Ocean Water Desalination
Water Quality Integration Study

Final Report

Updated

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Executive Summary

West Basin Municipal Water District (West Basin) led a Desalinated Ocean Water Quality Integration Study in partnership with Metropolitan Water District of Southern California (MWD). The purpose of the study was to evaluate potential impacts of a new, desalinated ocean water source when introduced into distribution systems that have previously been exposed to MWD water and/or groundwater sources.

A four-month pipe loop study was conducted by Hazen and Sawyer, with assistance from Separation Processes, Inc. (SPI) and Technical Advisors Dr. Michael J. McGuire (Michael J. McGuire Inc.), Mr. Frank Baumann (FJB Water Technology) and Mr. Michael Schock (USEPA). The study evaluated corrosion-related impacts of stabilized desalinated ocean water and blends with MWD water and a West Basin customer agency's groundwater on different pipe and household plumbing materials in pilot-scale pipe loops. Two additional aspects of the testing - disinfectant residual stability and disinfection byproduct formation - were investigated both at pilot-scale and through more in-depth testing in the laboratory by MWD.

Desalinated ocean water must be stabilized before entering distribution systems, because removal of calcium and alkalinity by the reverse osmosis process used in desalination makes the water corrosive to many piping materials. Stabilization, or post treatment, involves the addition of select minerals and other buffering constituents, including calcium and alkalinity in combination with pH adjustment to condition the water. Desalinated ocean water produced at West Basin's Ocean Water Desalination Demonstration Facility (OWDDF) was stabilized using calcite (calcium carbonate) contactors prior to introducing the water to the pipe loops and being used in the bench-scale studies.

At the commencement of the study, a literature search and utility survey were conducted to review the current knowledge and water utility experience on desalinated ocean water stabilization in terms of water quality targets for corrosion control. The major water quality parameters known to primarily influence pipe corrosion include alkalinity, calcium and pH. Calcium Carbonate Precipitation Potential (CCPP) and Langelier Saturation Index (LSI) are commonly used indices for evaluating water corrosivity toward cementitious materials and for determining how protective films are applied to metal surfaces. Additional parameters such as chloride, sulfate, disinfectant, and dissolved oxygen may have impacts on the potential corrosion of piping materials but the impact is less definitive than the aforementioned parameters.

Table ES-1 summarizes the target water quality parameters for stabilized desalinated ocean water, which were selected based on the literature review results. Specifically, the target ranges for alkalinity, calcium and pH were expected to generate positive CCPP and LSI values, which indicate a non-aggressive water with respect to distribution system materials. In addition to the parameters affecting corrosion, the target total chlorine residual and total ammonia concentration were selected to match the typical disinfectant residual in the distribution systems.

Table ES-1. Target Water Quality Parameters for Stabilized Desalinated Ocean Water

Constituent	Target Concentration
Alkalinity	65 – 80 mg/L as $CaCO_3$
Calcium	> 65 mg/L as $CaCO_3$
pH	8.2 ± 0.2
CCPP	Between 0 and 10 mg/L as $CaCO_3$
LSI	Between 0 and 0.5
Total Chlorine Residual	2.5 mg/L
Total Ammonia	0.5 mg/L as N

The pipe loop study was conducted with new cement mortar-lined steel pipes (CML loops), unlined cast iron pipes harvested from a local distribution system (UCI loops), and new copper pipes with lead solder and harvested brass meters (CU loops). These pipes and materials represent the different types of distribution system materials that are susceptible to corrosion if the desalinated ocean water has corrosive tendencies. The pipe loops were tested with stabilized desalinated ocean water (100% Desal), MWD water (100% MWD), a blend of desalinated water and MWD water (50% Desal/50% MWD), a blend of MWD water and groundwater (25% MWD/75% groundwater), and a blend of desalinated ocean water and groundwater (25% Desal/75% groundwater), as listed in

Table ES-2.

The source waters tested represent the range of impacts that varying water quality may have on the pipe materials. Groundwater used in the study was from a West Basin customer agency. In the initial stages of the study, the team contacted the retail agencies in West Basin's service area that may receive desalinated ocean water when a full-scale facility is built. Each agency was contacted to assess water quality from groundwater wells, treatment processes (including disinfection), and piping materials in the distribution system. Groundwater from one West Basin customer agency was selected for this study for the following reasons:

- The groundwater represents the most challenging water quality in West Basin's service area, with high levels of bromide, naturally-occurring ammonia, iron, and manganese.
- Unlined cast iron piping remains in service in the distribution system, with significant deposits of iron and manganese.
- The agency had a main replacement program underway, allowing for an ample supply of used pipe that could be harvesting for the project.

Pipe loops were operated on a weekly basis, with "**uncirculated water**" introduced on Day 1 and "**recirculated**" water discharged on Day 7. Water was continuously recirculated through the UCI and CML pipe loops during this period. Note that the recirculation operation was selected due to pilot test constraints in obtaining and discharging water at the site. Recirculation does not represent typical flow through conditions in a distribution system but is informative when comparing potential impacts of different water qualities. Metal concentrations can increase in recirculated water over each recirculation, which can amplify corrosion issues, if any occur. With each pipe loop group tested under the same operational conditions, the results provide relative evaluation of the test waters. 100% MWD and 25% MWD/75% groundwater serve as controls (as existing water qualities in the distribution system) for 100% Desal and 50% Desal/50% MWD and 25% Desal/75% groundwater.

The CU loops were operated with an alternating flow-through and stagnation cycle, with 0.5 hours of flow followed by 11.5 hours of stagnation. Separate first-flush samples were collected after approximately 8 hours of stagnation from the brass meters and from the copper pipes. Water from all loops was sampled on Day 1 and Day 7 to monitor water quality changes (primarily metal concentrations) over each week. The pipe loop study continued for 4 months to allow pipe stabilization after harvesting.

Table ES-2. Test Waters for Pipe Loops

Test Water	UCI Loops	CML Loops	CU Loops
100% Stabilized Desalinated Ocean Water	✓	✓	✓
100% MWD Water	✓	✓	✓
50% Desalinated Ocean Water and 50% MWD Water	✓	✓	✓
25% MWD Water and 75% Groundwater	✓	✓	✓
25% Desalinated Ocean Water and 75% Groundwater	✓	✓	✓
Duplicate Loop	✓	✓	✓

It is important to note that the results from the pipe loops must be viewed in relation to each other, rather than considered absolute values to be expected in the distribution system. For the highly tuberculated unlined cast iron pipe loops, an initial stabilization period of approximately 2 months was necessary to reach more stable operating conditions even for the pipe loops receiving the same water quality as when the UCI pipes were in service. This stabilization period was consistent with prior experience with corrosion testing of harvested pipes and is an artifact of harvesting pipes from the distribution system. This period is not expected for real distribution systems. For the pipe loop testing, iron and manganese concentrations in the recirculated test water fell below the secondary maximum contaminant levels (MCLs) after this period (i.e., <0.3 mg/L total iron, < 50 µg/L manganese). CCPP values in recirculated water were positive for all test waters (except one occasion for 100% Desal during the stabilization period). Results showed that 100% Desal water and blends of 50% Desal/50% MWD and 25% Desal/75% groundwater did not cause higher total iron release compared with 100% MWD water.

For CML pipe loops, aluminum and pH were monitored as primary indicators of cement mortar dissolution. Throughout the testing, the recirculated waters were below the aluminum secondary MCL of 200 µg/L. pH increases were observed initially for all loops since the pipe surfaces were unsealed, although the degree of increase was much less than observed in prior testing when water was not sufficiently stabilized (Blute et al., 2008). After this initial increase, pH stabilized around 8.5 - 8.6, which was slightly above pH levels in uncirculated waters. CCPP values in recirculated water remained positive and were slightly higher than in the uncirculated test water due to the pH increases. Overall, all of the waters tested were non-aggressive toward the cement mortar-lined pipes.

For CU pipe loops, lead concentrations in the first flush samples of water taken from the brass meters and copper pipes with lead solder after a stagnant period were below the Action Level of 15 µg/L for 100% Desal and 100% MWD water. Levels were higher in one of the loops supplied with 25% MWD and 75% groundwater, which results indicated was primarily due to variations in the brass water meter installed in the loop. The 100% Desal water and Desal blends did not show an increased tendency to leach lead from lead solder or brass meters when compared with the other test waters. Copper and zinc concentrations in the stagnant water were well below the Action Level of 1,300 µg/L for copper and secondary MCL of 5,000 µg/L for zinc for both copper pipe segments and the brass meters.

The impact of desalinated ocean water on total chlorine residual was investigated in this study both in in the field with the pipe loop testing and in the laboratory on a bench scale. The UCI pipes contained significant tuberculation that appeared to be mainly iron and manganese deposits, which are consistent with elevated levels of these constituents in the groundwater. Nearly complete chlorine loss was observed for all UCI loops due to the chlorine demand exerted by the water, the iron and manganese deposits, and nitrite produced from nitrification. Nitrification (i.e., a loss of ammonia and increase in nitrite) was most severe in the pipe loops containing groundwater blends due to the presence of high levels of free ammonia. No corrosion-related outcomes of nitrification, such as a decrease in pH resulting in red water release, were observed in the pipe loop study indicating that the water was sufficiently buffered for the water and conditions tested.

By comparison, less total chlorine loss was observed in the CML pipe loops, with little evidence of nitrification. A high degree of chlorine loss was noted in the CU pipe loop first flush samples, compared to uncirculated waters. Severe nitrification occurred in the groundwater blends in the later study period but did not result in a noticeable drop in pH. New copper pipe is also known to cause chloramine decay.

Pilot testing showed that disinfection by products (DBPs), including total trihalomethane (TTHM) and haloacetic acids (HAA5), were very low in 100% Desal – both uncirculated and recirculated waters. No increase in DBPs was observed for blends of Desal when compared to the proportion of DBPs contributed by the original source water. Low levels of N-nitrosodimethylamine or NDMA (up to 5.8 ng/L) were detected in both uncirculated and recirculated 100% Desal waters, which was similar to the NDMA concentrations measured in 100% MWD water.

Bench testing was conducted by MWD to evaluate chloramine stability and DBPs (TTHM, HAA5, NDMA, and iodinated DBPs). Similar waters tested at pilot scale were evaluated, including stabilized Desal, MWD water, and blends of Desal or MWD water with groundwater. In addition to groundwater blends using natural ammonia, groundwater was also tested in blends after breakpoint chlorination (as practiced by West Basin customer agencies). All bench tests were conducted using simulated distribution system (SDS) methods under laboratory controlled conditions, which excluded the effects of pipes on chloramine stability and DBP formation. Testing evaluated chloramine stability at two pH levels, temperatures, and bromide concentrations. Results from this testing are shown in Appendix 2.

In sum, the introduction of stabilized desalinated ocean water into a range of typical and representative potable water distribution system materials did not negatively impact water quality, corrosion or disinfectant residual. The tested desalination water quality targets, determined by an extensive literature review and desalination plant survey, were shown to be protective of the distribution system and household plumbing materials.

1. Introduction

In 2013, West Basin Municipal Water District (West Basin) led a Desalinated Ocean Water Quality Integration Study (WQIS) in partnership with Metropolitan Water District of Southern California (MWD). Desalinated ocean water requires post-treatment to reintroduce minerals (calcium and alkalinity) to prevent corrosion in a distribution system. The purpose of the study was to select target water quality for a new desalinated ocean water source based on a literature review and survey, and to evaluate the impact of its introduction into distribution system materials that have previously been exposed to MWD water and groundwater sources.

A 4-month pipe loop study was conducted by Hazen and Sawyer, with assistance from Separation Processes, Inc. (SPI) and Technical Advisors Dr. Michael J. McGuire (Michael J. McGuire Inc.), Mr. Frank Baumann (FJB Water Technology) and Mr. Michael Schock (USEPA). The study evaluated the impacts of stabilized desalinated ocean water on various pipe materials under simulated distribution system conditions, including pipes from the distribution system and new materials. The pipe loop study provides a relative evaluation of the desalinated ocean water compared to MWD water and groundwater. Additionally, a bench-scale study was performed by MWD, which focused on disinfection stability and disinfection byproduct (DBP) formation potential of stabilized desalinated ocean water compared with MWD water, groundwater, and potential blends.

This report summarizes findings of the project, including desalinated ocean water stabilization, the testing approach, and results of the pipe loop study. Detailed project documents, including the pipe harvesting plan, the literature review and survey, and pipe loop design and operation, are included in Appendix 1. Bench testing results are presented in Appendix 2.

2. Desalinated Ocean Water Stabilization

Desalinated ocean water tested in this project was produced at West Basin's Ocean Water Desalination Demonstration Facility (OWDDF) located in Redondo Beach, California (Figure 2-1). The OWDDF employs ultrafiltration (UF) pre-treatment followed by reverse osmosis (RO) to produce approximately 22,000 gallons per day of desalinated ocean water. The desalinated ocean water was stabilized with calcite (calcium carbonate) followed by pH adjustment and chloramination before being introduced into the pipe loops. This section documents desalinated ocean water stabilization processes tested and stabilized water quality targets achieved in this study.

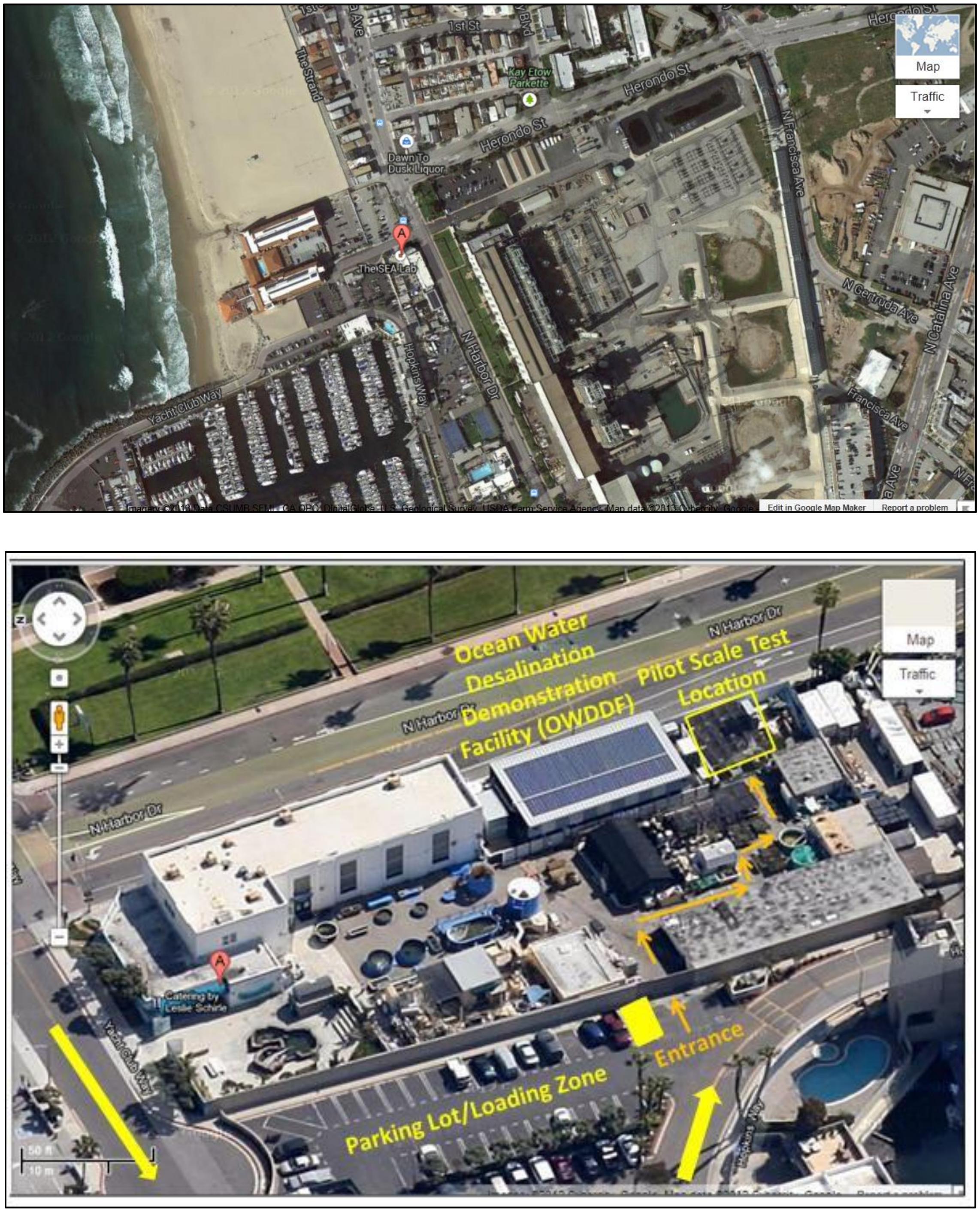

Figure 2-1. Study Location

2.1 Desalinated Ocean Water before Stabilization

The OWDDF RO system was operated to generate water quality similar to what would be produced at a full-scale desalination plant. Although higher targets may be selected for full-scale implementation, study objectives included a boron concentration of approximately 0.5 mg/L and a bromide concentration of approximately 0.3 mg/L that were selected by West Basin. No corrosion-related impacts from boron or bromide were anticipated. Boron limits are often selected based on agricultural crops in a system, which has not yet been assessed for West Basin. Bromide has previously been shown to impact chloramine residual stability and DBP formation. The bromide concentrations were selected because previous research had shown minimal bromamine degradation of chloramine residuals at concentrations below 0.3 mg/L (Zhang et al., 2012). A higher level of 0.5 mg/L was also tested by MWD in the bench-scale study.

To achieve the boron and bromide targets, RO permeate from the first pass (the front end) was blended with RO permeate from the second pass. The pH of the second pass (specifically, the feed to the second pass) was increased to test the ability to provide more boron rejection. The OWDDF RO system was normally operated to achieve a boron concentration of 0.5 mg/L in the blended RO permeate. However, for this pilot study, RO was specially operated to achieve a bromide concentration of 0.3 mg/L, which happened to also result in a boron concentration of 0.5 mg/L. Bromide cannot be easily measured in the field. To estimate bromide concentrations in the blended RO permeate for stabilization, conductivity was used as a surrogate measurement based on a conductivity-to-bromide ratio that was determined by SPI based on previous laboratory results. The target conductivity for the blended RO permeate was 200 µS/cm, which corresponded to a bromide concentration of 0.3 mg/L. Bromide concentrations in the desalinated ocean water used in the study were subsequently verified through laboratory testing.

Permeate from the lead RO elements in the first pass was blended with second pass permeate at an approximate ratio of 2:1, which was adjusted as water temperature varied during the study. When the study began in April 2013, the water temperature was approximately 16^{o}C. The conductivity of the permeate from the lead elements in the first pass was approximately 260 µS/cm, whereas the conductivity of the second pass permeate was approximately 75 µS/cm. Therefore, the blend ratio of first pass permeate to second pass permeate was 2:1. Since a 3 gpm flow was required for the calcite stabilization process, 2 gpm of first pass permeate was blended with 1 gpm of second pass permeate. The flow of each of the two streams was measured using rotameters installed on each of the two lines. As the temperature of the seawater increased in the summer, the ratio of first pass to second pass permeate for the blend was slightly adjusted to maintain the target conductivity of 200 µS/cm by using a higher proportion of second pass permeate. The highest blend ratio during the WQIS study was 5:1, which was 2.5 gpm of first pass permeate and 0.5 gpm of second pass permeate.

The two water streams were combined and stored in a 60-gallon equalization tank used to feed water to the desalinated ocean water stabilization process once a week. The following steps were used in preparation of each batch of desalinated ocean water:

1. The PVC lines bringing water from the OWDDF RO system to WQIS were flushed until conductivity of the permeate measured at the RO system matched the conductivity measured at the WQIS site. Typically, 5 to 10 minutes of flushing was required.
2. Conductivity and temperature of the RO first pass permeate and second pass permeate were measured with a Myron L Ultrameter II (Carlsbad, CA). The flow rates of the two streams were adjusted to obtain a conductivity of 200 µs/cm in the blend. Conductivity was monitored while the RO permeate streams were blended.

Table 2-1 summarizes the blended desalinated ocean water quality before stabilization.

Table 2-1. Desalinated Ocean Water Quality Before Stabilization

Constituent (Units)	Average	Range
Boron (mg/L)	0.53	0.46 – 0.61
Bromide (mg/L)	0.26	0.23 – 0.32
Chloride (mg/L)	54	46 - 65
Conductivity (µS/cm)	197	183 - 213
Temperature (^{o}C)	19.5	17.0 – 21.4
pH	10*	Not applicable

*Typical pH value in the blended desalinated ocean water due to raised pH for boron rejection in the second pass.
Note that a higher bromide level of 0.49 mg/L was also tested in the bench-scale study (Appendix 2).

2.2 Target Water Quality for Stabilized Desalinated Ocean Water

As a result of the RO process, desalinated ocean water contains little calcium and alkalinity, which makes the water corrosive to pipes and plumbing materials. Stabilization is required through the addition of minerals and adjustment of pH before desalinated ocean water can be introduced into distribution systems.

At the commencement of the study, a literature search and utility survey were conducted to review the current knowledge and industry experience regarding desalinated ocean water stabilization in terms of water quality targets for corrosion control. The primary water quality parameters known to have significant impacts on pipe corrosion include alkalinity, calcium and pH. The Calcium Carbonate Precipitation Potential (CCPP) and Langelier Saturation Index (LSI) are commonly used indices for evaluating water corrosivity toward cementitious materials and for determining how protective films are applied to metal surfaces. Additional parameters such as chloride, sulfate, disinfectant, and dissolved oxygen may also have impacts on the corrosion of piping materials but the impact is less definitive than the aforementioned parameters. More details are documented in the Appendix 1-B.[1]

Table 2-2 summarizes the target water quality parameters for stabilized desalinated ocean water, which were selected based on the literature review results (Appendix 1-B). Specifically, alkalinity concentrations between 65 - 80 mg/L as $CaCO_3$, calcium concentrations greater than 65 mg/L as $CaCO_3$, and pH values of 8.2 ± 0.2 were expected to generate positive CCPP and LSI values, indicating a non-corrosive water or a variety of piping materials. In addition to the parameters affecting corrosion, the target total chlorine residual and total ammonia concentration were selected to match the typical disinfectant residual in the distribution systems.

