_3$)	82	78	112 (110–114)	226 (225–227)
Total Organic Carbon (mg/L)	ND (< 0.2)	0.22	2.59 (2.52–2.76)	1.90 (1.86–1.92)
Calcium (mg/L as Ca)	64	63	59 (59–61)	105 (103–107)
Iodide (µg/L)	ND (< 10)	ND (< 10)	ND (< 10)	41
UV_{254} (abs/cm)	ND (< 0.004)	0.004	0.036 (0.033–0.038)	0.058 (0.057–0.064)
SUVA (L/m-mg)	ND	1.8	1.4	3.1
THMs (µg/L)	NA	NA	43 (35–45)	NA
HAA5 (µg/L)	NA	NA	16 (15–17)	NA
HAA9 (µg/L)	NA	NA	25 (24–27)	NA

ND = Not Detected
NA = Not Analyzed

*Parameters analyzed after chemical adjustments (i.e., pH adjustment and/or chlorine addition, ammonia addition)
** Median (and range) values shown

Section 4. CHLORAMINE STABILITY RESULTS

Desalinated Ocean Water Initial Chloramine Demand

The first objective of the Phase I tests was to determine the chlorine and ammonia dosages and the detention time required to minimize chloramine residual decay in the desalinated ocean water. Previous studies conducted in Long Beach and Carlsbad (Zhang et al., 2012 and McGuire Environmental Consultants & Poseidon Resources Corporation, 2004) show rapid chloramine decay was experienced in the desalinated ocean water for the first 4 hours. Both studies indicated that boosting chlorine after the initial chloramine decay could help to stabilize residuals in the distribution system. Figure 4-1 shows the chloramine decay trend for the desalinated ocean water at pH 8.2 and 25 °C. As shown in the graph, the total chloramine decay of the desalinated ocean water was reduced substantially after 5 hours of incubation. The chloramine decay rate dropped from 0.27 mg/L/hr in the first hour of incubation to 0.06 mg/L/hr after 4 hours and to 0.02 mg/L/hr after 5 hours of incubation. Although a 6-hour detention time was considered for the finished water reservoir in the WBMWD full-scale desalination preliminary master plan, time constraints during bench-scale testing limited the hold time to 4 hours. This was determined to be acceptable based on the greatly reduced decay rate after 4 hours. Thus, the 4-hour incubation period for the desalinated ocean water was selected in the pretreatment prior to reboosting the chlorine residuals and blending it with other source waters.

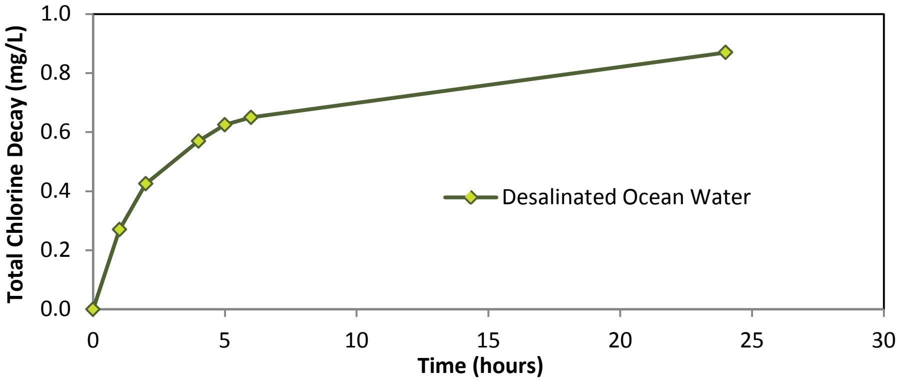


Figure 4-1. Chloramine Decay Curve for Corrosion Stabilized Desalinated Ocean Water (pH 8.2, 25 °C) with Initial Target Chloramine Residual of 2.5 mg/L

Chloramine Stability in Various Source Water Blends

Comparison of Chloramine Decay in Various Blends

LOWER BROMIDE DESAL, PH 8.2, 25 °C

The chloramine stability SDS tests were conducted over a 7-day period to assess potential impacts of the integration of desalinated ocean water into Metropolitan's system or into a WBMWD subagency system. Blend scenarios of 50% Desal/50% MWD water, 25% Desal/75% GW or 25% Desal/75% GWbp versus 25% MWD/75% GW or 25% Desal/75% GWbp, as well as 50% Desal/25% MWD/25% GW or 50% Desal/25% MWD/25% GWbp were compared at pH 8.2 and 25 °C with Desal bromide concentrations ranging from 0.23–0.28 mg/L. In addition, control samples of Desal and MWD water were analyzed for each test condition. Because the initial total chlorine residuals varied among the various test blends, chloramine decay rather than total chlorine residual was compared for each blend. Chloramine decay was calculated by subtracting the test chloramine residual from the initial chloramine residual. The results of these tests are shown in Figure 4-2 and the water quality parameters measured in the initial blends for these tests are shown in the Appendix A (Table A-1-3). Error bars on graphs indicate the range of values obtained from the same blend under the same test conditions, but conducted on different days (different test groups per Table 2-1).

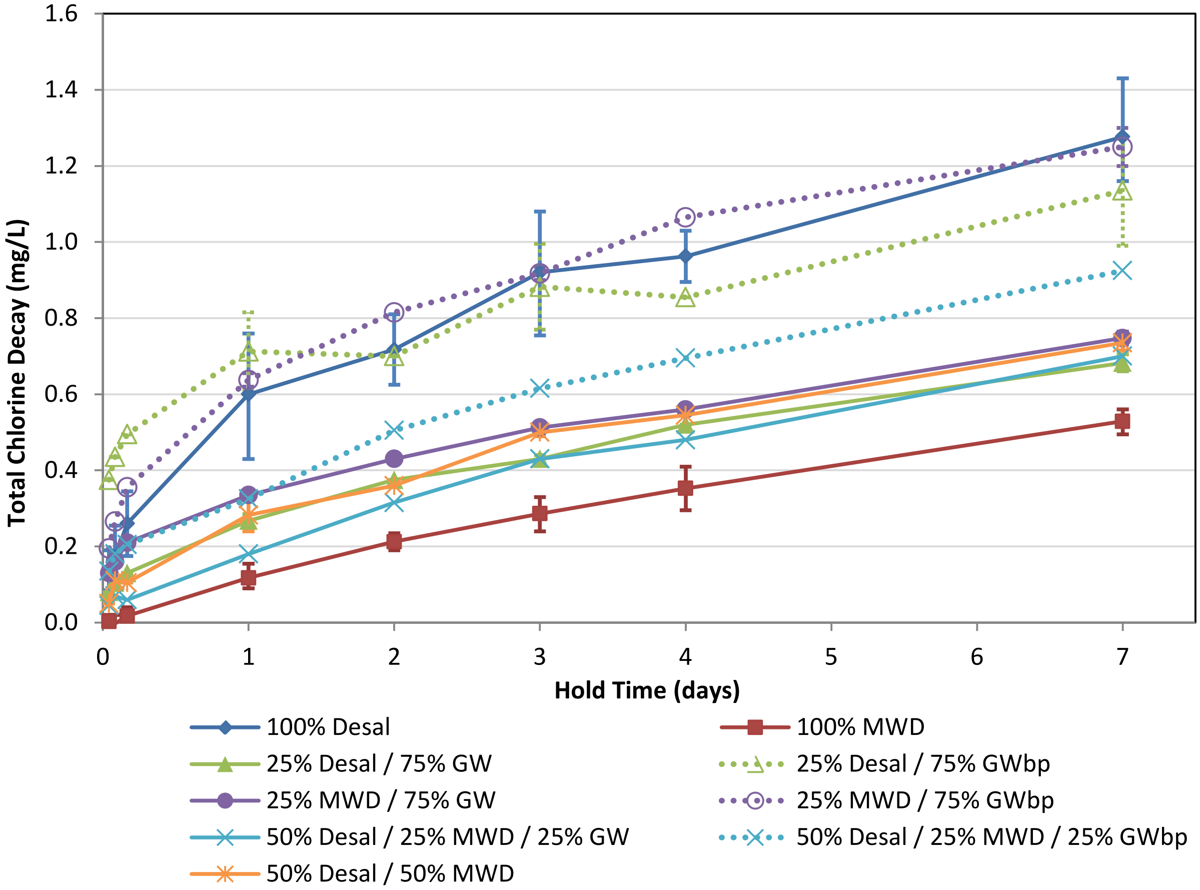


Figure 4-2. Total Chloramine Decay in Various Blends
(pH 8.2, 25 °C, Lower Bromide Desal)

It should be noted that chloramine residuals in the MWD water had already decayed in the distribution system for at least three days, and likely had the total chlorine residual boosted once at Garvey Reservoir prior to reaching the WB-4 service connection. This made the MWD water inherently more stable than the other water blends in the chloramine stability tests, and this result was borne out under all test conditions. At the end of 7 days incubation at 25 °C and pH 8.2, the total chloramine decay in MWD water was the lowest at an average of 0.53 mg/L.

In contrast, blends of breakpoint chlorinated groundwater with either MWD water or Desal exhibited the highest levels of decay. This was likely due to a combination of high total ammonia levels (1.33–1.54 mg/L NH_3-N) and high bromide levels (0.89–1.0 mg/L) in the groundwater (Table 3-1). In order to breakpoint chlorinate the ammonia to get a free chlorine residual of 2.5 mg/L, very high doses of chlorine (> 10 mg/L Cl_2) are required. This high chlorine dose coupled with high background bromide levels likely formed hypobromous acid and ultimately dibromamine—a compound that has been shown to decay more rapidly than monochloramines (Bongers et al., 1977; Tseng et al., 2005; and Zhang et al., 2012). This conclusion is supported by the rapid initial decay exhibited during the first 4 hours of the SDS test. A comparison of 25% Desal/75% GWbp and 25% MWD/75% GWbp shows little difference in decay rates. Both show high initial decay rates of 0.50 and 0.36 mg/L after 4 hours, respectively, and final chloramine residual decays of 1.1 and 1.3 mg/L, respectively, after 7 days.

Blends with non-breakpoint chlorinated groundwater were much more stable than the breakpoint chlorinated blends. This was due to two factors: 1) much lower doses of chlorine were required and 2) the high ammonia levels in the groundwater provided excess free ammonia. In the artificial environment of the SDS test, excess ammonia proved to have a stabilizing effect. However, in the distribution system, in the presence of ammonia oxidizing bacteria, high levels of free ammonia would likely promote nitrification and consequent disinfectant decay.

Little difference was seen between blends of 25% Desal/75% GW and 25% MWD/75% GW. At 4 hours the chloramine residual decay in these blends was 0.13 and 0.21 mg/L, respectively, and after 7 days the chloramine residuals decreased by 0.68 and 0.75 mg/L, respectively.

The “lower bromide” (0.23–0.28 mg/L Br) Desal water SDS tests consistently exhibited more chloramine decay than most of the other blends, trailing only the Desal/GWbp and MWD/GWbp blends. This water had been stabilized with calcite addition to achieve alkalinity levels of 69–76 mg/L and a 4-hour chloramine contact followed by a disinfectant boost to 2.5 mg/L chloramine residual. However, unlike MWD water, which had already undergone chloramine decay enroute to WB-4, the Desal water was tested immediately after the chloramines were boosted. Moreover, the Desal tests did not benefit from the chloramine stability afforded by the excess ammonia in all test blends that contained non-breakpoint chlorinated groundwater. Similar to the GWbp blends, the Desal water exhibited high initial losses, and decay rates decreased after the first day. This was likely due in part to the presence of bromide in the Desal water, which formed hypobromous acid and ultimately the relatively unstable dibromamine, which, as previously mentioned, decays more rapidly than monochloramines. In the first 4 hours of the SDS tests the chloramine residual in the Desal decreased by 0.26 mg/L and after 7 days the residual decreased by an average of 1.28 mg/L as compared to MWD water, which decreased by an average of 0.02 mg/L after 4 hours and 0.53 mg/L after 7 days.

However, the comparative instability of the Desal versus MWD water did not translate into greater instability of blends with Desal versus blends with MWD water. As described above, the 25% Desal/75% GW and 25% Desal/75% GWbp blends exhibited very similar decay curves to the 25% MWD/75% GW and 25% MWD/75% GWbp. Moreover, blends of 50% Desal/50% MWD exhibited a chloramine decay curve that was less than would be anticipated by averaging the Desal and MWD values. Discerning the mechanism responsible for the increased stability of the 50% Desal/50% MWD and 25% Desal/75% GW blends is beyond the scope of this project. However, it is likely that the excess ammonia in the non-breakpoint chlorinated groundwater blends served to stabilize the chloramine decay. The increased alkalinity of the 50% Desal/50% MWD (96–101 mg/L) and the 25% Desal/75% GW blends

(190–194 mg/L) versus the Desal (71–80 mg/L) for these tests may have also contributed to the greater stability of the blends.

The 3-way blend 50% Desal/25% MWD/25% GW exhibited only slightly more decay than the MWD water. The chloramine residuals decreased by 0.06 and 0.70 mg/L at 4 hours and 7 days, respectively. In contrast, the 3-way blend with 50% Desal/25% MWD/25% GWbp exhibited much higher chloramine decay rates—0.21 and 0.93 mg/L at 4 hours and at 7 days, respectively. As described above, this was likely due to the high chlorine dose in the GWbp blend and the lack of excess free ammonia, coupled with high background bromide levels forming the relatively unstable dibromamine—a compound that has been shown to decay more rapidly than monochloramines.

Effects of pH on Chloramine Decay

In general, chloramine decay increases with decreasing pH due to an increased rate of dichloramine formation at lower pH (Valentine et al., 1998). Thus, increasing potable water pH levels can potentially decrease chloramine decay in the distribution system. The bench-scale study included a series of chloramine stability SDS tests at pH 8.6 to evaluate the potential effectiveness of raising distribution system pH levels to increase the chloramine stability of desalinated ocean water blends. These tests were conducted at both 10 and 25 °C; the results are shown in Figure 4-3 and Table 4-1. The blended water quality for these tests are listed in Appendix A (Tables A-1-3, A-2-2, A-3-2, and A-4-2)

Under both temperature conditions, the increase of pH from 8.2 to 8.6 had very little impact on chloramine decay in the MWD and 50% Desal/50% MWD blend. Insignificant differences (less than 0.1 mg/L) in decay were measured for all but the 50% Desal/50% MWD blend and the MWD water. The 50% Desal/50% MWD blend exhibited 0.13 and 0.18 mg/L decreases in decay at day 3 and 7, respectively, (at 25 °C) and the MWD water exhibited a 0.11 mg/L decrease in decay at day 7 (25 °C) due to the higher pH. A greater pH impact was seen on the Desal, which at 10 °C exhibited decreases in decay of 0.15 mg/L on day 3 and 0.23 mg/L on day 7, and at 25 °C showed an unexpected increase in chloramine decay at the higher pH, ranging from 0.28 mg/L at day 1 to 0.11 mg/L by day 7. The Desal/GWbp blends also exhibited increased chloramine decay at pH 8.6 at both temperatures, with increases in decay ranging from 0.05 to 0.11 mg/L for days 1, 3, and 7 at 10 °C and from 0.11 to 0.22 mg/L for days 1, 3, and 7 at 25 °C. Only the 25% Desal/75% GW blend exhibited the expected decrease in chloramine decay at the higher pH for both temperatures at days 1, 3, and 7. Those decreases ranged from 0 to 0.19 mg/L over the course of the SDS tests. The reasons for these unexpected results are not clear and warrant further investigation. It appears however, that increasing distribution system pH to 8.6 will not improve the chloramine stability under all water quality conditions.

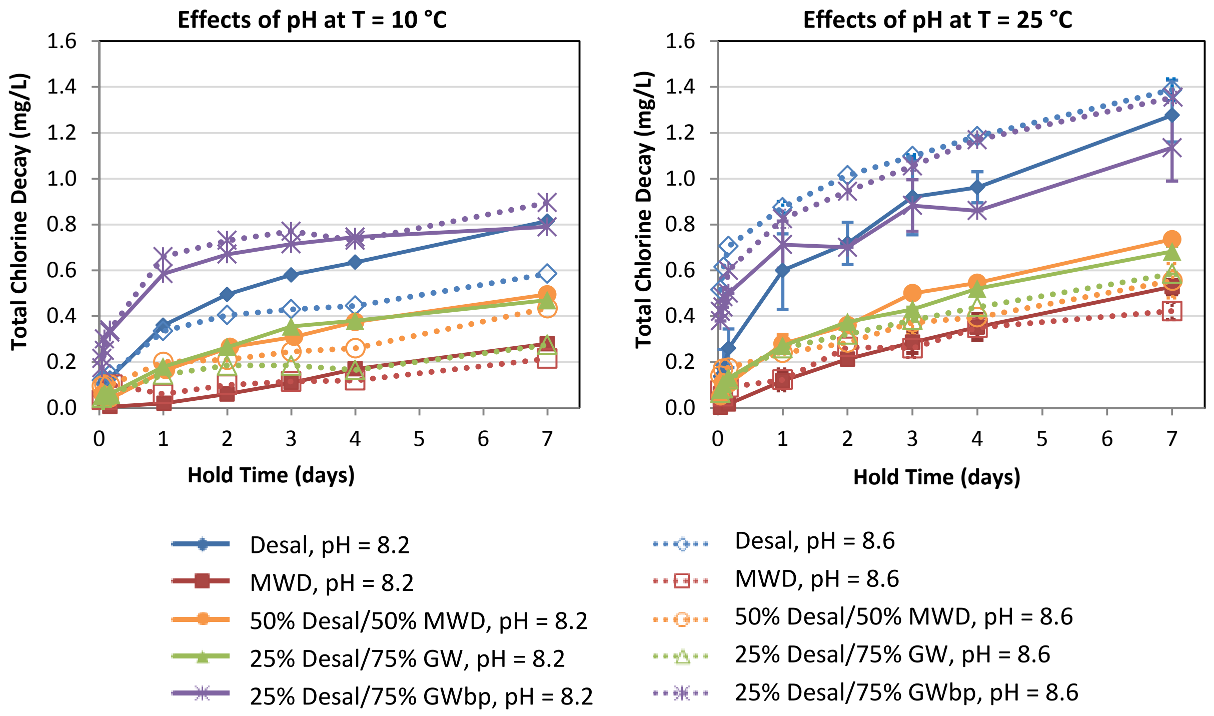


Figure 4-3. Effect of pH on Total Chloramine Decay
(10 °C and 25 °C, Lower Bromide Desal)

Table 4-1. Effect of pH on Total Chloramine Decay
(10 °C and 25 °C, Lower Bromide Desal)

		Chloramine Decay after Specified Days (mg/L)					
		10 °C			25 °C		
Blend	*Days*	*pH 8.2*	*pH 8.6*	***Decrease in decay at 8.6***	*pH 8.2*	*pH 8.6*	***Decrease in decay at 8.6***
Desal	1	0.36	0.34	**0.02**	0.60	0.88	**-0.28**
	3	0.58	0.43	**0.15**	0.92	1.10	**-0.18**
	7	0.82	0.59	**0.23**	1.28	1.39	**-0.11**
MWD	1	0.02	0.06	**-0.04**	0.12	0.12	**0.00**
	3	0.11	0.12	**-0.01**	0.29	0.26	**0.03**
	7	0.28	0.22	**0.06**	0.53	0.42	**0.11**
50% Desal/50% MWD	1	0.17	0.20	**-0.03**	0.28	0.24	**0.04**
	3	0.31	0.25	**0.06**	0.50	0.37	**0.13**
	7	0.50	0.44	**0.06**	0.74	0.56	**0.18**
25% Desal/75% GW	1	0.18	0.15	**0.03**	0.27	0.26	**0.01**
	3	0.36	0.19	**0.17**	0.43	0.38	**0.05**
	7	0.47	0.28	**0.19**	0.68	0.59	**0.09**
25% Desal/75% GWbp	1	0.59	0.66	**-0.07**	0.71	0.83	**-0.12**
	3	0.72	0.77	**-0.05**	0.88	1.06	**-0.18**
	7	0.79	0.90	**-0.11**	1.14	1.36	**-0.22**

Effects of Temperature on Chloramine Decay

Decreased temperatures typically slow the rates of reactions and were expected to decrease the chloramine decay rates in the chloramine stability SDS tests. The SDS tests were conducted at both the low and high ends of the distribution system temperature range to exhibit the span of chloramine decay rates. Figure 4-4 and Table 4-2 compare the chloramine decay trend in the various water blends at 10 and 25 °C for both pH 8.2 and 8.6 conditions. As expected, in each test blend the chloramine residual was more stable at lower temperature. SDS tests conducted at 10 °C exhibited 0.12 to 0.80 mg/L less chloramine decay over 7 days than those conducted at 25 °C. Interestingly, the differences between the higher temperature and lower temperature decay rates increased over time for each test, i.e., the greatest differences were seen on day 7. The greatest differences between the higher and lower temperature decay rates were observed in both the Desal water and the Desal/GWbp at pH 8.6. Another interesting result was observed in the SDS tests conducted at pH 8.2. In the 10 °C tests, the 25% Desal/75% GWbp blend exhibited greater decay than the Desal water until day 7. In contrast, in the 25 °C SDS tests, the 25% Desal/75% GWbp blend exhibited greater decay than the Desal water only through day 1, after which the decay rates in the Desal water were the highest. This same phenomenon was not seen at pH 8.6 and 25 °C; in those tests the Desal and the 25% Desal/75% GWbp blend exhibited very similar decay rates, with the decay in the Desal water slightly higher throughout.

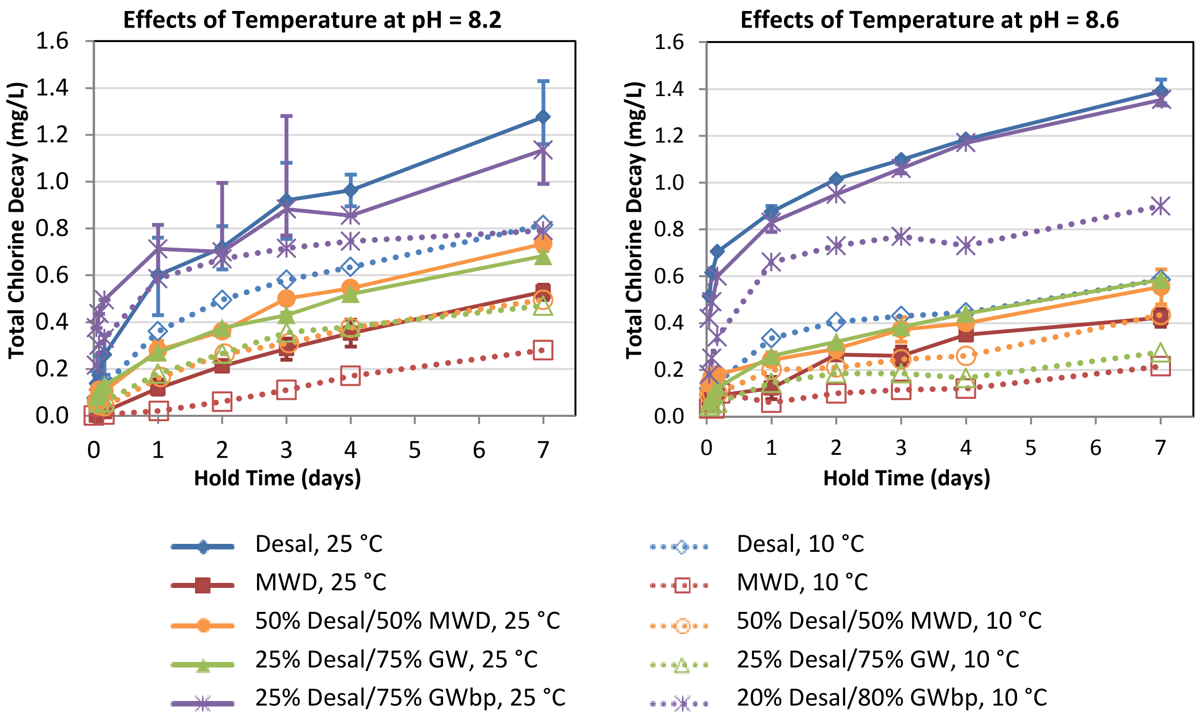


Figure 4-4. Effect of Temperature on Total Chloramine Decay
(pH 8.2 and pH 8.6; Lower Bromide Desal)

Table 4-2. Effect of Temperature on Total Chloramine Decay
(pH 8.2 and pH 8.6; Lower Bromide Desal)

		Chloramine Decay after Specified Days (mg/L)					
		pH 8.2			pH 8.6		
Blend	*Days*	*25 °C*	*10 °C*	***Decrease in decay at 10 °C***	*25 °C*	*10 °C*	***Decrease in decay at 10 °C***
Desal	1	0.60	0.36	**0.24**	0.88	0.34	**0.54**
	3	0.92	0.58	**0.34**	1.10	0.43	**0.67**
	7	1.28	0.82	**0.46**	1.39	0.59	**0.80**
MWD	1	0.12	0.02	**0.10**	0.12	0.06	**0.06**
	3	0.29	0.11	**0.18**	0.26	0.12	**0.14**
	7	0.53	0.28	**0.25**	0.42	0.22	**0.20**
50% Desal/50% MWD	1	0.28	0.17	**0.11**	0.24	0.20	**0.04**
	3	0.50	0.31	**0.19**	0.37	0.25	**0.12**
	7	0.74	0.50	**0.24**	0.56	0.44	**0.12**
25% Desal/75% GW	1	0.27	0.18	**0.09**	0.26	0.15	**0.11**
	3	0.43	0.36	**0.07**	0.38	0.19	**0.19**
	7	0.68	0.47	**0.21**	0.59	0.28	**0.31**
25% Desal/75% GWbp	1	0.71	0.59	**0.12**	0.83	0.66	**0.17**
	3	0.88	0.72	**0.16**	1.06	0.77	**0.29**
	7	1.14	0.79	**0.35**	1.36	0.90	**0.46**

Effects of Bromide Concentration in Desalinated Ocean Water on Chloramine Decay

The effect of bromide on disinfectant stability is an area of concern when integrating desalinated ocean water into an existing chloraminated distribution system. As mentioned previously, the elevated bromide concentrations associated with ocean water quickly react with free chlorine to form hypobromous acid, which represents a source of chlorine demand. In addition, when ammonia is added, bromamines will form and, subsequently, rapidly decompose, resulting in an unstable disinfectant residual. (Tseng et al., 2012; Le Gouellec et al., 2006; Loveland et al., 2010; Zhang et al., 2012). Most of the chloramine stability SDS tests were conducted utilizing desalinated ocean water with target bromide concentrations of approximately 0.3 mg/L ("lower bromide"), as this is the level targeted in this study and one of the potential target concentrations for the WBMWD full-scale plant. However, since bromide rejection will likely decrease with membrane age, evaluations were also conducted at a target bromide concentration of 0.5 mg/L ("higher bromide") in the desalinated ocean water. Figure 4-5 and Table 4-3 compare the chloramine decay trends for the lower and higher desalinated ocean water bromide evaluations (conducted at pH 8.2 and 25 °C).

Increasing the bromide concentration in the desalinated ocean water by approximately 0.24 mg/L (to a bromide level of 0.49 mg/L) increased the bromide concentration in the 50% Desal/50% MWD blend by 0.13 mg/L and by ~0.06 mg/L in the 25% Desal/75% GW and 25% Desal/75% GWbp blends. These slight rises in bromide concentration noticeably increased the chloramine decay rates in all but the 25% Desal/75% GW blend. After 7 days, the chloramine decay in the higher bromide blends of Desal, 50% Desal/50% MWD, and 25% Desal/75% GWbp, increased by 0.18, 0.13, and 0.33 mg/L, respectively. The excess ammonia in the 25% Desal/75% GW blend likely served to stabilize chloramine residual and minimize the impact of increased bromide levels.

Overall, the chloramine decay at 7 days in Desal and blends with Desal ranged from 0.68–1.28 mg/L in the lower bromide tests and from 0.73–1.47 mg/L in the higher bromide tests as compared to 0.53 mg/L decay in MWD water. Chloramine decay was especially rapid for the first 4 hours in the 25% Desal/75% GWbp blend and the Desal water at both bromide test conditions. Chloramine decay at 4 hours ranged from 0.26 mg/L for the lower bromide Desal up to 0.79 mg/L for the higher bromide Desal/GWbp. This was likely due in part to the rapid decomposition of bromamine formed in these waters without the stabilizing influence of the excess ammonia. Although bromide increases will raise chloramine decay rates, other factors are obviously influencing the decay rate. This is shown by the greater decay rate observed in the "higher bromide" Desal with 0.49 mg/L bromide versus the "lower bromide" 25% Desal/75% GWbp with 0.79 mg/L bromide.

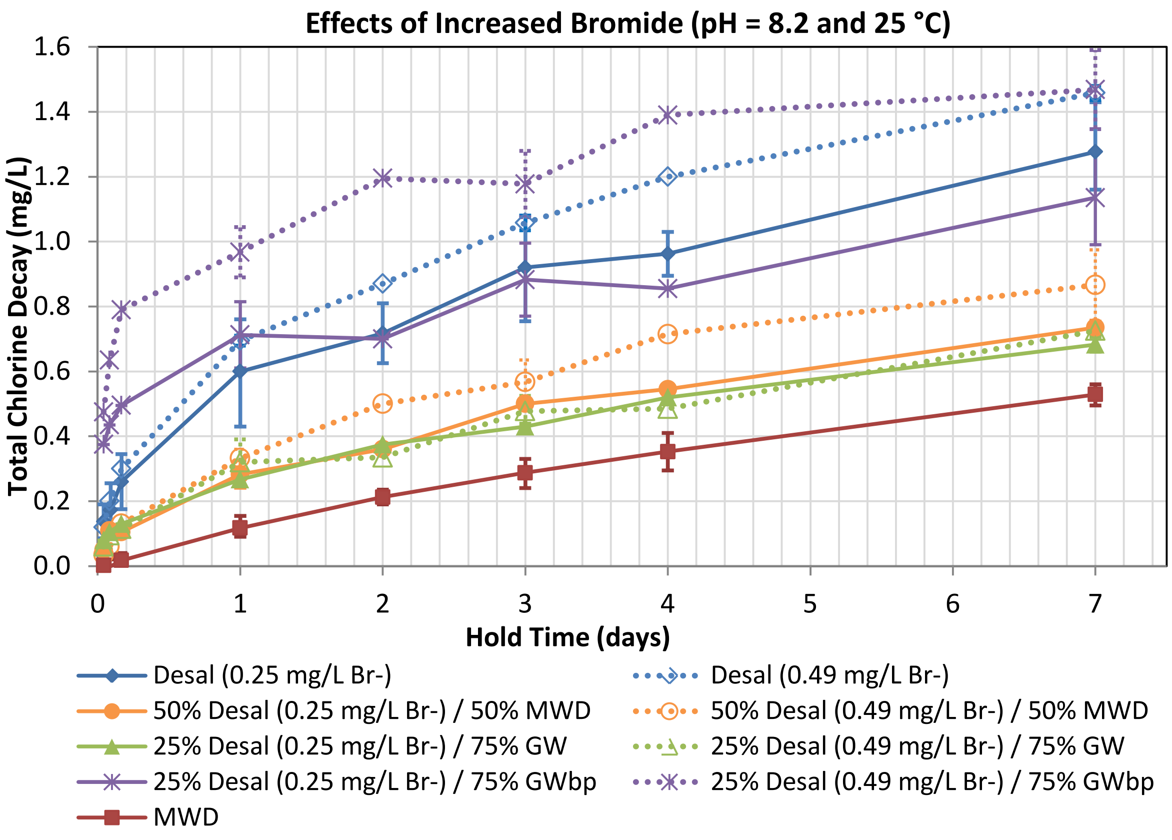


Figure 4-5. Effect of Increased Desal Bromide Concentrations on Chloramine Decay (pH 8.2, 25 °C)

Table 4-3. Effect of Increased Desal Bromide Concentrations on Chloramine Decay (pH 8.2, 25 °C)

		Chloramine Decay after Specified Days (mg/L)			Calculated Br$^-$ Concentration in Blend	
Blends	Days	Desal Br$^-$ @ 0.25 mg/L	Desal Br$^-$ @ 0.49 mg/L	Increase in decay at higher Br$^-$ (mg/L)	Blend with Low Br$^-$ Desal (mg/L)	Blend with High Br$^-$ Desal (mg/L)
Desal	1	0.60	0.70	**0.10**	0.25	0.49
	3	0.92	1.06	**0.14**		
	7	1.28	1.46	**0.18**		
MWD	1	0.12		**Not applicable**	0.05 (0.04–0.05) Not blended w/ Desal	
	3	0.29				
	7	0.53				
50% Desal/ 50% MWD	1	0.28	0.33	**0.05**	0.14 (0.13–0.15)	0.27 (0.27–0.27)
	3	0.50	0.57	**0.07**		
	7	0.74	0.87	**0.13**		
25% Desal/ 75% GW	1	0.27	0.32	**0.05**	0.77 (0.77–0.77)	0.84 (0.84–0.84)
	3	0.43	0.48	**0.05**		
	7	0.68	0.73	**0.05**		
25% Desal/ 75% GWbp	1	0.71	0.97	**0.26**	0.79 (0.77–0.81)	0.84 (0.84–0.84)
	3	0.88	1.18	**0.30**		
	7	1.14	1.47	**0.33**		

Summary of Chloramine Stability Tests

The Phase I tests compared the chloramine decay rates of various source water blends, assessed the effects of pH (8.6 vs 8.2), temperature (10 °C vs 25 °C) and Desal bromide levels (0.49 mg/L vs 0.25 mg/L), resulting in the following findings:

1. In general, under the various test conditions evaluated in this study, the relative ranking of blend stability from most to least stable in the 7-day SDS tests were as follows:
    i. MWD (Test water had gone through decay in the distribution system)
    ii. 25% Desal/75% GW; 50% Desal/25% MWD/25% GW; 50% Desal/50% MWD; and 25% MWD/75% GW
    iii. 50% Desal/25% MWD/25% GWbp
    iv. 25% Desal/75% GWbp; Desal; and 25% MWD/75% GWbp
2. Raising the pH from 8.2 to 8.6 had mixed results on the chloramine decay rates in the various source water blends. Changes in the MWD water and in 50% Desal/50% MWD blend were not significant. Slight decreases in chloramine decay were achieved in Desal/GW blend, and in the Desal water at 10 °C. Increases in chloramine decay were obtained in the Desal at 25 °C and in the Desal/GWbp samples at both temperatures.
3. Lowering the water temperature from 25 to 10 °C decreased the chloramine decay in all test conditions. Decay rates in the various blends dropped by 0.12–0.80 mg/L after 7 days, with the greatest decreases observed in the Desal tests.
4. Increasing the Desal bromide levels from 0.25 to 0.49 mg/L had little effect on the chloramine stability of the Desal/MWD or the Desal/GW blends, but did increase the chloramine decay in the Desal and the Desal/GWbp tests. Increases in decay after 7 days were 0.18 mg/L in the Desal and 0.33 mg/L in the Desal/GWbp blend.

Section 5. DISINFECTION BYPRODUCTS FORMATION RESULTS

In Phase II of the bench-scale study, the impact of desalinated ocean water integration on DBP formation was evaluated. Previous studies have shown that DBP precursors include natural organic matter and bromide, and formation is affected by various parameters such as pH, temperature, time, and disinfectant dose (Singer, 1999). Three conditions from the Phase I SDS tests (Table 2-1) were repeated to evaluate the impact of bromide, pH, and reaction time on DBP formation in the various blends. The results of the THM, HAA9, NDMA, iodinated THM, and iodinated HAA analyses are presented below.

Regulated THM Evaluations

Comparison of THM Formation in Various Blends

pH 8.2, 25 °C, LOWER BROMIDE DESAL

The total THMs formed in the various SDS blends after 3 and 7 days at pH 8.2 and 25 °C with lower bromide Desal are compared in Figure 5-1. The water quality parameters for each source water are presented in Table 3-2 and in Appendix C (Table C-1-2) for each blend.

As expected, the Desal exhibited very little (0.7 µg/L) THM formation due to the very low level of organics in the permeate (< 0.2 mg/L TOC). In contrast, MWD water with TOC levels of approximately 2.76 mg/L and longer disinfectant contact time formed 43 µg/L TTHMs. This level was measured at time zero and did not increase over the course of the 7-day SDS test. The integration of the desalinated ocean water served to dilute the MWD THM levels: the 50% Desal/50% MWD blend produced a weighted average of the two THM levels after 3 and 7 days (21 µg/L).

The groundwater tested had a relatively high TOC concentration (1.90 mg/L), high SUVA (3.0 L/m-mg), and high bromide concentration (0.95 mg/L). All of these characteristics increase THM formation. However, due to the high concentration of ammonia (1.46 mg/L) in this groundwater, there was no free chlorine available to produce THMs in the non-breakpoint chlorinated GW blends. After 7 days, THM concentrations in the 25% Desal/75% GW and in the 25% MWD/75% GW were 1.8 and 11 µg/L, respectively. In contrast, blends with breakpoint chlorinated groundwater had been subject to a 15-minute free chlorine contact time and consequently formed relatively high levels of THMs. The THM concentrations in the 25% Desal/75% GWbp and in the 25% MWD/75% GWbp after 7 days were 56 and 65 µg/L, respectively.

Overall, little difference was observed in the THM levels measured on day 3 versus day 7, and substitution of MWD water with desalinated ocean water would likely decrease distribution system THMs. The THMs for all of the blends on day 7 were below the 80 µg/L MCL. However, utilities typically target 80 percent of the MCL (64 µg/L) to ensure regulatory compliance. Only the 25% MWD/75% GWbp blend exceeded this target THM level.

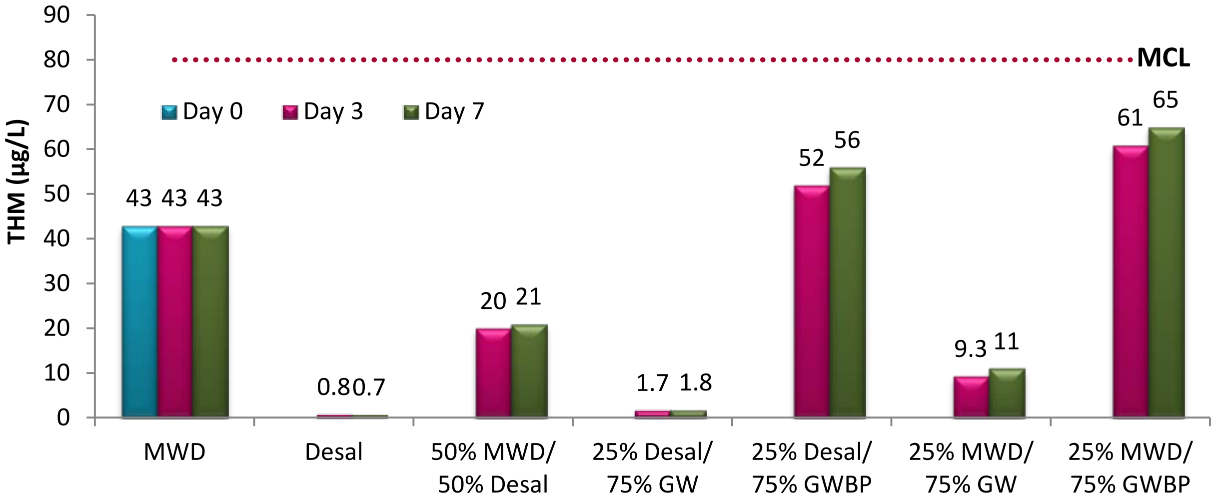


Figure 5-1. THM Formation for Various Blends (pH 8.2, 25 °C, Lower Bromide Desal: 0.22 mg/L)

Figure 5-2 shows a breakdown of the THM species formed in all of the blends (at pH 8.2 and 25 °C with lower bromide Desal). In MWD, 50% Desal/50% MWD, and 25% MWD/75% GW blends, the THM species with the lowest concentration was $CHBr_3$. In contrast, $CHBr_3$ was the only THM species formed in Desal, and in the breakpoint chlorinated groundwater blends, the more brominated THM species were found in higher concentration than the less brominated THM species. The MWD samples exhibited a higher percentage of the more chlorinated species due to its low bromide levels (0.05 mg/L), and the 50% Desal/50% MWD blend showed that the Desal water diluted the MWD DBPs. Interestingly, the DBP speciation in the 25% Desal/ 75% GWbp and the 25% MWD/75% GWbp blends were very similar, indicating that the GWbp contributed most of the DBPs. Finally, speciation varied little between day 3 and day 7 samples, indicating that most of the THMs were formed within the first 3 days.

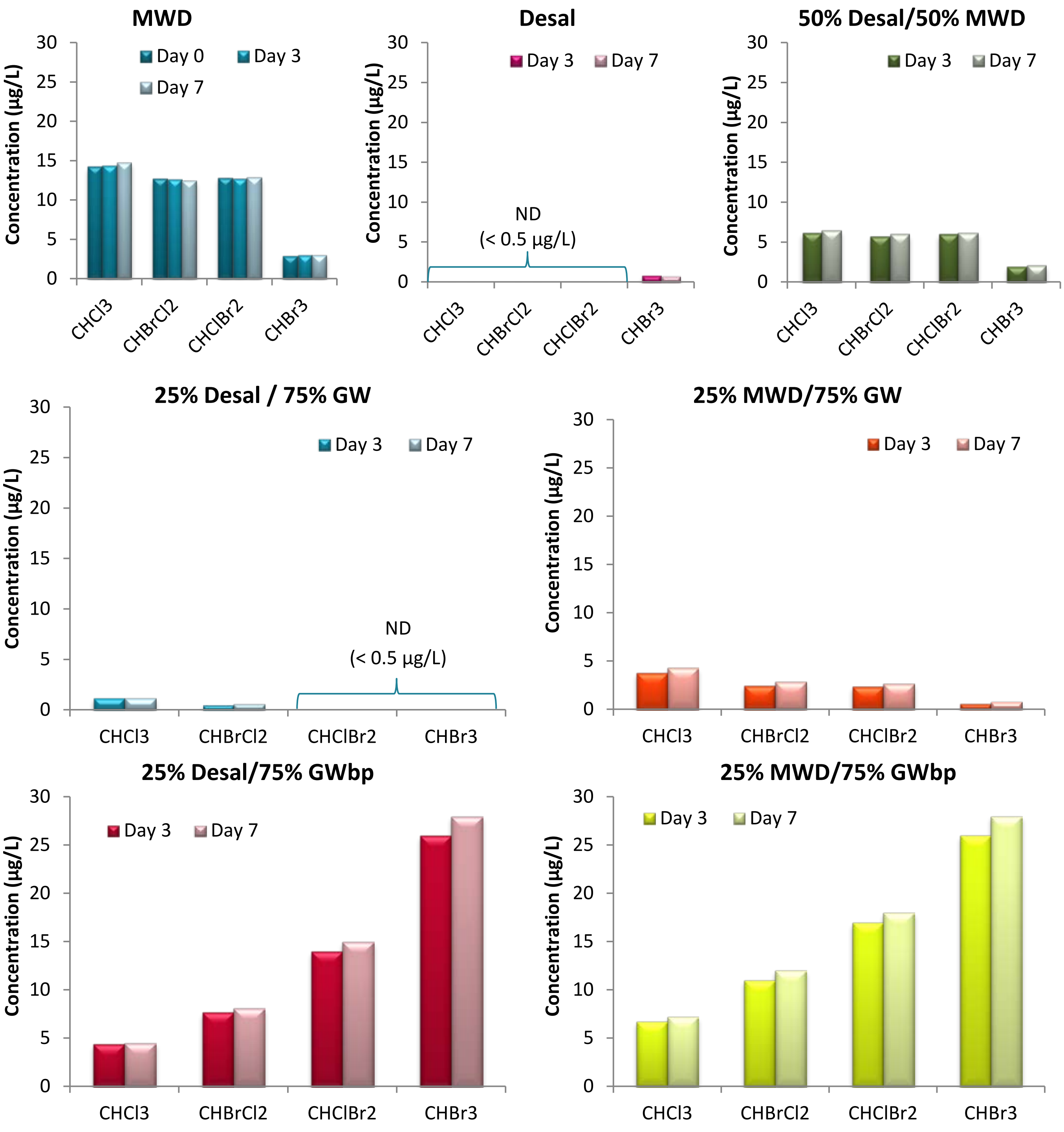


Figure 5-2. THM Species for Various Blends
(pH 8.2, 25 °C, Lower Bromide Desal: 0.22 mg/L)

Impact of pH on THM Formation

The effect of increasing the pH from 8.2 to 8.6 (after chloramine formation) was evaluated at 25 °C with lower bromide (0.22 mg/L) Desal water. Figure 5-3 shows slight decreases in total

THM concentration for all blends at pH 8.6 vs pH 8.2. Relative THM speciation was unaffected. These differences are not significant. This is somewhat unexpected as other studies have shown that THM formation increases at higher pH (Singer 1999). Refer to Tables B-1-5 and B-2-5 in Appendix B for THM speciation data comparison.

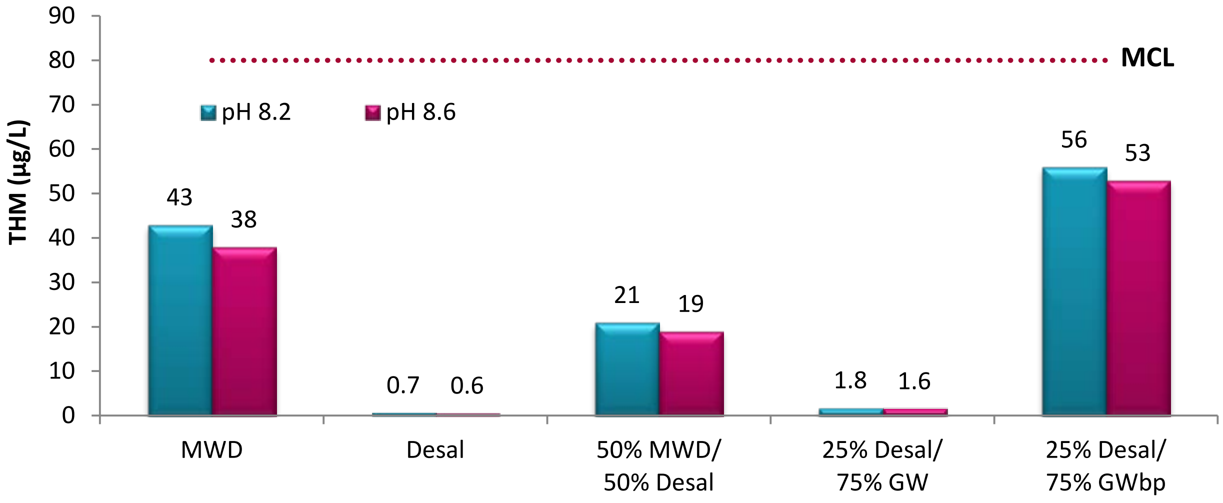


Figure 5-3. 7-day THM Formation Comparison for Various Blends (pH 8.2 and pH 8.6, 25 °C, Lower Bromide Desal: 0.22 mg/L)

Impact of Higher Desal Bromide Levels on THM Formation

The effect of increasing the bromide level of the desalinated ocean water from 0.22 to 0.49 mg/L was evaluated at pH 8.2 and 25 °C. It must be noted that increasing the bromide in the Desal water by 0.27 mg/L resulted in an increase of 0.14 mg/L in the 50% Desal/50% MWD blend and an increase of only 0.07 mg/L in the 25% Desal/75% GW and 25% Desal/75% GWbp blends. The bromide in the final 50% Desal/50% MWD blend increased from 0.13 to 0.27 mg/L and in the 25% Desal/75% GW and 25% Desal/75% GWbp blend increased from 0.77 to 0.84 mg/L. As shown in Figure 5-4 these small increases in overall bromide levels did not afford significant increases in THM formation; THM increases ranged from 0.9–2 µg/L in the 7-day SDS test. Due to low organic precursor concentrations, the THM formation in the desalinated ocean water (2.7 µg/L) was still much lower than in the MWD water (40 µg/L) despite the increase in bromide concentration. Overall, as with the lower bromide tests, the THMs for all blends on day 7 were below the MCL, substitution of MWD water with desalinated ocean water would likely decrease distribution system THMs. The increase in bromide concentration in desalinated ocean water from 0.22 to 0.49 mg/L also had very little impact on the THM speciation (Appendix C, Tables C-1-5 and C-3-5).

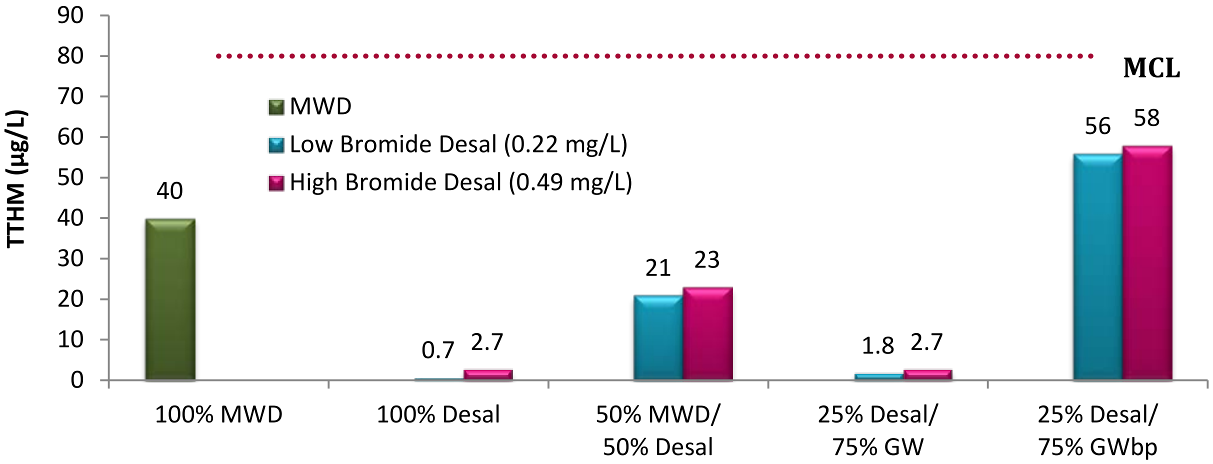


Figure 5-4. 7-Day THM Formation Comparison for Various Blends
(pH 8.2 and 25 °C, 0.22 mg/L and 0.49 mg/L Bromide Concentrations in Desalinated Ocean Water)

HAA Evaluations

Comparison of HAA Formation in Various Blends

PH 8.2 AND 25 °C

The total HAA9 and HAA5 formed in the various SDS blends after 3 and 7 days at pH 8.2 and 25 °C with lower bromide Desal are presented in Figure 5-5 and Figure 5-6, respectively. The water quality parameters for each source water are presented in Table 3-2 and for each blend are presented in Appendix C (Table C-1-2).

The desalinated ocean water formed the fewest HAA9 (4.5 µg/L) followed by the 25% Desal/ 75% GW blend (15 µg/L), then the 50% Desal/50% MWD blend (18 µg/L), and finally the 25% MWD/75% GW blend (24 µg/L). The MWD water (31 µg/L) and the breakpoint chlorinated groundwater blends formed the highest concentrations of HAA9 (48 µg/L in 25% Desal/75% GWbp and 58 µg/L in 25% MWD/75% GWbp) at day 7. The relative HAA formation in the test blends is attributable to the same source water quality parameters that impacted the THM formation: the desalinated ocean water had no organic precursors, the non-breakpoint chlorinated groundwater had excess ammonia and no free chlorine contact time, MWD water had higher TOC levels and longer disinfectant contact time, and the breakpoint chlorinated groundwater had a high chlorine dose and a 15-minute free chlorine contact time coupled with high bromide and moderate TOC levels.

The HAA9 concentrations exhibited very slight increases from day 3 to day 7, as HAA formation is rapid. As with the THMs, the integration of the desalinated ocean water served to dilute the MWD HAA9 levels: the 50% Desal/50% MWD blend produced a weighted average of the Desal and MWD HAA9 levels after 3 and 7 days (15 and 18 µg/L, respectively). Finally, as shown in Figure 5-6, the levels of regulated HAAs (HAA5) for all of the blends were below the MCL.