Table 2-2. Target Parameters for Stabilized Desalinated Ocean Water

Constituent	Target Concentration
Alkalinity	65 – 80 mg/L as $CaCO_3$
Calcium$^{\neq}$	> 65 mg/L as $CaCO_3$
pH	8.2 ± 0.2
CCPP	Between 0 and 10 mg/L as $CaCO_3$
LSI	Between 0 and 0.5
Total Chlorine Residual	2.5 mg/L
Total Ammonia	0.5 mg/L as N

$^{\neq}$ The calcium level is of secondary importance in the CCPP calculations.

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[1] Appendix 1 of Ocean Water Desalination Water Quality Integration Study Pipe Loop Design, Installation, and Testing Plan dated May 8, 2013.

2.3 Desalinated Ocean Water Stabilization using Calcite Contactors

Post-treatment processes identified in the literature review and survey for desalinated ocean water stabilization include addition of lime (calcium hydroxide, $Ca(OH)_2$), carbon dioxide (CO_2), sodium hydroxide ("caustic soda" or NaOH), sodium bicarbonate ($NaHCO_3$), sodium carbonate ("soda ash" or Na_2CO_3), pH adjustment, use of a calcite (calcium carbonate) contactor or blending with raw water (for groundwater sources).

Literature and full-scale experience has shown that calcite contactors can be used to provide alkalinity values of more than 40 mg/L as $CaCO_3$ and calcium concentrations greater than 60 mg/L as $CaCO_3$ (Shih et al., 2012; Blute et al., 2008). Calcite contactors were used to stabilize the desalinated ocean water in this study due to ease of use in piloting, and also considering the potential to minimize the post-treatment process footprint and life cycle cost in a full-scale facility. Additionally, operation of calcite contactors may be simpler than lime addition.

Figure 2-2 illustrates the process used to stabilize the desalinated ocean water in the pilot study. Sulfuric acid was added upstream of the calcite contactors to reduce pH and improve calcium carbonate dissolution. Sulfuric acid was necessary rather than carbon dioxide to achieve the low pH values necessary to sufficiently dissolve calcite. The pH-adjusted water then pumped into the bottom of calcite contactors that were operated in an upflow mode, increasing alkalinity, calcium and pH while the calcite media dissolved. Three calcite contactors were operated in parallel to provide sufficient water conditioning within a reasonable time frame of approximately 2 hours for 400 gallons (stored in a 500 gallon tank). The combined effluent of the calcite contactors was filtered through a cartridge filter to prevent carry-over. Chlorine and ammonia were added to the storage tank to form chloramines as disinfectant. The target chloramine concentration in the stabilized desalinated ocean water was 2.5 mg/L as Cl_2 with a chlorine-to-ammonia mass ratio (Cl_2: NH_3-N) of 4.75:1. Caustic soda was added to the storage tank to raise the pH of the stabilized water to the target of 8.2 ± 0.2. Further detail about chemical additions is provided later in this section. The process was designed with flexibility to bypass the calcite contactors and recirculate flow through the cartridge filter. The calcite contactors were made of translucent plastic to allow visual inspection of the calcite beds in operation. When not being inspected, the contactor columns were covered with opaque material to prevent algae growth.

Stabilization of Desalinated Water

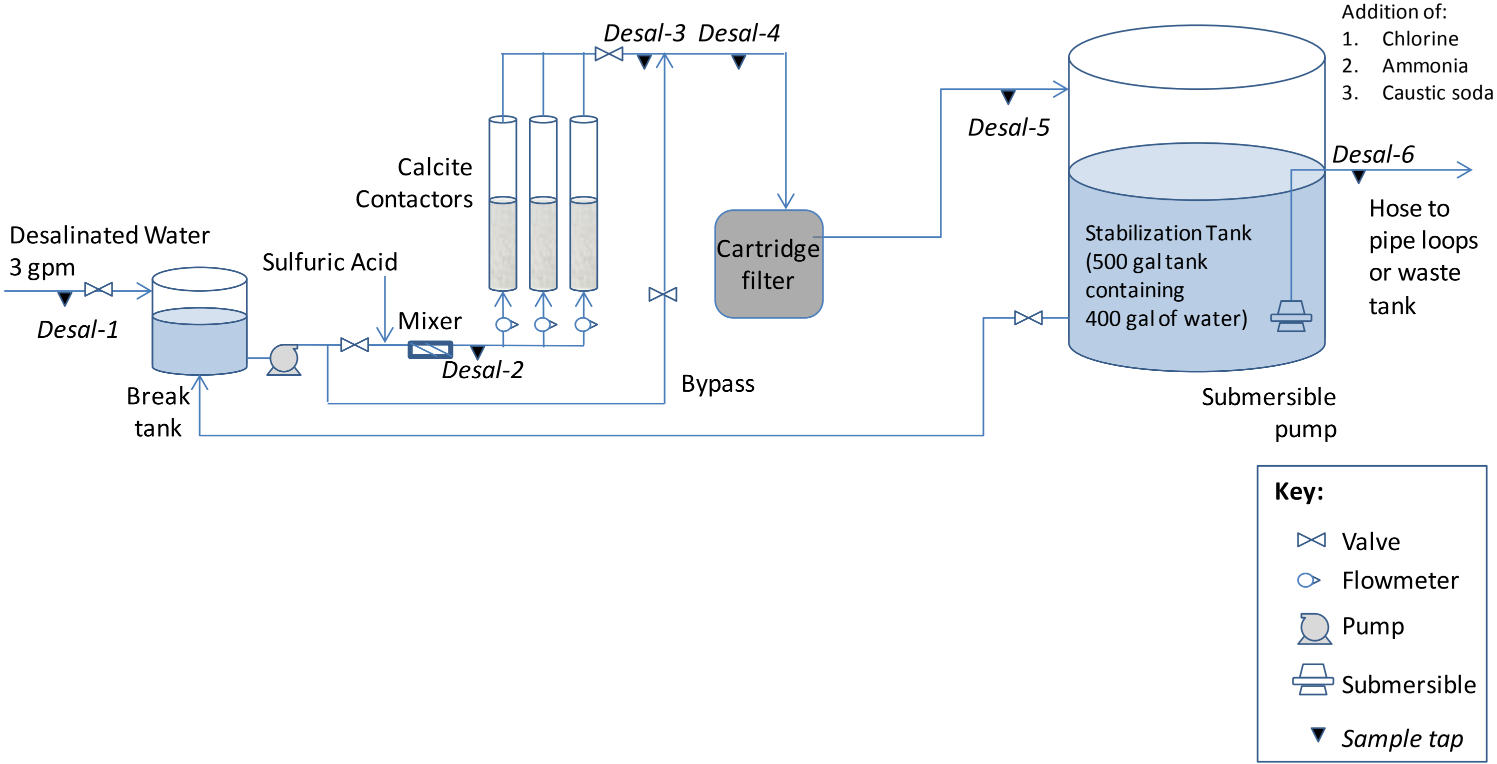

Figure 2-2. Desalinated Ocean Water Stabilization Process

Note: Chloramine addition and final pH adjustment are described in more detail in the text.

Table 2-3 summarizes the operating conditions of the pilot calcite contactors. The total flow rate into the three contactors was 3 gpm. Influent pH after acid addition was initially selected as 5.5, based on a pilot study of calcite contactors[2] and previous experience with desalinated ocean water stabilization using a calcite contactor[3]. However, initial testing using the desalinated ocean water on site showed that a lower pH was necessary to achieve the target alkalinity concentration. Figure 2-3 shows the calcite contactor effluent water quality with a 5-min empty bed contact time (EBCT) at various influent pH levels. Influent pH between 2.7 and 2.8 was needed to achieve target alkalinity above 65 mg/L as $CaCO_3$, which may be caused by higher pH (typically around 10) in the blended desalinated ocean water at OWDDF to control boron. The average sulfuric acid dose was 82 mg/L (in the range of 69 – 89 mg/L) to achieve the influent pH between 2.7 and 2.8, which is above the NSF International's maximum use level for sulfuric acid of 50 mg/L. Therefore, an alternative approach to reduce pH to 2.7 will be needed if a calcite contactor is selected for full-scale design. For example, a combination of carbon dioxide and sulfuric acid may be used if shown to be effective.

The design EBCT was 5 minutes, which was selected based on modeling results for calcite contactor design[4]. At the startup of this study, a longer EBCT (10 minutes) was tested to see if it would result in higher alkalinity and calcium concentrations. With pH between 2.8 and 3.8, the longer EBCT did not result in higher alkalinity (Figure 2-4) or calcium (not shown in figure) concentrations. Therefore, the calcite contactor was designed and operated based on a 5-minute EBCT in this study. A 5-micron cartridge filter was initially used for turbidity removal, which was later replaced with a 1-micron filter to improve turbidity control.

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[2] Shih et al, 2012. *Upflow Calcite Contactor Study*. Final report prepared for Texas Development Board.

[3] Wu and Blute, 2009. *Bench-Scale Study of BARDP Pilot Study Finished Water Quality and Compatibility Analysis*. Appendix E of the Bay Area Regional Desalination Pilot Plant Final Report.

[4] The DESCON model developed by Letterman and Kothari (1995) and the program developed by Schott (2002) named Limestone Bed Contactor: Corrosion Control and Treatment Process Analysis Program Version 1.02.

Table 2-3. Design Criteria for Calcite Contactors

Parameter	Operating Conditions
Flow Rate (gpm)	3 (including three contactors each receiving 1 gpm of flow)
Sulfuric acid dose (mg/L as H_2SO_4)	82 (average dose)
Influent water pH (after acid addition)	2.7 – 2.8
Calcite product	Puri-Cal^{TM} from Columbia River Carbonates[1]
Calcite mean particle size (millimeter, mm)	0.55
Calcite contactor diameter (inch)	6
Calcite contactor bed depth (feet)	3.3
Calcite contactor volume (cubic feet, cf)	0.66
Hydraulic loading rate (gpm/square feet, gpm/sf)	5
Empty bed contact time (minutes)	5
Cartridge filter size (micron)	1 (initially used 5-micron filter)
pH in calcite contactor effluent	7.7
Chloramination then pH adjustment	
Chloramine target concentration (mg/L as Cl_2)[2]	2.5
Chlorine dose (mg/L as Cl_2)[3]	See note
Ammonia dose (mg/L)	Based on Cl_2:NH_3-N ratio of 4.75:1
Caustic soda dose (mg/L as NaOH)	Average 1.6 (Range: 1.5 – 1.8)
pH adjustment then chloramination	
Chloramine target concentration (mg/L as Cl_2)	2.5
Chlorine dose (mg/L as Cl_2)	3.0 – 3.3
Ammonia dose (mg/L)	Based on Cl_2:NH_3-N ratio of 4.75:1
Caustic soda dose (mg/L as NaOH)	Average 3.8 (Range: 3.0 – 5.0)

[1] NSF certified.

[2] Chloramines were formed by adding chlorine to water, mixing, then adding ammonia.

[3] In this study, an initial chloramine dose of 2.5 mg/L was added and monitored for chloramines degradation. The typical chlorine loss was approximately 1 mg/L in 18 hours. Then chloramine was boosted to the target level before the stabilized desalinated ocean water was tested in the pipe loops. More details are provided in the text.

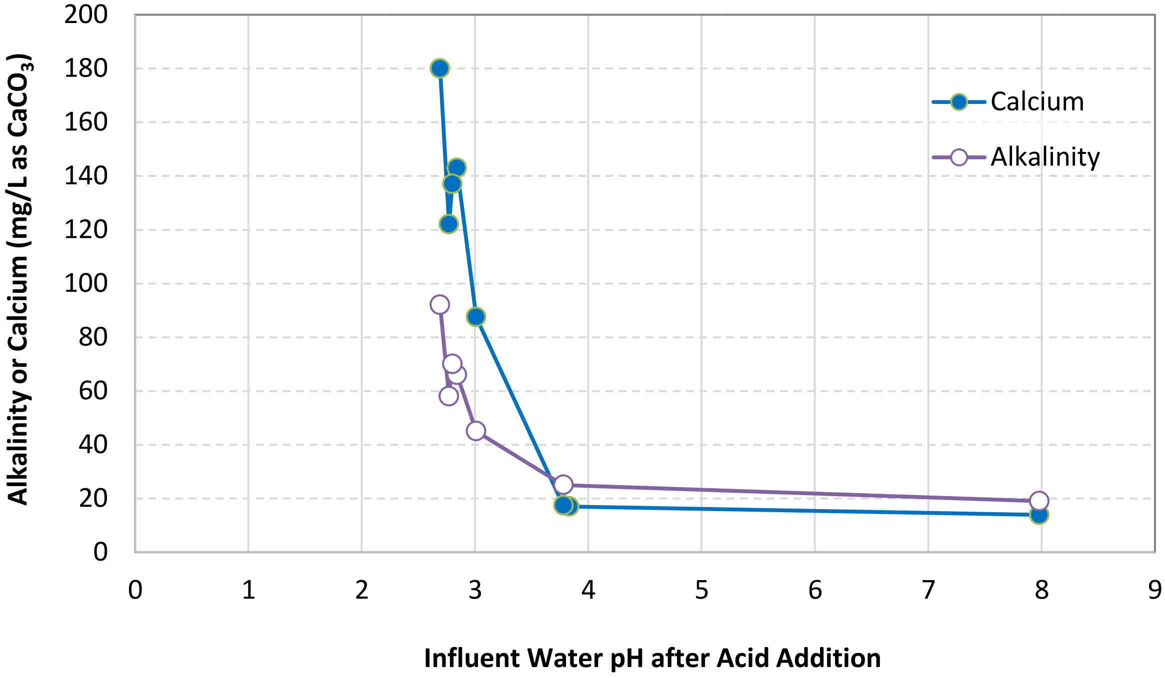

Figure 2-3. Calcite Contactor Effluent Alkalinity and Calcium with 5-min EBCT

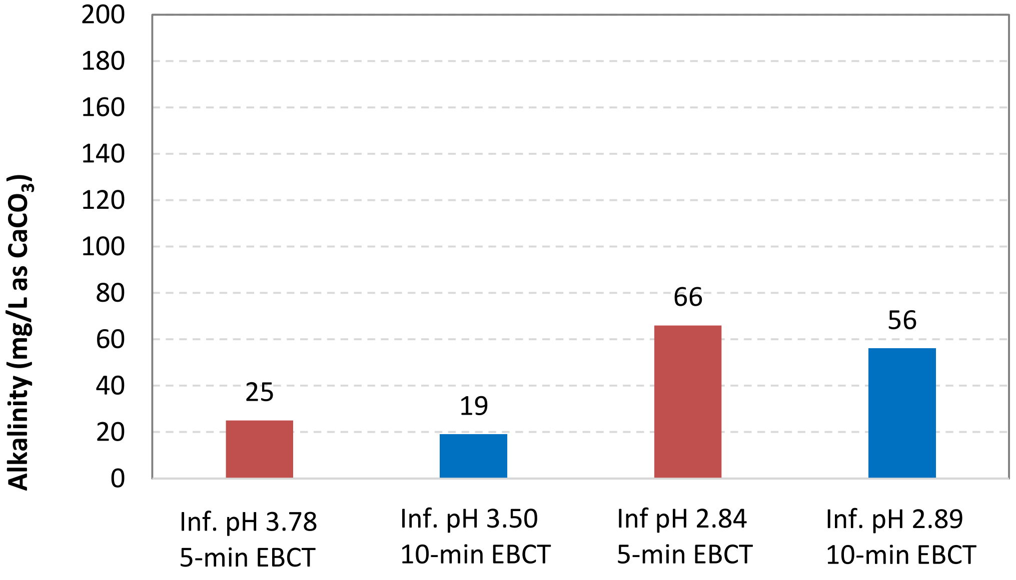

Figure 2-4. Calcite Contactor Effluent Alkalinity vs. EBCT

The cartridge filter effluent was collected in the 500-gal storage tank, to which chlorine was added first to generate a free chlorine residual to provide 0.5 log *Giardia* inactivation (assuming the RO process provide 2.5 log *Giardia* removal, for a total of 3 log *Giardia* credit). The cartridge filter effluent had an average pH of 7.7 and an average temperature of 22 °C. A CT of 16 mg-min/L is required for 0.5 log *Giardia* inactivation with free chlorine at 20 °C and pH 8.0 (slightly more conservative than 22 °C and pH 7.7). For a free chlorine residual of 2.5 mg/L, 6.4 minutes of contact time is needed. For 4-log virus inactivation, a contact time of 1.2 minutes is required for 2.5 mg/L free chlorine at pH 6.0 – 9.0 and 20 °C. RO membrane usually receives a credit of 1.0 to 2.0 for virus inactivation, which is system specific and requires testing. The contact times have not accounted for baffling factors. Overall, the contact times for *Giardia* and virus inactivation using free chlorine are relatively short and can be easily met.

Alternatively, a CT of 185 mg-min/L is required at 20 °C with a pH between 6 and 9 for 0.5 log *Giardia* inactivation with chloramines. A chloramine concentration of 2.5 mg/L translates into a required contact time of 74 minutes. A greater CT is required for virus inactivation at 20 °C, which is 321, 534 and 746 mg-min/L for 2, 3 and 4-log inactivation, respectively. If a 1 log virus credit is granted for the RO process and the clearwell has a baffling factor of 0.5 (baffled inlet or outlet with some intra-basin baffles), the required contact time for 3-log virus inactivation would be 427 minutes with 2.5 mg/L chloramines at 20 °C. If a 2 log virus credit is granted for the RO process and a baffling factor of 0.7 is provided, the required contact time for 2-log virus inactivation would be 183 minutes. As stated in West Basin's Ocean Water Desalination Program Master Plan, a detention time of 6 hours is anticipated for the full-scale system. Therefore, chloramines can provide a sufficient CT for 0.5 log *Giardia* inactivation with adequate detention time. However, chloramines may only provide sufficient CT for virus inactivation with effective baffles and 1 to 2 log virus credit for RO. This will need to be considered when West Basin considers pre-chloramination compared with a period of free chlorine contact time in the design.

During the pilot study, the disinfection procedures for stabilized desalinated ocean water were optimized to achieve the target total chlorine residual with minimized chlorine and ammonia boosting. Stabilized desalinated ocean water was typically prepared on Wednesdays, with calcite contactors operated in the morning and disinfection performed in the afternoon. Due to logistical reasons, the disinfected stabilized desalinated ocean water was held in the storage tank overnight. Total chlorine degradation was observed during the holding time. Chlorine and ammonia boosting was often necessary to achieve the total chlorine residual target on Thursday morning, when the water was needed to fill the pipe loop tanks.

Chloramine formation procedures were optimized during the study with different initial chlorine and ammonia doses as well as contact times to identify the appropriate doses that required minimal or no boosting. Chlorine degradation was monitored when possible in the pilot study; it was more thoroughly evaluated in the bench-scale study under controlled lab conditions. The procedures and results of the various runs are summarized below.

An initial chlorine dose (between 2.5 mg/L and 3.8 mg/L) was added and the water was mixed for approximately two hours via recirculation (bypassing the calcite contactors). The higher initial chlorine dose was used in the later part of the pilot study, to account for chlorine degradation on Wednesday and avoid chlorine boosting on Thursday. The 2-hour time provided sufficient mixing for the relatively large water volume in the storage tank. Typically, approximately 0.2 mg/L of free chlorine demand was observed, which was the difference between the chlorine dose and free chlorine residual tested in the end of mixing. If free chlorine residual was below 2.5 mg/L after mixing, a second chlorine dose was added to aim for 2.5 mg/L free chlorine residual.

Following chlorination, ammonia was added to the storage tank to form chloramines. The ammonia dose was calculated based on a chlorine-to-ammonia mass ratio (Cl_2: NH_3-N) of 4.75:1. Total ammonia and total chlorine residual were monitored while the water was mixed. Total ammonia was typically not boosted on Wednesday, unless it was below 0.4 mg/L as N. The stabilized desalinated ocean water was held over tonight and tested again for total chlorine and total ammonia on Thursday morning. Total ammonia was boosted when the ammonia level was not sufficient for the target chlorine residual of 2.5 mg/L ± 0.2 mg/L and a Cl_2: NH_3-N ratio of 4.75:1. When the total chlorine residual was below the target, chlorine was boosted again (following ammonia boosting if any). Subsequently, caustic soda was added to the chloraminated water to adjust pH to the target level of 8.2. Caustic was typically added approximately two hours after the last chlorine boosting. However, in some runs, it was added sooner (as less as 15 minutes after chlorine boosting) to prepare the water in time for pipe loop test. The average dose was 1.6 mg/L as NaOH, with a range of 1.5 – 1.8 mg/L.

Figure 2-5 shows the chloramine residual loss as a function of time, which was after the first ammonia addition (thus chloramination) and before caustic addition. The chlorine residual at time zero was free chlorine residual tested immediately before the ammonia dose. The contact time represents the time after the first ammonia dose was added. With an initial chlorine dose of 2.5 mg/L, the total chlorine residual typically decreased by 1 mg/L in 18 hours (Figure 2-6). Most of the total chlorine degradation occurred in the first three to four hours. More total chlorine loss was observed on June 6th, which was likely a result of accidental localized breakpoint chlorination due to the large water volume, considering most loss occurred in the first hour and total ammonia also decreased.