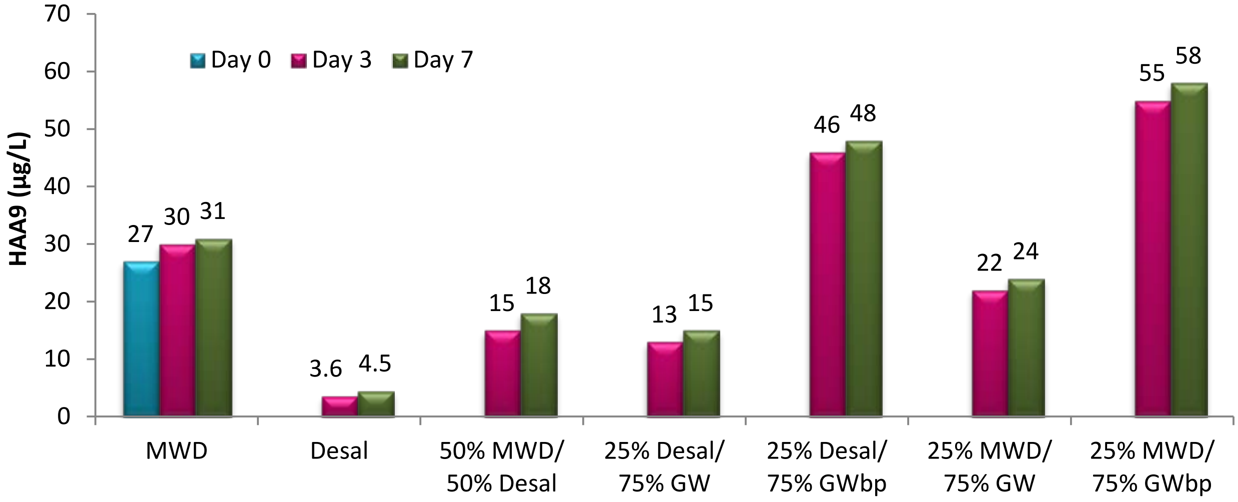


Figure 5-5. HAA9 Formation for Various Blends (pH 8.2 and 25 °C, Lower Bromide Desal: 0.22 mg/L)

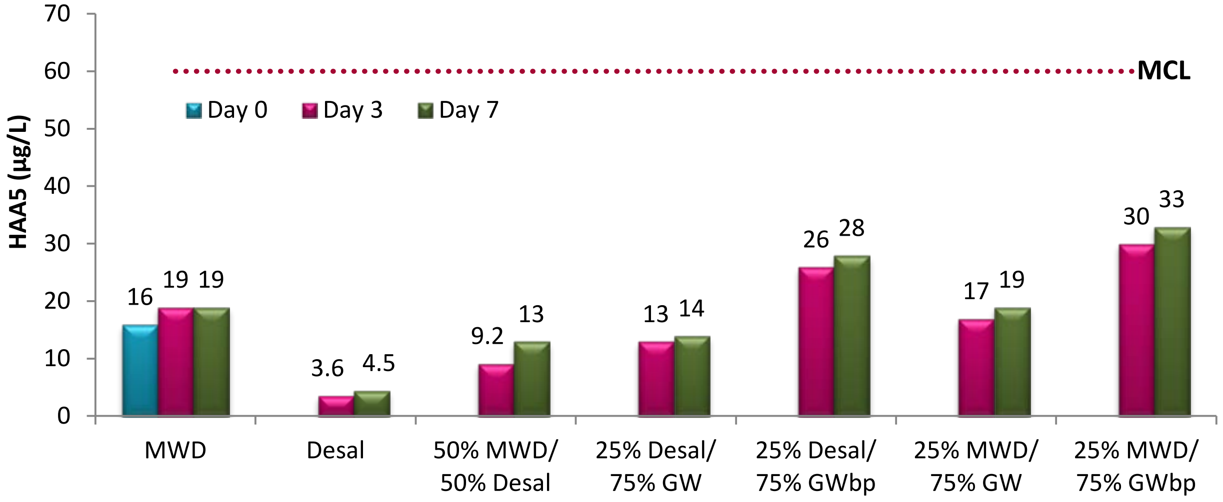
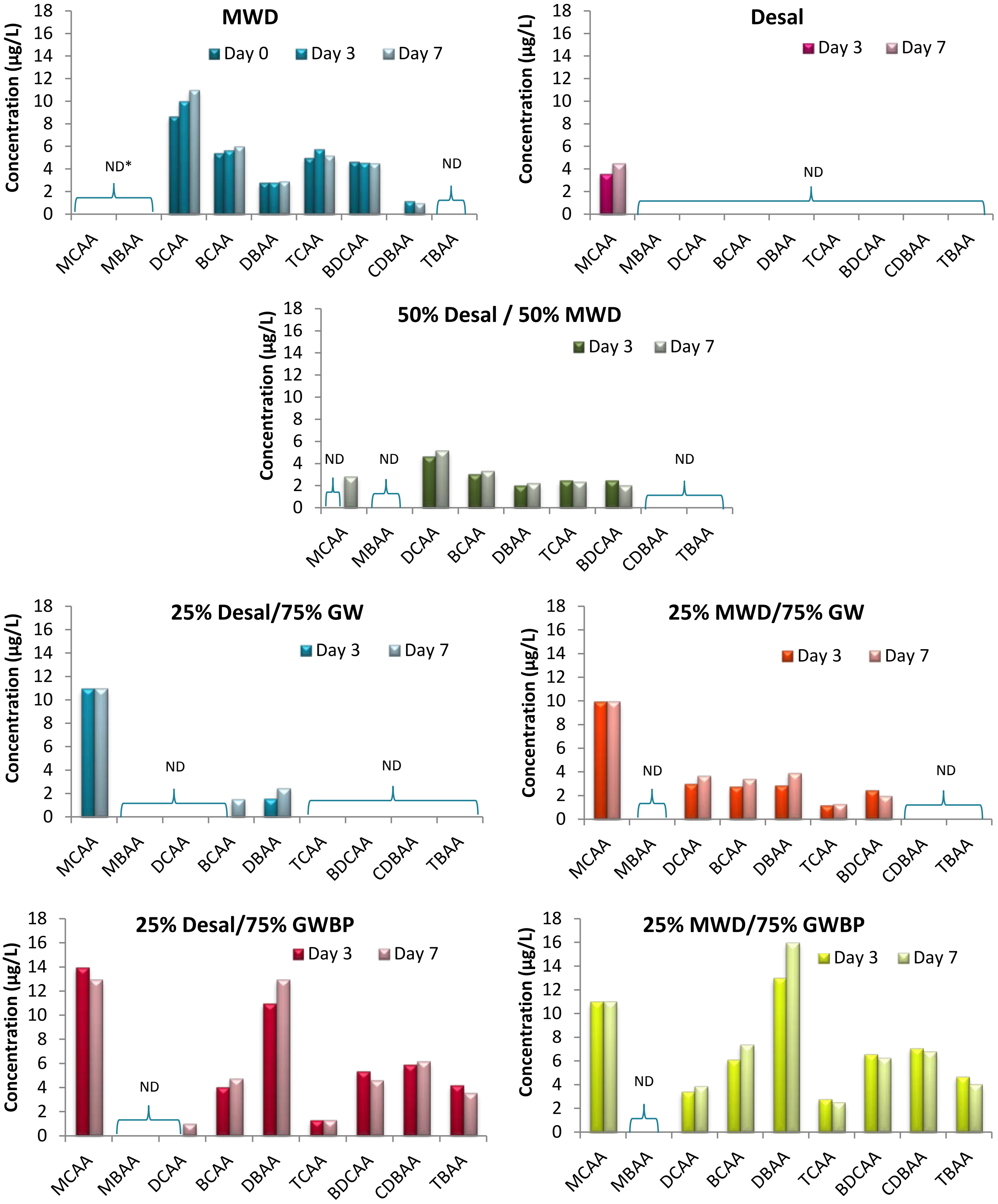


Figure 5-6. HAA5 Formation for Various Blends (pH 8.2 and 25 °C, Lower Bromide Desal: 0.22 mg/L)

Figure 5-7 shows the HAA9 species formed in all of the blends (at pH 8.2, 25 °C, lower bromide Desal). The HAA9 speciation shifted from the chlorinated species to the brominated species in the breakpoint chlorinated groundwater blends, with the predominant species being the dibromoacetic acid. The shift in the speciation towards the more brominated species in these blends can be attributed to the free chlorine contact period with the high groundwater bromide level. MBAA for all blends was below the reporting level. It should be noted that in all blends of source water, except for MWD, the weight percent of MCAA ranged from 16 to 100%, which is suspiciously high. Typically, the DCAA and TCAA levels in surface and ground waters are much higher than the MCAA levels (Cowman and Singer, 1995). From a kinetics standpoint, the MCAA results should be much lower. However, subsequent inspection of the second column results gas chromatograph supported the MCAA results reported herein. This could not be confirmed later or duplicated in another set of samples, thus the presence of some other interference compound other than MCAA could not definitively be ruled out. Therefore, the HAA9 results shown include the suspicious MCAA results and are likely to be an overestimate of the HAA9 produced in the SDS tests.



*ND – for MCAA and TBAA, ND < 2 µg/L, for all other HAA species, ND < 1 µg/L

Figure 5-7. HAAs Species for Various Blends (pH 8.2, 25 °C, Lower Bromide Desal: 0.22 mg/L)

Effects of pH on HAA Formation

Figure 5-8 compares the HAA9 formation in the test blends at pH 8.2 versus pH 8.6 (at 25 °C and Desal bromide of 0.22 mg/L). The small increase in pH from 8.2 to 8.6 had very little effect on HAA9 formation or speciation. Except for the 25% Desal/75% GWbp, which decreased by 8 µg/L at the higher pH, these differences are not significant. Lower HAAs would generally be expected at the higher pH due to the increased reaction rate of ammonia and chlorine to form chloramines (Appendix B, Tables B-1-8 and B-2-8). The regulated HAA5 levels for all blends remained below the MCL.

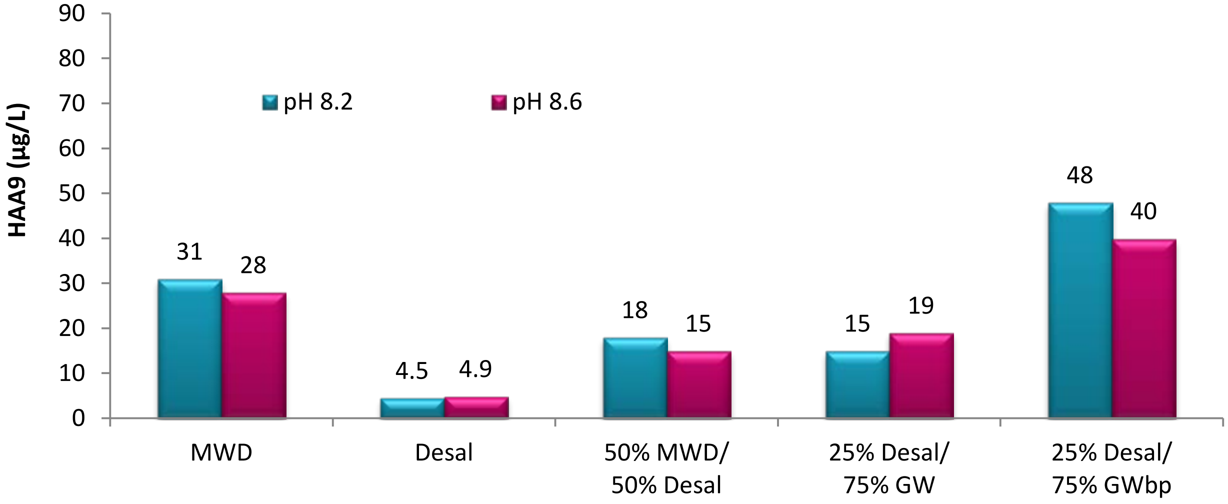


Figure 5-8. 7-Day HAA9 Formation Comparison for Various Blends (pH 8.2 and pH 8.6, 25 °C, Lower Bromide Desal: 0.22 mg/L)

Impact of Increased Desalinated Ocean Water Bromide Concentration on HAA Formation

Figure 5-9 compares the HAA9 formation in the test blends when utilizing desalinated ocean water with bromide levels of 0.22 mg/L and 0.49 mg/L, respectively (at pH 8.2 and 25 °C). As previously discussed, increasing the bromide in the Desal water by 0.27 mg/L resulted in an increase of 0.14 mg/L bromide in the 50% Desal/50% MWD blend and an increase of only 0.07 mg/L bromide in the 25% Desal/75% GW and 25% Desal/75% GWbp blends. The bromide in the final 50% Desal/50% MWD blend increased from 0.13 to 0.27 mg/L and in the 25% Desal/75% GW and GWbp blend increased from 0.77 to 0.84 mg/L. As such, the HAA9 formation for all blends with desalinated ocean water increased only slightly (from 2–5 µg/L) at the higher bromide level. Similarly, the increase in bromide concentration had very little impact on the HAA9 speciation (Appendix B, Tables B-1-8 and B-3-8). The HAA5 for all of the blends with the higher concentration of bromide in desalinated ocean water remained below the 60 µg/L MCL. The HAA9 levels in all blends, except the 25% Desal/75% GWbp, remained well below the MWD HAA9 level (32 µg/L) even with the higher bromide concentration Desal. The relative HAA formation in the test blends did not change with the slightly higher bromide level in the desalinated water. The source water quality parameters impacted the relative HAA9 formation in each test blend: the desalinated ocean water had no organic precursors, the non-breakpoint chlorinated groundwater had excess ammonia and no free chlorine contact time, MWD water had higher TOC levels and longer disinfectant contact time, and the breakpoint chlorinated groundwater had a 15-minute free chlorine contact time coupled with high bromide and moderate TOC levels.

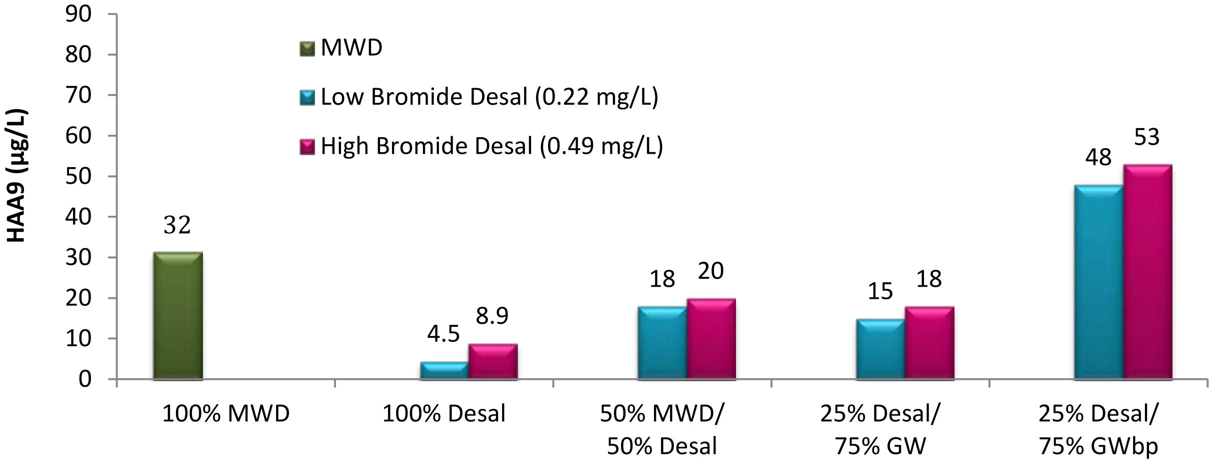


Figure 5-9. HAA9 Formation Comparison for Various Blends
(pH 8.2 and 25 °C, 0.22 mg/L and 0.49 mg/L Bromide Concentrations in Desalinated Ocean Water)

NDMA Formation

Nitrosamine analyses (including NDMA) were conducted because recent studies have indicated that increases in bromide from 0.1 to 0.3 mg/L result in increased formation of NDMA (Yates, 2010). Table 5-1 compares the NDMA formation in each of the test blends after 7-day SDS tests at pH 8.2 and 25 °C. All other nitrosamines were below the reporting level (< 2 ng/L) in each of the test blends (Appendix B, Table B-1-9). NDMA formation was similar among the different blends of source waters, ranging from 2.0 to 4.1 ng/L, and well below the CDPH notification level of 10 ng/L. NDMA was unexpectedly measured in the desalinated ocean water, albeit at low levels (< 4 ng/L). The source of this could possibly be NDMA precursors that were present in ocean water or leachate from the polyamide membranes used in the desalination process. Interestingly, the highest levels of NDMA were measured in the 50% Desal/50% MWD blend: unlike THMs and HAAs, NDMA concentrations in MWD water were not diluted by the Desal. Overall, these tests exhibited very low levels of NDMA formation and indicated that the integration of desalinated ocean water in lieu of MWD would not increase NDMA levels in the groundwater blends tested.

Although high bromide levels increase NDMA formation, little difference was noted in the NDMA formation when utilizing the higher bromide (0.49 mg/L) versus the lower bromide (0.22 mg/L) desalinated ocean water. Blending of the desalinated ocean water with the other source waters lessened the bromide increase in the final blend and diminished impacts on

NDMA formation. The bromide levels in the Desal/MWD blend only increased from 0.13 mg/L in the lower bromide test to 0.27 mg/L in the higher bromide test (Table 5-1). The bromide levels in the Desal/GW and Desal/GWbp blends only increased from 0.77 mg/L in the lower bromide test to 0.84 mg/L in the higher bromide test. The test results at the higher bromide level remained near or below the 2 ng/L NDMA reporting level.

Table 5-1. NDMA Formation for Various Blends
(pH 8.2 and 25 °C)

Blends	0.22 mg/L Bromide in Desal Water		0.49 mg/L Bromide in Desal Water	
	Calculated Initial Bromide Concentration (mg/L)	NDMA on Day 7 (ng/L)	Calculated Initial Bromide Concentration (mg/L)	NDMA on Day 7 (ng/L)
MWD	0.04	4.0	0.05	4.0
Desal	0.22	2.5	0.49	3.9
50% Desal/ 50% MWD	0.13	4.1	0.27	4.5
25% Desal/ 75% GW	0.77	2.0	0.84	ND* (1.3)
25% Desal/ 75% GWbp	0.77	3.0	0.84	ND (1.6)
25% MWD/ 75% GW	0.72	2.5		
25% MWD/ 75% GWbp	0.72	2.1		

* ND – 2 mg/L

Iodinated-THM Formation in Various Blends of Source Waters

Comparison of Iodo-THM Formation in Different Blends

pH 8.2, 25 °C WITH LOWER BROMIDE DESAL

Because ocean water can often contain appreciable levels of iodide, the formation of iodinated disinfection byproducts, iodo-THMs, and iodo-HAAs were evaluated. However, the desalinated ocean water iodine concentration was below the 10 µg/L reporting level (Table 3-2). Consequently, with no organics and no detectable iodine present, the desalinated ocean water formed no iodo-THMs (Figure 5-10 and Figure 5-11). MWD water also had no detectable iodine present; however, a very low concentration (0.7 µg/L) of iodo-THMs was detected. Due to relatively high iodide concentration (41 µg/L) in groundwater, all of the blends containing groundwater formed higher iodo-THMs, ranging from 1.3 to 2.9 µg/L on day 7. Blends with breakpoint chlorinated groundwater formed the highest level of iodo-THMs with the most dominant species being dibromoiodomethane. As with the regulated THMs and HAAs, the GWbp formed the highest iodo-THMs due to the relatively higher levels of precursors (iodine and organics) as well as a free chlorine contact time. The high levels of ammonia in the non-breakpoint chlorinated GW prevented free chlorine contact and, therefore, formed lower levels of iodo-THMs. Overall, very low levels of iodo-THMs were formed in the test blends on day 7 and the integration of desalinated ocean water appeared to cause a modest decrease in iodo-THM formation.

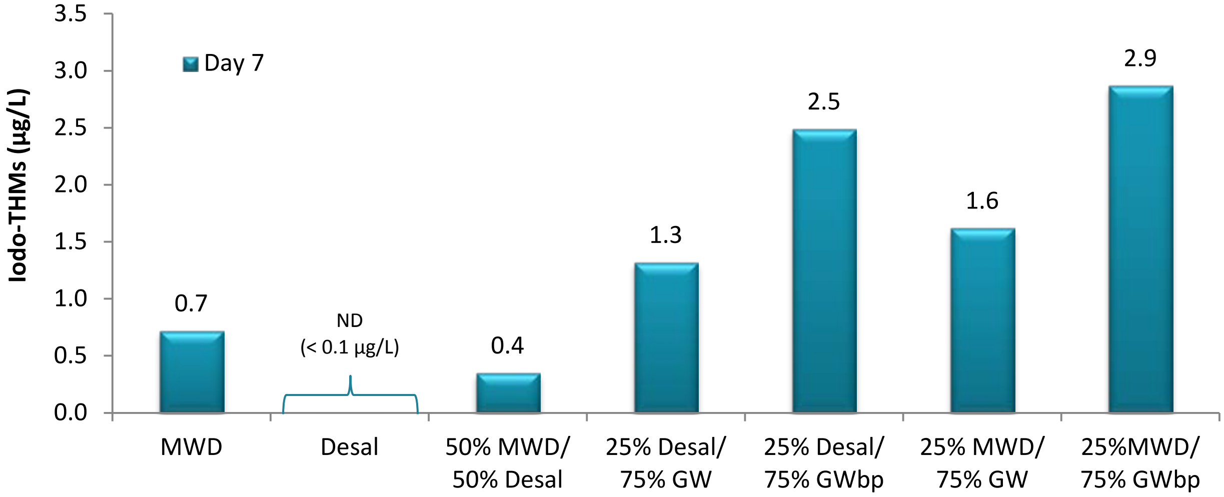


Figure 5-10. 7-Day Iodo-THM Formation in Various Blends (pH 8.2, 25 °C, Lower Bromide Desal: 0.22 mg/L)

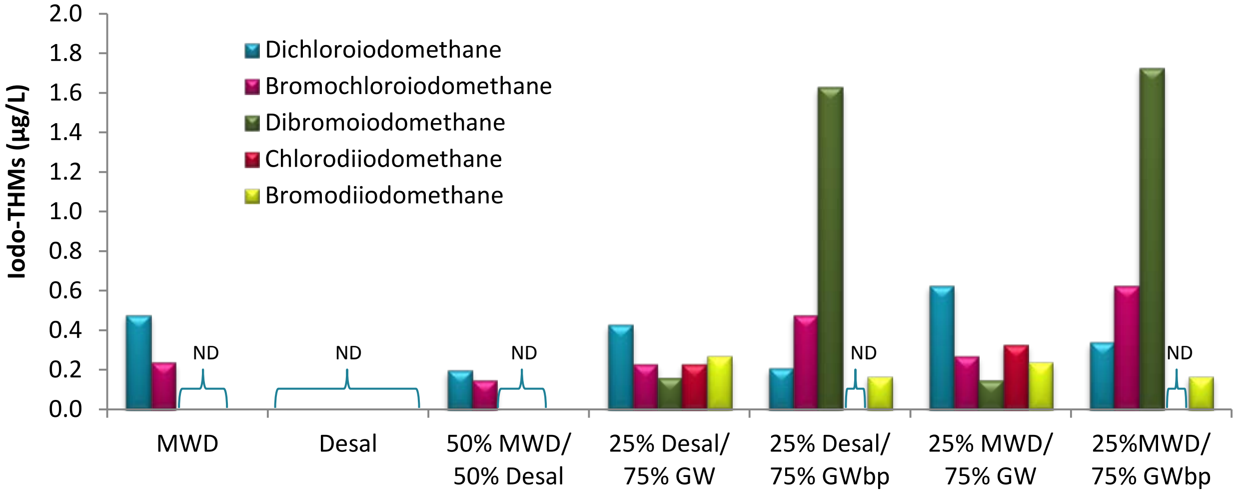


Figure 5-11. 7-Day Iodo-THM Species for Various Blends (pH 8.2, 25 °C, Lower Bromide Desal: 0.22 mg/L)

Effects of Bromide Concentration in Desalinated Ocean Water on Iodo-THM Formation

The iodo-THM formation was compared for various blends utilizing desalinated ocean water with bromide measuring 0.22 mg/L versus 0.49 mg/L (Figure 5-12). The results indicated that increasing the bromide concentration to 0.49 mg/L in the desalinated ocean water had only a minor effect on overall bromide levels in the blends and very little effect on the 7-day iodo-THM formation or speciation. As such, even at the higher bromide levels, the relative iodo-THM formation from lowest to highest remained Desal < MWD < GW < GWbp. Refer to Appendix B, Tables B-1-10 and B-3-10 for iodo-THM speciation data.

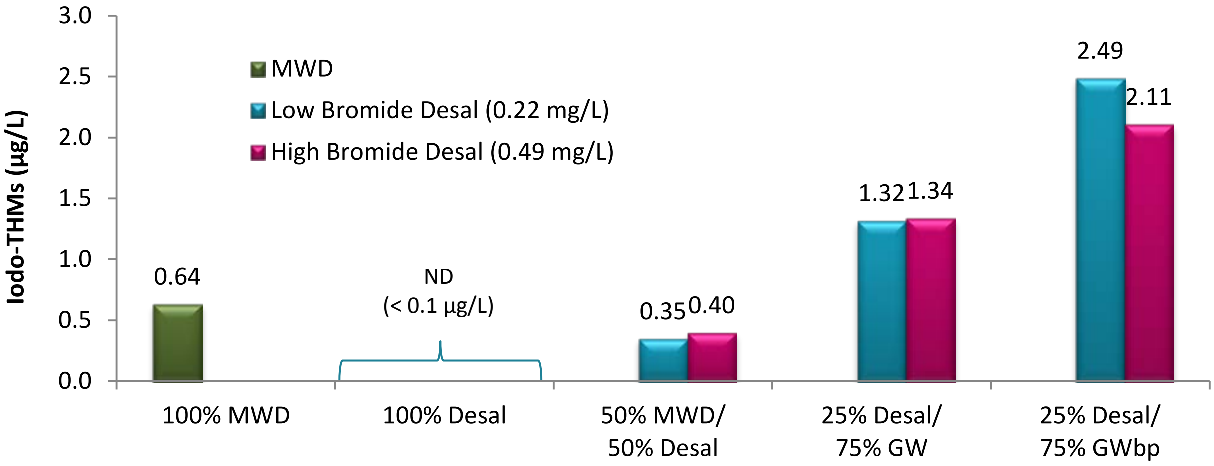


Figure 5-12. 7-Day Iodo-THM Formation Comparison for Various Blends of Lower Bromide and Higher Bromide Desalinated Ocean Water (pH 8.2, 25 °C)

Iodo-HAA Formation in Various Blends of Source Waters

Lower Bromide Desal

Iodo-HAA samples were collected after a 7-day SDS test at pH 8.2 and 25 °C. Figure 5-13 shows the total iodo-HAAs formation for the various blends and Figure 5-14 shows the iodo-HAA species that made up the total iodo-HAA concentration. Due to the lack of precursors (organics and iodide), the lowest 7-day iodo-HAA concentration was formed in the Desal. MWD water also had low levels of iodine and formed fairly low levels of iodo-HAAs (247 µg/L). The Desal water served to dilute the levels of iodo-HAAs in MWD water as seen in the 50% Desal/50% MWD blend. As with the iodo-THMs, due to the relatively high iodide concentration in groundwater, the blends containing groundwater formed the highest levels of iodo-HAAs. It is interesting to note that the 7-day iodo-HAA levels were higher in blends with non-breakpoint chlorinated groundwater than in blends with breakpoint chlorinated groundwater. This may have been the result of the free chlorine in the breakpoint chlorinated groundwater reacting with hypoiodous acid (HOI) to form iodate, thereby making less HOI available to form iodo-HAAs. The predominant iodo-HAA species in non-breakpoint chlorinated groundwater blends is monoiodoacetic acid. Overall, the relative contribution of iodo-HAAs from each of the source waters from lowest to highest was Desal< MWD < GWbp < GW.

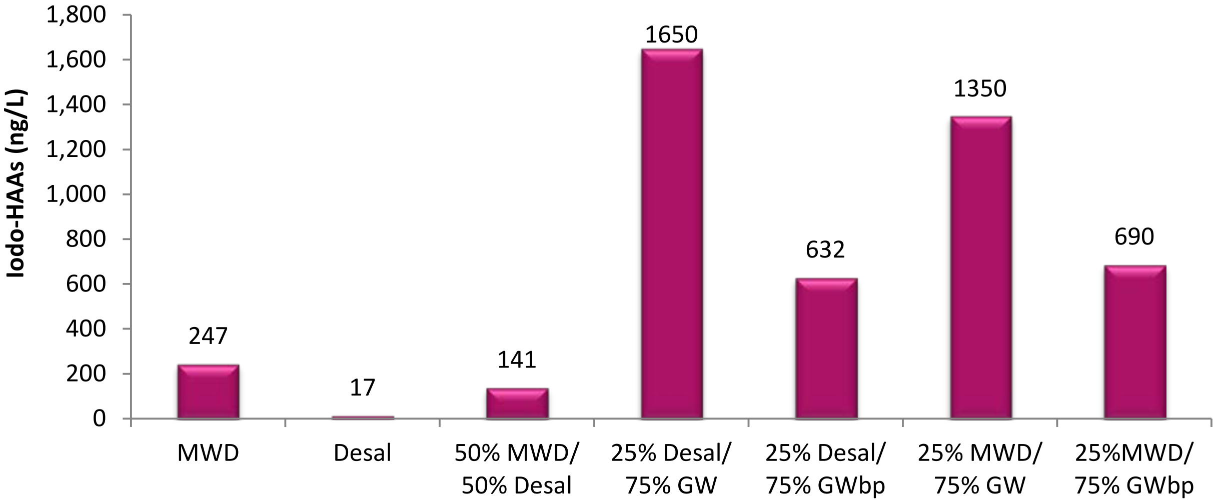


Figure 5-13. 7-Day Iodo-HAA Formation for Various Blends (pH 8.2, 25 °C, Lower Bromide Desal: 0.22 mg/L)

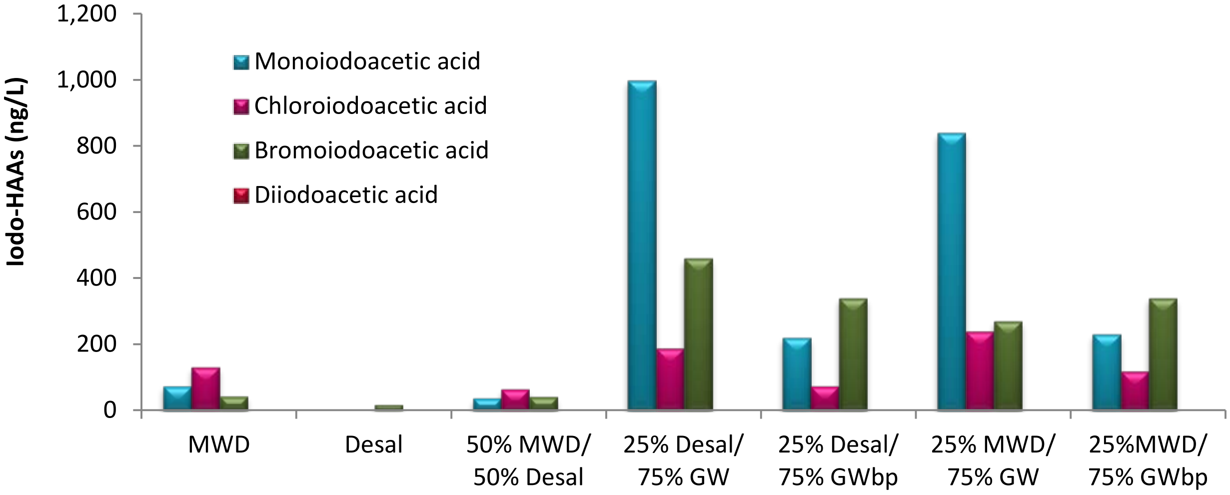


Figure 5-14. 7-Day Iodo-HAA Species for Various Blends (pH 8.2, 25 °C, Lower Bromide Desal: 0.22 mg/L)

Effects of Bromide Concentration in Desalinated Ocean Water on Iodo-HAAs

The effect of increasing the desalinated ocean water bromide levels from 0.22 to 0.49 mg/L bromide on the iodo-HAA formation in the 7-day SDS tests (at pH 8.2 and 25 °C) is shown in Figure 5-15. Increasing the bromide concentration in the desalinated ocean water had very little effect on iodo-HAA formation and speciation (Appendix B, Tables B-1-11 and B-3-11) in all blends except the anomalous 25% Desal/75% GWbp blend. This test was not repeated thus these results were not confirmed. Because this was the only blend that exhibited a large difference between the lower and higher bromide test, the 25% Desal/75% GWbp iodo-HAA results are suspicious and merit further investigation. However, these anomalous results do not affect the overall conclusion that integrating desalinated ocean water with these source waters will not increase the formation of iodo-HAAs.

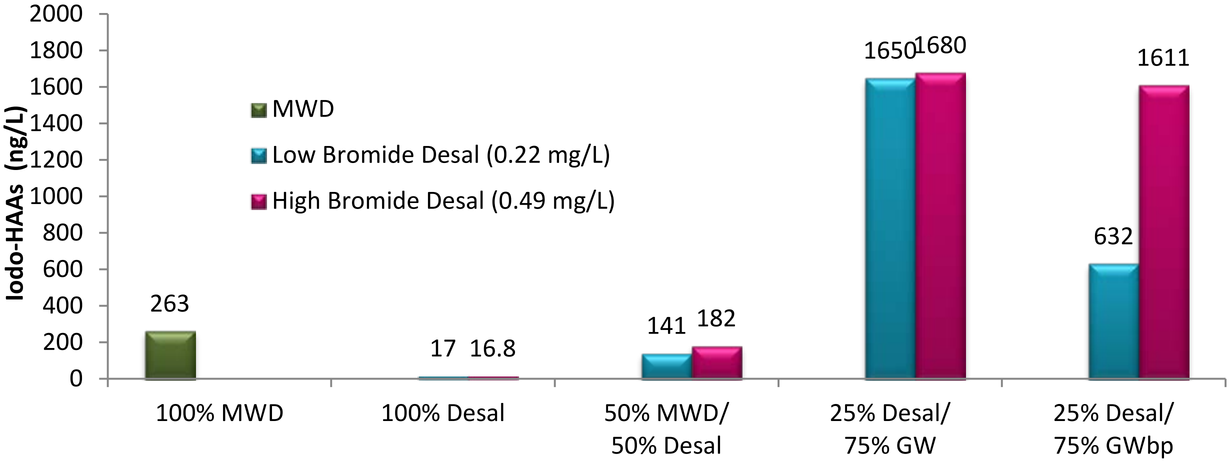


Figure 5-15. 7-Day Iodo-Haas Formation Comparison for Various Blends of Lower Bromide and Higher Bromide Desalinated Ocean Water (pH 8.2, 25 °C)

Summary of DBP Formation Tests

The Phase II SDS tests compared DBP formation in various source water blends, assessed the effects of Desal bromide levels (0.22 mg/L vs 0.49 mg/L), and for THMs and HAAs, the effects of increasing pH from 8.2 to 8.6 were examined. The results are as follows:

1. Relative ranking of THM formation in the various source water blends from lowest to highest are:
   i. Desal
   ii. 25% Desal/75% GW
   iii. 25% MWD/75% GW
   iv. 50% Desal/50% MWD
   v. MWD
   vi. 25% Desal/75% GWbp
   vii. 25% MWD/75% GWbp
2. The THMs and HAAs for all of the blends on days 3 and 7 were well below their respective MCLs of 80 µg/L and 60 µg/L.
3. Little difference was observed in the THM or HAA levels measured on day 3 versus day 7.
4. Substitution of MWD water with desalinated ocean water would likely decrease distribution system THMs, HAAs, iodo-THMs, and iodo-HAAs.
5. Raising the pH from 8.2 to 8.6 had little impact on THM and HAA formation.

6. Increases in Desal bromide levels from 0.22 to 0.49 mg/L had little impact on THM, HAA, NDMA, and iodo-THM formation and speciation. Increasing the bromide in the Desal water by 0.27 mg/L resulted in small bromide increases of 0.14 mg/L in the 50% Desal/50% MWD blend and only 0.07 mg/L bromide in the 25% Desal/75% GW and GWbp blends.
7. Very low levels of NDMA were formed (< 5 ng/L), and the integration of desalinated ocean water in lieu of MWD would not increase NDMA levels in the water blends tested.
8. Iodo-THMs were not detected in the Desal water; the highest levels were found in the groundwater blends due to the relatively high iodide concentration (41 μg/L) in the groundwater.
9. Very low levels of iodo-HAAs were detected in the Desal water; the highest levels were found in the groundwater blends due to the relatively high iodide concentration (41 μg/L) in the groundwater.

Section 6. CONCLUSIONS

This bench-scale study established a possible method for post-treatment stabilization of desalinated ocean water to maintain a stable chloramine residual; evaluated the impact of integrating desalinated ocean water in lieu of MWD water in various blends of source waters on chloramine stability and DBP formation and speciation; and evaluated the effects of varying temperature, pH, and bromide concentration on chloramine stability and DBP formation and speciation. The lessons learned from this SDS testing are summarized below.

1. Post-Treatment Stabilization. The strategy used in this study was to chloraminate corrosion-stabilized desalinated ocean water, provide an initial disinfectant decay period for 4 hours, and then boost the chlorine and ammonia back up to desired levels. This mitigated much of the rapid chloramine decay rates in the SDS tests. It is recommended that the full-scale desalination facility design incorporate a chloramine contact time of at least 5 hours with subsequent chlorine and ammonia feed systems to stabilize chloramine residual prior to distribution of the desalinated ocean water.

2. Chloramine Stability. The chloramine residual decayed more quickly in the desalinated ocean water than in the MWD water due to the fact that the MWD water had already undergone a chloramine decay period in the distribution system prior to sampling. This made the MWD water inherently more stable than the other water blends in the chloramine stability tests. Despite this advantage, the chloramine stability testing indicated that there was very little difference in chloramine decay rates between blends with desalinated ocean water versus the same blends with MWD water. This same result was obtained with lower bromide (0.25 mg/L) and higher bromide (0.49 mg/L) desalinated ocean water. Thus, in the artificial environment of SDS testing, with clean glassware, no biofilms, and no corrosion scale, the integration of desalinated ocean water in lieu of MWD water when blended 50/50 with MWD water and 25/75 with non-breakpoint chlorinated or breakpoint chlorinated groundwater, had little impact on chloramine stability. However, changing source waters can have a dramatic impact on older corroded piping and biofilms, causing destabilization of metals, colored water, and loss of disinfectant residual. Therefore, it is of critical importance to examine the results of the pipe loop study conducted with harvested distribution piping.

   In all of chloramine stability tests, the order of stability, ranked from most stable to least stable was generally: MWD > blends with non-breakpoint chlorinated groundwater > Desal > blends with breakpoint chlorinated groundwater. As previously mentioned, the chloramine residuals in the MWD test water had already decayed in the distribution system when it was collected, affording it greater stability in these tests. High ammonia levels in the non-breakpoint chlorinated groundwater stabilized the chloramine residual in the GW blends. Once the GW was breakpoint chlorinated there was no free ammonia to stabilize the residual and the relatively high organics and high bromide levels increased decay in the GWbp blends. It is important to note that even though these SDS tests showed that non-breakpoint chlorinated groundwater blends experienced low levels of chloramine decay, this may not be true in the distribution system. High levels of free ammonia in the distribution system can promote the growth of ammonia oxidizing bacteria and result in nitrification and subsequent rapid loss of disinfectant residual.

Overall chloramine decay for all conditions and blends ranged from 0.02–0.97 mg/L on day 1, 0.11–1.18 mg/L on day 3, and 0.22–1.47 mg/L after 7 days in the SDS tests. Higher decay rates are anticipated in the distribution system due to the chloramine demand exerted by piping and biofilms.

Temperature effects. Chloramine decay rates decreased at lower temperatures. A decrease in temperature from 25 to 10 °C reduced chloramine decay in the various blends by 0.04–0.54 mg/L on day 1, 0.07–0.67 on day 3, and 0.12–0.80 mg/L over the course of the 7-day SDS tests. Thus, the distribution system chloramine residuals can be expected to be significantly more stable in the cooler winter months than in the summer.

pH effects. Increasing pH from 8.2 to 8.6 after the addition of ammonia had mixed results, but overall very little impact on chloramine decay. Chloramine decay was relatively unchanged in the MWD water and decreased slightly in the 50% Desal/ 50% MWD and in the 25% Desal/75% GW. In contrast, decay increased slightly in the 25% Desal/75% GWbp and in the 25 °C Desal. This unexpected result indicates that a pH increase from 8.2 to 8.6 after the formation of chloramines may not be a good tool to increase chloramine stability – particularly in systems that breakpoint chlorinate.

3. DBP formation. With the exception of NDMA, the integration of desalinated ocean water with MWD water and both non-breakpoint chlorinated and breakpoint chlorinated groundwater had a beneficial impact on regulated and unregulated DBP formation in the SDS tests. Due to low levels of organic DBP precursors, very low levels of regulated THMs, HAA9, NDMA, and iodo-HAAs were formed and no detectable level of iodo-THMs were formed in desalinated ocean water. Increasing the desalinated ocean water bromide from 0.22 to 0.49 mg/L had little impact on DBP formation, except for one suspect result where the 25% Desal/75% GWbp formed much greater iodo-HAAs at the higher bromide level. Blending desalinated ocean water with other water sources provided a dilution effect on all DBP concentrations with the exception of NDMA. The highest NDMA formation was in the 50% Desal/50% MWD blend. However, the NDMA concentration was below 4.5 ng/L in all blends of source waters; well below the CDPH notification level of 10 ng/L.

   Overall, the levels of all DBPs were low, and all regulated DBPs were well below drinking water MCLs. Examination of THMs and HAAs demonstrated little DBP increase from day 3 to day 7 of the SDS test, as DBP formation was rapid. Blends with breakpoint chlorinated groundwater formed the highest THMs, HAAs, and iodo-THMs due to the presence of bromide, iodide, and organic precursors. Blends with non-breakpoint chlorinated groundwater formed the highest iodo-HAAs. Finally, increasing pH from 8.2 to 8.6 had little impact on THM or HAA9 formation.

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Appendix A

Test Plans

Ocean Water Desalination Water Quality Integration Study
Task 7: Bench-Scale Testing for Disinfectant Stability and DBP Formation
Phase 1–Disinfectant Stability Test Plan
Revision Date 5/24/2013

Introduction

The West Basin Municipal Water District (WB) is currently evaluating options to develop a desalinated water source using sea water reverse osmosis (SWRO). As part of the evaluation, WB, in partnership with the Metropolitan Water District of Southern California (MWD), is conducting the Ocean Water Desalination Water Quality Integration Study (Study) to evaluate the potential water quality impacts of integrating desalinated ocean water into existing drinking water distribution systems in the WB service area. These systems currently transport blends of MWD water and various local groundwater sources from California Water Service Company, city of Manhattan Beach, city of El Segundo, and Golden State Water Company Southwest District. The point(s) of introduction of the desalinated water have not yet been determined.

This study is comprised of 8 tasks and is expected to be completed by December 2013. Seven of the tasks will be completed by Hazen and Sawyer Environmental Engineers & Scientists, and MWD will complete Task 7–Bench-Scale Testing for Disinfectant Stability and Disinfection Byproduct (DBP) Formation. This task will be conducted using a phased approach as information from the first phase will be required to determine which conditions warrant further testing. This memorandum provides the test plan for the Phase 1 of the Task 7 bench-scale study, which encompasses the disinfectant stability testing. Phase 2 testing will evaluate formation of DBPs.

Background

The integration of desalinated water directly into a treated water distribution system could potentially impact the stability of the chloramine residual and the formation of DBPs. These issues are described below.

Chloramine Stability—Desalinated water will require disinfection with free chlorine to meet regulatory disinfection requirements, then ammonia must be added to form chloramines prior to pumping into the distribution system(s). The target chloramine residual and chlorine-to-ammonia ratios of the desalinated ocean water will match distribution system target levels of 2.5 mg/L of total chlorine and 0.526 mg/L of ammonia as nitrogen. Previous studies of desalinated ocean water have indicated that elevated bromide concentrations associated with seawater quickly react with free chlorine to form hypobromous acid, which represents a source of chlorine demand [1]. Furthermore, when ammonia is subsequently added, bromamines will form in addition to the chloramines. Because dibromamine is very active compared to chloramines, it decomposes rapidly, resulting in an unstable disinfectant residual. To ensure distribution system water quality and regulatory compliance, the disinfectant residual must be stabilized such that it will not cause a rapid decay of disinfectant within the distribution system. Recent studies suggest that bromide concentrations < 0.3 mg/L in the desalinated water may reduce the problems associated with disinfectant stability and DBP formation [2]. If decay issues persist, provision of a stabilization period (3–8 hours) may be required to reduce disinfectant stability issues by ensuring near complete decay of the bromamines prior to pumping into the distribution system.

Disinfection Byproducts—The Stage 1 and Stage 2 Disinfectants/Disinfection Byproduct (D/DBP) Rules established by the US Environmental Protection Agency (USEPA) currently regulate four trihalomethanes (THMs) (chloroform, bromoform, bromodichloromethane, and dibromochloromethane) and five haloacetic acids (HAA5) (monochloro-, dichloro-, trichloro-, monobromo-, and dibromo-acetic acid). Because SWRO removes a substantial amount of the natural organic matter that reacts with chlorine to form these THMs and HAA5, SWRO treatment results in very low regulated DBP concentrations. However, waters high in bromide that are blended with water containing organics will continue to form DBPs with increasing water age in the distribution system. When desalinated ocean water is blended with surface water containing total organic carbon (TOC), the dibromamine and hypobromous acid will react with the TOC to form brominated DBPs. Studies conducted at Long Beach Water District and Santa Cruz Water District have demonstrated that the blending of low DBP, high bromide (> 0.3 mg/L) desalinated water with distribution system water increased the DBPs in the blended water above that of the original distribution system water after 5 days [3,4]. Additionally, the presence of bromide and iodide typically found in SWRO permeate will shift the types of DBPs found in the water toward currently unregulated brominated and iodated compounds.

Unregulated DBPs—Approximately 600 to 700 DBPs have been reported in the literature; however, at present, only nine such species are regulated. Many of the currently unregulated DBPs may become regulated in the future, and it is therefore prudent to understand the byproduct formation potential of unregulated compounds as well. Chloramines are less reactive than free chlorine, and are therefore less susceptible to decay and formation of THMs and HAA5. The exception to this rule is when moderate to high amounts of bromide and/or iodide are present in the water to be treated with chloramine. With chloramination, dihalogenated acetic acids become more prevalent relative to chlorination, and the speciation tends towards brominated and iodinated compounds. In addition to the regulated DBPs, HAA9 (i.e., the sum of monochloro-, dichloro-, trichloro-, monobromo-, dibromo-, bromochloro-, bromodichloro-, chlorodibromo-, and tribromo-acetic acids), iodoacid, iodo-THM, haloamide, haloaldehyde, and 3-chloro-4-(dichloromethyl)-5-hydroxy-2(5H)-furanone (MX)/brominated MX (BMX) formation are potential issues for water high in bromide and iodide when disinfected with chloramines [5].

NDMA—Recent studies conducted at MWD indicate that increases in bromide from 0.1 mg/L to 0.3 mg/L result in increased formation of another unregulated chloramine disinfection byproduct: N-nitrosodimethylamine (NDMA) [6]. NDMA has received increased scrutiny in the past few years as it is considered by both the USEPA and the California Department of Public Health (CDPH) to be a probable human carcinogen. Although there is currently no maximum contaminant level (MCL), it is a likely candidate for future regulations. NDMA currently has a CDPH notification level of 0.01 µg/L and a public health goal of 3 ng/L set by the California State Office for Environmental Health Hazard Assessment. Quarterly sampling of MWD's system from 2000–2009 shows that NDMA is present in the effluents of the treatment plants at levels ranging from < 2 ng/L to 10 ng/L, with averages ranging from < 2 ng/L to 2.50 ng/L. Therefore, any changes in the system that could potentially increase NDMA formation in the distribution system must be carefully evaluated prior to implementation.

Task Objectives

The objectives of this bench-scale study are to identify criteria for post-treatment stabilization in order to maintain a stable chloramine residual in various blends of desalinated, MWD, and groundwater and to evaluate potential impacts of desalinated water integration on DBP formation. To meet these objectives, the bench scale testing will be conducted in two phases:

1. Phase 1 – pre-testing and simulated distribution system chloramine stability testing and,
2. Phase 2 – disinfection byproduct formation

Phase 1 will be conducted from April through mid-July, and Phase 2 will be conducted from mid- July to mid-August. The following sections describe the activities to be conducted during Phase 1 of the testing, and give a preliminary description of Phase 2 testing.

Task 7 objectives have been divided into five sub tasks and allocated to Phase 1 or Phase 2 as detailed below. Initial Phase 1 tests will be conducted with bromide concentrations of approximately 0.3 mg/L in the desalinated water. Depending on the results of the initial tests, subsequent testing may be conducted at higher or lower bromide concentrations.

Phase 1. Chloramine Stability

7a. Determine the proper test methods and evaluate the number of replicates for each test in order to achieve a level of standard significance.
7b. Determine the chlorine and ammonia dosages and detention times needed to achieve a stable chloramine residual of 2.5 mg/L with a 4.75:1 chlorine:ammonia-N in the desalinated water.
7c. Determine the effects of varying water quality parameters (pH, temperature, bromide) on the chloramine stability in various blends of desalinated water/MWD water/local groundwater (GW)

Phase 2. DBP Formation

7d. Determine the changes in DBP formation at various blends of desalinated water/MWD water/GW and at to-be-determined water quality conditions.
7e. Determine the changes in DBP speciation towards next-generation iodinated and brominated DBP compounds and NDMA at various blends of desalinated water/MWD water/GW and at to-be-determined water quality conditions

Testing Approach

Phase 1 –Chloramine Stability

Pre-Tests

Prior to conducting the SDS disinfectant stability testing, some preliminary testing must be conducted in order to develop proper test methods for conducting the chloramine stability tests (Sub Task 7a) and to determine the protocol for producing a stable chloramine residual in the desalinated water (Sub Task 7b).

The pre-testing "shake-down" period will be used to develop the best, most reproducible methods for sampling, dosing the chemicals, measuring the residuals, and conducting the chloramine stability tests. Replicate analyses conducted during this period will be used to determine the number of replicates required for the ensuing chloramine stability tests.

The second part of the pre-testing is the determination of the chlorine and ammonia dosages and hydraulic retention time needed to achieve a stable chloramine residual (2.5 mg/L) in the desalinated water at a 4.75:1 chlorine:ammonia-N (Sub Task 7b).

Because chloramines will decay in all water types, a standard must be established to define a "stabilized" chloramine residual. For this study, chloramine decay in MWD water will be used as the benchmark for chloramine decay in stabilized desalinated water. The pre-testing protocol is listed below.

Pre-Test Steps

1. Sample MWD water at WB-4 service connection in 2-L amber glass bottles. (The Sea Lab service connection will not be used due to low total chlorine residuals.) Ensure line has been well flushed (stable temperature and total chlorine residual of approximately 2 mg/L) before sampling. Measure total chlorine in the field. Aliquot samples for pH, TOC and total alkalinity analyses in the lab.
2. Pre-warm the sample in a 25 °C waterbath. Aliquot portions into five 60-mL (chlorine demand-free) bottles and hold in a 25 °C waterbath. Measure the total chlorine and total ammonia residuals at the following times: 0, 1, 2, 4, and 24 hrs. This should be the benchmark chloramine decay rate.
3. Sample stabilized desalinated water (blended first and second pass permeate post-calcite treatment) in 2-L amber glass bottles. This will be collected from the stabilization loop prior to chlorine and ammonia addition. Record turbidity of collected sample (from consultant data sheet). If turbidity is greater than 0.4 NTU, sample must be pre-filtered prior to use. Water samples will be stored in the refrigerator (less than 2 weeks) until testing commences. Aliquot samples for pH, bromide, TOC and total alkalinity analyses.
4. Pre-warm the sample in a 25 °C waterbath. Aliquot small portions for pre-testing to determine initial chlorine demand.
5. Once initial chlorine demand has been determined, add required NaOCl dosage to obtain a 2.5 mg/L free chlorine residual at the end of 15 mins incubation. (Free chlorine contact time will be required at the full scale in order for WB to meet their disinfection requirements for 0.5-log *Giardia* inactivation and 2-log virus inactivation.) Next add 0.526 mg/L NH_3-N and adjust pH to 8.2 with NaOH.
6. Measure total chlorine and total ammonia.
7. Aliquot total portions into five 60-mL bottles and hold in a 25 °C waterbath. Measure the total chlorine residual and pH at the following times: 0, 1, 2, 4, and 24 hrs.
8. Compare decay rates in desalinated water versus MWD water.
9. If decay rates in desalinated water are higher than in MWD water, dose the chemicals to achieve an initial 2.5 mg/L residual chlorine and 0.526 mg/L NH_3-N residual, hold for 4 hrs, then repeat steps 4–7. Note: if adjustment of ammonia is required to maintain a 0.526 mg/L NH_3-N residual, add the ammonia prior to adding the chlorine.
10. If decay rates in desalinated water are still higher than in MWD water, repeat the test and adjust chemical dosage and hold time as necessary.