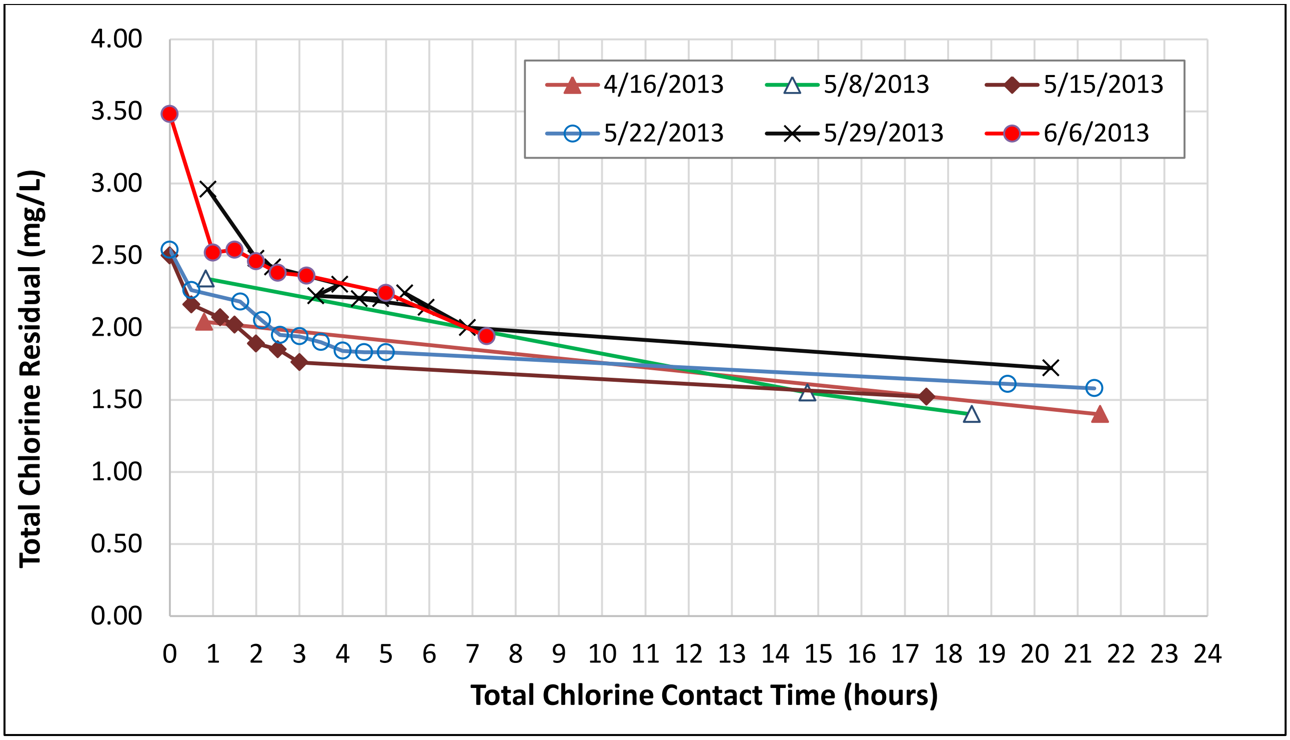

Figure 2-5. Total Chlorine Degradation in Stabilized Desal Water

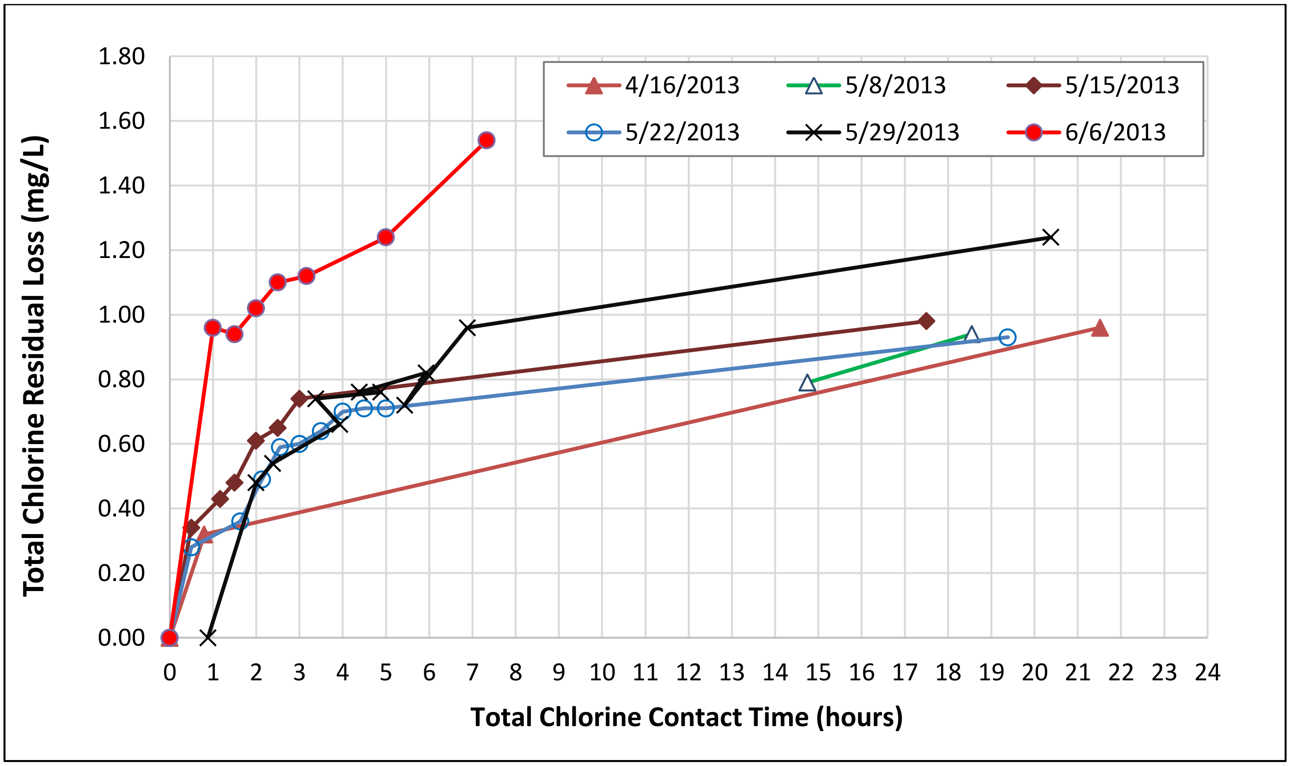

Figure 2-6. Total Chlorine Residual Loss in Stabilized Desal Water

An alternative approach to chloramination was tested to improve chloramines stability. Two new studies[5,6] report chloramines were more stable at a higher pH (e.g., 8.2) in desalinated ocean water. In the alternative approach tested, pH was adjusted to 8.2 ± 0.2 first, followed by a chlorine dose with mixing, then an ammonia dose with mixing. Figure 2-7 and Figure 2-8 illustrate total chlorine degradation and chlorine residual loss, respectively. The chlorine residual at time zero was free chlorine residual tested immediately before the ammonia dose. The contact time represents the time after the first ammonia dose was added, thus chloramination. An initial total chlorine concentration between 3.0 and 3.3 mg/L yielded a chlorine residual of approximately 2.4 mg/L in 18 hours. The higher initial concentration achieved the target of approximately 2.5 mg/L, whereas starting with a 2.5 mg/L dose resulted in less than 2.0 mg/L after the decay period. Average total chlorine residual loss was 0.8 mg/L in 18 hours, which was slightly improved compared to the approach of chloramination followed by pH adjustment. With pH adjustment followed by chloramination, total chlorine degradation occurred mostly in the first 4 to 5 hours after ammonia addition. Afterwards, total chlorine appeared to be relatively stable, as illustrated by the curves in Figure 2-8. In comparison, chloramination prepared by the other approach (chloramination followed by pH adjustment) appeared to be less stable, as the curves in Figure 2-6 indicated.

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[5] Pope, G. and Musullam, H. 2013. Impacts of Chloramine Formation Conditions on DBP Formation and Chloramine Stability in a High-Bromide Source Water. Presented at 2013 AWWA Annual Conference and Exposition.

[6] Erdal, U. and Lozier, J. 2013. Chloramine Stability and DBP Formation in Distribution System Carrying Blended Stream of Desalinated and Treated Surface Waters. Presented at 2013 AWWA Annual Conference and Exposition.

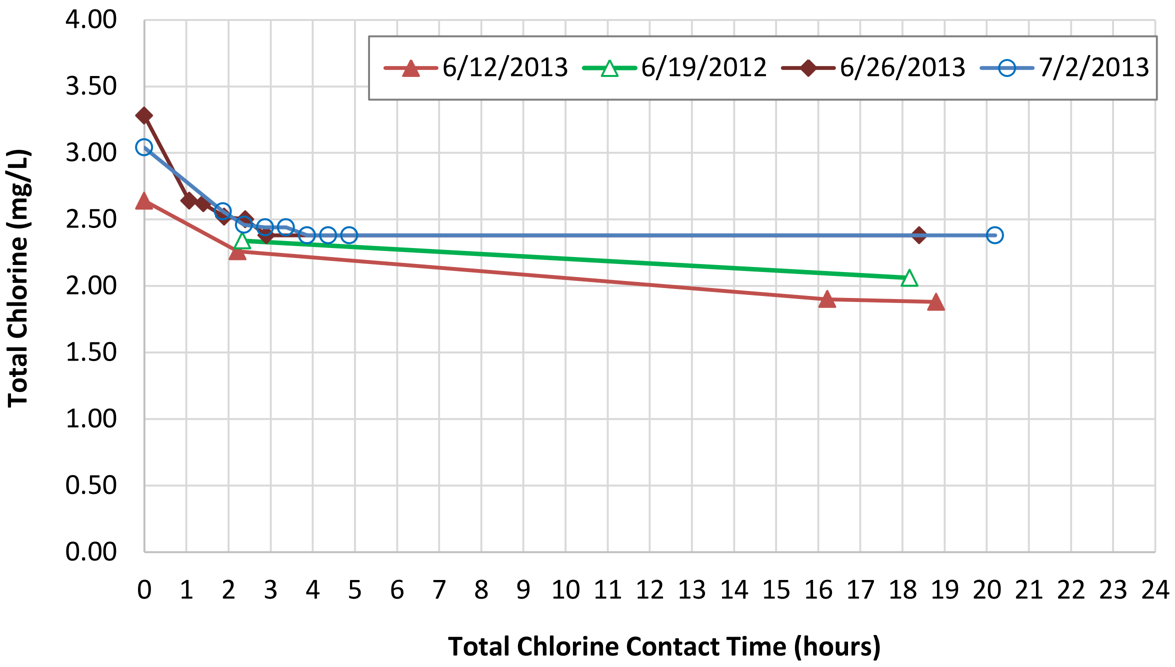

Figure 2-7. Total Chlorine Degradation in pH Adjusted Stabilized Desal Water

On 6/19/2012, the free chlorine residual tested ten minutes before ammonia addition was 2.9 mg/L. Total chlorine was not tested right after ammonia addition.

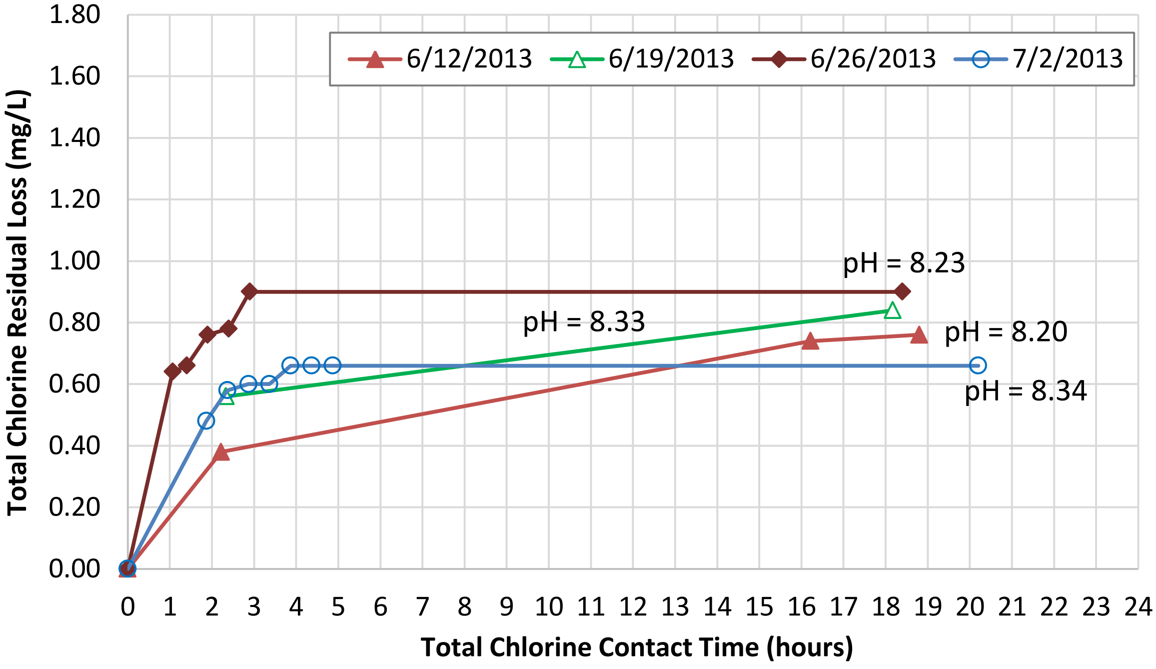

Figure 2-8. Total Chlorine Residual Loss in pH Adjusted Stabilized Desal Water

2.4 Stabilized Desalinated Ocean Water Quality

Stabilized desalinated ocean water quality is summarized in Table 2-4. CCPP and LSI values were both positive during the entire study period. The water quality met the targets selected for the stabilized desalinated ocean water.

Turbidity was elevated during the startup period as the fines in the calcite bed were flushed out. Turbidity was 4.95 NTU in the first week (still below the secondary MCL of 5 NTU), decreasing to 2.77 NTU in the second week and 1.27 NTU by the third week. The cartridge filter initially used was 5 micron, but was changed to 1 micron in the second week. The desalinated ocean water was routed through the cartridge filter during the chemical mixing process to remove calcite fines and lower the turbidity of the chloraminated water in the storage tank. Other water quality parameters, which have no significant impact on water stabilization, are described in Section 3.1.1.

Table 2-4. Stabilized Desalinated Ocean Water Quality

Parameter	Average	Range	Target
Alkalinity (mg/L as $CaCO_3$)	71	65 - 80	65 - 80
Calcium (mg/L as $CaCO_3$)	143	116 - 161	> 65
CCPP (mg/L as $CaCO_3$)	4.0	2.3 – 5.6	>0
LSI	0.5	0.3 – 0.7	>0
pH	8.3	8.1 – 8.4	8.2 ± 0.2
Total Chlorine Residual (mg/L)^	2.4	2.2 – 2.7	2.5
Total Ammonia Residual (mg/L as N)^	0.50	0.38 – 0.56	0.5
Turbidity (NTU)	0.24*	0.08 - 0.76*	Not applicable

^Total chlorine residual and total ammonia residual refer to the final results right before the stabilized desalinated ocean water was used to fill the pipe loop tanks.

*Turbidity results for the initial three weeks of the study were excluded due to calcite carryover to the storage tank for stabilized desalinated ocean water.

2.5 Alternative Stabilization Approach

Bench-scale testing was conducted to evaluate the alternative of using carbon dioxide (CO_2) and lime (calcium hydroxide or $Ca(OH)_2$) for desalinated ocean water stabilization. OWDDF RO permeate from the first and second passes was collected and blended based on a 2:1 ratio on August 29, 2013. First, CO_2 was used to reduce the pH to approximately 5.3, which helped to increase lime solubility in water. Then, a liquid lime dose of 51.7 mg/L as $Ca(OH)_2$ was added, which increased pH to above 9. Finally, CO_2 was added again to reduce water pH to 8.2. Because of control and monitoring challenges, CO_2 was added in two separate doses at bench-scale. Finished water was tested for alkalinity, calcium, pH, and turbidity.

Table 2-5 summarizes the 3 test runs of the bench-scale CO_2 and liquid lime testing. A CO_2 dose of 62 to 63 mg/L was estimated using the Tetra Tech RTW model, based on initial water quality, liquid lime dose and finished pH level at 22 ^oC. A liquid lime dose of 51.7 mg/L as $Ca(OH)_2$ was sufficient to achieve alkalinity and calcium above 65 mg/L as $CaCO_3$. Finished pH was between 8.17 and 8.34. The finished water had positive CCPP and LSI values, in the range of 0.61 – 2.32 mg/L as $CaCO_3$ and 0.10 - 0.91, respectively. Turbidity in CO_2 and lime-treated water was high, ranging from 4.49 to 11.1 NTU in the three test runs. Three filter pore sizes, 5, 1.2 and 0.45 micron were used to remove turbidity. Turbidity was removed to 0.3 NTU or below using a 1.2 micron filter, while slightly lower turbidity was achieved using a 0.45 micron filter.

Table 2-5. Water Quality Stabilized using CO_2 and Lime

Parameter	Run 1	Run 2	Run 3
pH before CO_2 and lime	9.55	9.49	9.42
CO_2 Dose (mg/L)[1]	63	63	62.5
Lime Dose (mg/L as $Ca(OH)_2$)	51.7	51.7	51.7
pH after CO_2, lime without filtration	8.23	8.17	8.24
Turbidity without filtration (NTU)	4.49	11.1	7.87
Turbidity, 5 µm filtered (NTU)	0.98	1.79	0.41
Turbidity, 1.2 µm filtered (NTU)	0.29	0.30	0.18
Turbidity, 0.45 µm filtered (NTU)	0.19	0.09	0.10
Alkalinity, 1.2 µm filtered (mg/L as $CaCO_3$)	67	70	72
Calcium, 1.2 µm filtered (mg/L as $CaCO_3$)	61	68	68
CCPP (mg/L as $CaCO_3$)[2]	2.32	0.61	1.24
LSI[2]	0.26	0.10	0.91

1. CO_2 dose was estimated using the Tetra Tech RTW model, based on initial water quality, liquid lime dose and finished pH level at 22 ^oC. Initial alkalinity and calcium concentrations were assumed to be 2 mg/L as $CaCO_3$. Initial pH, liquid lime dose and finished pH are listed in the table.
2. CCPP and LSI were estimated using the Tetra Tech RTW model, based on the finished alkalinity, calcium, pH listed in the table at 22 ^oC.

An approach of using CO_2 with saturated lime has been applied at many full-scale desalination treatment plants as detailed in the utility survey, although the systems can have operational challenges. Typically, a saturator is used to avoid the high turbidities observed in this testing.

This study focused on testing an alternative approach using calcite with pH adjustment for ease of use at pilot-scale and to gain operational experience with this stabilization technique.

3. Approach

This section documents the approach used for the pilot-scale pipe loop study and the bench-scale study.

3.1 Pilot-Scale Pipe Loop Study

During the pilot-scale pipe loop study, 3 source waters were tested for 3 types of pipe materials and meters for corrosion evaluation. This section describes the test waters, pipe materials, pipe loop configuration and operations, sampling schedule, analytical methods and the study schedule.

3.1.1 Source Waters

Three source waters were tested in the pipe loop study, including stabilized desalinated ocean water, MWD water and groundwater. The generation of stabilized desalinated ocean water is described in Section 2 - Desalinated Ocean Water Stabilization.

MWD water was obtained from a connection at the OWDDF using a hose with a flow totalizer. The hose was typically flushed for more than 20 minutes to ensure the water was from the distribution pipe rather than water that had been stagnant in the Sea Lab piping. Total chlorine, conductivity and pH were analyzed in the field to characterize the water. Conductivity measurements were used to ensure it was primarily MWD water, as the connection is occasionally supplied by a mix of MWD water and groundwater from California Water Service Company Hermosa-Redondo wells. During testing, the nearby Hermosa-Redondo well was not being used and California Water Service Company anticipated that the water delivered to the Sea Lab was all MWD water.

Typical conductivity of MWD water is 500 µS/cm from the Jensen Water Treatment Plant and approximately 800 µS/cm from the Weymouth Water Treatment Plant, while typical groundwater conductivity is much higher (approximately 1,400-1,800 µS/cm). During the study, typical conductivity of the MWD water at the site was 800 µS/cm, which confirmed the water was primarily MWD water and was in agreement with MWD’s water supply for this area during the study period. Total chlorine was approximately 1.8 mg/L, with occasionally lower levels. The MWD water quality tested during the course of this study is summarized in Table 3-1.

Groundwater used in the study was collected from a retail agency within West Basin's service area. In the initial stages of the study, Hazen and Sawyer collaborated with West Basin to identify retail agencies within West Basin's service area that use groundwater as a part of their water supply portfolio. Retail agencies with distribution systems that are likely to receive a mix of groundwater and desalinated ocean water in their potable water distribution systems were identified. The primary conveyance schemes identified in the Master Plan include connection into the West Basin Feeder (West or East Ends), West Coast Feeder, or the Sepulveda Feeder for a larger regional facility. Potential distribution systems likely to receive the desalinated ocean water supply at the West Basin Feeder or West Coast Feeder (depending on the selected conveyance scheme) include Cal Water's Hermosa-Redondo system, the City of Manhattan Beach, the City of El Segundo, and Golden State Water Company's Southwest District (Gardena). Each of these agencies were contacted to assess water quality from groundwater wells, treatment (including disinfection) processes, and piping materials in the distribution system. The West Basin customer agency selected for this study was identified for the following reasons:

- The groundwater represents the most challenging water quality in West Basin's service area, with high levels of bromide, naturally-occurring ammonia, iron, and manganese.
- Unlined cast iron piping remains in service in the distribution system, with significant deposits of iron and manganese.
- The agency had a main replacement program underway, allowing for an ample supply of used pipe that could be harvesting for the project.

To collect groundwater, Hazen and Sawyer field engineers used dedicated 65-gallon tanks to obtain water from a West Basin customer agency groundwater well for the 4-month study.

Table 3-1 provides a summary of water qualities for the 3 source waters, including the stabilized desalinated ocean water, MWD water, and groundwater. MWD water and stabilized desalinated ocean water were similar with respect to the key parameters influencing corrosion, including pH, and calcium, which affect CCPP and LSI corrosion indices. Alkalinity and calcium in groundwater were much higher than the stabilized desalinated ocean water and MWD water. All three waters had positive CCPP and LSI values throughout the study.

Groundwater also contained manganese above the secondary MCL of 50 µg/L is permitted to blend its groundwater with 25% MWD water to dilute the manganese concentrations of the groundwater to below 50 µg/L. Groundwater has higher chloride, much higher bromide and lower sulfate concentrations compared to the other 2 waters. The total dissolved solids (TDS) concentration was much higher in groundwater than the other waters.