11. Select the best dosage and holding time to use for the remaining tests.

Chloramine Stability Tests

Once the sampling, dosing and testing methodology has been refined in the pre-testing, the effects of varying water quality parameters (pH, temperature and bromide) on the chloramine stability in various blends of desalinated water, MWD water, and GW can be evaluated (SubTask 7c). The conditions to be tested are listed in Tables 1 and 2, and the analytes are listed in Table 3. The testing protocol is listed below.

Chloramine Stability Testing Steps

1. Sample Preparation
    a. *Desalinated water*. Sample stabilized desalinated water (blended first and second pass permeate post-calcite treatment) in 2L-amber glass bottles. This will be collected from the pipe loop stabilization tank prior to chlorine and ammonia addition. Record turbidity of collected sample. If turbidity is greater than 0.4 NTU, sample must be pre-filtered prior to use. Water samples will be stored in the refrigerator (less than 2 weeks) until testing commences. Aliquot samples for total alkalinity, bromide, TOC, turbidity and calcium analyses in the lab.
    b. *MWD water*. Sample MWD water from the WB-4 service connection in 2-L amber glass bottles. Approximately 3 L will be required for each test. Ensure line has been well flushed (stable temperature and total chlorine values of approximately 2 mg/L) before sampling. Measure total chlorine in the field. Aliquot samples for total alkalinity, TOC, turbidity and calcium analyses in the lab. MWD samples will be transported to the laboratory for immediate testing. The water will be used as is, with no chlorine or ammonia adjustment prior to blending with other water. This provides the best simulation of potential blend conditions.
    c. *GW without breakpoint chlorination*. GW from Manhattan Beach will be sampled and transported to the laboratory for immediate testing. Total nitrite samples will initially be tested in the field and compared to samples analyzed in the lab; if little change is seen, field analyses will be dropped. Aliquot samples for total alkalinity, bromide, TOC, turbidity and calcium analyses in the lab. The GW will be blended either with MWD water, with chloraminated desalinated water or with both. After blending, sodium hypochlorite will be added boost the total chlorine to 2.5 mg/L and the pH will be adjusted as required. Ammonia will not be added due to the high background levels of the groundwater; high free ammonia levels will be present in the groundwater blends.
    d. *GW with breakpoint chlorination* ($GW_{(bp)}$). A portion of the GW collected from Manhattan Beach (above) will be breakpoint chlorinated to achieve a free chlorine residual of 2.5 mg/L after 15 mins incubation in the waterbath. Next, 0.526 mg/L of ammonia (as N) will be added. This chloraminated $GW_{(bp)}$ will be added to a separate beaker that either with MWD water, chloraminated desalinated water or with both. After blending the waters, sodium hypochlorite will be added if needed to boost the total chlorine to 2.5 mg/L and the pH will be adjusted as required.
2. Chloramine stability will be measured for test conditions listed in Tables 1 & 2.

3. For each test condition, place the large 2-L sample bottles in the appropriate temperature waterbath (10 °C or 25 °C).
4. Prepare the desalinated water. The test results from Sub Task 7b will be used to determine chlorine/ammonia dosage and detention time protocol for the desalinated water. This procedure will be used on all desalinated water samples prior to blending with any other water.
5. Measure the conductivity of the chloraminated desalinated water, the MWD water, the unchlorinated GW, and the breakpoint chlorinated/chloraminated water, $GW_{(bp)}$.
6. For each test condition, blend the appropriate water sources in a 4-L beaker, then measure the conductivity. Note, when conducting the tests with 3 source waters , blend desalinated water with MWD water prior to mixing in either the GW or the $GW_{(bp)}$.
7. For each test with GW or $GW_{(bp)}$ in the blend, adjust the total chlorine of the final blend to 2.5 mg/L. If needed, adjust pH (to 8.2 or 8.6).
8. Immediately after completing the final blend and chemical additions, carefully fill and cap two 300 mL BOD bottles (for T_0 measurements), fourteen 60 mL BOD bottles ,then two more 300 mL BOD bottles (for Tfinal measurements) sequentially, with as little aeration as possible and with no head space. Place bottles immediately in the waterbath.
9. Measure T_0 total chlorine, total ammonia, free ammonia, nitrite, and pH. Aliquot samples for total alkalinity and calcium (500 mL); total organic carbon (40 mL); and turbidity (50 mL) for later analysis.
10. Chloramine and total ammonia measurements will be taken from duplicate BOD bottles at the following times: 0, 1, 2, 4, hrs; and 1, 2, 3, 4, and 7 days for each condition.
11. Waterbath temperatures will be monitored daily.
12. At T_{final}, total chlorine, total ammonia, free ammonia, nitrite, and pH will be analyzed.
13. For test 1e only, sulfide, total manganese, and total iron will be measured in each source water and at T_0 and T_{final}.

Phase 2. DBP Formation

The DBP formation sub tasks (Sub Tasks 7d and 7e) will be addressed in Phase 2. The conditions to be evaluated will be determined based on the results of the Phase 1 tests. Trihalomethanes (THM), haloacetic acids (HAA9), NDMA, and iodinated THM concentrations will be measured in simulated distribution system (SDS) tests that will be conducted on relevant test conditions selected from Table 2. Because evaluations conducted by the Long Beach Water Department showed that blends of desalinated water and ground water had lower DBPs than groundwater at 3 days, but at 5 days they were higher in blends, the SDS evaluations will be conducted at 3 days and at 7 days.

Methods

The Hach DR850 will be used for the following analyses:

- Total chlorine - DPD method (10250)
- Free Cl_2 –DPD method (10245)
- Total NH_3 -- Salicylate method (8155) for total NH_3 analysis
- Nitrite method 8507

Free ammonia will be measured using an ion selective electrode method. A pH analyzer will be used to monitor the initial and final pH for all tests, and temperatures will be maintained by waterbath and monitored daily.

All other analyses will be conducted by the MWD Water Quality Laboratory using methods outlined in the current revision of Standard Methods for the Examination of Water and Wastewater.

Table 1. Phase 1 Stability Test Variables and Permutations

Test Variable	Test levels	# of Permutations/comments
Bromide (mg/L)	Desal (0.3, + TBD); MWD (~0.2); GW (ambient)	2
pH	8.2, 8.6	2
TOC	Ambient (MWD & GW ~2 mg/L)	1
Temperature	25 °C, 10 °C	2
		Total permutations =2 x 2 x 1 x 2 = 8
Blend (%)	Desal/MWD/GW/GW$_{(bp)}$	# Tests for each blend
	100 / 0 / 0 / 0	5 –control sample for desal
	0 / 100 / 0 / 0	5 – control sample for MWD
	50 / 50 / 0 / 0	5 –extreme blend for MWD
	25 / 0 / 75 / 0	5—likely blend for Manhattan Beach
	0 / 25 / 75 / 0	1—control for Manhattan Beach /MWD
	50 / 25 / 25 / 0	1—extreme blend with all 3 sources
	25 / 0 /0 / 75	5—likely blend for GW w/breakpoint Cl_2
	0 / 25 /0 / 75	1—control for GW w/breakpoint Cl_2/MWD
	50 / 25 /0 / 25	1—extreme blend with all 3 sources (GW w/breakpoint Cl_2)

Table 2. Phase 1 Chloramine Stability Test Conditions

Test	Desal Br	pH	TOC	Temp °C	Blend (%) Desal/MWD/GW/GW$_{(bp)}$	Tot Cl Stability	Target Date
1a	0.3	8.2	ambient	25	100 /0 /0 /0	x	Week 4 6/24/13
1b					0/100/0 /0	x	
1c					50 /50 /0 /0	x	
1d					0 /25 /75 /0	x	
1e					25 /0 /75 /0	x	
1f					0 /25 /0 /75	x	Week 5 7/8/13
1g					25 /0 /0 /75	x	
1h					50 /25 /25 /0	x	
1i					50 /25 /0 /25	x	
1j					100 /0 /0 /0	x	
2a	0.3	8.6	ambient	25	100 /0 /0 /0	x	Week 1 6/3/13
2b					0/100/0 /0	x	
2c					50 /50 /0 /0	x	
2d					25 /0 /75 /0	x	
2e					25 /0 /0 /75	x	
3a	0.3	8.2	ambient	10	100 /0 /0 /0	x	Week 2 6/10/13
3b					0/100/0 /0	x	
3c					50 /50 /0 /0	x	
3d					25 /0 /75 /0	x	
3e					25 /0 /0 /75	x	
4a	0.3	8.6	ambient	10	100 /0 /0 /0	x	Week 3 6/17/13
4b					0/100/0 /0	x	
4c					50 /50 /0 /0	x	
4d					25 /0 /75 /0	x	
4e					25 /0 /0 /75	x	
5a	TBD	8.2	ambient	TBD	100 /0 /0 /0	x	Week 6 7/15/13
5b					0/100/0 /0	x	
5c					50 /50 /0 /0	x	
5d					25 /0 /75 /0	x	
5e					25 /0 /0 /75	x	
					Total Number of Tests	30	

Table 3. Phase 1 –Stability Test Analytes

Analyte	Source Waters (Before add'l chemicals)	Test Blend (after chemicals/blend)	*Sample Time (post blend)*	*Total Number of Samples**
Total Chlorine	X (MWD)	X	*All*	*576*
Total Ammonia	X	X	*All*	*588*
Free Ammonia	X	X	T_0 *and* T_{final}	*138*
Nitrite	X	X	T_0 *and* T_{final}	*78*
Total Alkalinity	X	X	T_0	*48*
Bromide**	X			*18*
pH	X	X	T_0 *and* T_{final}	*78*
Total Organic Carbon	X	X	T_0	*48*
Temperature	X	X	*daily*	*daily*
Conductivity[xx]	X	xx		*31*
Sulfide	X once only	*test 1e only*	T_0 *and* T_{final}	*5*
Manganese	X once only	*test 1e only*	T_0 *and* T_{final}	*5*
Iron	X once only	*test 1e only*	T_0 *and* T_{final}	*5*
Turbidity	X			*18*
Calcium	X			*18*

T_0 = Time 0 T_{final} = final sample time

🟨 = analyzed by Chemistry Unit

* Assumes test blend total chlorine, total ammonia and free ammonia analyses are run in duplicate. Stability samples collected at 0, 1 2, 4, hrs; and 1, 2, 3, 4, and 7 days for each condition.

** NOTE: Bromide must not be measured in chlorinated water. Jensen Plant Influent bromide values will be used for MWD values.

xx Conductivity to be measured in source water before chemical addition, chloraminated desalinated water, and in final blends <u>before</u> chemical addition to serve as a check on blending.

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Ocean Water Desalination Water Quality Integration Study
Task 7: Bench-Scale Testing for Disinfectant Stability and DBP Formation
Phase 2- Disinfection Byproduct Test Plan

Revision Date 7/29/2013

Introduction

The West Basin Municipal Water District (WB) is currently evaluating options to develop a desalinated water source using ocean water reverse osmosis (OWRO). As part of the evaluation, WB, in partnership with the Metropolitan Water District of Southern California (MWD), is conducting the Ocean Water Desalination Water Quality Integration Study (Study) to evaluate the potential water quality impacts of integrating desalinated ocean water into existing drinking water distribution systems in the WB service area. These systems currently transport blends of MWD water and various local groundwater sources from California Water Service Company, city of Manhattan Beach, city of El Segundo, and Golden State Water Company Southwest District. The point(s) of introduction of the desalinated water have not yet been determined.

This memorandum provides the test plan for the Phase 2 of the Task 7 bench-scale study, which will evaluate formation of disinfection byproducts (DBPs) in various blends of desalinated water, MWD water, and groundwater from the WB service area.

Background

The integration of desalinated water into a treated water distribution system could potentially impact the formation of DBPs. These issues are described below.

Disinfection Byproducts—The Stage 1 and Stage 2 Disinfectants/Disinfection Byproduct (D/DBP) Rules established by the US Environmental Protection Agency (USEPA) currently regulate four trihalomethanes (THMs) (chloroform, bromoform, bromodichloromethane, and dibromochloromethane) and five haloacetic acids (HAA5) (monochloro-, dichloro-, trichloro-, monobromo-, and dibromo-acetic acid). Because OWRO removes a substantial amount of the natural organic matter that reacts with chlorine to form these THMs and HAA5, OWRO treatment results in very low regulated DBP concentrations. However, waters high in bromide that are blended with water containing organics will continue to form DBPs with increasing water age in the distribution system. When desalinated ocean water is blended with surface water containing total organic carbon (TOC), the dibromamine and hypobromous acid will react with the TOC to form brominated DBPs. Studies conducted at Long Beach Water District and Santa Cruz Water District have demonstrated that the blending of low DBP, high bromide (> 0.3 mg/L) desalinated water with distribution system water increased the DBPs in the blended water above that of the original distribution system water after 5 days [1,2]. Additionally, the presence of bromide and iodide typically found in OWRO permeate will shift the types of DBPs found in the water toward currently unregulated brominated and iodated compounds.

Unregulated DBPs—Approximately 600 to 700 DBPs have been reported in the literature; however, at present, only nine such species are regulated. Many of the currently unregulated DBPs may become regulated in the future, and it is therefore prudent to understand the byproduct formation potential of unregulated compounds as well. Chloramines are less reactive than free chlorine, and are therefore less susceptible to decay and formation of THMs and HAA5. The exception to this rule is when moderate to high amounts of bromide and/or iodide are present in the water to be treated with chloramine. With chloramination, dihalogenated acetic acids become more prevalent relative to chlorination, and the speciation tends towards brominated and iodinated compounds. In addition to the regulated DBPs, HAA9 (i.e., the sum of monochloro-, dichloro-, trichloro-, monobromo-, dibromo-, bromochloro-, bromodichloro-, chlorodibromo-, and tribromo-acetic acids), iodoacid, and iodo-THM formation are potential issues for water high in bromide and iodide when disinfected with chloramines [3].

NDMA—Recent studies conducted at Metropolitan indicate that increases in bromide from 0.1 mg/L to 0.3 mg/L result in increased formation of another unregulated chloramine disinfection byproduct: N-nitrosodimethylamine (NDMA) [4]. NDMA has received increased scrutiny in the past few years as it is considered by both the USEPA and CDPH to be a probable human carcinogen. Although there is currently no MCL, it is a likely candidate for future regulations. NDMA currently has a CDPH notification level of 0.01 µg/L and a public health goal of 3 ng/L set by the California State Office for Environmental Health Hazard Assessment. Quarterly sampling of Metropolitan's system from 2000–2009 shows that NDMA is present in the effluents of the treatment plants at levels ranging from < 2 ng/L to 10 ng/L, with averages ranging from < 2 ng/L to 2.50 ng/L. Therefore, any changes in the system that could potentially increase NDMA formation in the distribution system must be carefully evaluated prior to implementation.

Task Objectives

The objective of Phase 2 of the bench-scale study is to evaluate potential impacts of desalinated water integration on DBP formation. In this phase, select conditions from the Phase 1 testing will be repeated, with additional analyses for regulated THMs, HAA9, NDMA (and other nitrosamines), and if possible, iodo-THMs and iodoacids. This testing will be conducted from July to mid-August. The following sections describe the activities to be conducted during Phase 2 testing.

Phase 2. DBP Formation

7d. Determine the changes in DBP formation at various blends of desalinated water/MWD water/GW at 25 °C, with desalinated water bromide levels of 0.3 and 0.5 mg/L and at pH 8.2 and 8.6.

7e. Determine the changes in DBP speciation towards next-generation iodinated DBP compounds and NDMA at various blends of desalinated water/MWD water/GW at 25 °C, and pH 8.2 with desalinated water bromide levels of 0.3 and 0.5 mg/L.

Testing Approach

Regulated THMs, HAA9, NDMA (and other nitrosamines), unregulated iodinated THMs, and iodoacid concentrations will be measured as well as the chloramine stability analytes in the simulated distribution system (SDS) tests as shown in Table 1. Test conditions from the Phase 1 tests 1a–1g and 5a–5e will be repeated. These are the pH 8.2, 25 °C tests with bromide levels of 0.3 and 0.5 mg/L respectively. These test conditions were selected because pH 8.2 is most representative of typical pH conditions, and 25 °C represents the worst case (i.e. most reactive) condition. Bromide levels of 0.3 and 0.5 mg/L should also represent typical and worst case conditions. In addition, test conditions from Phase 1 tests 2a–2e will be repeated to monitor the impact of the higher pH (8.6) on the regulated THM and HAA9 formation at 25 °C and 0.3 mg/L bromide. The analytes to be measured are shown in Table 2. Because evaluations conducted by the Long Beach Water Department showed that blends of desalinated water and ground water had lower THMs than groundwater at 3 days, but at 5 days they were higher in blends, the regulated THM and HAA9 evaluations will be conducted at 3 days and at 7 days. The testing protocol is listed below.

1. *Sample Preparation*
   a) *Desalinated water*. Sample stabilized desalinated water (blended first and second pass permeate post-calcite treatment) in 2 L-amber glass bottles. 9.9 L will be required for the low bromide pH 8.2 tests 1a(2)–1g(2), 7.9 L will be required for the low bromide pH 8.6 tests 2a(2)–2e(2) and another 9.9 L will be required for the higher bromide tests. This will be collected from the pipe loop stabilization tank prior to chlorine and ammonia addition. Record turbidity of collected sample. If turbidity is greater than 0.4 NTU, sample must be pre-filtered prior to use. Water samples will be stored in the refrigerator (less than 2 weeks) until testing commences.

      On the collection date, aliquot samples for total alkalinity, bromide, iodide, TOC, UV_{254}, turbidity and calcium analyses in the lab. Pre-warm the sample in a 25 °C waterbath. Aliquot small portions for pre-testing to determine initial chlorine demand. Once initial chlorine demand has been determined, add required NaOCl dosage to obtain a 2.5 mg/L free chlorine residual at the end of 15 mins incubation. Next add 0.526 mg/L NH_3-N and adjust pH to 8.2 with NaOH. Place water back in the waterbath for 4 hours, then measure chlorine and ammonia residuals. Add required ammonia, then NaOCL to obtain final residuals of 0.526 mg/L NH_3-N and 2.5 mg/L of total chlorine.

   b) *MWD water.* Sample MWD water from the WB-4 service connection in 2 L-amber glass bottles. Approximately 9.9 L will be required for the low bromide pH 8.2 tests, 6.2 L will be required for the low bromide pH 8.6 tests, and 7.7 L will be required for the high bromide tests. Ensure line has been well flushed (stable temperature and total chlorine values of approximately 2 mg/L) before sampling. Measure total chlorine in the field and transport samples to the laboratory for immediate testing. Aliquot samples for total alkalinity, TOC, turbidity and calcium analyses in the lab. UV_{254} samples must be collected at Jensen or Weymouth plant influent (whichever plant is supplying WB-4 that day). MWD water will be used as is, with no chlorine or ammonia adjustment prior to blending with other water. This provides the best simulation of potential blend conditions.

   c) *GW without breakpoint chlorination.* GW from Manhattan Beach will be sampled in 2 L-amber glass bottles and transported to the laboratory for immediate testing. Approximately 14.4 L will be required for the low bromide pH 8.2 tests, 6.2 L will be required for the low bromide pH 8.6 tests, and 7.7 L will be required for the high bromide tests. Aliquot samples for total alkalinity, bromide, iodide, TOC, turbidity and calcium analyses in the lab. The GW will be blended either with MWD water or with chloraminated desalinated water. After blending, sodium hypochlorite will be added boost the total chlorine to 2.5 mg/L and the pH will be adjusted as required. Ammonia will not be added due to the high background levels of the groundwater; high free ammonia levels will be present in the groundwater blends.

   d) *GW with breakpoint chlorination (GW$_{(bp)}$).* A portion of the GW collected from Manhattan Beach (above) will be breakpoint chlorinated to achieve a free chlorine residual of 2.5 mg/L after 15 mins incubation in the waterbath. Next, 0.526 mg/L of ammonia (as N) will be added. This chloraminated GW$_{(bp)}$ will be added to a separate beaker that contains already chloraminated desalinated water or to MWD water. After blending the waters, sodium hypochlorite will be added if needed to boost the total chlorine to 2.5 mg/L and the pH will be adjusted as required.

2. Chloramine stability, regulated THMs, HAA9, (I-THMs, iodoacids) and NDMA will be measured for the test conditions listed in Tables 1 & 2.
3. For each test condition, place the large 2-L sample bottles in the 25 °C waterbath.
4. Measure the conductivity of the chloraminated desalinated water, the MWD water, the unchlorinated GW, and the breakpoint chlorinated/chloraminated water, GW$_{(bp)}$.
5. For each test condition, blend the appropriate water sources in a 6-L flask, then measure the conductivity.
6. For each test with GW or GW$_{(bp)}$ in the blend, adjust the total chlorine of the final blend to 2.5 mg/L. If needed, adjust pH (to 8.2 or 8.6 as required).
7. For each test, immediately after completing the final blend and chemical additions, carefully fill and cap ten 300 mL BOD bottles (for T0, 3-day, and 7-day chloramine stability measurements; 3-day and 7-day THM and HAA9; and 7-day iodoacid and I-THM samples), two 60 mL BOD bottles (for duplicate 1-day chloramine stability measurements), two 500 mL amber glass bottles (for NDMA) with as little aeration as possible and with no head space. Place bottles immediately in the waterbath and place the lid on the waterbath
8. Measure T0 total chlorine, total ammonia, free ammonia, nitrite, nitrate, and pH. Aliquot samples from the 6-L flask for total alkalinity (150 mL), calcium (200 mL) and turbidity (50 mL) for later analysis.
9. Chloramine and total ammonia measurements will be taken from duplicate BOD bottles at the following times: 0, 1, 3 and 7 days for each condition.
10. At 3 days, samples from two 300 mL BOD bottles will be used to fill three 60 mL THM vials and three 60 mL HAA9 vials all with appropriate quenching agents.
11. At 7 days, samples from two 300 mL BOD bottles will be used to fill three 60 mL THM vials, three 60 mL HAA9 vials, three 40 mL I-THM vials and three 40 mL iodoacid vials all with appropriate quenching agents.
12. At 7 days, the two 500 mL amber glass NDMA bottles will be removed from the waterbath and sodium sulfite will be added to quench any remaining chlorine.
13. Waterbath temperatures will be monitored daily.
14. At 3 days and 7 days, total chlorine, total ammonia, free ammonia, nitrite, and pH will be measured. Nitrate will be measured at 7 days.

Methods

Analyses Conducted by MWD

The Hach DR850 will be used for the following analyses:

- Total chlorine - DPD method (10250)
- Free Cl_2 –DPD method (10245)
- Total NH_3 -- Salicylate method (8155) for total NH_3 analysis,
- Nitrite method (8507)

Free ammonia will be measured using an ion selective electrode method. A pH analyzer will be used to monitor the initial and final pH for all tests, and temperatures will be maintained by waterbath and monitored daily.

The MWD Water Quality Laboratory will utilize EPA method 551.1 for regulated THMs, and EPA methods 552.2 and 552.3 for HAA9. Nitrosamine analyses will be conducted according to the method referenced by Cheng et al [5]. This method detects NDMA, N-nitrosodi-*n*-butylamine (NDBA), N-nitrosodiethylamine (NDEA), N-nitrosodi-*n*-propylamine (NDPA), N-nitrosomethyl-ethylamine (NMEA), N-nitrosomorpholine (NMOR), N-nitrosopyrrolidine (NPYR), and N-nitrosopiperidine (NPIP). Analytical methods for all other analytes are outlined in the current revision of Standard Methods for the Examination of Water and Wastewater.

Analyses Conducted by Other Laboratories

Total iodide samples sent to Weck Laboratories (EPA Method 9056); I-THMs and iodoacids will be analyzed by Underwriters Laboratory (method to be determined).

Table 1. Phase 1 & 2 Bench Scale Test Conditions

	Conditions				**Phase 1**	**Phase 2**
Test	Desal Br	pH	Temp °C	Blend (%) Desal/MWD/GW/GW$_{(bp)}$	Tot Cl Stability	Tot Cl Stability THM & HAA9 (3&7day) Iodo-THMs/acids (7day) NDMA (Nitrosamines) (7day)
1a	0.3	8.2	25	100 /0 /0 /0	x	x
1b				0/100/0 /0	x	x
1c				50 /50 /0 /0	x	x
1d				0 /25 /75 /0	x	x
1e				25 /0 /75 /0	x	x
1f				0 /25 /0 /75	x	x
1g				25 /0 /0 /75	x	x
1h				50 /25 /25 /0	x	
1i				50 /25 /0 /25	x	
1j				100 /0 /0 /0	x	
2a	0.3	8.6	25	100 /0 /0 /0	x	x*
2b				0/100/0 /0	x	x*
2c				50 /50 /0 /0	x	x*
2d				25 /0 /75 /0	x	x*
2e				25 /0 /0 /75	x	x*
3a	0.3	8.2	10	100 /0 /0 /0	x	
3b				0/100/0 /0	x	
3c				50 /50 /0 /0	x	
3d				25 /0 /75 /0	x	
3e				25 /0 /0 /75	x	
4a	0.3	8.6	10	100 /0 /0 /0	x	
4b				0/100/0 /0	x	
4c				50 /50 /0 /0	x	
4d				25 /0 /75 /0	x	
4e				25 /0 /0 /75	x	
5a	0.5	8.2	25	100 /0 /0 /0	x	x
5b				0/100/0 /0	x	x
5c				50 /50 /0 /0	x	x
5d				25 /0 /75 /0	x	x
5e				25 /0 /0 /75	x	x

x*= I-THMs, iodoacids, and nitrosamines will not be analyzed for these tests.