Table 3-1. Source Water Quality During the Pipe Loop Study

Constituent	Stabilized Desalinated Ocean Water		MWD Water		Groundwater	
	Average	Range	Average	Range	Average	Range
Alkalinity (mg/L as $CaCO_3$)	71	65 – 80	114	105 – 122	219	202 – 230
Boron (mg/L)	0.51	0.48 – 0.57	0.15	0.14 – 0.15	0.23	0.22 – 0.24
Bromide (mg/L)	0.26	0.22 - 0.32	0.069	0.042 –	0.959	0.880 – 1.100
Calcium (mg/L as $CaCO_3$)	143	116 - 161	147	128 – 171	267	241 – 299
CCPP (mg/L as $CaCO_3$)	4.0	2.3 – 5.6	7.0	5.1 – 11.0	32.8	25.3 – 39.3
Chloride (mg/L)	58	52 - 69	90	83 – 98	294	270 – 300
Chlorine, Total (mg/L)	2.39	2.18 – 2.72	1.83	1.62 – 2.02	N/A	N/A
Conductivity (µS/cm)	529	479 – 584	913	836 – 994	1,561	1,459 – 1,670
Copper (µg/L)	4	1 – 9	5	3 – 12	2.9[1]	1.4 – 6.9[1]
Iron, Total (mg/L)	0.01	0.01 – 0.03	0.01	0.01	0.08	0.03 – 0.09
Lead (µg/L)	0.54	0.3 – 1.3	0.33	0.2 – 1.3	0.23	0.15 – 0.47
LSI	0.5	0.3 – 0.7	0.5	0.4 – 0.8	0.9	0.7 – 1.1
Manganese (µg/L)	4.5[2]	2.6 – 6.3[2]	0.5[2]	0.4 – 0.6[2]	56[1,2]	53 – 62[1,2]
pH	8.3	8.1 – 8.4	8.1	8.0 – 8.3	8.0	7.8 – 8.2
Sulfate (mg/L)	80	68 – 87	176	150 – 200	129	120 – 130
Temperature (°C)	22.2	19.7 – 25.1	21.5	17.4 – 24.5	21.0	19.0 – 24.0
TOC (mg/L)	0.28	0.18 – 0.37	2.48	2.30 – 2.60	2.11	1.97 – 2.20
TDS (mg/L)	N/A	290[3]	N/A	530[3]	N/A	910[3]
Turbidity (NTU)	0.2[4]	0.1 – 0.8[4]	0.2	0.1 – 0.5	0.3	0.2 – 0.5

[1] Calculated based on mass balance of copper or manganese concentrations in uncirculated MWD water and in the uncirculated blend of 25% MWD/75% groundwater for the copper loops from May 30 to August 8, 2013 (after the pipe loop pumps were replaced, as described at the end of Section 3.1.3). For manganese, the sample result (16 µg/L) for June 27, 2013 was excluded as the result was much lower than typical concentration of 40 µg/L in the blend.

[2] Based on the results from May 30 to August 8, 2013 (after the pipe loop pumps were replaced).

[3] Based on one sampling event on July 18, 2013.

[4] The turbidity data from the first three weeks are excluded due to calcite fines during startup.

TOC – Total Organic Carbon

The test waters and blends of waters evaluated in the pipe loop study are listed in Table 3-2. A large number of potential blends may be present in the distribution system when the full-scale desalination plant comes online, so this study was designed to span the range of water qualities potentially present in the distribution system and to investigate whether blending has any unanticipated impacts under worst-case conditions. The test waters represent the range of impacts that varying water qualities may have on the pipe materials. A blend of desalinated ocean water and MWD water (50% each) was tested to determine if the blend results in a water quality that is more corrosive. West Basin's Ocean Water Desalination Program Master Plan assumes that desalinated ocean water from a full-scale facility will be introduced into local distribution systems on the low pressure side of existing turnouts along the MWD West Coast and West Basin Feeders. The West Basin customer agency who participated in this study is permitted by CDPH to use 25% MWD water and 75% groundwater in the system, with the groundwater percentage limited by the blending needed to decrease manganese levels. This proportion of MWD to groundwater was tested, along with the potential replacement of the 25% MWD water with 25% desalinated ocean water that could occur with the introduction of desalinated ocean water at the existing MWD turnouts.

Table 3-2. Test Waters for Pipe Loops

Loop Number	Test Water
1	100% Stabilized Desalinated Ocean Water (100% Desal)
2	100% MWD Water (100% MWD)
3	50% Desalinated Ocean Water and 50% MWD Water (50% Desal/50% MWD)
4	25% MWD Water and 75% Groundwater (25% MWD/75% groundwater)
5	25% Desalinated Ocean Water and 75% Groundwater (25% Desal/75% groundwater)
6	Duplicate Loop*

*Initially 100% MWD water, then switched to evaluate specific trends in various loops.

For the pilot testing, the target total chlorine residual was 2.5 mg/L ± 0.2 mg/L for 100% Desal, 25% MWD/75% Groundwater, 25% Desal/75% Groundwater, 1.8 mg/L ± 0.2 mg/L for 100% MWD water, 2.2 ± 0.2 mg/L for 50% Desal/50% MWD. The target total chlorine residual for MWD water was selected considering the typical chlorine residual observed at the existing MWD turnouts. Desalinated ocean water was prepared and chloraminated as described in Section 2.3. All test waters were filled in the pipe loop tanks. For blended test water, each source water was filled in a tank sequentially (using a totalizer for volume control) and then mixed using a Teflon-coated mixer. Conductivity was measured to ensure the correct blending as desalinated ocean water, MWD water and groundwater had distinctive conductivity levels. Total chlorine residual and total ammonia were tested after the mixing. If the total chlorine residual was below the target level by 0.2 mg/L or more, sodium hypochlorite solution was added to the prepared test water to boost chlorine residual. A Cl_2:NH_3-N ratio of 4.75:1 was targeted, except for blends with groundwater that contained a relatively high level of natural ammonia. For these blends, chloramines were formed using the natural ammonia without breakpoint chlorination to mimic the current treatment at the West Basin customer agency from which groundwater was obtained.

Total chlorine, total ammonia and nitrite were monitored on Day 1, Day 5 and Day 7 for each circulation cycle during the pipe loop test period. In the first month, the total chlorine residual was not boosted while the extent of chlorine degradation was monitored. Starting the beginning of the second month, total chlorine was boosted to the target levels on Day 5 of each cycle. On Day 5, total chlorine and total ammonia in the pipe loop tanks were tested. If total ammonia was below the ammonia target level ± 0.02 mg/L as N (calculated based on the target chlorine residual and Cl: NH_3-N ratio of 4.75:1), ammonia was boosted and tested after mixing. Chlorine was then boosted using sodium hypochlorite. Total chlorine residual was tested after mixing to confirm the target level was achieved. Mixing was performed using an electrical mixer for typically 3 minutes in the tank. Pipe loops operations were continued while chlorine and ammonia monitoring and adjustments were conducted.

3.1.2 Pipe Materials

Pipe materials tested include new cement mortar-lined (CML) steel pipes, unlined cast iron (UCI) pipes harvested from a local distribution system and new copper pipes (CU) with lead-solder joints and harvested brass meters. UCI pipe and brass meters were harvested from a local distribution system. This assortment of pipes and materials represent the different types of materials in the distribution systems that are susceptible to corrosion.

The rationale for the pipe materials selection and harvesting procedures are described in detail in Appendix 1-A.

Table 3-3. Pipe Materials Selection Rational

Material	Source	Rationale
CML Ductile Iron Pipe	New pipe	Cement mortar-lined pipe will reflect water corrosivity toward cement, concrete and asbestos cement pipe. New pipe will be most susceptible to corrosion as the pores are open and no scale has been deposited to protect the mortar lining; evaluation of pitting and cracking will also be possible for the new pipe. MWD's distribution system and West Basin customer agencies have this type of pipe.
UCI Pipe	Harvested from the distribution system	Tuberculated, old iron pipe is susceptible to causing colored water if water is corrosive. New iron pipe is lined, so testing is needed on unlined pipe harvested from the distribution system, as UCI exists in West Basin customer agency systems.
CU Pipe	New pipe	Copper pipe is commonly used in household plumbing. Evaluation of copper corrosion will be possible for new pipe, and copper release from new pipe is expected to present a worst-case leaching scenario if the water is not properly stabilized.
Lead Components, including Lead Solder and Brass Meters	New solder, Harvested brass meters	Lead solder may be present in older homes, although harvesting of household plumbing can be logistically difficult. As a result, newly soldered joints will provide surfaces to test susceptibility of joints to lead release in this study. Harvested brass meters were also be tested to investigate corrosivity of the water with materials in the distribution system, which are expected to have a higher lead content than new brass materials.

3.1.3 Pipe Loop Design and Operations

To evaluate the effects of the desalinated ocean water on the existing distribution system piping and residential copper plumbing, 3 separate pipe loop systems were fabricated, including:

- Six harvested 4-foot lengths of 6-inch diameter UCI distribution pipe
- Six new 8-foot lengths of 4-inch diameter unlined (bare cement) CML steel pipe
- Six ¾-inch lead-soldered copper pipe loops with harvested brass meters

Figure 3-1 shows a process flow diagram of the test loops. Water was continuously recirculated through the UCI and CML pipe loops for 6 days, followed by replacement of the water on the 7th day. The recirculation approach resulted in the accumulation of metals for easier detection of corrosion, and the detention time is typical of distribution system detention times for customer agencies within West Basin's service area.

The new copper pipes with lead solder and harvested brass meters were tested with alternating cycles of 30 minutes of flow through to waste, followed by 11.5 hours of stagnation to represent a diurnal household plumbing flow scenario. Samples were collected after at least 6 hours of stagnation but less than 12 hours to mimic sampling requirements in the Lead and Copper Rule (LCR)[7]. The LCR establishes this stagnation window because previous research has shown that "near-equilibrium" lead concentrations are observed with this strategy[8]. All test water was replaced with uncirculated water once a week, and stored in dedicated tanks for each pipe loop.

At the beginning of each week, all test waters were introduced into 65-gallon pipe tanks for pipe loop testing, with 50 gallons used in the testing of UCI and CML pipes, and 60 gallons used in the copper pipe loops (due to the flow-through operation, with an additional 10 gallons provided to ensure that the pipe would have a consistent flow of water through the end of the testing period). For blended waters, a totalizer was used to monitor the water volumes added to the tanks during the blending operation. A Teflon-coated tank mixer was used to mix the blended water thoroughly (at least 3 minutes).

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[7] http://www.cdph.ca.gov/certlic/drinkingwater/Documents/Lawbook/dwregulations-2012-06-21c.pdf

[8] American Water Works Association Research Foundation. 1996. Internal Corrosion of Water Distribution Systems. 2nd Edition.

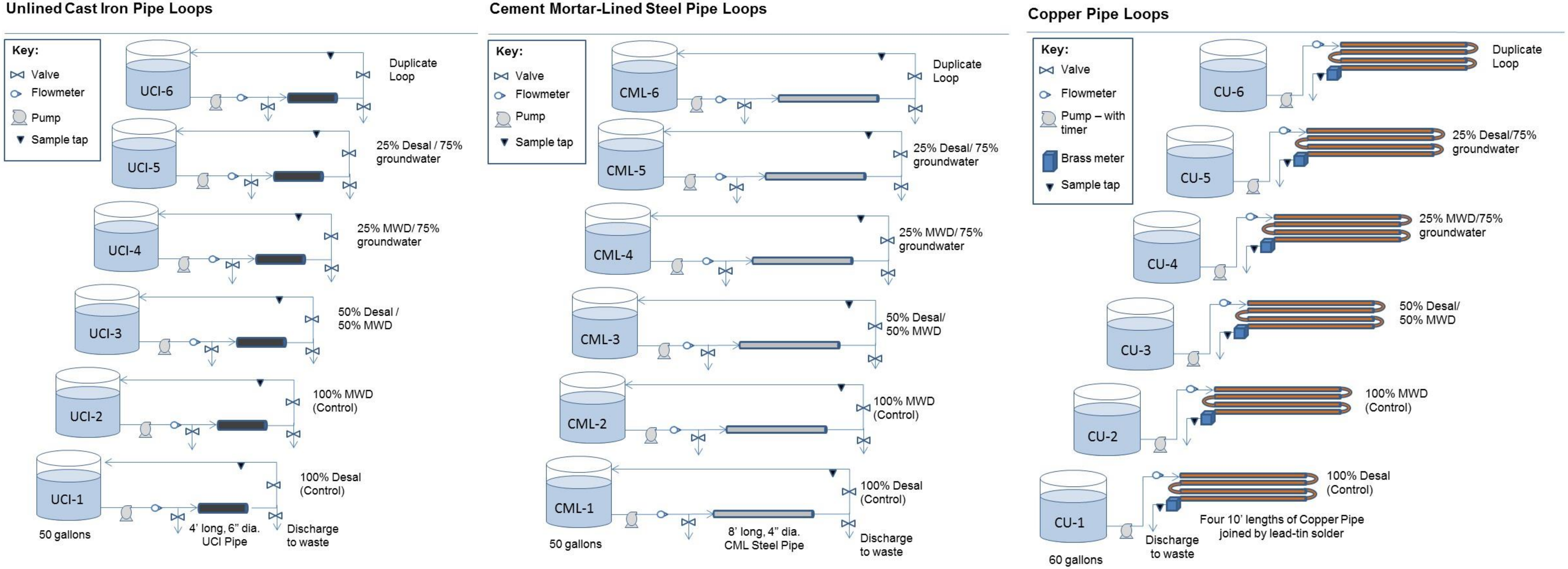

Figure 3-1. Integration Study Pipe Loops

Note: Water was continuously circulated through the UCI and CML pipe loops for 6 days, followed by replacement of the water on the 7th day. Copper pipe loops were operated in an alternating cycle of flow-through to waste for 0.5 hours followed by 11.5 hours of stagnation. Additional water was available in the copper loops to support the flow-through operation.

Unlined Cast Iron Pipe

UCI pipes were harvested from the distribution system on March 21, 2013. Selection of materials and detailed harvesting procedures are provided in Appendix 1-A. In summary, UCI pipe was harvested by Vido Samarzich Inc. (Alta Loma, California). The contractor took measurements of the pipe outer diameter in advance of the pipe harvesting to ensure that the correct fittings were available during the harvesting to protect the pipe during transport. The fittings for each pipe end were comprised of a mechanical joint with restraining gland and a blind flange that was tapped and threaded to receive 1-inch PVC pipe. Exposed fitting surfaces came coated with bituminous tar lining, as is typical for use in drinking water distribution systems.

Hazen and Sawyer staff ensured that the pipes were properly sealed during pipe harvesting to contain existing moisture in the pipes during the time of removal. The contractor carefully delivered the harvested pipes to the site to minimize potential damage to the existing tuberculation. The pipes were placed onto the pipe loop test racks and uncirculated MWD water was used to fill the pipes to keep the pipe tuberculation wet on the same day as harvesting. The pipes were refilled again with uncirculated MWD water on April 3, 2013. MWD water was circulated in the harvested UCI pipe from April 4th to 11th. During this period, the UCI pipe loop tanks were refilled with uncirculated MWD water three times before the study began.

The pipe loops were constructed on racks designed to fit into the available space, provide access for staff activities onsite, and to avoid disturbance of the pipe during testing. Figure 3-2 and Figure 3-3 show a schematic of the pipe loops and photos of the UCI pipe loops and the tuberculation inside a pipe segment. The recirculation pumps were placed on a shelf located at the front of the rack. New 65- gallon capacity, black, food-grade polyethylene tanks were placed behind the rack. One-inch Schedule 40 piping was used to connect piping throughout the system and provide the return from the pipe to the recirculation tank. All glue was NSF-certified for use in potable water systems.

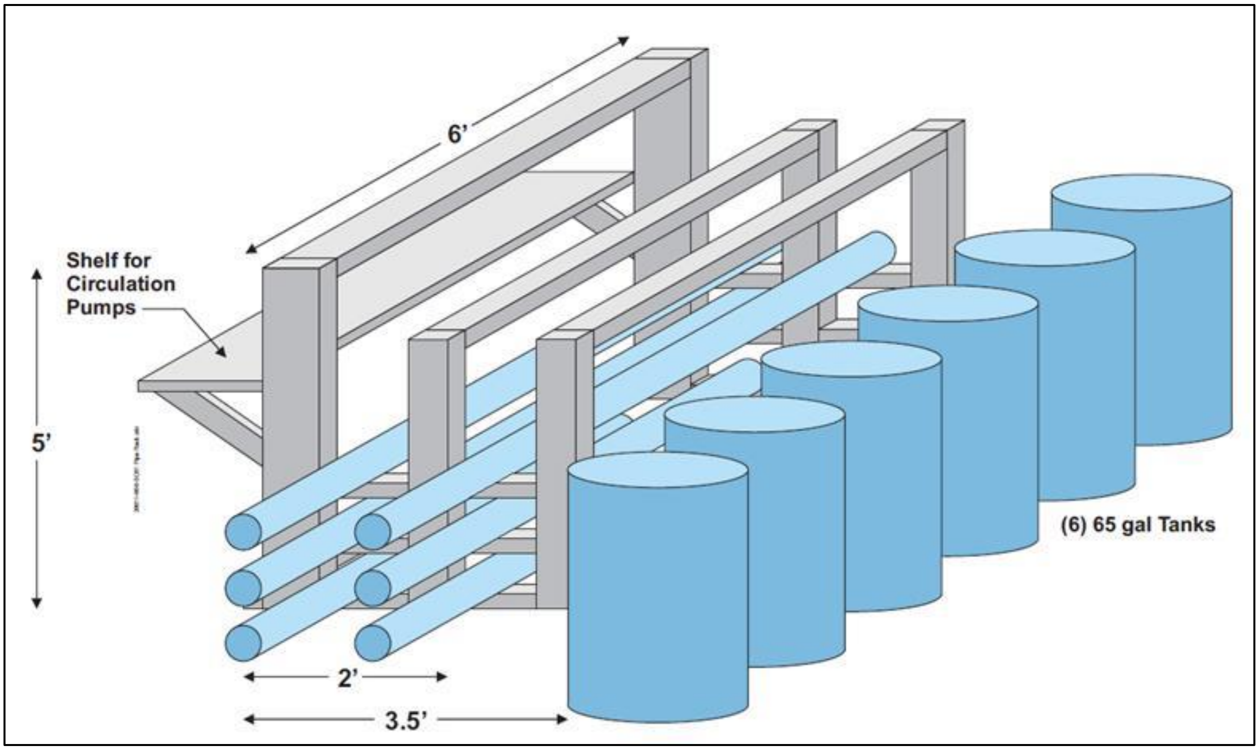

Figure 3-2. Pipe Loop Schematic

Figure 3-3. UCI Pipe Loops (top) and Cross Area (bottom) of UCI Pipe

A process flow diagram of the UCI pipe loops is shown in Figure 3-1. As shown in the process flow diagram, one pump was used to recirculate water through each pipe loop. Each UCI pipe loop was sampled from a sample tap on the PVC recirculation line after 6 days of recirculation (on Day 7). The isolation valve was closed after sampling to keep water in the pipe during change-out of the recirculation tank water, and the return PVC line was built at an elevation greater than the tank to avoid draining the tank during the change-out. The volume of water held in the pipe was sent to waste by measuring the quantity of water discharged, then the valve to waste was closed and the water recirculated for the next 6 days.

Table 3-4 provides design criteria for the UCI pipe loops. UCI pipe loops were operated continuously at a velocity of approximately 0.05 feet per second (ft/s), corresponding to a recirculation flow rate of 4.0 gpm. The selected velocity corresponds to the range of average day demand for the pipelines[9] and was not expected to induce physical erosion of pipe deposits.

Table 3-4. UCI Pipe Loop Design Criteria

Design Parameter	Design Value
Pipe Diameter	6 in.
Length	4 ft.
PVC Diameter for Return and Connecting Pipe	1 in.
Velocity	0.045 ft/s
Flow Rate	4.0 gpm
Volume of UCI Pipe	0.7 ft^3
Volume of PVC	0.04 ft^3
Total Volume in Pipe	6 gal
Recirculation Tank (initially filled at 50 gallons)	44 gal
Pipe Surface Area to Water Volume	0.11 sf surface area/ cf volume

Cement Mortar-Lined Steel Iron Pipe

Ferguson Waterworks, a local supplier, delivered uncoated CML steel pipe with bituminous tar-coated fittings to the pipe loop test location. The CML pipe was fabricated in accordance with AWWA C205 specifications. The CML pipes were stored on site with other materials until ready to be placed onto the test rack and were protected from the elements by covering the open

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[9] Hydraulic modeling of average day demand for the West Basin customer agency, showing a majority of pipes' average day demands were 0.00 – 0.25 ft/s.

ends. The CML pipes were not exposed to water until April 11, 2013, when the test waters were introduced to all loops. No pretreatment of the pipes was performed (e.g., acid addition) prior to use.

The construction methods for CML pipe loops were similar to the methods described for the UCI pipe loops. Figure 3-4 shows the layout of the CML pipe loop test rack. The process flow diagram for the CML pipe loops is illustrated in Figure 3-1. Operational conditions for the CML pipe loops are shown in Table 3-5. Velocities through the CML pipe were approximately 0.1 ft/s. The CML pipe loops were designed with the same pipe surface area to water volume ratio as the UCI pipe loops, which was a result of the longer lengths of smaller diameter CML pipe compared with UCI pipe.

Table 3-5. CML Steel Pipe Loop Design Criteria

Design Parameter	Design Value
Pipe Diameter	4 in.
Length	8 ft.
PVC Diameter for Return and Connecting Pipe	1 in.
Velocity	0.1 ft/s
Flow Rate	3.9 gpm
Volume of CML Pipe	0.7 ft^3
Volume of PVC	0.04 ft^3
Total Volume in Pipe	6 gal
Recirculation Tank (initially filled at 50 gallons)	44 gal
Pipe Surface Area to Water Volume	0.11 sf surface area/ cf volume

Figure 3-4. CML Pipe Loops

Copper Pipe with Lead Solder and Brass Meters

For each copper pipe loop, four 40-foot lengths of ¾-inch diameter copper pipe (type "L," representative of typical materials installed in Southern California households) were joined with 50:50 lead-tin solder at 9 of the 13 total joints (the remainder being lead-free solder to provide a typical number of soldered joints per length in a home). Joints were made neatly to represent a standard household plumbing installation. Forty feet of copper pipe was selected to hold enough water during the stagnant period to provide the necessary volumes for sampling. Harvested brass meters were extracted from the distribution system and placed at the end of the copper pipe length on each test loop. Brass meters of similar age, gallons served and manufacturer were selected from an excess that were harvested. Figure 3-5 shows the copper loops with lead solder and brass meters.

Figure 3-5. CU Pipe Loops (top) and Brass Meters (bottom)

The copper pipe loops were equipped with a timer to operate intermittently with flow through to waste for 30 minutes, followed by stagnation for 11.5 hours. This cycle was repeated throughout the 4 month testing period. To ensure consistency, samples were taken from each pipe loop after 8 hours of stagnation. Sampling 6 loops usually required 30 minutes. A velocity of 0.1 ft/s (corresponding to a flow of 0.14 gpm) for the flow through period of 30 minutes was selected due to constraints on the quantities of water available in the pipe loop tanks for the 6-day testing period. The period of time for flushing has been shown to be less critical with respect to the potential for copper and lead leaching compared with the stagnation period, as described by Lagos et al.[10] and indicated by the stagnant sampling regime of LCR.

Figure 3-1 provides a process flow diagram for the copper pipe loops and Table 3-6 details the design criteria. Sixty five gallon tanks were filled with 60 gallons of water to provide the necessary volume of water for pipe loop operation during the 6-day period. At 8 hours after the beginning of a stagnation period, discrete samples were collected from the brass meter at the end of each loop. The remaining water contained in the copper pipe loops was collected into one container to provide a composite sample, which was then sampled for lead and other constituents at the end of the stagnation period. Additional details are provided in Section 3.1.4 Testing Approach.

Table 3-6. Copper Pipe Loops Design Criteria

Design Parameter	Design Value
Pipe Diameter	¾ inch
Length	40 ft.
Velocity	0.1 ft/s
Flow Rate	0.14 gpm
Volume of Pipe	0.12 ft^3
Flowing Period	30 minutes twice per day
Total Volume in Pipe	0.92 gal
Total Volume in Pipe	3.47 L
Total Volume of Water Flowing in 1 Day	8.3 gal
Quantity of Water Flow through Pipe in 6 Days	50 gal
Quantity of Water Prepared in the Tank	60 gal

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[10] Lagos, G.E., Cuadrado, C.A., and M.V. Letelier. 2001. Aging of Copper Pipes by Drinking Water. *Journal of AWWA*, 93:11:94-103.

Duplicate Pipe Loops

For each pipe material, a duplicate pipe loop was included to facilitate further investigation where warranted by variability in the test results. For example, higher metal releases might occur in one loop compared with others due to variability in the tuberculation rather than as a result of the different water qualities. All duplicate pipe loops were initially operated with 100% MWD water, since MWD water was not expected to cause corrosion, until the data results suggested a benefit to using the duplicate loop to explore trends. The UCI and CML duplicate loops were both switched to 100% Desal on June 6, 2013, to compare test results with those from Loop 1 (100% Desal). The CU duplicate loop was switched to 25% MWD/75% groundwater on August 8, 2013, to compare test results with those from Loop 4 (25% MWD/75% groundwater).

Pump Replacements

The pumps used to circulate water through the test loops were initially bronze gear pumps, which were later discovered to contain lead at levels sufficient to be observed in the water during pipe loop testing. The CU pipe loop pumps were replaced with pumps made of grade 316 stainless steel by May 30, 2013. The UCI and CML pumps were replaced with the same stainless steel pumps by June 13 (except UCI-6 by June 26 due to pump availability).

3.1.4 Testing Approach

This section describes the testing approach, water quality parameters of interest, sampling locations and sampling frequency during the 4-month pipe loop study. Water quality parameters were selected to investigate the following characteristics of the test waters:

1. Stability (measured using CCPP and LSI)
2. Corrosivity (both indicators of corrosion and parameters influencing corrosion)
3. Disinfectant concentrations (and parameters impacting disinfectant residual stability)
4. Disinfection byproduct concentrations
5. Aesthetics (taste and odor)
6. Performance of upstream RO process (i.e., boron rejection)

Sampling Locations

Stabilized desalinated ocean water, MWD water and groundwater sources were monitored over the course of the study for variability in the baseline water quality. Once a week, the pipe loop tanks were filled using the 3 source waters based on blends described in Table 3-2 and as illustrated in the process flow diagram in Figure 3-1. Water in the pipe loop tanks were sampled 3 times a week: once the tanks were freshly filled (Day 1), once in the middle of the week (Day 5) and once at the end of the week (Day 7). The uncirculated water served to establish the baseline water quality for the weekly testing, and also ensured proper blending in the pipe loop tanks where required. Samples from the middle of the week were monitored to measure chloramine degradation. Samples from the end of week were monitored for corrosion products.

Table 3-7 summarizes the sampling locations and rationale for selecting the locations.

Table 3-7. Sampling Locations and Rationale

Sampling Location Category	Testing Purpose
Source Waters: Stabilized desalinated ocean water, MWD water, and groundwater	Monitor source water qualities each week
Pipe Loop Tanks – Day 1 Uncirculated Water (All Pipe Loops)	Provide baseline water qualities for pipe loop testing comparison with water recirculated for 6 days; ensure proper blending in loops with blended water
Pipe Loop Tanks – Day 5 Recirculated Water (All Pipe Loops)	Monitor chloramine degradation and boost chloramines residual starting the second month
Pipe Loop Tanks - Day 7 Recirculated Water (UCI and CML Pipe Loops)	Monitor metal releases accumulated over the week from UCI or CML pipes
First Flush of Stagnant Water – Day 7 (CU Pipe Loops Only)	Monitor metal releases after 8 hours of stagnation with copper pipe and brass meters

UCI – Unlined cast iron pipe; CML – Cement mortar-lined steel pipe; CU – Copper pipe with lead solder and brass meters

Stabilized desalinated ocean water was sampled from the tap at the bottom of the 500-gallon tank (shown in Figure 2-2). MWD water was sampled from a water line provided from the Cal Water Hermosa-Redondo system at the OWDDF. Groundwater was sampled from one of the 65-gallon tanks that were used for transporting groundwater to the pilot site. Groundwater samples were drawn from the top of the tanks using a hand pump since these tanks were for transit of water and were not connected to the pipe loops.

Pipe loop tanks were sampled from the top of the tanks on Day 1 (prior to introduction of water into the loops) and from the sample tap (Figure 3-3 and Figure 3-4) on Days 5 and 7. For the copper pipe loops only, stagnant water was collected from the sample tap next to the brass meter (Figure 3-5) at the end of the stagnation period on Day 7. First, an initial 225 mL of water was measured and discarded before the first-flush sample as this was the volume in contact with the pipe between the brass meter and the sample tap. The volume of interest was the next 250 mL of first-flush water that had been in contact with the brass meter during the stagnation period. The remaining water held in the copper pipe was then collected as a composite sample and analyzed for lead, copper and zinc.

Testing Parameters and Frequency

Table 3-8 through Table 3-11 summarize the water quality parameters and testing frequencies for the field and lab analyses. The field and lab analyses were conducted twice a week (initial and final) to characterize the water qualities from the pipe loops, with the exception of chloride, sulfate and total organic carbon (TOC). Chloride, sulfate, TOC, boron and bromide concentrations were not expected to change within the pipe loops, and therefore were analyzed once a month in the uncirculated water to characterize the baseline water quality.

MWD conducted bench-scale testing to explore DBP formation including trihalomethanes (THMs), haloacetic acids (HAA9), iodinated THMs, iodinated HAAs, and NDMA (Appendix 2). Based on the preliminary results from the MWD bench-scale testing, samples were collected from the UCI and CML pipe loops to evaluate DBPs in the pilot testing. In addition to DBPs, one set of samples was collected for taste and odor analysis by Hazen and Sawyer's Flavor Profile Analysis (FPA) panel. One set of HPC samples were also collected for the UCI, CML and CU pipe loops to characterize the biological growth in the pipe loops.

Table 3-8. Field Sample Analysis Frequency for All Pipe Loops

	Unblended Source Waters			Pipe Loop Tanks (18 loops)			First Flush of Stagnant Water
Analyte	**Stabilized Desalinated Ocean Water**	**MWD Water***	**Ground-water**	**Day 1 – Uncircul-ated Water**	**Day 5 – Recirculated Water (All Pipe Loops)**	**Day 7 – Recirculated Water (UCI and CML Pipe Loops)**	**Day 7 - (CU Pipe Loops Only)**
Alkalinity, Total	1/W	1/W	1/W	1/W	-	1/W	1/W
Ammonia, Total	1/W	1/W	1/W	1/W	1/W	1/W	1/W
Calcium^	1/W	1/W	1/W	-	-	-	-
Chlorine, Total	1/W	1/W	1/W	1/W	1/W	1/W	1/W
Color, Apparent[&]	1/W	1/W	1/W	1/W	-	1/W	1/W
Conductivity	1/W	1/W	1/W	1/W	-	1/W	1/W
Dissolved Oxygen	1/W	1/W	1/W	1/W	-	1/W	1/W
Nitrite	1/W	1/W	1/W	1/W	1/W	1/W	1/W
ORP	1/W	1/W	1/W	1/W	-	1/W	1/W
pH/Temperature	1/W	1/W	1/W	1/W	-	1/W	1/W
Turbidity	1/W	1/W	1/W	1/W	-	1/W	1/W

1/W – Once per week; ORP –Oxidation Reduction Potential

* MWD water for bench testing was from the WB-4 turnout; MWD water for pilot testing was water available at the Redondo Beach Sea Lab and may have included a minor contribution from well water.

[&] Apparent color was added to the field analysis since 7/17/13.

Table 3-9 through 3-11 summarize the sample collection frequency for the laboratory analyses performed on each of the test loops. In addition, one set of bromide samples was collected weekly on the desalinated ocean water and groundwater prior to chloramination. Chloride and sulfate were analyzed for chloraminated stabilized desalinated ocean water, MWD and groundwater on a weekly basis starting the third week (April 25, 2013).

Table 3-9. Laboratory Sample Analysis Frequency for Unlined Cast Iron Pipe Loops

Analyte	Raw Source Waters	Day 1 - Uncirculated Water in Pipe Loop Tanks*	Day 7 - Recirculated Water in Pipe Loop Tanks
Iron	-	1/W	1/W
Manganese	-	1/W	1/W
Boron	-	1/M	-
Bromide	1/W≠	1/W	-
Calcium	1/W&	1/W	1/W
Chloride	1/W&	1/M	-
Sulfate	1/W&	1/M	-
TOC	-	1/M	-
TTHM	-	Once^	Once^
HAA5	-	Once^	Once^
HPC	-	Once^	Once^
Taste and Odor	-	Once^	Once^
NDMA	-	Once^	Once^

*A single set of samples taken from the uncirculated water was analyzed to establish the baseline water quality for all three groups of pipe loops (UCI, CML, and CU).

≠ Samples collected prior to chloramination for desalinated ocean water (post-calcite, pre-chloramination) and groundwater (pre-chloramination).

&Samples collected post-chloramination for desalinated ocean water (post-calcite, post-chloramination), MWD and groundwater (pre-chloramination).

^Once during the pipe loop study, collected on the same day (TTHM, HAA5, NDMA, and taste and odor for Loops 1 to 5; HPC for Loops 1 to 6).

Table 3-10. Laboratory Sample Analysis Frequency for Cement Mortar Lined Steel Pipe Loops

Analyte	Day 1 – Uncirculated Water in Pipe Loop Tanks*	Day 7 - Recirculated Water in Pipe Loop Tanks
Aluminum	1/W	1/W
Iron	1/W	1/W
Manganese	1/W	1/W (only CML-4 and CML-5)&
Bromide	1/W	-
Boron	1/M	-
Calcium	1/W	1/W
Chloride	1/M	-
Sulfate	1/M	-
TOC	1/M	-

Analyte	Day 1 – Uncirculated Water in Pipe Loop Tanks*	Day 7 - Recirculated Water in Pipe Loop Tanks
TTHM	Once^	Once^
HAA5	Once^	Once^
HPC	Once^	Once^
Taste and Odor	Once^	Once^
NDMA	Once^	Once^

* A single set of samples taken from the uncirculated water was analyzed to establish the baseline water quality for all three groups of pipe loops (UCI, CML, and CU).

^ Once during the pipe loop study, collected on the same day (TTHM, HAA5 for Loops 1 to 5; HPC for Loops 1 to 6).

& Manganese samples were only taken from the pipe loops containing blends of groundwater with high naturally-occurring manganese concentrations (CML-4 and CML-5).

Table 3-11. Laboratory Sample Analysis Frequency for Copper Pipe Loops

Analyte	Day 1 - Uncirculated Water in Pipe Loop Tanks*	Day 7 - Stagnant Water from Pipe Loops
Calcium	1/W	1/W#
Copper	1/W	1/W#
Lead	1/W	1/W#
Zinc	1/W	1/W#
Bromide	1/W	
Boron	1/M	-
Chloride	1/M	-
Sulfate	1/M	-
TOC	1/M	-
TTHM	-	-
HAA5	-	-
HPC	Once^	Once^
Taste and Odor	Once^	Once^
NDMA	-	-

* A single set of samples taken from the uncirculated water was analyzed to establish the baseline water quality for all three groups of pipe loops (UCI, CML, and CU).

Samples for calcium, lead, copper, and zinc taken from both the brass meter and the remainder of the water contained the within the copper pipe.

^Once during the pipe loop study, collected on the same day from one loop in each set for Loops 1 to 6.

3.1.5 Analytical Methods

The field and lab analytical methods used in the pipe loop study are summarized in Table 3-12 and Table 3-13, respectively. WECK Laboratories (City of Industry, CA) was the contract laboratory for all samples in this study except the TTHM, HAA5, NDMA and HPC samples, which were analyzed by Eurofins Eaton Analytical (Monrovia, CA) due to a lower cost for these tests. Both laboratories are California Accredited certified by the Environmental Laboratory Accreditation Program (ELAP). Taste and odor samples were analyzed by Hazen and Sawyer trained FPA panelists (Los Angeles, CA).

Table 3-12. Field Analytical Methods

Analyte	Analytical Method / Instrument	Sample Volume Required (mL)	Method Reporting Limit
Alkalinity	Hach 8203 (Digital Titration)	100	10 mg/L as $CaCO_3$
Ammonia, Total	Hach 8155 (Salicylate Method) / DR-890 colorimeter	10	0.02 mg/L as N
Calcium	Hach 8204 (Digital Titration)	100	10 mg/L as $CaCO_3$
Chlorine, Total	Hach 8167 (DPD Method) / DR-890 colorimeter	10	0.02 mg/L
Conductivity	SM 2510B (Conductance) / DO610: ExStik® II DO/pH/Conductivity Kit	30	N/A
Dissolved Oxygen	DO Probe / DO610: ExStik® II DO/pH/Conductivity Kit	100	0.1 mg/L
ORP	ORP Probe / RE300: ExStik® ORP Meter	30	-2000 mV
Nitrite	Hach 8507 (Diazotization Method)	10	0.005 mg/L as N
pH/Temperature	SM 2550 (Thermometric)/ SM 4500H-B (Electrometric) DO610: ExStik® II DO/pH/Conductivity Kit	30	N/A
Turbidity	SM 2130B (Nephelometric) / Hach 2100Q	30	0.02 NTU

N/A – Not Applicable

Table 3-13. Laboratory Analytical Methods

Analyte	Analytical Method	Sample Volume (mL)	Preservatives	Method Reporting Limit	Method Detection Limit	Holding Time (days)	California MCL	California SMCL (or Notification Level*)
Aluminum	EPA 200.8	250	HNO_3	5.0 µg/L	2.1 µg/L	180	1 mg/L	0.2 mg/L
Copper	EPA 200.8	250	HNO_3	0.5 µg/L	0.27 µg/L	180	1.3 mg/L^	1.0 mg/L
Calcium	EPA 200.7	250	HNO_3	0.1 mg/L	0.016 mg/L	180	N/A	N/A
Lead	EPA 200.8	250	HNO_3	0.20 µg/L	0.035 µg/L	185	0.015 mg/L^	N/A
Iron	EPA 200.7	250	HNO_3	0.010 mg/L	0.0011 mg/L	180	N/A	0.3 mg/L
Manganese	EPA 200.8	100	HNO_3	0.2 µg/L	0.15 µg/L	180	N/A	50 µg/L
Zinc	EPA 200.8	100	HNO_3	5 µg/L	1.1 µg/L	180	N/A	5 mg/L
Boron	EPA 200.8	250	HNO_3	1.0 µg/L	0.28 µg/L	180	N/A	1 mg/L*
Bromide	EPA 300.1	250	None	10 µg/L	1.7 µg/L	28	N/A	N/A
Chloride	EPA 300.0	250	None	0.5 mg/L	0.10 mg/L	28	N/A	250 mg/L
Sulfate	EPA 300.0	250	None	0.50 mg/L	0.10 mg/L	28	N/A	250 mg/L
TOC	SM 5310B	80	HCl	0.10 mg/L	0.016 mg/L	28	N/A	N/A
TTHM	EPA 551.1	120	$Na_2S_2O_3$	0.5 µg/L	N/A	14	80 µg/L	N/A
HAA5	SM 6251B	250	NH_4Cl	1.0 µg/L	0.41 µg/L	14	60 µg/L	N/A
Taste & Odor	FPA (SM 2170)	500	None	N/A	N/A	1	N/A	N/A
NDMA	EPA 521	1000	$Na_2S_2O_3$	0.002 µg/L	0.00050 µg/L	7	N/A	0.010 µg/L*
HPC	SM 9215B	125	$Na_2S_2O_3$	1 CFU/mL	1 CFU/mL	1	N/A	N/A

N/A – Not Applicable
SMCL – Secondary MCL
^Action level under the Lead and Copper Rule.
*Notification level

Table 3-14 lists the sample codes used during the pipe loop study. Each pilot-testing loop and sampling point was assigned a code that represented relevant sampling information. Samples collected from the stabilization skid were labeled "Desal." Samples collected from the MWD connection were coded as "MWD." Groundwater samples collected from the 65-gallon tanks for groundwater transportation were coded as "GW." The sampling date and time were recorded for each sample collected.

Table 3-14. Sampling Codes for Laboratory Samples

Source Water	Code		
Stabilized Desalinated Ocean Water	Desal-1 (Raw water) Desal-2 (Raw water after sulfuric acid addition) Desal-3 (Raw water after calcite, before bypass) Desal-4 (Raw water after calcite, after bypass) Desal-5 (Water entering stabilization tank) Desal-6 (Water leaving stabilization tank fully adjusted)		
MWD Water	MWD		
Groundwater	GW (before chloramines are added)		
Pipe Loop	**Code for UCI Pipe Loops**	**Code for CML Pipe Loops**	**Code for CU Pipe Loops**
100% Stabilized Desalinated Ocean Water	UCI-1	CML-1	CU-1m, CU-1p
100% MWD Water	UCI-2	CML-2	CU-2m, CU-2p
50% Desalinated Ocean Water and 50% MWD Water	UCI-3	CML-3	CU-3m, CU-3p
25% MWD Water and 75% Groundwater	UCI-4	CML-4	CU-4m, CU-4p
25% Desalinated Ocean Water and 75% Groundwater	UCI-5	CML-5	CU-5m, CU-5p
Duplicate	UCI-6	CML-6	CU-6m, CU-6p

- "F" added for samples collected on Day 1 after filling of tank, e.g. UCI-1-F.
- "D" added for samples collected on Day 5 after recirculation for a check of disinfectant residual, e.g., UCI-1-D.
- "R" added to represent samples collected on Day 7 after recirculation, e.g., UCI-1-R.
- "m" refers to water collected first from the water stored within the brass meter. "p" refers to the subsequent flush of water from the copper pipe.

Three types of samples were added for quality assurance/quality control (QA/QC). Duplicate samples were used to sample representativeness and analytical precision (5% of all samples sent to the laboratory and performed in the field). Field blank samples were used to detect potential contamination during sample collection and preservation (5% of all samples). Matrix spike samples were used by the laboratories to assess the accuracy of laboratory procedures in at least 5% of the samples. Field measurements were tested for accuracy by calibration checks of equipment; for precision by duplicate analyses of parameters; and for any contamination that may occur during sample handling and transfer by analyzing blanks and collecting replicate samples. More details of QA/QC are provided in Appendix 1.

3.1.6 Schedule

Table 3-15 shows the pipe loop study schedule as executed. The study was conducted for a period of 4 months. A period of less than 2 months was anticipated for stabilization with weekly flushing of the pipes after pipe harvesting based on previous studies of a similar nature.[11,12] The remaining 2 months allowed for collection of assessment of potential corrosion impacts of the water sources.

Table 3-15. Pipe Loop Study Schedule

Period or Date	Activities
March 2013	Site preparation
March 21, 2013	UCI pipes harvesting
March 21 – April 10, 2013	Desalinated ocean water stabilization
April 11, 2013	Pipe loop testing startup (Day 1 of Week 1)
August 14, 2013	Pipe loop testing complete

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[11] Blute, K.N., McGuire, M.J., West, N., Voutchkov, N., Maclaggan, P. and Reich, K., 2008. “Integration of Desalinated Seawater into a Distribution System”. *J. AWWA*, 100:9:117.

[12] Zhang, Y., Tseng, T.J., Andrews-Tate, C., Cheng, R.C., and Wattier, K. 2012. “Pilot-Scale Evaluation of Blending Desalinated Seawater into a Distribution System”, *J. AWWA*, 104:7:43.

3.2 Bench-Scale Study

Bench-scale testing was conducted by MWD using simulated distribution system (SDS) methods to evaluate chlorine stability and DBP formation under controlled laboratory conditions. Water tested at the bench-scale included stabilized desalinated ocean water, blends of Desal with MWD water and/or groundwater, and MWD water. In addition to these water sources, several other variables were tested for Desal water and MWD water, including temperature (10 and 25 ^{o}C), pH (8.2 and 8.6), and bromide concentrations (0.3 and 0.5 mg/L). The test matrix is summarized in

The detailed study approach and findings are documented in Appendix 2.

Table 3-16.

The detailed study approach and findings are documented in Appendix 2.