Table 2. Phase 2 –DBP Formation Test Analytes

Analyte	Source Waters (Before add'l chemicals)	Test Blend (after chemicals/ blend)	*Sample Time (post blend)*	*Total Number of Samples**	*Sample Dates (# of samples)*
Total Chlorine	X (MWD)	X	*T_0, 1,3,7 days*	*139*	
Total Ammonia	X	X	*T_0, 1,3,7 days*	*145*	
Free Ammonia	X	X	*T_0, 3,7 days*	*111*	
Nitrite	X	X	*T_0, 3,7 days*	*111*	
Nitrate		X	*T_o, 7 days*	*34*	7/29 (5), 8/5(12), 8/12(12) 8/19 (5)
Total Alkalinity	X	X	*T_0*	*26*	7/29 (8), 8/5(10), 8/12 (8)
Bromide**	X			*9*	7/29, 8/5, 8/12 (3 each date)
Total Iodide**	X (Test 1 & 5)			*6 (Weck)*	7/29, 8/5, (3 each date)
pH	X	X	*T_0 and T_{final}*	*37*	
Total Organic Carbon	X			*9*	7/29, 8/5, 8/12 (3 each date)
UV_{254}**	X			*9*	
Temperature	X	X	*daily*		
Conductivity^{xx}	X	xx		*26*	
Turbidity	X			*9*	
Calcium	X			*9*	7/29, 8/5, 8/12 (3 each date)
Regulated THMs	X (MWD only)		*3 & 7 days*	*37*	7/29 (1), 8/1 (5), 8/5 (6), 8/8 (7), 8/12 (8), 8/15 (5), 8/19 (5)
HAA9	X (MWD only)		*3 & 7 days*	*37*	
Nitrosamines	X (Test 1 & 5)		*7 days*	*12*	8/5 (5) 8/12 (7)
Iodo-THMs/Iodoacid	X (Test 1 & 5)		*7 days*	*12 (UL)*	

T_0 = Time 0 🟨 = analyzed by Chemistry Unit

* Assumes test blend total chlorine, total ammonia and free ammonia analyses are run in duplicate. Stability samples collected at 0, 1, 3, and 7 days for each condition. Each THM and HAA9 sample is collected in triplicate, but counted as 1 sample. Each Nitrosamine sample is collected in duplicate, but counted as 1 sample.

** NOTE: Bromide, iodide, and UV_{254} must not be measured in chlorinated water. Weymouth or Jensen Plant Influent bromide, iodide and UV_{254} values will be used for MWD values (depending on which plant is supplying WB-4).

xx Conductivity to be measured in source water before chemical addition, chloraminated desalinated water, and in final blends <u>before</u> chemical addition to serve as a check on blending.

References

[1] Tseng, T.; Grebel, J.; Cheng, R.; Vuong, D.; & Wattier, K. L. (2005). Emerging Water Quality Concerns Associated with Integrating Desalinated Seawater into Existing Distribution Systems. *AWWA Annual Conference and Exposition.* San Francisco.

[2] CDM. (2010). *SCWD2: Seawater Reverse Osmosis Desalination Pilot Test Program Report.* Final Report, City of Santa Cruz and Soquel Creek Water District.

[3] Foellmi, S. (2007). *Mitigating Water Quality Effects of Desalinated Seawater Literature Report* to Chris Pincherli, Long Beach Water Department Post-Treatment Project, B&V Project 149364.

[4] Yates, R. (July 5, 2010). *Key Findings from Metropolitan's NDMA Formation and Control Tests*. Memorandum to Sun Liang.

[5] Cheng, Robert C.; Hwang, Cordelia J.; Andrews-Tate, Cynthia; Guo, Yingbo "Carrie"; Carr, Steve; Suffet, U.H. "Mel". (2006). Alternative Methods for the Analysis of NDMA and Other Nitrosamines in Water. *Jour. AWWA* 98:12.

Appendix B

Chloramine Stability Tests Raw Data

Test 1a–1j: 0.3 mg/L Target Br^- Desal, pH = 8.2, Temperature = 25 °C

Table B-1-1. Source Water Quality for Test 1a–1e (pH 8.2, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Water Source:	Desal	MWD	Groundwater
Sample Date:	6/12/2013	6/24/2013	6/24/2013
Temperature (°C)	19.4	NA‡	24.0
pH	7.67	8.14	7.84
Total Chlorine (mg/L)	ND† (< 0.05)	2.00	ND (< 0.05)
Total Ammonia (mg/L NH_3-N)	ND (< 0.03)	0.55*	1.46
Free Ammonia (mg/L NH_3-N)	NA	0.09*	0.75
Nitrite (mg/L NO_2-N)	ND (< 0.005)	ND* (< 0.005)	0.005
Conductivity (µS/cm)	532*	889	1552
Turbidity (NTU)	0.33	0.11	0.34
Total Alkalinity (mg/L)	76	124	227
Calcium (mg/L)	62	63	106
Total Organic Carbon (mg/L)	ND (< 0.2)	2.64	1.94
Bromide (mg/L)	0.25	0.05#	0.94
Sulfide (mg/L)	ND (< 0.01)	ND (< 0.01)	ND (< 0.01)
Manganese (µg/L)	10	ND (< 5)	63
Iron (µg/L)	ND (< 50)	ND (< 50)	100

† ND = Not Detected

* Parameters analyzed after chemical adjustments (i.e., pH adjustment and/or chlorine addition, ammonia addition)

‡ NA = Not Analyzed

Weymouth plant influent bromide value was used for WB-4 sample

Table B-1-2. Source Water Quality for Test 1f–1j (pH 8.2, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Water Source:	**Desal**	**MWD**	**Groundwater**
Sample Date:	**7/2/2013**	**7/8/2013**	**7/8/2013**
Temperature (°C)	22.4	24.6	22.3
pH	7.96	8.06	7.80
Total Chlorine (mg/L)	ND† (< 0.05)	1.91	ND (< 0.05)
Total Ammonia (mg/L NH_3-N)	ND (< 0.03)	NA‡	1.36
Free Ammonia (mg/L NH_3-N)	NA	0.07*	1.21
Nitrite (mg/L NO_2-N)	ND (< 0.005)	NA	ND (< 0.005)
Conductivity (µS/cm)	501*	912	1590
Turbidity (NTU)	0.11	0.05	0.55
Total Alkalinity (mg/L)	69	118	208
Calcium (mg/L)	57	64	113
Total Organic Carbon (mg/L)	ND (< 0.2)	2.69	1.44
Bromide (mg/L)	0.23	0.06#	1.00

† ND = Not Detected

* Parameters analyzed after chemical adjustments (i.e., pH adjustment and/or chlorine addition, ammonia addition)

‡ NA = Not Analyzed

Weymouth plant influent bromide value was used for WB-4 sample

Table B-1-3. Test 1a–1j Initial Blend Conditions (pH 8.2, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

	Desal	MWD	50% Desal/ 50% MWD	25% MWD/ 75% GW	25% Desal/ 75% GW	25% MWD/ 75% GWbp	25% Desal/ 75% GWbp	50% Desal/ 25% MWD/ 25% GW	50% Desal/ 25% MWD/ 25% GWbp
Total Chlorine (mg/L)	2.47 (2.46–2.47)	2.05	2.24	2.54	2.52	2.46	2.28	2.53	2.52
Total Ammonia (mg/L NH_3-N)	0.52 (0.52–0.52)	0.55	0.51	1.24	1.24	0.54	0.54	0.66	0.56
Free Ammonia (mg/L NH_3-N)	ND* (< 0.03) (ND–ND)	0.09	0.04	0.54	0.57	0.06†	0.12	0.15	0.05
pH	8.25 (8.22–8.27)	8.25	8.17	8.17	8.19	8.20	8.33	8.16	8.25
Nitrite (mg/L NO_2-N)	ND (<0.005) (ND–0.006)	ND (<0.005)	0.003	ND (< 0.005)	ND (< 0.005)	0.008	0.008	0.002	0.004
Conductivity (µS/cm)	517 (501–532)	889	726	1387	1296	1482	1392	888	910
Sulfide (mg/L)	NA‡	NA	NA	NA	ND	NA	NA	NA	NA
Manganese (µg/L)	NA	NA	NA	NA	50	NA	NA	NA	NA
Iron (µg/L)	NA	NA	NA	NA	76	NA	NA	NA	NA
Total Alkalinity (mg/L)	73 (71-75)	123	101	206	190	176	168	114	115
TOC (mg/L)	ND (< 0.2) (ND–0.22)	2.64	1.40	2.10	1.49	1.63	1.05	0.98	1.01
Bromide (mg/L)	0.24 (0.23–0.25)	0.05	0.15†	0.72†	0.77†	0.77†	0.81†	0.38†	0.38†

* ND = Not Detected

‡ NA = Not Analyzed

† Bromide values were calculated from source water bromide values

Table B-1-4. Test 1a–1j Chloramine Stability Results
(pH 8.2, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Desal (Test 1a)

	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
Time	**S1**	**S2**	**Avg**		**S1**	**S2**	**Avg**	
0 hr	2.47		2.47		0.52		0.52	
1 hr	2.28	2.28	2.28	0.19	0.49	0.51	0.50	0.02
3 hr	2.19	2.24	2.22	0.26	0.48	0.46	0.47	0.05
4 hr	2.11	2.14	2.13	0.35	0.45	0.48	0.47	0.06
1 day	1.85	1.87	1.86	0.61	0.41	0.43	0.42	0.10
2 day	1.66	1.66	1.66	0.81	0.40	0.41	0.41	0.12
3 day	1.54	1.55	1.55	0.93	0.38	0.37	0.38	0.15
4 day	1.44	1.44	1.44	1.03	0.34	0.37	0.36	0.17
7 day	1.23	1.23	1.23	1.24	0.35	0.36	0.36	0.17

MWD (Test 1b)

	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
Time	**S1**	**S2**	**Avg**		**S1**	**S2**	**Avg**	
0 hr	2.05		2.05		0.55		0.55	
1 hr	2.05	2.08	2.07	-0.02	0.55	0.54	0.55	0.01
3 hr	2.07	2.08	2.08	-0.03	0.53	0.51	0.52	0.03
4 hr	2.06	2.05	2.06	0.00	0.50	0.51	0.51	0.05
1 day	1.97	1.94	1.96	0.09	0.52	0.51	0.52	0.04
2 day	1.86	1.86	1.86	0.19	0.52	0.50	0.51	0.04
3 day	1.81	1.81	1.81	0.24	0.50	0.49	0.50	0.06
4 day	1.76	1.75	1.76	0.30	0.50	0.49	0.50	0.06
7 day	1.56	1.55	1.56	0.50	0.49	0.48	0.49	0.07

50% MWD/50% Desal (Test 1c)

	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
Time	**S1**	**S2**	**Avg**		**S1**	**S2**	**Avg**	
0 hr	2.24		2.24		0.51		0.51	
1 hr	2.17	2.21	2.19	0.05	0.51	0.52	0.51	-0.01
3 hr	2.13	2.13	2.13	0.11	0.48	0.50	0.49	0.02
4 hr	2.13	2.14	2.14	0.11	0.49	0.50	0.49	0.02
1 day	1.99	2.01	2.00	0.24	0.49	0.49	0.49	0.02
2 day	1.87	1.89	1.88	0.36	0.47	0.48	0.47	0.04
3 day	1.75	1.75	1.75	0.49	0.46	0.47	0.46	0.05
4 day	1.69	1.70	1.70	0.55	0.45	0.46	0.45	0.06
7 day	1.53	1.52	1.53	0.72	0.42	0.4	0.41	0.10

25% MWD/75% GW (Test 1d)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.54		2.54		1.24		1.24	
1 hr	2.41	2.42	2.41	0.13	1.24	1.22	1.23	0.01
3 hr	2.37	2.39	2.38	0.16	1.16	1.22	1.19	0.05
4 hr	2.32	2.35	2.33	0.21	1.08	1.12	1.10	0.14
1 day	2.22	2.20	2.21	0.33	1.04	1.08	1.06	0.18
2 day	2.13	2.09	2.11	0.43	1.20	1.12	1.16	0.08
3 day	2.04	2.03	2.03	0.51	1.20	1.14	1.17	0.07
4 day	1.99	1.98	1.98	0.56	1.14	1.12	1.13	0.11
7 day	1.81	1.81	1.81	0.73	1.14	1.16	1.15	0.09

25% Desal/75% GW (Test 1e)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.52		2.52		1.24		1.24	
1 hr	2.42	2.46	2.44	0.08	1.16	1.18	1.17	0.07
3 hr	2.43	2.40	2.42	0.11	1.18	1.18	1.18	0.06
4 hr	2.40	2.38	2.39	0.13	1.16	1.20	1.18	0.06
1 day	2.26	2.28	2.27	0.25	1.10	1.24	1.17	0.07
2 day	2.14	2.15	2.15	0.38	1.22	1.22	1.22	0.02
3 day	2.10	2.10	2.10	0.42	1.10	1.14	1.12	0.12
4 day	2.00	2.00	2.00	0.52	1.20	1.14	1.17	0.07
7 day	1.86	1.86	1.86	0.66	1.14	1.08	1.11	0.13

25% MWD/75% GWbp (Test 1f)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.46		2.46		0.54		0.54	
1 hr	2.26	2.27	2.27	0.20	0.51	0.48	0.50	0.05
3 hr	2.18	2.21	2.20	0.27	0.47	0.46	0.47	0.08
4 hr	2.11	2.10	2.11	0.36	0.45	0.46	0.46	0.09
1 day	1.85	1.83	1.84	0.62	0.44	0.47	0.46	0.09
2 day	1.65	1.64	1.65	0.82	0.40	0.45	0.43	0.12
3 day	1.53	1.52	1.53	0.94	0.44	0.45	0.45	0.10
4 day	1.40	1.39	1.40	1.07	0.43	0.44	0.44	0.11
7 day	1.16	1.16	1.16	1.30	0.42	0.42	0.42	0.12

25% Desal/75% GWbp (Test 1g)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.28		2.28		0.54		0.54	
1 hr	1.90	1.91	1.91	0.38	0.48	0.50	0.49	0.05
3 hr	1.84	1.85	1.85	0.44	0.49	0.49	0.49	0.05
4 hr	1.77	1.80	1.79	0.50	0.49	0.46	0.48	0.07
1 day	1.67	1.67	1.67	0.61	0.48	0.52	0.50	0.04
2 day	1.58	1.58	1.58	0.70	0.44	0.45	0.45	0.10
3 day	1.51	1.51	1.51	0.77	0.48	0.49	0.49	0.06
4 day	1.43	1.42	1.43	0.86	0.47	0.45	0.46	0.08
7 day	1.28	1.30	1.29	0.99	0.44	0.45	0.45	0.10

50% Desal/25% MWD/25% GW (Test 1h)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.53		2.53		0.66		0.66	
1 hr	2.48	2.49	2.49	0.04	0.66	0.70	0.68	-0.02
3 hr	2.45	2.47	2.46	0.07	0.65	0.70	0.68	-0.02
4 hr	2.48	2.46	2.47	0.06	0.66	0.61	0.64	0.03
1 day	2.33	2.37	2.35	0.18	0.70	0.68	0.69	-0.03
2 day	2.21	2.22	2.22	0.32	0.65	0.65	0.65	0.01
3 day	2.09	2.11	2.10	0.43	0.67	0.67	0.67	-0.01
4 day	2.05	2.05	2.05	0.48	0.63	0.64	0.64	0.03
7 day	1.82	1.84	1.83	0.70	0.64	0.65	0.65	0.02

50% Desal/25% MWD/25% GWbp (Test 1i)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.52		2.52		0.56		0.56	
1 hr	2.39	2.38	2.39	0.14	0.55	0.54	0.55	0.02
3 hr	2.34	2.34	2.34	0.18	0.57	0.55	0.56	0.00
4 hr	2.31	2.32	2.32	0.21	0.52	0.54	0.53	0.03
1 day	2.20	2.19	2.20	0.33	0.52	0.50	0.51	0.05
2 day	2.00	2.03	2.02	0.51	0.47	0.50	0.49	0.08
3 day	1.91	1.90	1.91	0.62	0.49	0.50	0.50	0.07
4 day	1.83	1.82	1.83	0.70	0.47	0.47	0.47	0.09
7 day	1.60	1.59	1.60	0.93	0.48	0.46	0.47	0.09

Desal (Test 1j)

	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
Time	**S1**	**S2**	**Avg**		**S1**	**S2**	**Avg**	
0 hr	2.46		2.46		0.52		0.52	
1 hr	2.38	2.37	2.38	0.09	0.49	0.51	0.50	0.02
3 hr	2.39	2.35	2.37	0.09	0.49	0.50	0.50	0.03
4 hr	2.28	2.29	2.29	0.18	0.46	0.48	0.47	0.05
1 day	2.03	2.03	2.03	0.43	0.49	0.50	0.50	0.03
2 day	1.82	1.85	1.84	0.63	0.44	0.43	0.44	0.09
3 day	1.71	1.70	1.71	0.76	0.41	0.44	0.43	0.10
4 day	1.55	1.58	1.57	0.90	0.40	0.40	0.40	0.12
7 day	1.30	1.30	1.30	1.16	0.37	0.38	0.38	0.15

Test 2a–2e: 0.3 mg/L Target Br^- Desal, pH = 8.6, Temperature = 25 °C

Table B-2-1. Source Water Quality for Test 2a–2e (pH 8.6, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Water Source:	Desal	MWD	Groundwater
Sample Date:	5/29/2013	6/3/2013	6/3/2013
Temperature (°C)	21.2	20.3	22.7
pH	8.04	7.96	7.76
Total Chlorine (mg/L)	ND† (< 0.05)	1.84	ND (< 0.05)
Total Ammonia (mg/L NH_3-N)	ND (< 0.03)	0.48*	1.34
Free Ammonia (mg/L NH_3-N)	NA‡	0.12*	1.23
Nitrite (mg/L NO_2-N)	ND (< 0.005)	ND* (< 0.005)	ND (< 0.005)
Conductivity (µS/cm)	551*	905	1551
Turbidity (NTU)	0.29	0.08	0.58
Total Alkalinity (mg/L)	74	122	227
Calcium (mg/L)	59	64	105
Total Organic Carbon (mg/L)	ND (< 0.2)	2.51	1.87
Bromide (mg/L)	0.28	0.05#	0.94

† ND = Not Detected

* Parameters analyzed after chemical adjustments (i.e., pH adjustment and/or chlorine addition, ammonia addition)

‡ NA = Not Analyzed

Weymouth plant influent bromide value was used for WB-4 sample

Table B-2-2. Test 2a–2e Initial Blend Conditions (pH 8.6, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

	Desal	MWD	50% Desal/ 50% MWD	25% Desal/ 75% GW	25% Desal/ 75% GWbp
Total Chlorine (mg/L)	2.25	1.93	1.92	2.48	2.31
Total Ammonia (mg/L NH_3-N)	0.44	0.48	0.39	0.98	0.39
Free Ammonia (mg/L NH_3-N)	ND* (< 0.03)	0.12	0.05	0.71	ND (< 0.03)
pH	8.56	8.59	8.59	8.56	8.55
Nitrite (mg/L NO_2-N)	ND (< 0.005)	ND (< 0.005)	ND (< 0.005)	ND (< 0.005)	0.007
Conductivity (µS/cm)	551	905	731	1286	1372
Total Alkalinity (mg/L)	76	130	105	201	189
TOC (mg/L)	ND (<0.2)	2.46	1.34	1.50	1.42
Bromide (mg/L)	0.28	0.05	0.17†	0.78†	0.78†

* ND = Not Detected

† Bromide values were calculated from source water bromide values

Table B-2-3. Test 2a–2e Chloramine Stability Results (pH 8.6, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Desal (Test 2a)

	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
Time	**S1**	**S2**	**Avg**		**S1**	**S2**	**Avg**	
0 hr	2.25		2.25		0.44		0.44	
1 hr	1.74	1.73	1.74	0.52	0.40	0.40	0.40	0.04
3 hr	1.66	1.61	1.64	0.62	0.42	0.40	0.41	0.03
4 hr	1.55	1.54	1.55	0.71	0.29	0.31	0.30	0.14
1 day	1.38	1.32	1.35	0.90	0.31	0.31	0.31	0.13
2 day	1.23	1.24	1.24	1.02	0.30	0.31	0.31	0.14
3 day	1.14	1.15	1.15	1.11	0.28	0.26	0.27	0.17
4 day	1.06	1.07	1.07	1.19	0.25	0.27	0.26	0.18
7 day	0.92	0.90	0.91	1.34	0.21	0.20	0.21	0.24

MWD (Test 2b)

	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
Time	**S1**	**S2**	**Avg**		**S1**	**S2**	**Avg**	
0 hr	1.93		1.93		0.48		0.48	
1 hr	1.86	1.85	1.86	0.08	0.51	0.52	0.52	-0.04
3 hr	1.87	1.89	1.88	0.05	0.48	0.46	0.47	0.01
4 hr	1.84	1.84	1.84	0.09	0.53	0.55	0.54	-0.06
1 day	1.77	1.75	1.76	0.17	0.58	0.58	0.58	-0.10
2 day	1.67	1.66	1.67	0.27	0.43	0.42	0.43	0.06
3 day	1.62	1.64	1.63	0.30	0.44	0.46	0.45	0.03
4 day	1.58	1.58	1.58	0.35	0.43	0.44	0.44	0.05
7 day	1.47	1.47	1.47	0.46	0.38	0.38	0.38	0.10

50% MWD/50% Desal (Test 2c)

	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
Time	**S1**	**S2**	**Avg**		**S1**	**S2**	**Avg**	
0 hr	1.92		1.92		0.39		0.39	
1 hr	1.80	1.76	1.78	0.14	0.47	0.48	0.48	-0.09
3 hr	1.76	1.74	1.75	0.17	0.51	0.55	0.53	-0.14
4 hr	1.76	1.73	1.75	0.18	0.49	0.51	0.50	-0.11
1 day	1.66	1.71	1.69	0.24	0.40	0.40	0.40	-0.01
2 day	1.65	1.62	1.64	0.29	0.39	0.40	0.40	-0.01
3 day	1.60	1.60	1.60	0.32	0.35	0.37	0.36	0.03
4 day	1.52	1.53	1.53	0.40	0.39	0.41	0.40	-0.01
7 day	1.46	1.42	1.44	0.48	0.32	0.33	0.33	0.07

25% Desal/75% GW (Test 2d)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.48		2.48		1.04		1.04	
1 hr	2.43	2.40	2.42	0.06	1.30	1.40	1.35	-0.31
3 hr	2.43	2.36	2.40	0.09	1.30	1.32	1.31	-0.27
4 hr	2.30	2.41	2.36	0.13	1.28	1.28	1.28	-0.24
1 day	2.24	2.23	2.24	0.25	1.36	1.28	1.32	-0.28
2 day	2.18	2.14	2.16	0.32	1.02	1.06	1.04	0.00
3 day	2.11	2.09	2.10	0.38	1.06	1.04	1.05	-0.01
4 day	2.03	2.05	2.04	0.44	1.05	1.03	1.04	0.00
7 day	1.91	1.89	1.90	0.58	0.94	0.90	0.92	0.12

25% Desal/75% GWbp (Test 2e)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.31		2.31		0.39		0.39	
1 hr	1.89	1.89	1.89	0.42	0.43	0.44	0.44	-0.05
3 hr	1.81	1.84	1.83	0.49	0.44	0.40	0.42	-0.03
4 hr	1.70	1.72	1.71	0.60	0.44	0.45	0.45	-0.06
1 day	1.52	1.53	1.53	0.79	0.43	0.43	0.43	-0.04
2 day	1.37	1.36	1.37	0.95	0.31	0.35	0.33	0.06
3 day	1.23	1.24	1.24	1.08	0.32	0.30	0.31	0.08
4 day	1.13	1.15	1.14	1.17	0.29	0.31	0.30	0.09
7 day	0.93	0.93	0.93	1.38	0.26	0.28	0.27	0.12

Test 3a–3e: 0.3 mg/L Target Br$^-$ Desal, pH = 8.2, Temperature = 10 °C

Table B-3-1. Test 2a–2e Chloramine Stability Results (pH 8.6, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Water Source:	Desal	MWD	Groundwater
Sample Date:	5/29/2013	6/10/2013	6/10/2013
Temperature (°C)	21.2	22.1	22.8
pH	8.04	7.96	7.82
Total Chlorine (mg/L)	ND† (< 0.05)	1.86	ND (< 0.05)
Total Ammonia (mg/L NH$_3$-N)	ND (< 0.03)	0.46*	1.33
Free Ammonia (mg/L NH$_3$-N)	NA‡	0.08*	0.95
Nitrite (mg/L NO$_2$-N)	ND (< 0.005)	ND* (< 0.005)	ND (< 0.005)
Conductivity (µS/cm)	514*	915	1507
Turbidity (NTU)	0.29	0.05	0.43
Total Alkalinity (mg/L)	74	121	229
Calcium (mg/L)	59	64	103
Total Organic Carbon (mg/L)	ND (< 0.2)	2.60	1.90
Bromide (mg/L)	0.28	0.05#	0.94

† ND = Not Detected

* Parameters analyzed after chemical adjustments (i.e., pH adjustment and/or chlorine addition, ammonia addition)

‡ NA = Not Analyzed

Weymouth plant influent bromide value was used for WB-4 sample

Table B-3-2. Test 3a–3e Initial Blend Conditions (pH 8.2, 10 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

	Desal	MWD	50% Desal/ 50% MWD	25% Desal/ 75% GW	25% Desal/ 75% GWbp
Total Chlorine (mg/L)	2.50	1.91	2.19	2.45	2.41
Total Ammonia (mg/L NH$_3$-N)	0.53	0.46	0.54	1.14	0.58
Free Ammonia (mg/L NH$_3$-N)	0.05	0.08	0.07	0.47	0.17
pH	8.15	8.19	8.25	8.20	8.44
Nitrite (mg/L NO$_2$-N)	0.005	ND* (< 0.005)	0.007	ND (< 0.005)	0.008
Conductivity (µS/cm)	514	915	707	1268	1317
Total Alkalinity (mg/L)	76	120	98	200	194
TOC (mg/L)	0.20	2.60	1.44	1.56	1.49
Bromide (mg/L)	0.28	0.05	0.17†	0.78†	0.78†

* ND = Not Detected

† Bromide values were calculated from source water bromide values

Table B-3-3. Test 3a–3e Chloramine Stability Results (pH 8.2, 10 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Desal (Test 3a)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.50		2.50		0.53		0.53	
1 hr	2.41	2.44	2.43	0.08	0.52	0.58	0.55	-0.03
3 hr	2.39	2.39	2.39	0.11	0.53	0.51	0.52	0.01
4 hr	2.39	2.35	2.37	0.13	0.48	0.50	0.49	0.04
1 day	2.12	2.16	2.14	0.36	0.53	0.51	0.52	0.01
2 day	2.01	2.00	2.01	0.50	0.52	0.53	0.53	0.00
3 day	1.92	1.92	1.92	0.58	0.52	0.51	0.52	0.01
4 day	1.88	1.85	1.87	0.64	0.49	0.51	0.50	0.03
7 day	1.70	1.67	1.69	0.82	0.44	0.44	0.44	0.09