Table 3-16. Bench-Scale Test and Sampling Matrix

Test Number	Test Conditions				Sampling Matrix	
	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) Total Chlorine* Total Ammonia* Free Ammonia ($t_{initial}$ & t_{final} only) Nitrite ($t_{initial}$ & t_{final} only)	THMs (3 and 7 days) HAA9 (3 & 7 days) Iodo-THMs (7 days) Iodo-HAAs (7 days) Nitrosamines (7 days)
1b				0/100/0/0		
1c				50/50/0/0		
1d				0/25/75/0		
1e				25/0/75/0		
1f				0/25/0/75		
1g				25/0/0/75		
1h				50/25/25/0 ł		
1i				50/25/0/25 ł		
1j				100/0/0/0 ł		
2a	0.3	8.6	25	100/0/0/0	pH ($t_{initial}$ & t_{final} only) Total Chlorine* Total Ammonia* Free Ammonia ($t_{initial}$ & t_{final} only) Nitrite ($t_{initial}$ & t_{final} only)	THMs (3 and 7 days) HAA9 (3 & 7 days)
2b				0/100/0/0		
2c				50/50/0/0		
2d				25/0/75/0		
2e				25/0/0/75		
3a	0.3	8.2	10	100/0/0/0	pH ($t_{initial}$ & t_{final} only) Total Chlorine* Total Ammonia* Free Ammonia ($t_{initial}$ & t_{final} only) Nitrite ($t_{initial}$ & t_{final} only)	
3b				0/100/0/0		
3c				50/50/0/0		
3d				25/0/75/0		
3e				25/0/0/75		
4a	0.3	8.6	10	100/0/0/0	pH ($t_{initial}$ & t_{final} only) Total Chlorine* Total Ammonia* Free Ammonia ($t_{initial}$ & t_{final} only) Nitrite ($t_{initial}$ & t_{final} only)	
4b				0/100/0/0		
4c				50/50/0/0		
4d				25/0/75/0		
4e				25/0/0/75		
5a	0.5	8.2	25	100/0/0/0	pH ($t_{initial}$ & t_{final} only) Total Chlorine* Total Ammonia* Free Ammonia ($t_{initial}$ & t_{final} only) Nitrite ($t_{initial}$ & t_{final} only)	THMs (3 and 7 days) HAA9 (3 & 7 days) Iodo-THMs (7 days) Iodo-HAAs (7 days) Nitrosamines (7 days)
5b				0/100/0/0		
5c				50/50/0/0		
5d				25/0/75/0		
5e				25/0/0/75		

ł Phase I 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.

GWbp = Breakpoint chlorinated groundwater

4. Results

This section summarizes the results for the pilot-scale pipe loop study. All references to Desal in this section refer to stabilized desalinated ocean water. The bench-scale study results are documented in Appendix 2.

When interpreting pipe loop pilot testing data, it is important to focus on overall trends in comparing pipe loops, as a higher baseline is observed compared with what will occur in distribution systems as a result of pipe harvesting and pipe loop testing protocols with harvested materials. With a recirculation approach in UCI and CML pipe loops, metal concentrations in test waters accumulated through each cycle, providing easier detection of differences in corrosion for different water qualities corrosion. The overall trends observed are discussed in the results presented below.

4.1 Pilot-Scale Pipe Loop Study

The pipe loop study results are summarized for UCI, CML and CU pipes with lead solder and brass meters, respectively. In addition, disinfection byproduct (NDMA, TTHM and HAA5) results for the samples collected from the pipe loops are also presented.

4.1.1 Test Waters

CCPP and LSI values of the test waters used in the pipe loop study are shown in Figure 4-1 and Figure 4-2, respectively. Generally, higher numbers correspond to less corrosion (i.e., tendency to precipitate, rather than dissolve, calcium carbonate). Ranges such as those shown in Table 2-2 are desired to avoid precipitating too much calcium carbonate scale. CCPP values for 100% Desal water ranged from 2.3 to 5.6 mg/L as $CaCO_3$. 100% MWD water had CCPP values in the range of 5.1 to 11.0 mg/L as $CaCO_3$. The 50% Desal/50% MWD blend had CCPP values between 1.2 and 7.8 mg/L as $CaCO_3$. Groundwater contained high levels of alkalinity and calcium, which contributed to high CCPP values (25.3 – 39.3 mg/L as $CaCO_3$). Consequently, the blends of 25% MWD/75% groundwater and 25% Desal/75% groundwater showed high CCPP values of 23.1-30.4 and 20.3-30.7 mg/L as $CaCO_3$, respectively.

LSI results were similar to CCPP. 100% Desal water had LSI values between 0.3 and 0.7, indicating stabilized water quality. 100% MWD water showed slightly higher LSI values than 100% Desal. Blends with 25% MWD/75% groundwater and 25% Desal/75% groundwater had higher LSI values than 100% Desal and 100% MWD. Overall, all uncirculated test waters had positive CCPP and LSI values during the entire study period. Desal water that was stabilized through calcite contactors and post-pH adjustment achieved the target values for CCPP and LSI established at the beginning of the study.

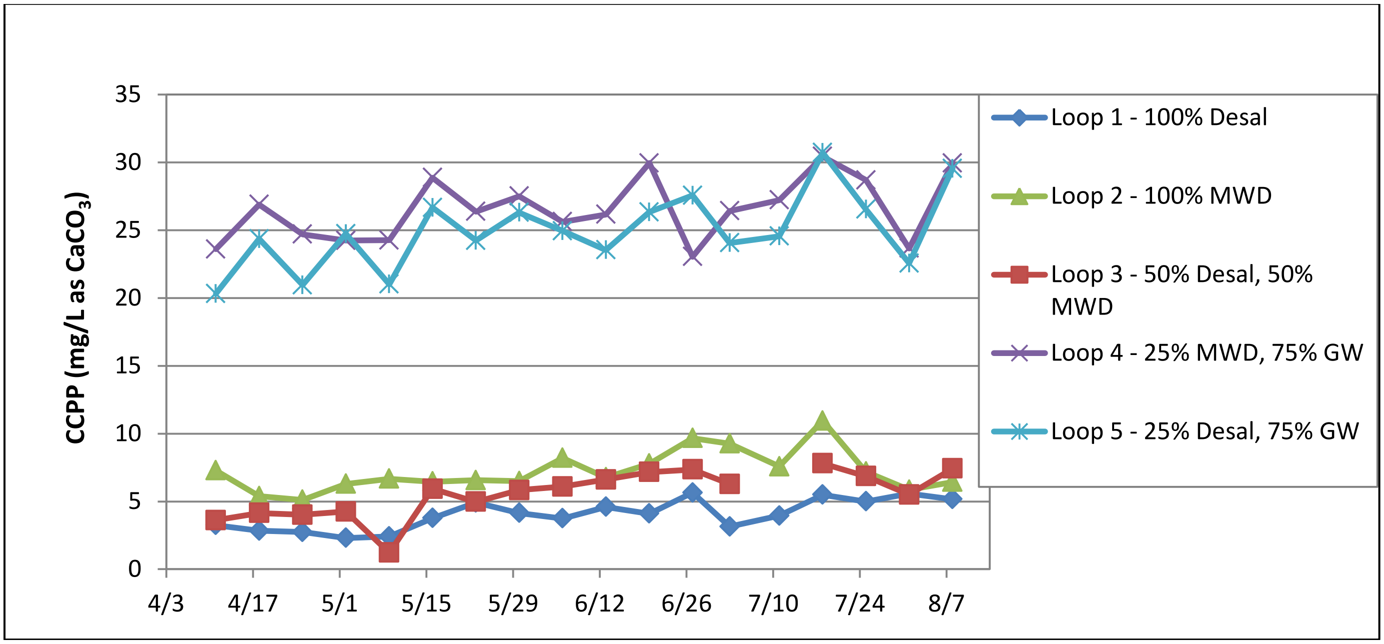


Figure 4-1. CCPP Values for Uncirculated Test Waters – Day 1

Note: For Loop 3, the CCPP value for July 11 is not shown as the field pH measurement based on loop CU-3 was likely not representative (pH 7.79 compared to pH 8.24 for CML-3 and pH 8.13 for UCI-3 for the same source water).

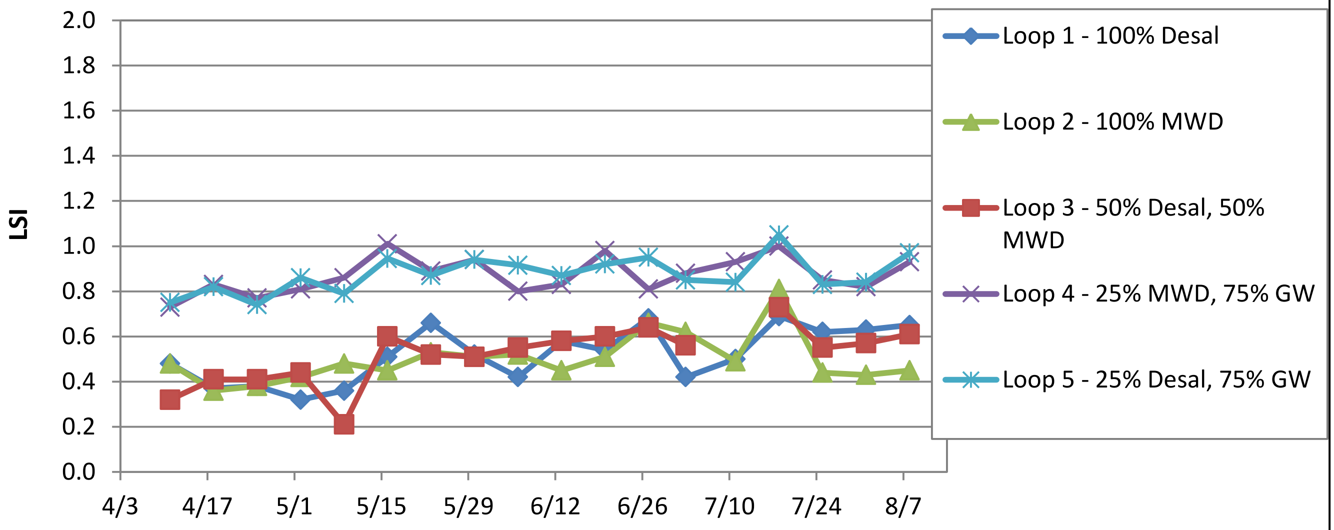


Figure 4-2. LSI Values for Uncirculated Test Waters – Day 1

Note: For Loop 3, the LSI value for July 11 is not shown as the field pH measurement based on CU-3 loop was likely not representative (pH 7.79 compared to pH 8.24 for CML-3 and pH 8.13 for UCI-3 for the same source water).

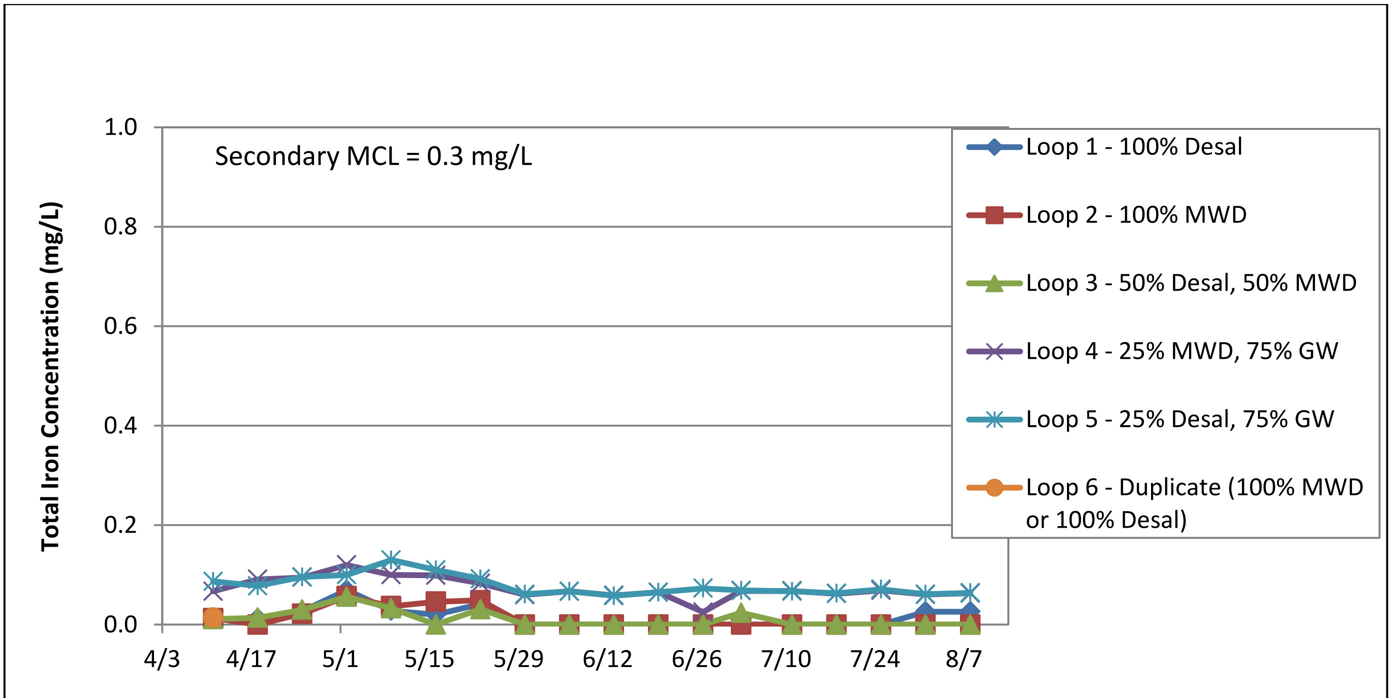
4.1.2 UCI Pipes

Total iron concentrations in the uncirculated waters on Day 1 and in the recirculated water on Day 7 are shown in Figure 4-3 and Figure 4-4, respectively. Iron levels in the uncirculated waters were below 0.1 mg/L for 100% Desal, 100% MWD and the 50%Desal/50% MWD blend. Groundwater contained higher iron concentrations, which contributed to slightly higher iron levels in the blends of 25% MWD/75% groundwater (0.03 – 0.12 mg/L) and 25% Desal/75% groundwater (0.06 – 0.13 mg/L).

After 1 week of recirculation, total iron levels in all test waters increased (Figure 4-4), which was not surprising considering the existing deposits observed in the pipes and the disruptive pipe harvesting process. For 100% Desal, iron concentrations rose from 0.31 mg/L in Week 1 to 0.67 mg/L in Week 5 (May 15, 2013), then gradually decreased to 0.21 mg/L (below the secondary MCL) by the end of the test period. Given the variability in the pipe loop deposits, the concentrations observed in the water are considered to be similar.

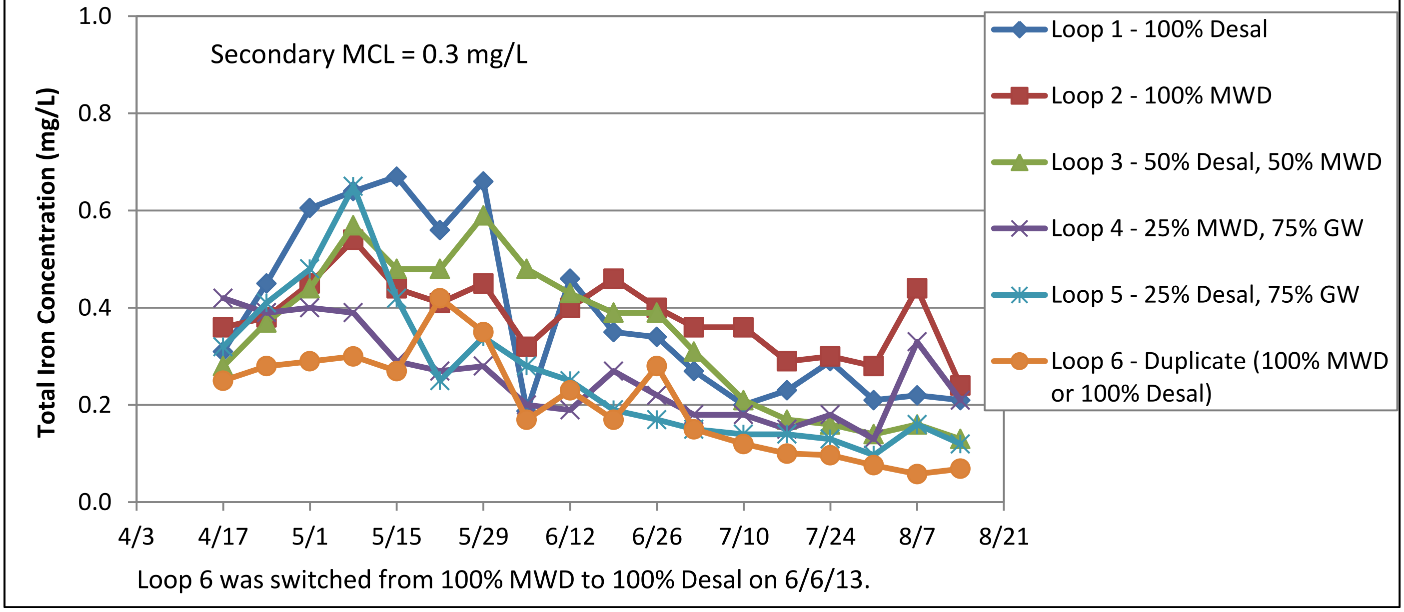
The duplicate loop (Loop 6) was switched from 100% MWD to 100% Desal on June 6, 2013, to determine whether the initial higher iron concentrations observed in the 100% Desal loop were due to the physical release of the pipe deposits or the impacts of the water quality on releasing iron. Total iron levels in samples taken from Loop 6 decreased from 0.23 mg/L in early June to 0.07 mg/L by the end of testing, which was lower than in Loop 1- 100% Desal. The results reflect variations in iron release between the pipe loops even when the same water was introduced, which was likely due to the variability of the tuberculation within the UCI pipe segments used in the different loops.

Overall, the iron UCI data showed that 100% Desal or Desal blends tested did not result in higher iron release than 100% MWD water.



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-3. Iron Concentrations in Uncirculated Test Waters – Day 1, UCI Pipe Loops



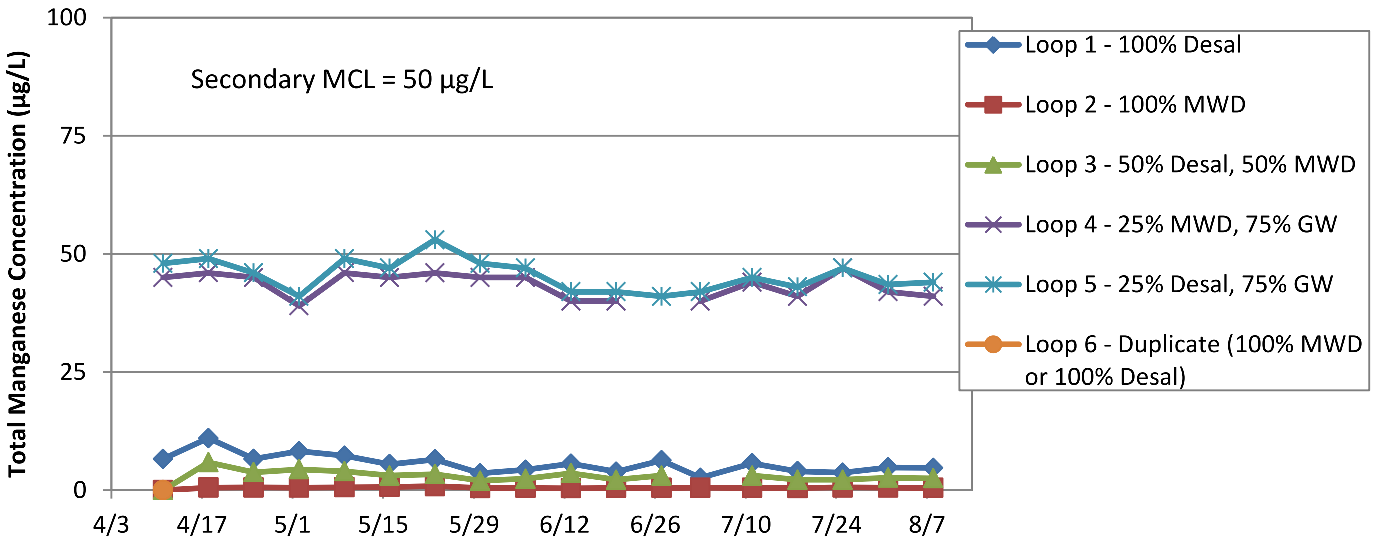
Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-4. Iron Concentrations in Recirculated Waters - 1 Week, UCI Pipe Loops

Total manganese concentrations in uncirculated waters on Day 1 and in the recirculated waters on Day 7 are shown in Figure 4-5 and Figure 4-6, respectively. 100% Desal and 100% MWD waters contained low manganese concentrations, typically below 10 µg/L. Groundwater contained manganese at levels between 53 and 62 µg/L. Consequently, the groundwater blends showed relatively high manganese concentrations, in the range of 39-47 µg/L for 25% MWD water/75% groundwater and 41-53 µg/L for 25% Desal/75% groundwater.

Manganese levels in the recirculated waters for all the loops were elevated initially due to manganese release from pipe deposits. The results were not surprising considering the extent of existing deposits in the UCI pipes, which had been exposed to groundwater with high manganese levels for decades. Manganese concentrations decreased over time to below the secondary MCL of 50 µg/L for all loops. By the end of the study, manganese concentrations in the loops with 100% Desal water (Loop 1 and Loop 6 after June 6th) were 3.1 and 0.77 µg/L, respectively, which were lower than the manganese concentration of 11 µg/L observed in Loop 2 with 100% MWD water. Similar to iron, differences between 100% Desal and 100% MWD loops were likely the results of pipe deposit variations rather than due to differences in water quality. The 25% MWD/75% groundwater and 25% Desal/75% groundwater blends showed higher manganese concentrations, due to the elevated manganese concentrations in the groundwater. Variations in the manganese concentrations for the blend loops reflect precipitation of manganese out of solution onto the pipe surfaces.