MWD (Test 3b)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	1.91		1.91		0.46		0.46	
1 hr	1.91	1.95	1.93	-0.02	0.44	0.43	0.44	0.03
3 hr	1.87	1.87	1.87	0.04	0.51	0.45	0.48	-0.02
4 hr	1.90	1.91	1.91	0.01	0.43	0.44	0.44	0.03
1 day	1.88	1.90	1.89	0.02	0.46	0.47	0.47	0.00
2 day	1.84	1.86	1.85	0.06	0.48	0.50	0.49	-0.03
3 day	1.80	1.80	1.80	0.11	0.48	0.50	0.49	-0.03
4 day	1.75	1.73	1.74	0.17	0.52	0.53	0.53	-0.07
7 day	1.64	1.62	1.63	0.28	0.44	0.43	0.44	0.03

50% MWD/50% Desal (Test 3c)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.19		2.19		0.54		0.54	
1 hr	2.14	2.12	2.13	0.06	0.52	0.52	0.52	0.02
3 hr	2.13	2.16	2.15	0.04	0.49	0.50	0.50	0.05
4 hr	2.17	2.13	2.15	0.04	0.49	0.48	0.49	0.06
1 day	2.02	2.03	2.03	0.17	0.50	0.49	0.50	0.05
2 day	1.92	1.93	1.93	0.27	0.49	0.50	0.50	0.05
3 day	1.88	1.88	1.88	0.31	0.51	0.49	0.50	0.04
4 day	1.81	1.82	1.82	0.38	0.51	0.55	0.53	0.01
7 day	1.70	1.69	1.70	0.50	0.45	0.47	0.46	0.08

20% Desal/80% GW (Test 3d)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.45		2.45		1.14		1.14	
1 hr	2.49	2.47	2.48	-0.03	1.02	1.06	1.04	0.10
3 hr	2.40	2.39	2.40	0.06	1.18	1.12	1.15	-0.01
4 hr	2.38	2.40	2.39	0.06	1.08	1.14	1.11	0.03
1 day	2.27	2.27	2.27	0.18	1.06	1.10	1.08	0.06
2 day	2.19	2.18	2.19	0.27	1.20	1.24	1.22	-0.08
3 day	2.11	2.08	2.10	0.36	1.12	1.14	1.13	0.01
4 day	2.09	2.05	2.07	0.38	1.20	1.20	1.20	-0.06
7 day	1.97	1.99	1.98	0.47	1.06	1.10	1.08	0.06

25% Desal/75% GWbp (Test 3e)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.41		2.41		0.58		0.58	
1 hr	2.18	2.21	2.20	0.22	0.58	0.59	0.59	-0.01
3 hr	2.15	2.07	2.11	0.30	0.63	0.59	0.61	-0.03
4 hr	2.09	2.07	2.08	0.33	0.59	0.57	0.58	0.00
1 day	1.82	1.83	1.83	0.59	0.61	0.59	0.60	-0.02
2 day	1.76	1.72	1.74	0.67	0.62	0.63	0.63	-0.05
3 day	1.71	1.68	1.70	0.72	0.60	0.59	0.60	-0.02
4 day	1.67	1.66	1.67	0.75	0.58	0.57	0.58	0.01
7 day	1.63	1.61	1.62	0.79	0.59	0.56	0.58	0.01

Test 4a–4e: 0.3 mg/L Target Br^- Desal, pH = 8.6, Temperature = 10 °C

Table B-4-1 . Source Water Quality for Test 4a–4e (pH 8.6, 10 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Water Source:	Desal	MWD	Groundwater
Sample Date:	6/12/2013	6/17/2013	6/17/2013
Temperature (°C)	19.4	23.0	22.9
pH	7.67	8.20	NA‡
Total Chlorine (mg/L)	ND† (< 0.05)	2.10	ND (< 0.05)
Total Ammonia (mg/L NH3-N)	ND (< 0.03)	0.58*	1.44
Free Ammonia (mg/L NH3-N)	NA	0.10*	1.14
Nitrite (mg/L NO2-N)	ND (< 0.005)	ND* (< 0.005)	ND (< 0.005)
Conductivity (μS/cm)	515*	883	1513
Turbidity (NTU)	0.33	0.07	0.17
Total Alkalinity (mg/L)	76	127	224
Calcium (mg/L)	62	64	106
Total Organic Carbon (mg/L)	ND (< 0.2)	2.62	1.94
Bromide (mg/L)	0.25	0.05#	0.89

† ND = Not Detected

* Parameters analyzed after chemical adjustments (i.e., pH adjustment and/or chlorine addition, ammonia addition)

‡ NA = Not Analyzed

Weymouth plant influent bromide value was used for WB-4 sample

Table B-4-2. Test 4a–4e Initial Blend Conditions (pH 8.6, 10 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

	Desal	MWD	50% Desal/ 50% MWD	25% Desal/ 75% GW	25% Desal/ 75% GWbp
Total Chlorine (mg/L)	2.47	2.25	2.35	2.64	2.34
Total Ammonia (mg/L NH_3-N)	0.53	0.58	0.58	1.12	0.46
Free Ammonia (mg/L NH_3-N)	0.06	0.10	0.09	0.64	0.11
pH	8.59	8.58	8.65	8.58	8.57
Nitrite (mg/L NO_2-N)	0.004	ND* (< 0.005)	0.006	ND (< 0.005)	ND (< 0.005)
Conductivity (μS/cm)	515	883	686	1259	1318
Total Alkalinity (mg/L)	94	126	103	198	196
TOC (mg/L)	0.25	2.58	1.44	1.52	1.50
Bromide (mg/L) (Calculated)	0.25	0.05	0.15†	0.73†	0.73†

* ND = Not Detected

† Bromide values were calculated from source water bromide values

Table B-4-3. Test 4a–4e Chloramine Stability Results
(pH 8.2, 25 °C, and 0.5 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Desal (Test 4a)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.47		2.47		0.53		0.53	
1 hr	2.37	2.33	2.35	0.12	0.52	0.55	0.54	-0.01
3 hr	2.35	2.36	2.36	0.12	0.53	0.52	0.53	0.01
4 hr	2.32	2.33	2.33	0.15	0.52	0.53	0.53	0.01
1 day	2.13	2.14	2.14	0.34	0.53	0.56	0.55	-0.02
2 day	2.06	2.07	2.07	0.41	0.52	0.52	0.52	0.01
3 day	2.03	2.05	2.04	0.43	0.53	0.51	0.52	0.01
4 day	2.01	2.04	2.03	0.45	0.46	0.49	0.48	0.06
7 day	1.88	1.89	1.89	0.59	0.47	0.45	0.46	0.07

MWD (Test 4b)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.25		2.25		0.58		0.58	
1 hr	2.23	2.20	2.22	0.04	0.59	0.59	0.59	-0.01
3 hr	2.22	2.21	2.22	0.04	0.59	0.62	0.61	-0.03
4 hr	2.16	2.14	2.15	0.10	0.55	0.57	0.56	0.02
1 day	2.19	2.19	2.19	0.06	0.59	0.63	0.61	-0.03
2 day	2.16	2.14	2.15	0.10	0.60	0.63	0.62	-0.04
3 day	2.14	2.13	2.14	0.12	0.59	0.62	0.61	-0.03
4 day	2.14	2.12	2.13	0.12	0.50	0.51	0.51	0.08
7 day	2.03	2.04	2.04	0.22	0.56	0.55	0.56	0.02

50% MWD/50% Desal (Test 4c)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.35		2.35		0.58		0.58	
1 hr	2.24	2.27	2.26	0.10	0.52	0.54	0.53	0.05
3 hr	2.25	2.25	2.25	0.10	0.54	0.52	0.53	0.05
4 hr	2.23	2.27	2.25	0.10	0.54	0.56	0.55	0.03
1 day	2.17	2.13	2.15	0.20	0.57	0.60	0.59	-0.01
2 day	2.14	2.14	2.14	0.21	0.56	0.60	0.58	0.00
3 day	2.10	2.11	2.11	0.25	0.51	0.55	0.53	0.05
4 day	2.10	2.08	2.09	0.26	0.44	0.45	0.45	0.14
7 day	1.89	1.94	1.92	0.44	0.54	0.51	0.53	0.05

25% Desal/75% GW (Test 4d)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.64		2.64		1.12		1.12	
1 hr	2.60	2.59	2.60	0.05	1.12	1.08	1.10	0.02
3 hr	2.59	2.58	2.59	0.06	1.08	1.02	1.05	0.07
4 hr	2.58	2.58	2.58	0.06	1.18	1.22	1.20	-0.08
1 day	2.51	2.48	2.50	0.15	1.16	1.22	1.19	-0.07
2 day	2.45	2.46	2.46	0.19	1.20	1.24	1.22	-0.10
3 day	2.46	2.45	2.46	0.19	1.18	1.24	1.21	-0.09
4 day	2.49	2.46	2.48	0.17	1.16	1.17	1.17	-0.04
7 day	2.39	2.34	2.37	0.28	1.22	1.30	1.26	-0.14

25% Desal/75% GWbp (Test 4e)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.34		2.34		0.46		0.46	
1 hr	2.16	2.17	2.17	0.18	0.45	0.45	0.45	0.01
3 hr	2.07	2.11	2.09	0.25	0.42	0.42	0.42	0.04
4 hr	1.98	2.02	2.00	0.34	0.42	0.43	0.43	0.04
1 day	1.68	1.68	1.68	0.66	0.43	0.44	0.44	0.03
2 day	1.60	1.62	1.61	0.73	0.43	0.46	0.45	0.02
3 day	1.57	1.57	1.57	0.77	0.43	0.44	0.44	0.03
4 day	1.62	1.60	1.61	0.73	0.43	0.46	0.45	0.02
7 day	1.44	1.45	1.45	0.90	0.44	0.47	0.46	0.01

Test 5a–5e: 0.5 mg/L Target Br^- Desal, pH = 8.2, Temperature = 25 °C

Table B-5-1 . Source Water Quality for Test 5a–5e (pH 8.2, 25 °C, and 0.5 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Water Source:	Desal	MWD	Groundwater
Sample Date:	7/17/2013	7/22/2013	7/22/2013
Temperature (°C)	20.2	25.8	22.5
pH	7.93	8.34	7.95
Total Chlorine (mg/L)	ND† (< 0.05)	1.99	ND (< 0.05)
Total Ammonia (mg/L NH_3-N)	ND (< 0.03)	0.61*	1.54
Free Ammonia (mg/L NH_3-N)	NA‡	0.07*	1.13
Nitrite (mg/L NO_2-N)	ND (< 0.005)	ND* (< 0.005)	ND (< 0.005)
Conductivity (µS/cm)	702*	885	1584
Turbidity (NTU)	0.11	0.12	0.59
Total Alkalinity (mg/L)	78	112	192
Calcium (mg/L)	63	62	114
Total Organic Carbon (mg/L)	0.22	2.44	1.42
Bromide (mg/L)	0.49	0.04#	0.96

† ND = Not Detected

* Parameters analyzed after chemical adjustments (i.e., pH adjustment and/or chlorine addition, ammonia addition)

‡ NA = Not Analyzed

Weymouth plant influent bromide value was used for WB-4 sample

Table B-5-2. Test 5a–5e Initial Blends Conditions (pH 8.2, 25 °C, and 0.5 mg/L Target Bromide Concentration in Desalinated Ocean Water)

	Desal	MWD	50% Desal/ 50% MWD	25% Desal/ 75% GW	25% Desal/ 75% GWbp
Total Chlorine (mg/L)	2.45	2.14	2.28	2.66	2.44
Total Ammonia (mg/L NH_3-N)	0.56	0.61	0.55	1.15	0.47
Free Ammonia (mg/L NH_3-N)	ND* (<0.03)	0.07	0.05	0.44	0.08
pH	8.16	8.23	8.19	8.22	8.22
Nitrite (mg/L NO_2-N)	0.006	ND (< 0.005)	0.005	ND (< 0.005)	0.006
Conductivity (µS/cm)	702	885	798	1385	1464
Total Alkalinity (mg/L)	78	112	93	165	165
TOC (mg/L)	ND (<0.2)	2.44	1.39	1.04	1.00
Bromide (mg/L)	0.49	0.04	0.27†	0.84†	0.84†

* ND = Not Detected

† Bromide values were calculated from source water bromide values

Table B-5-3. Test 5a–5e Chloramine Stability Results
(pH 8.2, 25 °C, and 0.5 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Desal (Test 5a)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.45		2.45		0.56		0.56	
1 hr	2.30	2.34	2.32	0.13	0.52	0.52	0.52	0.04
3 hr	2.23	2.25	2.24	0.21	0.50	0.52	0.51	0.05
4 hr	2.13	2.15	2.14	0.31	0.47	0.48	0.48	0.08
1 day	1.74	1.72	1.73	0.72	0.43	0.45	0.44	0.12
2 day	1.58	1.56	1.57	0.88	0.40	0.40	0.40	0.16
3 day	1.37	1.36	1.37	1.08	0.38	0.39	0.39	0.17
4 day	1.26	1.23	1.25	1.20	0.36	0.39	0.38	0.18
7 day	0.95	0.97	0.96	1.49	0.31	0.32	0.32	0.24

MWD (Test 5b)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.14		2.14		0.61		0.61	
1 hr	2.12	2.12	2.12	0.02	0.59	0.57	0.58	0.03
3 hr	2.12	2.12	2.12	0.02	0.57	0.55	0.56	0.04
4 hr	2.08	2.12	2.10	0.04	0.55	0.54	0.55	0.06
1 day	1.98	1.99	1.99	0.16	0.55	0.54	0.55	0.06
2 day	1.91	1.90	1.91	0.24	0.55	0.56	0.56	0.05
3 day	1.80	1.82	1.81	0.33	0.55	0.56	0.56	0.05
4 day	1.72	1.74	1.73	0.41	0.51	0.54	0.53	0.08
7 day	1.58	1.58	1.58	0.56	0.51	0.49	0.50	0.11

50% MWD/50% Desal (Test 5c)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.28		2.28		0.55		0.55	
1 hr	2.22	2.26	2.24	0.03	0.52	0.53	0.53	0.03
3 hr	2.21	2.22	2.22	0.06	0.55	0.53	0.54	0.01
4 hr	2.13	2.16	2.15	0.13	0.50	0.54	0.52	0.03
1 day	1.92	1.91	1.92	0.36	0.51	0.52	0.52	0.04
2 day	1.78	1.77	1.78	0.50	0.48	0.48	0.48	0.07
3 day	1.62	1.66	1.64	0.64	0.47	0.51	0.49	0.06
4 day	1.56	1.56	1.56	0.72	0.47	0.47	0.47	0.08
7 day	1.29	1.31	1.30	0.98	0.40	0.43	0.42	0.14

25% Desal/75% GW (Test 5d)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.66		2.66		1.15		1.15	
1 hr	2.59	2.60	2.60	0.06	1.14	1.18	1.16	-0.01
3 hr	2.56	2.56	2.56	0.10	1.01	1.00	1.01	0.15
4 hr	2.52	2.56	2.54	0.12	1.14	1.14	1.14	0.01
1 day	2.40	2.41	2.41	0.25	1.12	1.12	1.12	0.03
2 day	2.31	2.33	2.32	0.34	1.12	1.10	1.11	0.04
3 day	2.23	2.22	2.23	0.43	1.09	1.10	1.10	0.05
4 day	2.17	2.17	2.17	0.49	1.13	1.14	1.14	0.02
7 day	1.95	1.94	1.95	0.71	1.08	1.00	1.04	0.11

25% Desal/75% GWbp (Test 5e)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)
	S1	S2	Avg		S1	S2	Avg	
0 hr	2.44		2.44		0.47		0.47	
1 hr	1.95	1.98	1.97	0.48	0.45	0.46	0.46	0.02
3 hr	1.80	1.81	1.81	0.64	0.44	0.43	0.44	0.04
4 hr	1.63	1.67	1.65	0.79	0.42	0.41	0.42	0.06
1 day	1.40	1.39	1.40	1.05	0.42	0.40	0.41	0.06
2 day	1.24	1.25	1.25	1.20	0.37	0.36	0.37	0.11
3 day	1.15	1.17	1.16	1.28	0.40	0.40	0.40	0.07
4 day	1.06	1.04	1.05	1.39	0.38	0.39	0.39	0.09
7 day	0.84	0.86	0.85	1.59	0.38	0.38	0.38	0.09

Manganese (Mn) Interference in Total Chlorine Measurement

Table B-6-1 . Manganese Interference in Total Chlorine Measurement for Test 1a–1e (pH 8.2, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Time	Manganese Interference									
	Desal		MWD		50% Desal/ 50% MWD		25% Desal/ 75% GW		25% MWD/ 75% GW	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
0 hr	NA	NA	ND (< 0.05)	ND (< 0.05)	NA	NA	NA	NA	NA	NA
1 hr	ND (< 0.05)	ND (< 0.05)	NA	NA	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)
3 hr	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	NA	NA
4 hr	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	NA	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	0.05
1 day	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)
2 day	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	0.05
3 day	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)
4 day	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)
7 day	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)

Table B-6-2. Manganese Interference in Total Chlorine Measurement for Test 3a–3e (pH 8.2, 10 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Time	Manganese Interference									
	Desal		MWD		50% Desal/ 50% MWD		20% Desal/ 80% GW		25% Desal/ 75% GWbp	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
0 hr	NA	NA	NA	NA	NA	NA	0.07	0.07	0.07	0.07
1 hr	NA	NA	NA	NA	NA	NA	0.05	0.06	0.09	0.08
3 hr	ND (< 0.05)	ND (< 0.05)	NA	NA	ND (< 0.05)	ND (< 0.05)	0.07	0.09	0.09	0.10
4 hr	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	0.05	0.06	NA	NA
1 day	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	NA	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	0.06	0.07
2 day	NA	NA	NA	NA	NA	NA	ND (< 0.05)	ND (< 0.05)	0.06	0.06
3 day	NA	NA	NA	NA	NA	NA	ND (< 0.05)	0.05	0.06	0.06
4 day	NA	NA	NA	NA	NA	NA	ND (< 0.05)	ND (< 0.05)	0.05	0.07
7 day	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	0.05	0.05

Table B-6-3. Manganese Interference in Total Chlorine Measurement for Test 4a–4e (pH 8.6, 10 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Time	Manganese Interference									
	Desal		MWD		50% Desal/ 50% MWD		25% Desal/ 75% GW		25% Desal/ 75% GWbp	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
0 hr	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1 hr	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	0.07	0.07
3 hr	NA	NA	NA	NA	NA	NA	NA	NA	0.08	0.08
4 hr	ND (< 0.05)	ND (< 0.05)	NA	NA	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	0.07	0.08
1 day	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	0.07	0.07
2 day	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	0.08	0.06
3 day	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	0.07	0.08
4 day	0.06	0.07	ND (< 0.05)	ND (< 0.05)	0.06	0.07	ND (< 0.05)	ND (< 0.05)	0.11	0.11
7 day	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	ND (< 0.05)	0.07	0.05

Appendix C

DBP Formation Tests Raw Data

Test 1a–1g: 0.3 mg/L Target Br- Desal, pH = 8.2, Temperature = 25 °C

Table C-1-1. Source Water Quality for Test 1a–1g (pH 8.2 and 25 °C and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Water Source:	Desal	MWD	Groundwater
Sample Date:	7/31/2013	8/5/2013	8/5/2013
Temperature (°C)	20.4	25.9	22.8
pH	7.88	8.15	7.86
Total Chlorine (mg/L)	ND† (< 0.05)	1.90	ND (< 0.05)
Total Ammonia (mg/L NH_3-N)	ND (< 0.03)	0.51	1.46
Free Ammonia (mg/L NH_3-N)	NA‡	0.09*	1.16
Nitrite (mg/L NO_2-N)	ND (< 0.005)	ND* (< 0.005)	ND (< 0.005)
Conductivity (µS/cm)	540*	897	1571
Turbidity (NTU)	0.22	0.08	0.37
Total Alkalinity (mg/L)	82	114	225
Calcium (mg/L)	64	59	107
Total Organic Carbon (mg/L)	ND (< 0.2)	2.76	1.90
UV254 (abs/cm)	ND (< 0.004)	0.038	0.057
Bromide (mg/L)	0.22	0.04	0.95
Iodide (µg/L)	ND (< 10)	ND (< 10)	NA
TTHMs (µg/L)	NA	43	NA
HAA5 (µg/L)	NA	17	NA
HAA9 (µg/L)	NA	27	NA

† ND = Not Detected
‡ NA = Not Analyzed
* Parameters analyzed after chemical adjustments (i.e., pH adjustment and/or chlorine addition, ammonia addition)

Table C-1-2. Test 1a–1g Initial Blend Conditions (pH 8.2 and 25 °C and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

	Desal	MWD	50% Desal/ 50% MWD	25% MWD/ 75% GW	25% Desal/ 75%GW	25% MWD/ 75% GWbp	25% Desal/ 75% GWbp
Total Chlorine (mg/L)	2.46	1.91	2.15	2.55	2.57	2.36	2.39
Total Ammonia (mg/L NH_3-N)	0.52	0.51	0.51	1.29	1.17	0.44	0.57
Free Ammonia (mg/L NH_3-N)	ND† (< 0.03)	0.09	0.04	0.45	0.39	NA	NA‡
pH	8.17	8.15	8.22	8.17	8.21	8.17	8.23
Nitrite (mg/L NO_2-N)	ND (< 0.005)	ND (< 0.005)	ND (< 0.005)	ND (< 0.005)	ND (< 0.005)	ND (< 0.005)	0.010
Conductivity (µS/cm)	540	897	719	1407	1303	1471	1393
Total Alkalinity (mg/L)	80	114	96	199	194	196	186
Nitrate (mg/L NO_3-N)	ND (< 0.1)	R#	0.3	0.3	ND (<0.1)	0.2	0.2
Bromide (mg/L)	0.22	0.04	0.13*	0.72*	0.77*	0.72*	0.77*
TOC (mg/L)	ND (< 0.2)	2.76	1.47*	2.12*	1.47*	2.12*	1.47*

† ND = Not Detected
‡ NA = Not Analyzed
# R = Rejected
* Bromide and TOC values were calculated from source water bromide and TOC values

Table C-1-3. Test 1a–1g Chloramine Stability Results
(pH 8.2, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Desal (Test 1a)

	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
Time	S1	S2	Avg		S1	S2	Avg		
0 hr	2.46		2.46		0.52		0.52		ND† (< 0.03)
1 day	1.69	1.71	1.70	0.76	0.40	0.40	0.40	0.11	0.06
3 day	1.37	1.39	1.38	1.08	0.36	0.38	0.37	0.14	0.07
7 day	1.03	1.03	1.03	1.43	0.34	0.30	0.32	0.19	0.11

MWD (Test 1b)

	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
Time	S1	S2	Avg		S1	S2	Avg		
0 hr	1.91		1.91		0.51		0.51		0.09
1 day	1.81	1.83	1.82	0.09	0.51	0.54	0.53	-0.02	0.13
3 day	1.62	1.65	1.64	0.28	0.51	0.52	0.52	-0.01	0.14
7 day	1.39	1.39	1.39	0.52	0.51	0.47	0.49	0.02	0.17

50% Desal/50% MWD (Test 1c)

	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
Time	S1	S2	Avg		S1	S2	Avg		
0 hr	2.15		2.15		0.51		0.51		0.04
1 day	1.81	1.83	1.82	0.33	0.51	0.54	0.53	-0.02	0.08
3 day	1.62	1.65	1.64	0.51	0.51	0.52	0.52	-0.01	0.10
7 day	1.39	1.39	1.39	0.76	0.51	0.47	0.49	0.02	0.12

25% MWD/75% GW (Test 1d)

	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
Time	S1	S2	Avg		S1	S2	Avg		
0 hr	2.55		2.55		1.29		1.29		0.45
1 day	2.20	2.22	2.21	0.34	1.24	1.26	1.25	0.04	0.69
3 day	2.05	2.02	2.04	0.52	1.15	1.16	1.16	0.14	0.66
7 day	1.78	1.79	1.79	0.77	1.16	1.18	1.17	0.12	0.74

25% Desal/75% GW (Test 1e)

	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
Time	S1	S2	Avg		S1	S2	Avg		
0 hr	2.57		2.57		1.17		1.17		0.39
1 day	2.30	2.27	2.29	0.29	1.20	1.18	1.19	-0.02	0.74
3 day	2.13	2.13	2.13	0.44	1.18	1.20	1.19	-0.02	0.69
7 day	1.87	1.86	1.87	0.71	1.18	1.22	1.20	-0.03	0.68

25% MWD/75% GWbp (Test 1f)

	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
Time	**S1**	**S2**	**Avg**		**S1**	**S2**	**Avg**		
0 hr	2.36		2.36		0.44		0.44		NA‡
1 day	1.69	1.72	1.71	0.66	0.49	0.50	0.50	-0.06	0.17
3 day	1.46	1.46	1.46	0.90	0.49	0.49	0.49	-0.05	0.22
7 day	1.16	1.16	1.16	1.20	0.48	0.45	0.47	-0.03	0.21

25% Desal/75% GWbp (Test 1g)

	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
Time	**S1**	**S2**	**Avg**		**S1**	**S2**	**Avg**		
0 hr	2.39		2.39		0.57		0.57		NA
1 day	1.58	1.57	1.58	0.82	0.49	0.49	0.49	0.08	0.18
3 day	1.39	1.40	1.40	1.00	0.47	0.48	0.48	0.10	0.23
7 day	1.11	1.11	1.11	1.28	0.45	0.47	0.46	0.11	0.22

† ND = Not Detected
‡ NA = Not Analyzed

Table C-1-4. Test 1a–1g Total Trihalomethane (TTHM) Results (pH 8.2, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Time (Day)	TTHMs (µg/L)						
	Desal	MWD	50% MWD/ 50% Desal	25% MWD/ 75% GW	25% Desal/ 75% GW	25% MWD/ 75% GWbp	25% Desal/ 75% GWbp
Day 0	NA†	43	NA	NA	NA	NA	NA
Day 3	0.8	43	20	9.3	1.7	61	52
Day 7	0.7	43	21	11	1.8	65	56

†NA = Not Analyzed

Table C-1-5. Test 1a–1g THM Species Results (pH 8.2, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Desal (Test 1a)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 3	ND† (< 0.5)	ND (< 0.5)	ND (< 0.5)	0.8	0.8
Day 7	ND (< 0.5)	ND (< 0.5)	ND (< 0.5)	0.7	0.7

MWD (Test 1b)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 0	14	13	13	3.0	43
Day 3	14	13	13	3.0	43
Day 7	15	12	13	3.1	43

50% Desal/50% MWD (Test 1c)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 3	6.2	5.8	6.0	2.0	20
Day 7	6.5	6.0	6.2	2.1	21

25% MWD/75% GW (Test 1d)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 3	3.8	2.5	2.4	0.6	9.3
Day 7	4.3	2.9	2.7	0.8	11