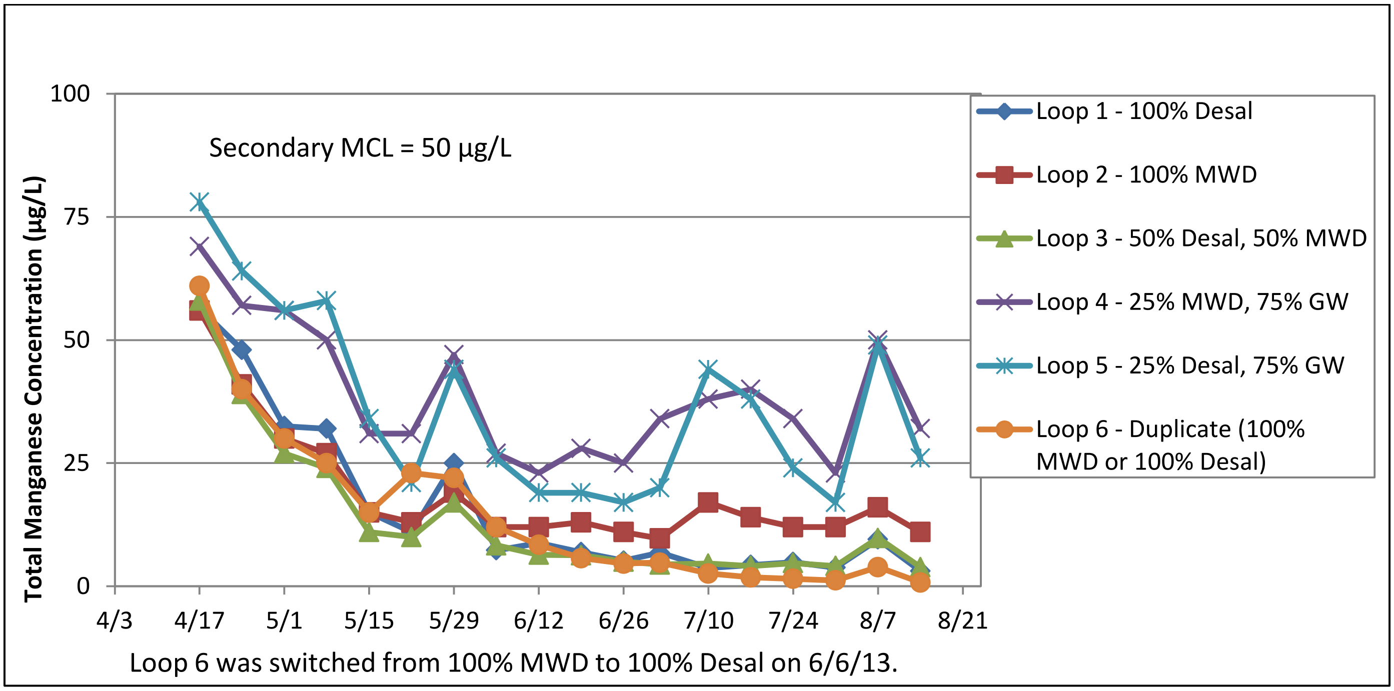
Overall, the test waters from each pipe loop showed that 100% Desal water and the 50% Desal/50% MWD blend did not cause more manganese release from the pipes than 100% MWD water.



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-5. Manganese Concentrations in Uncirculated Test Waters – Day 1, UCI Pipe Loops

Note: The manganese result for Loop 4 on June 27, 2013, is not shown, as the 16 µg/L measurement was likely an analytical or sampling error considering the average manganese concentration of 40 µg/L for this loop. The manganese result for Loop 3 on July 3, 2013, is not shown, as the 16 µg/L measurement was likely an analytical or sampling error considering the average manganese concentration of 3 µg/L for this loop.



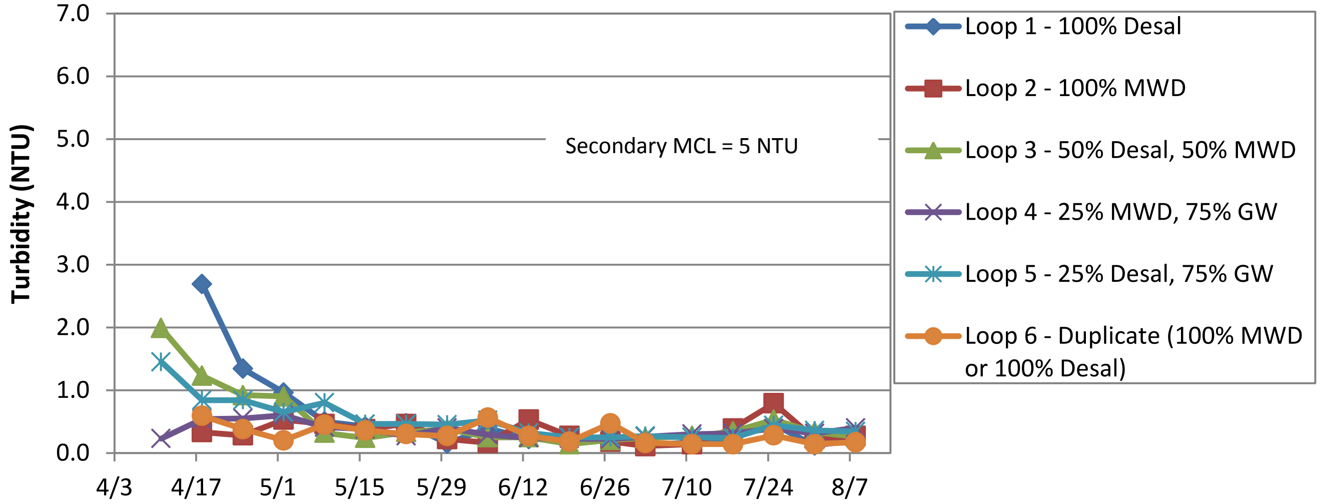
Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-6. Manganese Concentrations for Recirculated Waters - 1 Week, UCI Pipe Loops

Turbidities in the uncirculated waters on Day 1 and in the recirculated water on Day 7 are shown in Figure 4-7 and Figure 4-8, respectively. The uncirculated 100% Desal water contained relatively high turbidity at startup, which was due to initial flushing of calcite fines from the calcite contactors. Consequently, the blends of Desal with MWD and Desal with groundwater also showed relatively high turbidity at the beginning of the study. After the fines were flushed out of the calcite contactors, turbidities measured in all test waters were typically below 0.5 NTU.

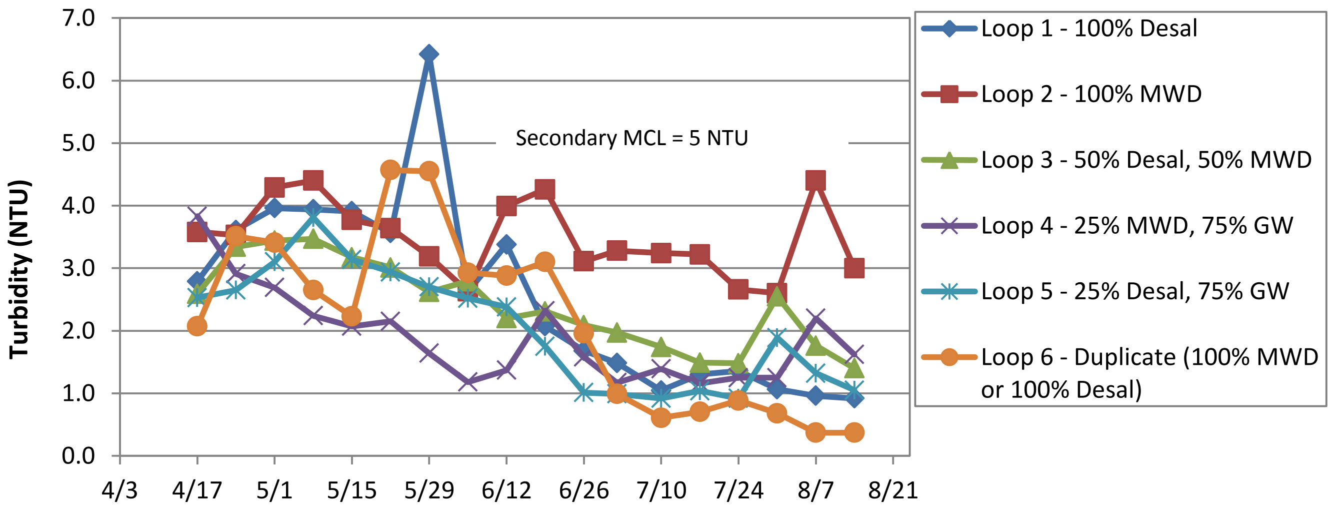
Recirculated waters showed elevated turbidity levels in all loops compared to uncirculated waters although most levels were below the secondary MCL of 5 NTU. 100% Desal water in Loop 1 and Loop 6 (after June 6, 2013) showed turbidity at levels similar to or lower than those measured in 100% MWD water, except a spike observed for Loop 1 on May 29, 2013. Turbidity in the 100% Desal loops decreased to 0.92 and 0.37 NTU, respectively (compared to 3.0 NTU in the 100% MWD loop), in the last half of the study. Therefore, 100% Desal water did not result in more turbidity release than MWD water. The blended water sources also showed turbidity levels similar to or lower than 100% MWD.

Overall, turbidity levels in recirculated waters for 100% Desal and the 25% Desal/75% groundwater blend did not result in higher turbidity than 100% MWD water.



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-7. Turbidity in Uncirculated Test Waters – Day 1, UCI Pipe Loops

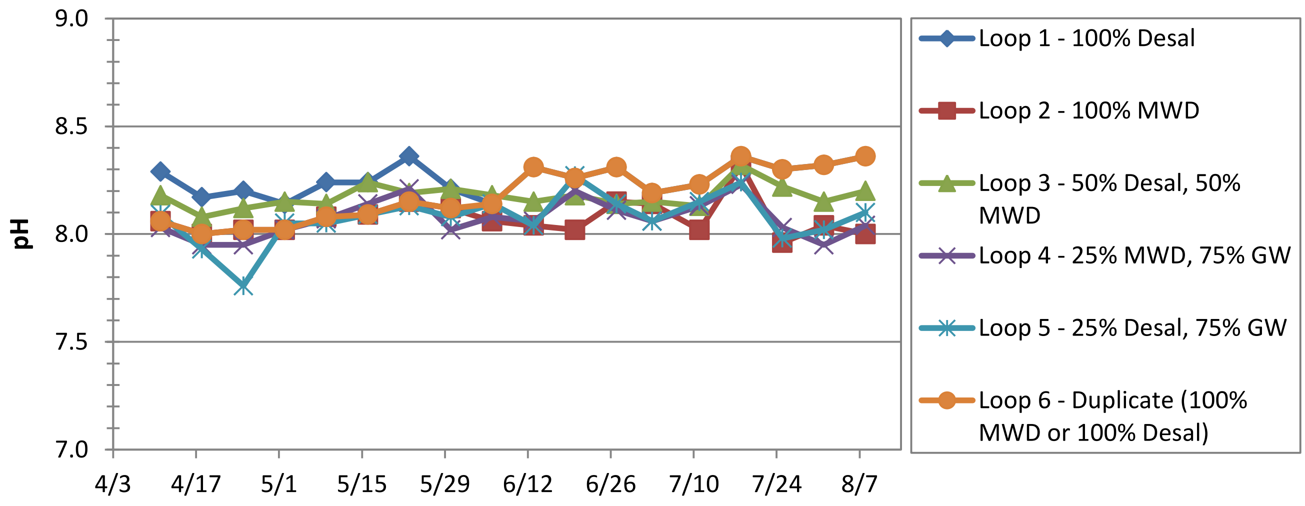


Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-8. Turbidity for Recirculated Waters - 1 Week, UCI Pipe Loops

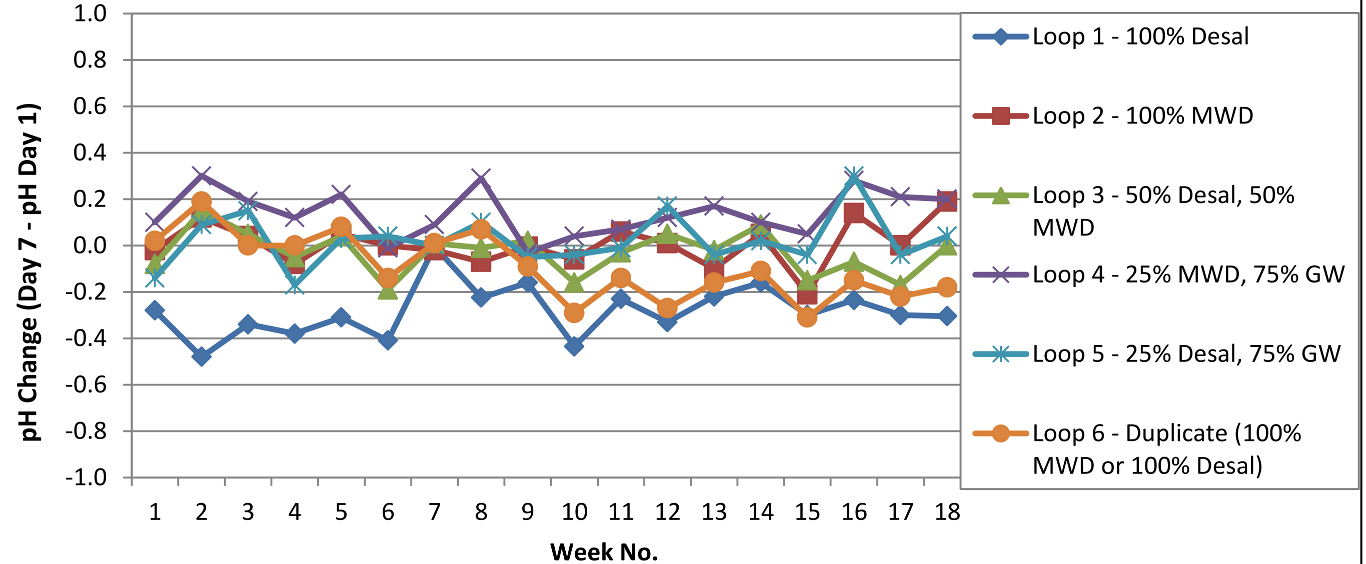
Figure 4-9 shows pH in uncirculated test waters during the study period. pH in Desal water ranged from 8.13 to 8.36. pH in MWD water ranged from 7.96 to 8.32 and from 7.84 to 8.23 in groundwater. Groundwater blended with Desal water had pH between 8.08 and 8.32. The groundwater blends had pH values similar to pH in groundwater.

Changes in pH (i.e., pH in recirculated water minus pH in uncirculated water) are shown in Figure 4-10. For 100% Desal, pH typically decreased after 1 week of recirculation. The average reduction was 0.28 pH units; the maximum reduction was 0.48. Consistent pH reductions measured in the recirculated water, although the changes were not dramatic, can indicate interactions between water and the pipe tuberculation or nitrification. It is unclear what reactions have caused these pH changes. For 100% MWD water, pH changes were between +0.19 (increase after recirculation) and -0.21 (decrease after recirculation). The blend of 50% MWD/ 50% Desal water had pH changes between +0.15 (increase after recirculation) and -0.19 (decrease after recirculation). The blends of 25% MWD/75% groundwater and 25% Desal/75% groundwater had pH changes in the range of +0.30 and -0.03, and +0.30 and -0.17, respectively. The pH changes for 100% Desal loop were generally slightly greater than the other test waters, which might be due to higher alkalinity and calcium levels in MWD and groundwater (thus higher buffer capacity).



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-9. pH in Uncirculated Test Waters – Day 1, UCI Pipe Loops

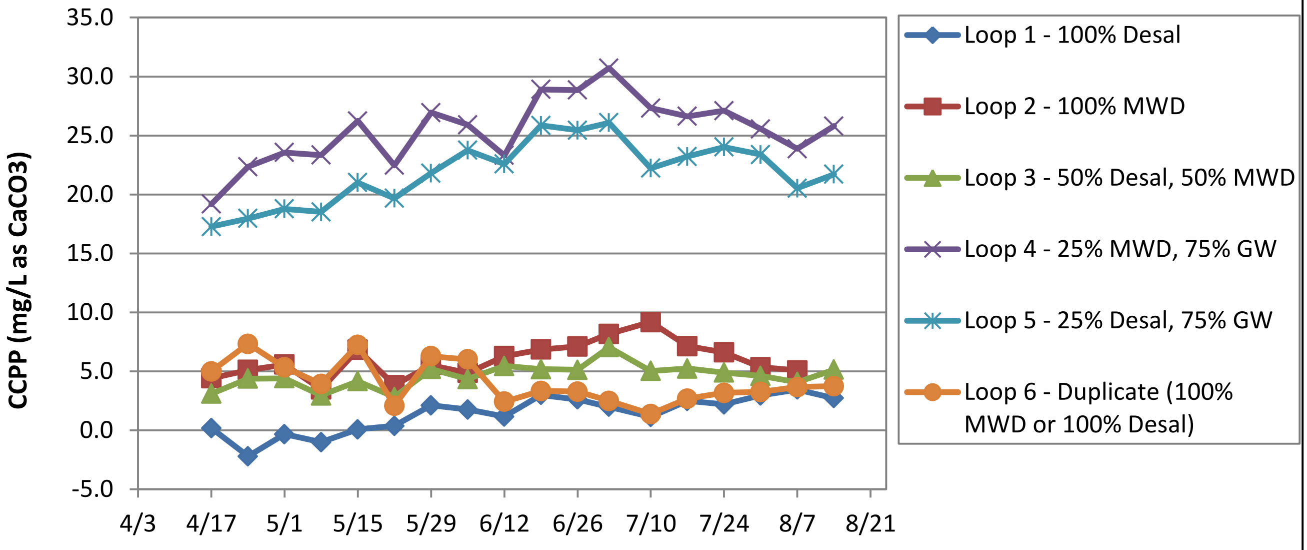


Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-10. pH Changes in Recirculated Waters - 1 Week, UCI Pipe Loops

Figure 4-11 shows CCPP values of the waters recirculated in the UCI pipes. CCPP values in recirculated Desal water were lower than the CCPP values measured in uncirculated 100% Desal (Figure 4-1), which is due to pH reduction as discussed above. After the first month of the study, CCPP values for the recirculated 100% Desal water remained positive. CCPPs for the other test waters remained positive throughout the study period. The results indicate sufficient buffering capacity is available in the test waters to minimize pH changes that could alter the stability of the water in the distribution system.

Further, more severe nitrification was observed in the groundwater loops due to the high levels of naturally-occurring ammonia present and degradation of chloramine residual during recirculation (see Section 4.1.5). The high buffering capacity of the groundwater mitigated decreases in pH that are sometimes observed as a result of nitrification.



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

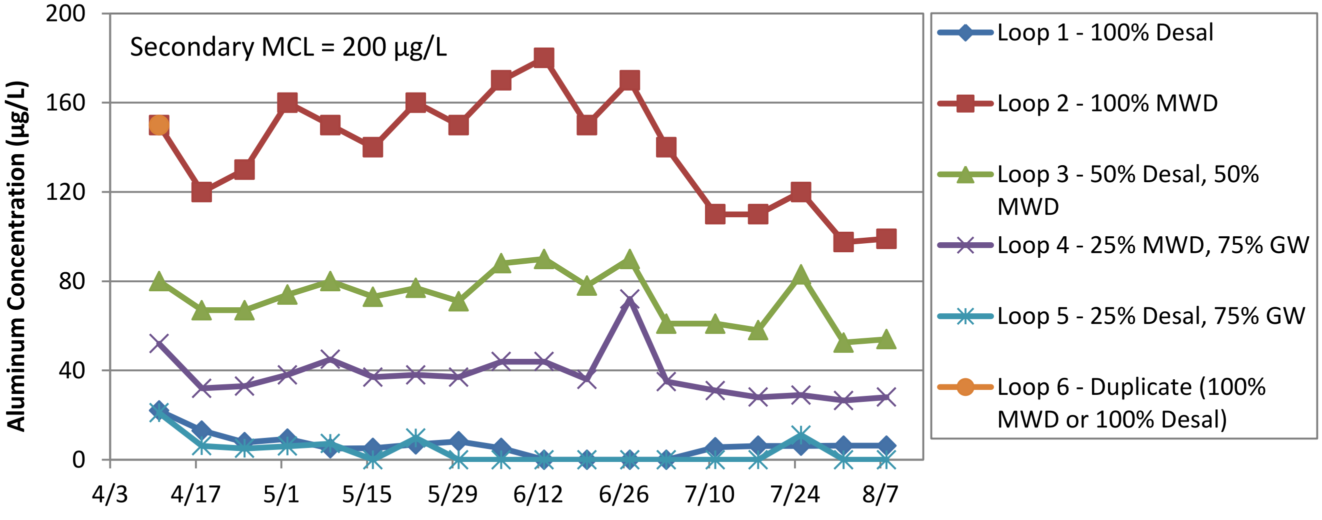
Figure 4-11. CCPP Values in Recirculated Waters - 1 Week, UCI Pipe Loops

4.1.3 CML Pipes

Aluminum concentrations in the uncirculated waters on Day 1 and in the recirculated water on Day 7 are shown in Figure 4-12 and Figure 4-13, respectively. Stabilized Desal water contained aluminum in the range of non-detect (<5 µg/L) to 22 µg/L. Groundwater contained aluminum in the range of non-detect (< 5 µg/L) to 39 µg/L. MWD water contained aluminum concentrations between 97 and 120 µg/L, which was due to alum coagulant application at MWD's Weymouth Water Treatment Plant. Aluminum concentrations in the blend of Desal and MWD water reflects the average aluminum concentrations of the two waters. The blends of 25% MWD/75% groundwater contained aluminum in the range of 27 to 72 µg/L, which was attributed to aluminum in MWD water. The blend of 25% Desal/75% groundwater had aluminum concentrations below 21 µg/L.