25% Desal/75% GW (Test 1e)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 3	1.2	0.5	ND (< 0.5)	ND (< 0.5)	1.7
Day 7	1.2	0.6	ND (< 0.5)	ND (< 0.5)	1.8

25% MWD/75% GWbp (Test 1f)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 3	6.7	11	17	26	61
Day 7	7.2	12	18	28	65

25% Desal/75% GWbp (Test 1g)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 3	4.4	7.7	14	26	52
Day 7	4.5	8.1	15	28	56

† ND = Not Detected

Table C-1-6. Test 1a–1g Nine Haloacetic Acids (HAA9) Results
(pH 8.2, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Time (Day)	HAA9 (µg/L)						
	Desal	MWD	50% MWD/ 50% Desal	25% MWD/ 75% GW	25% Desal/ 75% GW	25% MWD/ 75% GWbp	25% Desal/ 75% GWbp
Day 0	NA‡	27	NA	NA	NA	NA	NA
Day 3	3.6	30	15	22	13	55	46
Day 7	4.5	31	18	24	15	58	48

‡ NA = Not Analyzed

Table C-1-7. Test 1a–1g Five Haloacetic Acids (HAA5) Results
(pH 8.2, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Time (Day)	HAA5 (µg/L)						
	Desal	MWD	50% MWD/ 50% Desal	25% MWD/ 75% GW	25% Desal/ 75% GW	25% MWD/ 75% GWbp	25% Desal/ 75% GWbp
Day 0	NA‡	17	NA	NA	NA	NA	NA
Day 3	3.6	19	9.2	17	13	30	26
Day 7	4.5	19	13	19	14	33	28

‡ NA = Not Analyzed

Table C-1-8. Test 1a–1g HAA Species Results
(pH 8.2, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Desal (Test 1a)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 3	3.6	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 2)	3.6
Day 7	4.5	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 2)	4.5

MWD (Test 1b)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 0	ND (< 2)	ND (< 1)	8.7	5.4	2.8	5.1	4.7	ND	ND (< 2)	27
Day 3	ND (< 2)	ND (< 1)	10	5.7	2.8	5.8	4.6	1.2	ND (< 2)	30
Day 7	ND (< 2)	ND (< 1)	11	6	2.9	5.2	4.5	1.0	ND (< 2)	31

50% Desal/50% MWD (Test 1c)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 3	ND (< 2)	ND (< 1)	4.7	3.1	2.0	2.5	2.5	ND (< 1)	ND (< 2)	15
Day 7	2.8	ND (< 1)	5.2	3.3	2.2	2.4	2.0	ND (< 1)	ND (< 2)	18

25% MWD/75% GW (Test 1d)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 3	10	ND (< 1)	3.0	2.8	2.9	1.2	2.5	ND (< 1)	ND (< 2)	22
Day 7	10	ND (< 1)	3.7	3.4	3.9	1.3	2.0	ND (< 1)	ND (< 2)	24

25% Desal/75% GW (Test 1e)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 3	11	ND (< 1)	ND (< 1)	ND (< 1)	1.6	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 2)	13
Day 7	11	ND (< 1)	ND (< 1)	1.5	2.5	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 2)	15

25% MWD/75% GWbp (Test 1f)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 3	11	ND (< 1)	3.4	6.1	13	2.8	6.6	7.1	4.7	55
Day 7	11	ND (< 1)	3.9	7.4	16	2.5	6.3	6.8	4.0	58

25% Desal/75% GWbp (Test 1g)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 3	14	ND (< 1)	ND (<1)	4.1	11	1.3	5.4	5.9	4.2	46
Day 7	13	ND (< 1)	1.0	4.8	13	1.3	4.6	6.2	3.6	48

Table C-1-9. Nitrosamines Formation for Test 1a–1g
(pH 8.2 and 25 °C)

Constituent	MWD	Desal	50% MWD/50% Desal	25% MWD/75% GW	25% Desal/75% GW	25% MWD/75% GWbp	25% Desal/75% GWbp
NDMA	4.0	2.5	4.1	2.5	2.0	2.1	3.0
NMEA	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)
NDEA	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)
NDPA	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)
NMOR	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)
NPYR	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)
NPIP	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)
NDBA	ND (< 2) *0.8*	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)

All constituents measured in ng/L

Table C-1-10. Total Iodo-Trihalomethanes (Iodo-TTHMs) Results for Test 1a–1g (pH 8.2 and 25 °C)

Constituents	Desal	MWD	50% MWD/ 50% Desal	25% MWD/ 75% GW	25% Desal/ 75% GW	25% MWD/ 75% GWbp	25% Desal/ 75% GWbp
Dichloroiodomethane	ND (< 0.1)	0.48	0.2	0.63	0.43	0.34	0.21
Bromochloroiodomethane	ND (< 0.1)	0.24	0.15	0.27	0.23	0.63	0.48
Dibromoiodomethane	ND (< 0.1)	ND (< 0.1)	ND (< 0.1)	0.15	0.16	1.73	1.63
Chlorodiiodomethane	ND (< 0.1)	ND (< 0.1)	ND (< 0.1)	0.33	0.23	ND (< 0.1)	ND (< 0.1)
Bromodiiodomethane	ND (< 0.1)	ND (< 0.1)	ND (< 0.1)	0.24	0.27	0.17	0.17
Total Iodo-THMs	**ND (< 0.1)**	**0.72**	**0.35**	**1.62**	**1.32**	**2.87**	**2.49**

All constituents measured in µg/L

Table C-1-11. Total Iodo-Haloacetic Acids (Iodo-HAAs) Results for Test 1a–1g (pH 8.2 and 25 °C)

Constituents	Desal	MWD	50% MWD/ 50% Desal	25% MWD/ 75% GW	25% Desal/ 75% GW	25%MWD/75% GWbp	25% Desal/ 75% GWbp
Monoiodoacetic acid	ND (< 5)	74	37	840	1000	230	220
Chloroiodoacetic acid	ND (< 2.5)	130	64	240	190	120	72
Bromoiodoacetic acid	17	43	40	270	460	340	340
Diiodoacetic acid	ND (< 5)	ND (< 5)	ND (< 5)	ND (< 5)	ND (< 5)	ND (< 5)	ND (< 5)
Total Iodo-HAAs	**17**	**247**	**141**	**1350**	**1650**	**690**	**632**

All constituents measured in ng/L

Test 2a–2e: 0.3 mg/L Target Br^- Desal, pH = 8.6, Temperature = 25 °C

Table C-2-1. Source Water Quality for Test 2a–2e (pH 8.6, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Water Source:	Desal	MWD	Groundwater
Sample Date:	7/31/2013	8/12/2013	8/12/2013
Temperature (°C)	20.4	26.1	22.8
pH	7.88	NA	7.99
Total Chlorine (mg/L)	ND† (< 0.05)	1.94	ND (< 0.05)
Total Ammonia (mg/L NH_3-N)	ND (< 0.03)	0.58*	1.43
Free Ammonia (mg/L NH_3-N)	NA‡	0.11*	1.18
Nitrite (mg/L NO_2-N)	ND (< 0.005)	ND* (< 0.005)	ND (< 0.005)
Conductivity (µS/cm)	540*	925	1610
Turbidity (NTU)	0.22	0.07	0.31
Total Alkalinity (mg/L)	82	110	226
Calcium (mg/L)	64	59	104
Total Organic Carbon (mg/L)	ND (< 0.2)	2.59	1.86
UV254 (abs/cm)	ND (< 0.004)	0.033	0.058
Bromide (mg/L)	0.22	0.05#	0.95
TTHMs (µg/L)	NA	35	NA
HAA5 (µg/L)	NA	15	NA
HAA9 (µg/L)	NA	24	NA

† ND = Not Detected

‡ NA = Not Analyzed

* Parameters analyzed after chemical adjustments (i.e., pH adjustment and/or chlorine addition, ammonia addition)

Table C-2-2. Test 2a–2e Initial Blend Conditions (pH 8.6, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

	Desal	MWD	50% Desal/50% MWD	25% Desal/75% GW	25% Desal/75% GWbp
Total Chlorine (mg/L)	2.51	2.03	2.31	2.60	2.43
Total Ammonia (mg/L NH_3-N)	0.51	0.58	0.53	1.10	0.50
Free Ammonia (mg/L NH_3-N)	ND† (< 0.03)	0.107	0.038	0.52	0.10
pH	8.52	8.57	8.57	8.58	8.56
Nitrite (mg/L NO_2-N)	ND (< 0.005)	ND (< 0.005)	ND (< 0.005)	ND (< 0.005)	0.007
Conductivity (µS/cm)	560	925	746	1341	1428
Total Alkalinity (mg/L)	81	114	99	191	188
Nitrate (mg/L NO_3-N)	0.2	0.5	0.3	ND (< 0.1)	0.2
Bromide (mg/L)	0.22	0.05	0.14*	0.77*	0.77*
TOC (mg/L)	ND	2.59	1.39*	1.44*	1.44*

† ND = Not Detected

* Bromide and TOC values were calculated from source water bromide and TOC values

Table C-2-3. Test 2a–2e Chloramine Stability Results (pH 8.6, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Desal (Test 2a)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
	S1	S2	Avg		S1	S2	Avg		
0 hr	2.51		2.51		0.51		0.51		ND (< 0.03)
1 day	1.66	1.66	1.66	0.85	0.38	0.39	0.39	0.13	NA
3 day	1.43	1.41	1.42	1.09	0.30	0.30	0.30	0.21	0.05
7 day	1.06	1.09	1.08	1.44	0.30	0.30	0.30	0.21	0.09

MWD (Test 2b)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
	S1	S2	Avg		S1	S2	Avg		
0 hr	2.03		2.03		0.58		0.58		0.11
1 day	1.96	1.95	1.96	0.07	0.57	0.53	0.55	0.04	NA
3 day	1.82	1.80	1.81	0.22	0.49	0.50	0.50	0.09	0.09
7 day	1.64	1.65	1.65	0.39	0.48	0.50	0.49	0.09	0.19

50% Desal/50% MWD (Test 2c)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
	S1	S2	Avg		S1	S2	Avg		
0 hr	2.31		2.31		0.53		0.53		0.04
1 day	2.08	2.05	2.07	0.25	0.57	0.53	0.55	-0.01	NA
3 day	1.87	1.90	1.89	0.43	0.49	0.50	0.50	0.04	0.09
7 day	1.68	1.68	1.68	0.63	0.48	0.50	0.49	0.04	0.11

25% Desal/75% GW (Test 2d)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
	S1	S2	Avg		S1	S2	Avg		
0 hr	2.60		2.60		1.10		1.10		0.52
1 day	2.32	2.33	2.33	0.28	1.10	1.08	1.09	0.01	NA
3 day	2.20	2.23	2.22	0.39	0.98	0.98	0.98	0.12	0.45
7 day	2.00	2.02	2.01	0.59	1.07	1.04	1.06	0.04	0.86

25% Desal/75% GWbp (Test 2e)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
	S1	S2	Avg		S1	S2	Avg		
0 hr	2.43		2.43		0.50		0.50		0.10
1 day	1.57	1.56	1.57	0.87	0.42	0.44	0.43	0.08	NA
3 day	1.39	1.40	1.40	1.04	0.37	0.41	0.39	0.11	0.14
7 day	1.10	1.10	1.10	1.33	0.36	0.39	0.38	0.13	0.24

Table C-2-4. Test 2a–2e Total Trihalomethane (TTHM) Results
(pH 8.6, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Time (Day)	TTHM (µg/L)				
	Desal	MWD	50% MWD/50% Desal	25% Desal/75% GW	25% Desal/75% GWbp
Day 0	NA†	35	NA	NA	NA
Day 3	0.5	39	18	1	52
Day 7	0.6	38	19	1.6	53

†NA = Not Analyzed

Table C-2-5. Test 2a–2e THM Species Results
(pH 8.6, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Desal (Test 2a)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 3	ND (< 0.5)	ND (< 0.5)	ND (< 0.5)	0.5	0.5
Day 7	ND (< 0.5)	ND (< 0.5)	ND (< 0.5)	0.6	0.6

MWD (Test 2b)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 0	11	10	11	2.7	35
Day 3	13	11	12	2.9	39
Day 7	13	11	11	2.9	38

50% Desal/50% MWD (Test 2c)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 3	5.7	5.0	5.2	1.7	18
Day 7	6.3	5.3	5.4	1.8	19

25% Desal/75% GW (Test 2d)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 3	1.0	ND (< 0.5)	ND (< 0.5)	ND (< 0.5)	1.0
Day 7	1.1	0.5	ND (< 0.5)	ND (< 0.5)	1.6

25% Desal/75% GWbp (Test 2e)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 3	4.7	7.8	14	25	52
Day 7	4.8	8.0	14	26	53

Table C-2-6. Test 2a–2e Nine Haloacetic Acids (HAA9) Results (pH 8.6, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Time (Day)	HAA9 (µg/L)				
	Desal	MWD	50% MWD/50% Desal	25% Desal/75% GW	25% Desal/75% GWbp
Day 0	NA	24	NA	NA	NA
Day 3	3.1	24	13	14	36
Day 7	4.9	28	15	19	40

Table C-2-7. Test 2a–2e Five Haloacetic Acids (HAA5) Results (pH 8.6, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Time (Day)	HAA5 (µg/L)				
	Desal	MWD	50% MWD/50% Desal	25% Desal/75% GW	25% Desal/75% GWbp
Day 0	NA	15	NA	NA	NA
Day 3	3.1	15	7.7	12	21
Day 7	3.1	18	8.4	16	24

Table C-2-8. Test 2a–2e HAA Species Results (pH 8.6, 25 °C, and 0.3 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Desal (Test 2a)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 3	3.1	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 2)	3.1
Day 7	3.1	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	1.8	ND	4.9

MWD (Test 2b)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 0	ND (< 2)	ND (< 1)	7.7	4.6	2.4	4.5	4.4	ND	ND (< 2)	24
Day 3	ND (< 2)	ND (< 1)	8.4	4.2	2	4.6	2.9	2	ND (< 2)	24
Day 7	ND (< 2)	ND (< 1)	10	5.3	2.6	5.7	3.2	1.4	ND (< 2)	28

50% Desal/50% MWD (Test 2c)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 3	ND (< 2)	ND (< 1)	4.3	2.4	1.4	2	1.6	1.4	ND (< 2)	13
Day 7	ND (< 2)	ND (< 1)	4.4	3	1.8	2.2	1.9	1.7	ND (< 2)	15

25% Desal/75% GW (Test 2d)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 3	11	ND (< 1)	1.3	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	1.7	ND (< 2)	14
Day 7	13	ND (< 1)	1.9	ND (< 1)	1.5	ND (< 1)	1	1.7	ND (< 2)	19

25% Desal/75% GWbp (Test 2e)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 3	8.1	ND (< 1)	2.7	4.1	9.7	ND (< 1)	4.0	4.8	3.1	36
Day 7	9.8	ND (< 1)	3.3	4.6	11	ND (< 1)	3.7	4.5	2.8	40

Test 5a–5e: 0.5 mg/L Target Br^- Desal, pH = 8.2, Temperature = 25 °C

Table C-3-1. Source Water Quality for Test 5a–5e (pH 8.2, 25 °C, and 0.5 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Water Source:	Desal	MWD	Groundwater
Sample Date:	7/17/2013	7/29/2013	7/29/2013
Temperature (°C)	20.2	26.0	22.7
pH	7.93	8.22	8.07
Total Chlorine (mg/L)	ND† (< 0.05)	2.00	ND (< 0.05)
Total Ammonia (mg/L NH_3-N)	ND (< 0.03)	0.58*	1.51
Free Ammonia (mg/L NH_3-N)	NA‡	0.13*	1.35
Nitrite (mg/L NO_2-N)	ND (< 0.005)	ND* (< 0.005)	ND (< 0.005)
Conductivity (µS/cm)	704*	913	1562
Turbidity (NTU)	0.11	0.08	0.54
Total Alkalinity (mg/L)	78	112	227
Calcium (mg/L)	63	61	105
Total Organic Carbon (mg/L)	0.22	2.52	1.92
UV254 (abs/cm)	0.004	0.036	0.064
Bromide (mg/L)	0.49	0.05#	0.96
TTHMs (µg/L)	NA	45	NA
HAA5 (µg/L)	NA	16	NA
HAA9 (µg/L)	NA	25	NA

† ND = Not Detected

* Parameters analyzed after chemical adjustments (i.e. pH adjustment and/or chlorine addition, ammonia addition)

‡ NA = Not Analyzed

Table C-3-2. Test 5a–5e Initial Blend Conditions
(pH 8.2, 25 °C, and 0.5 mg/L Target Bromide Concentration in Desalinated Ocean Water)

	Desal	MWD	50% Desal/50% MWD	25% Desal/75% GW	25% Desal/75% GWbp
Total Chlorine (mg/L)	2.42	2.06	2.21	2.46	2.34
Total Ammonia (mg/L NH_3-N)	0.52	0.58	0.51	1.14	0.48
Free Ammonia (mg/L NH_3-N)	0.04	0.13	0.08	0.62	0.10
pH	8.23	8.22	8.16	8.24	8.24
Nitrite (mg/L NO_2-N)	ND† (< 0.005)	ND (< 0.005)	ND (< 0.005)	ND (< 0.005)	0.007
Conductivity (μS/cm)	704	913	823	1347	1443
Total Alkalinity (mg/L)	74	112	101	190	192
Nitrate (mg/L NO_3-N)	ND	0.15	0.08	ND	0.04
Bromide (mg/L)	0.49	0.05	0.27*	0.84*	0.84*
TOC (mg/L)	0.22	2.52	1.37*	1.50*	1.50*

† ND = Not Detected

* Bromide and TOC values were calculated from source water bromide and TOC values

Table C-3-3. Test 5a–5e Chloramine Stability Results
(pH 8.2, 25 °C, and 0.5 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Desal (Test 5a)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
	S1	S2	Avg		S1	S2	Avg		
0 hr	2.42		2.42		0.52		0.52		0.04
1 day	1.75	1.73	1.74	0.68	0.43	0.42	0.43	0.10	NA
3 day	1.38	1.39	1.39	1.04	0.39	0.40	0.40	0.13	0.08
7 day	0.98	NA	0.98	1.44	0.35	NA	0.35	0.17	0.09

MWD (Test 5b)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
	S1	S2	Avg		S1	S2	Avg		
0 hr	2.06		2.06		0.58		0.58		0.13
1 day	1.93	1.93	1.93	0.13	0.56	0.56	0.56	0.02	NA
3 day	1.76	1.76	1.76	0.30	0.52	0.55	0.54	0.04	0.14
7 day	1.53	1.51	1.52	0.54	0.49	0.50	0.50	0.09	0.20

50% Desal/50% MWD (Test 5c)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
	S1	S2	Avg		S1	S2	Avg		
0 hr	2.21		2.21		0.51		0.51		0.08
1 day	1.93	1.93	1.93	0.28	0.56	0.56	0.56	-0.05	NA
3 day	1.76	1.76	1.76	0.45	0.52	0.55	0.54	-0.03	0.09
7 day	1.53	1.51	1.52	0.69	0.49	0.50	0.50	0.02	0.10

25% Desal/75% GW (Test 5d)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
	S1	S2	Avg		S1	S2	Avg		
0 hr	2.46		2.46		1.14		1.14		0.62
1 day	2.08	2.06	2.07	0.39	1.10	1.14	1.12	0.02	NA
3 day	1.94	1.93	1.94	0.53	1.16	1.18	1.17	-0.03	0.58
7 day	1.72	NA	1.72	0.74	1.12	NA	1.12	0.02	0.50

25% Desal/75% GWbp (Test 5e)

Time	Total Cl_2 (mg/L)			Cl_2 Decay (mg/L)	Total NH_3 (mg/L)			NH_3 Decay (mg/L)	Avg Free NH_3 (mg/L)
	S1	S2	Avg		S1	S2	Avg		
0 hr	2.34		2.34		0.48		0.48		0.10
1 day	1.45	1.45	1.45	0.89	0.40	0.43	0.42	0.06	NA
3 day	1.26	1.27	1.27	1.08	0.42	0.43	0.43	0.06	0.12
7 day	0.99	NA	0.99	1.35	0.39	NA	0.39	0.09	0.14

Table C-3-4. Test 5a–5e Total Trihalomethanes (TTHMs) Results
(pH 8.2, 25 °C, and 0.5 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Time (Day)	TTHM (µg/L)				
	Desal	MWD	50% MWD/50% Desal	25% Desal/75% GW	25% Desal/75% GWbp
Day 0	NA†	45	NA	NA	NA
Day 3	2.4	35	21	2.5	57
Day 7	2.7	37	23	2.7	58

†NA = Not Analyzed

Table C-3-5. Test 5a–5e THM Species Results
(pH 8.2, 25 °C, and 0.5 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Desal (Test 5a)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 3	ND (< 0.5)	ND (< 0.5)	0.6	1.8	2.4
Day 7	ND (< 0.5)	ND (< 0.5)	0.7	2.0	2.7

MWD (Test 5b)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 0	15	13	14	3.1	45
Day 3	11	10	11	2.8	35
Day 7	12	11	11	2.9	37

50% Desal/50% MWD (Test 5c)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 3	5.9	5.8	6.4	2.9	21
Day 7	6.3	6.3	6.8	3.3	23

25% Desal/75% GW (Test 5d)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 3	1.2	0.8	0.5	ND (< 0.5)	2.5
Day 7	1.2	0.9	0.6	ND (< 0.5)	2.7

25% Desal/75% GWbp (Test 5e)

	$CHCl_3$ (µg/L)	$CHBrCl_2$ (µg/L)	$CHClBr_2$ (µg/L)	$CHBr_3$ (µg/L)	TTHM (µg/L)
Day 3	4.8	8	15	29	57
Day 7	5	8.4	15	30	58

Table C-3-6. Test 5a–5e Nine Haloacetic Acids (HAA9) Results
(pH 8.2, 25 °C, and 0.5 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Time (Day)	HAA9 (µg/L)				
	Desal	MWD	50% MWD/50% Desal	25% Desal/75% GW	25% Desal/75% GWbp
Day 0	NA	25	NA	NA	NA
Day 3	10	34	19	15	51
Day 7	8.9	33	20	18	53

Table C-3-7. Test 5a–5e Five Haloacetic Acids (HAA5) Results
(pH 8.2, 25 °C, and 0.5 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Time (Day)	HAA5 (µg/L)				
	Desal	MWD	50% MWD/50% Desal	25% Desal/75% GW	25% Desal/75% GWbp
Day 0	NA	16	NA	NA	NA
Day 3	10	19	13	14	29
Day 7	8.9	20	14	16	30

Table C-3-8. Test 5a–5e HAA Species Results (pH 8.2, 25 °C, and 0.5 mg/L Target Bromide Concentration in Desalinated Ocean Water)

Desal (Test 5a)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 3	10	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 2)	10
Day 7	8.9	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 2)	8.9

MWD (Test 5b)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 0	ND (< 2)	ND (< 1)	8.1	3.5	2.2	5.3	3.8	1.9	ND (< 2)	25
Day 3	ND (< 2)	ND (< 1)	10	6.2	3.2	5.5	6.0	3.3	ND (< 2)	34
Day 7	ND (< 2)	ND (< 1)	11	6.1	3.0	5.6	5.0	1.8	ND (< 2)	32

50% Desal/50% MWD (Test 5c)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 3	4.1	ND (< 1)	4	3	2.6	2.5	2.5	ND (< 1)	ND (< 2)	19
Day 7	3.9	ND (< 1)	4.8	3.5	3	2.7	2.5	ND (< 1)	ND (< 2)	20

25% Desal/75% GW (Test 5d)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 3	12	ND (< 1)	ND (< 1)	1.1	2.1	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 2)	15
Day 7	13	ND (< 1)	ND (< 1)	1.7	3	ND (< 1)	ND (< 1)	ND (< 1)	ND (< 2)	18

25% Desal/75% GWbp (Test 5e)

	MCAA (µg/L)	MBAA (µg/L)	DCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	TCAA (µg/L)	BDCAA (µg/L)	CDBAA (µg/L)	TBAA (µg/L)	HAA9 (µg/L)
Day 3	15	ND (< 1)	ND (< 1)	4.3	12	1.5	5.4	6.7	6	51
Day 7	13	ND (< 1)	1.2	5.3	14	1.5	5	7.3	5.7	53

Table C-3-9. Nitrosamines Formation for Test 5a–5e (pH 8.2 and 25 °C)

Constituent	Desal	MWD	50% MWD/50% Desal	25% Desal/75% GW	25% Desal/75% GWbp
NDMA	3.9	4.0	4.5	ND (< 2) *1.3*	ND (< 2) *1.6*
NMEA	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)
NDEA	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)
NDPA	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)
NMOR	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)
NPYR	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)
NPIP	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)	ND (< 2)
NDBA	ND (< 2) *0.3*	ND (< 2)	ND (< 2) *0.4*	ND (< 2)	ND (< 2)

All constituents measured in ng/L

Table C-3-10. Total Iodo-Trihalomethanes (Iodo-TTHMs) Results for Test 5a–5e (pH 8.2 and 25 °C)

Constituent	Desal	MWD	50% MWD/ 50% Desal	25% Desal/ 75% GW	25% Desal/ 75% GWbp
Dichloroiodomethane	ND (< 0.1)	0.36	0.15	0.37	0.21
Bromochloroiodomethane	ND (< 0.1)	0.19	0.14	0.24	0.43
Dibromoiodomethane	ND (< 0.1)	ND	0.11	0.19	1.32
Chlorodiiodomethane	ND (< 0.1)	ND	ND (< 0.1)	0.25	ND (< 0.1)
Bromodiiodomethane	ND (< 0.1)	ND	ND (< 0.1)	0.29	0.15
Total Iodo-THMs	**ND (< 0.1)**	**0.55**	**0.4**	**1.34**	**2.11**

All constituents measured in µg/L

Table C-3-11. Total Iodo-Haloacetic Acids (Iodo-HAAs) Results for Test 5a–5e (pH 8.2 and 25 °C)

Constituent	Desal	MWD	50% MWD/ 50% Desal	25% Desal/ 75% GW	25% Desal/ 75% GWbp
Monoiodoacetic acid	6.8	67	47	950	590
Chloroiodoacetic acid	ND (< 2.5)	160	68	290	280
Bromoiodoacetic acid	10	52	67	440	730
Diiodoacetic acid	ND (< 5)	ND (< 5)	ND (< 5)	ND (< 5)	11
Total Iodo-HAAs	**16.8**	**279**	**182**	**1680**	**1611**

All constituents measured in ng/L