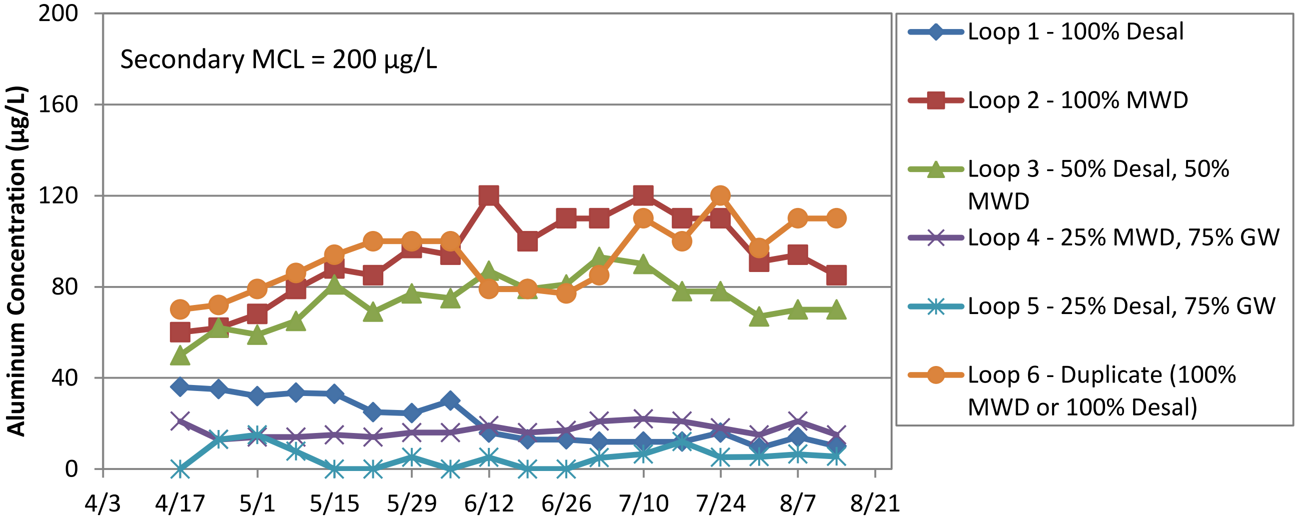
Aluminum concentrations in the waters changed after water recirculated through the CML pipe loops. Aluminum concentrations in the 100% Desal loop gradually decreased during the study period. The initial small increase in aluminum was due to release during passivation of the surfaces. For the 100% MWD loop, aluminum levels in recirculated water were lower than in the uncirculated water during the first three months, indicating potential incorporation of the aluminum into the cement mortar lining as the cement structure passivated. The 50% Desal/50% MWD blend showed similar aluminum concentrations in the recirculated water and the uncirculated water. For the 25% MWD/75% groundwater and 25% Desal/75% groundwater blends, aluminum concentrations in the recirculated waters were slightly lower than in the uncirculated waters. Overall, aluminum concentrations in all recirculated waters were well below the secondary MCL of 200 µg/L and Desal water or blends did not cause higher aluminum release from the CML pipe compared to 100% MWD water and 25% MWD/75% groundwater blend.

pH values in the waters recirculated through the CML pipe loops are shown in Figure 4-15. Compared with pH levels in the uncirculated waters (Figure 4-14), pH in the recirculated water increased in all loops, especially during the initial period when the cement matrix equilibrated with the water. pH in all loops decreased over time, indicating pipe passivation. pH values of the test waters in each of the loops increased by several tenths during the recirculation period. Figure 4-16 shows the changes of pH over the final week of the pilot test. The biggest pH increase was 0.5 pH unit for the 100% MWD water, while the smallest pH change was 0.1 - 0.2 pH unit for the 100% Desal loops (Loops 1 and 6). Overall, no major differences in pH levels were noted when comparing changes in the 100% Desal, blends or the 100% MWD water.



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

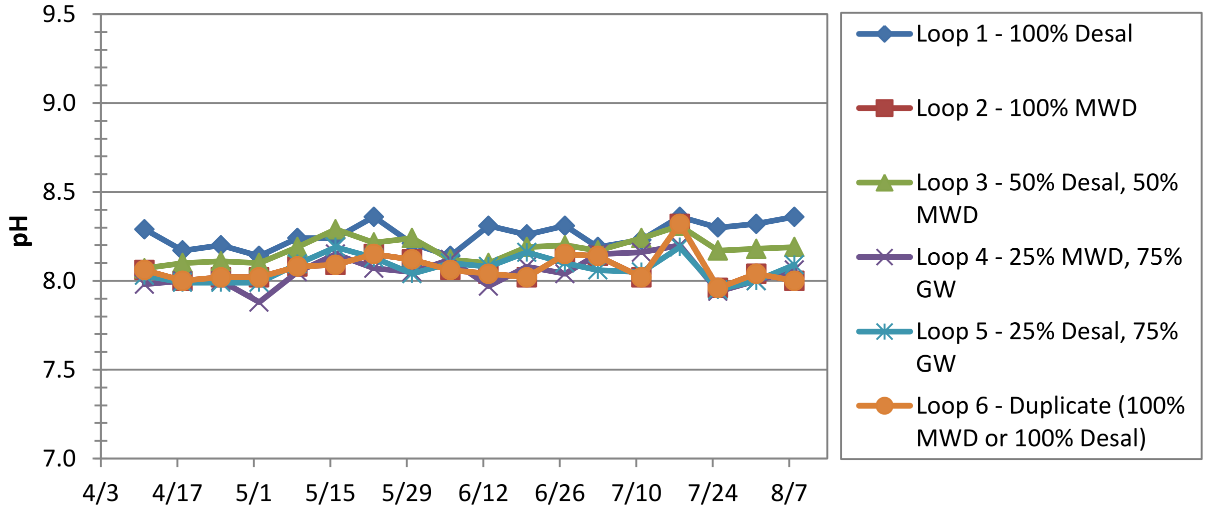
Figure 4-12. Aluminum Concentrations in Uncirculated Test Waters – Day 1, CML Pipe Loops



Secondary MCL = 200 µg/L

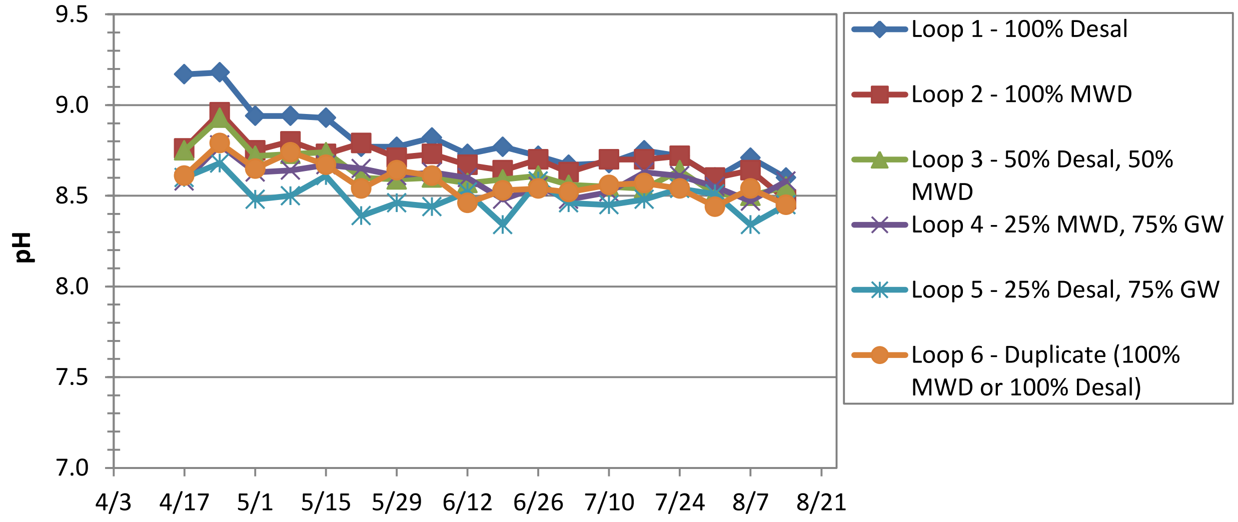
Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-13. Aluminum Concentrations in Recirculated Waters - 1 Week, CML Pipe Loops



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-14. pH in Recirculated Waters - 1 Week, CML Pipe Loops



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-15. pH in Recirculated Waters - 1 Week, CML Pipe Loops

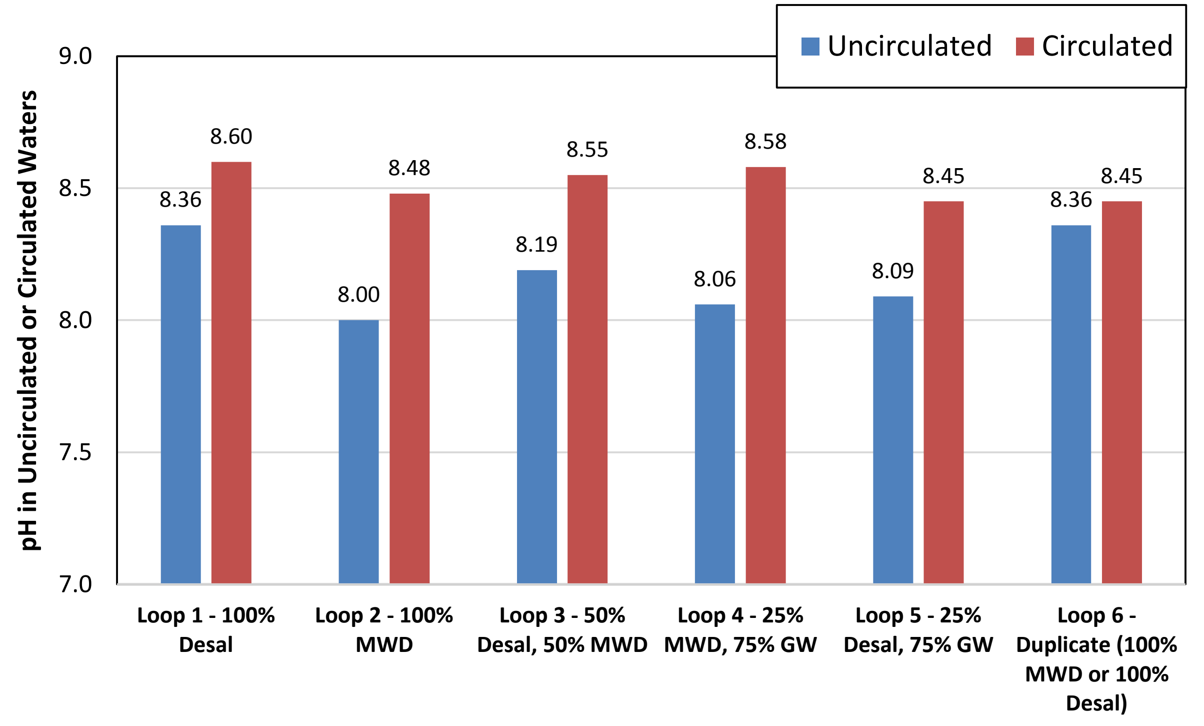
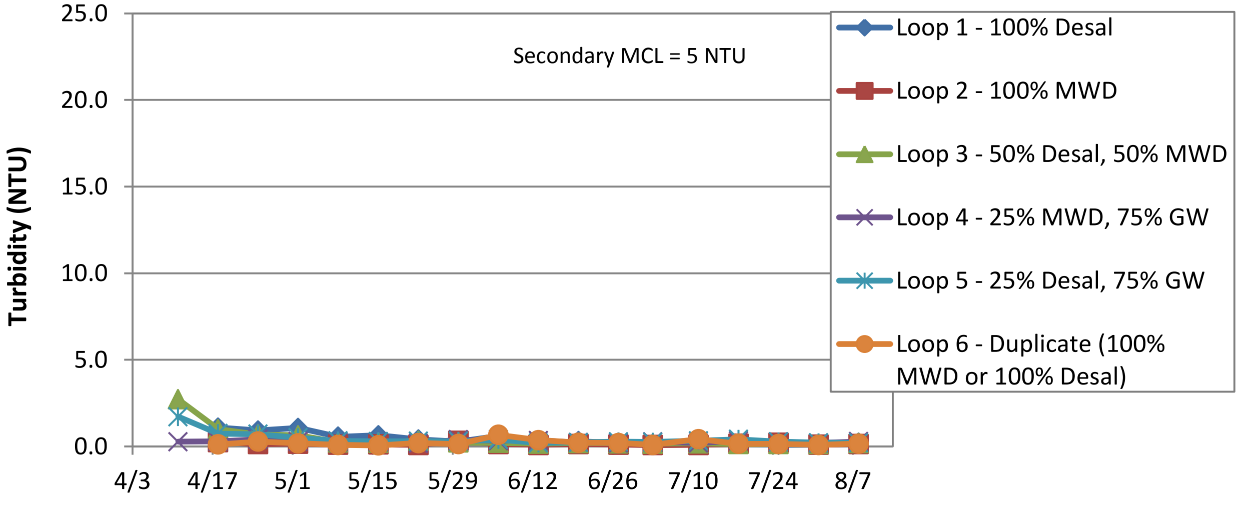


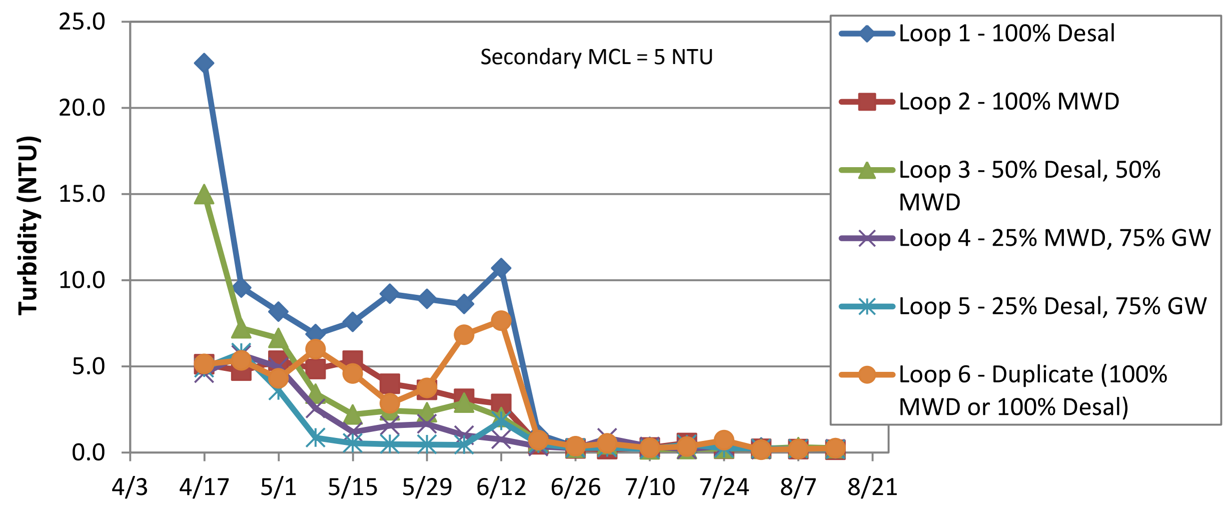
Figure 4-16. pH in Uncirculated vs. Recirculated Water in the Final Week, CML Pipe Loops

Turbidities in the uncirculated water and the test waters recirculated through the CML pipe loops are provided in Figure 4-17 and Figure 4-18, respectively. For all loops, higher turbidity levels were observed in the beginning after pipe harvesting, with turbidity decreasing to relatively low levels below the secondary MCL thereafter. For 100% Desal, turbidity in recirculated water stabilized at 0.20 NTU in Loop 1 and 0.25 NTU in Loop 6, similar to uncirculated water. The 100% MWD loop had a turbidity of 0.17 NTU at the end of the study. The 3 blends exhibited turbidities between 0.18 and 0.26 NTU by the end of the study. Overall, turbidity stabilized after two months of testing. No major differences in stabilized turbidity levels were noted for 100% Desal, blends or 100% MWD water.



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

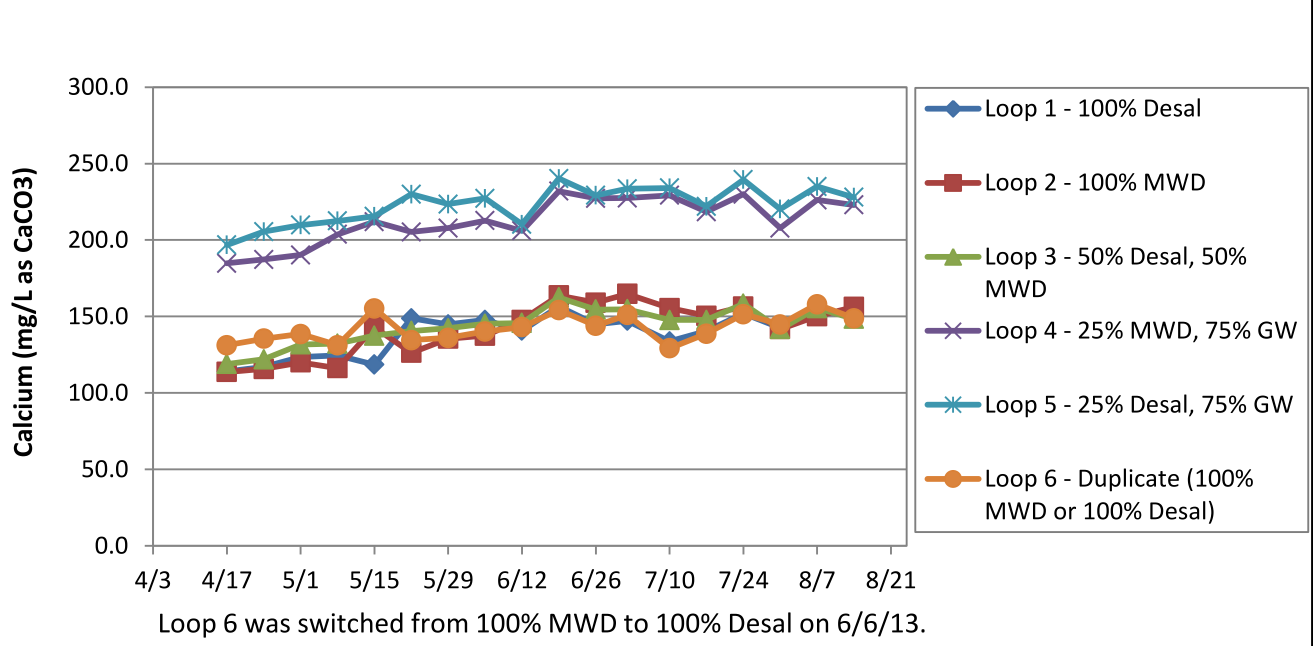
Figure 4-17. Turbidity in Uncirculated Test Waters – Day 1, CML Pipe Loops



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-18. Turbidity in Recirculated Waters - 1 Week, CML Pipe Loops

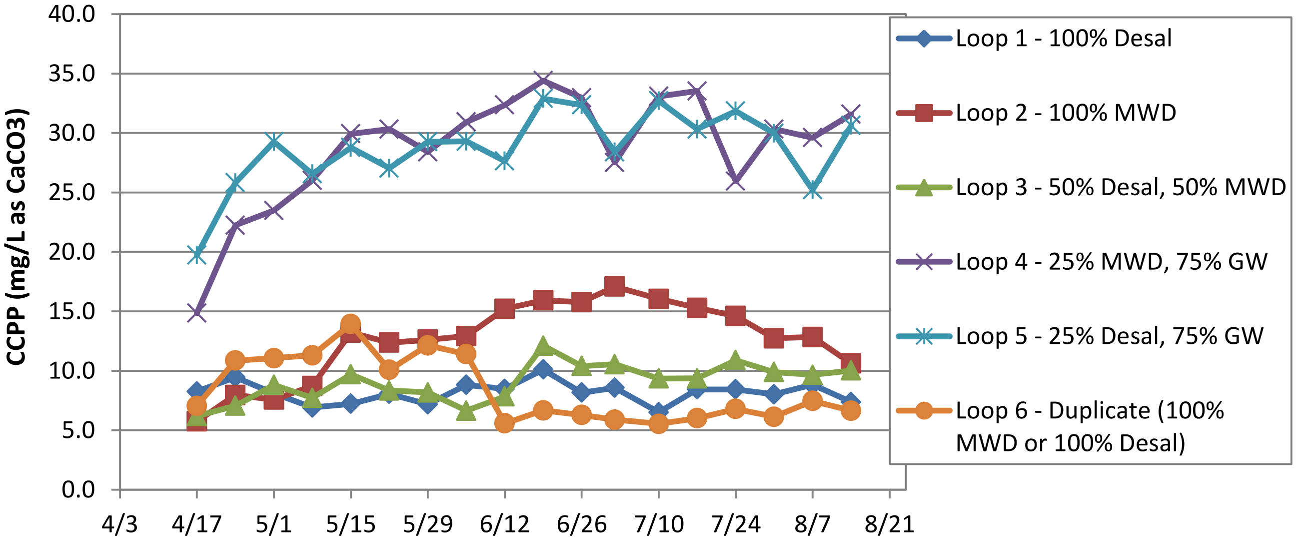
Calcium levels in the test waters recirculated through the CML pipe loops are shown in Figure 4-19. For all loops, the recirculated water calcium concentrations were initially lower than the levels in uncirculated waters, especially in the first month. For example, for 100% Desal water, the calcium concentration in recirculated water was 114 mg/L as $CaCO_3$ in the first week, compared to 141 mg/L as $CaCO_3$ in uncirculated Desal. For 100% MWD water, calcium in recirculated water was 114 mg/L in the first week, compared to 157 mg/L as $CaCO_3$ in uncirculated MWD water. Similar trends were observed for all loops. The initial reduction in calcium concentrations after recirculation was likely due to calcium precipitation or adsorption into the cement mortar lining of the pipe during the stabilization period. Overall, in the pipe loop testing, calcium in recirculated waters increased to levels similar to uncirculated waters after the first month of testing.



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-19. Calcium Concentrations in Recirculated Waters - 1 Week, CML Pipe Loops

CCPP values in test waters recirculated through the CML pipe loops are shown in Figure 4-20. Compared with CCPP values in the uncirculated test waters (Figure 4-1), CCPP values in all loops increased slightly in the recirculated waters. For example, average CCPPs increased from 4.0 to 8.2 mg/L as $CaCO_3$ for 100% Desal water and from 7.2 to 12.6 mg/L as $CaCO_3$ for 100% MWD water. For the blend of 50% Desal/50% MWD water, the average CCPP was 9.0 mg/L as $CaCO_3$ in recirculated water compared to 5.6 mg/L as $CaCO_3$ in uncirculated water. The blends of 25% MWD/75% groundwater and 25% Desal/75% groundwater had higher CCPPs due to the groundwater quality. The increases in CCPP observed during testing are mostly attributed to the increases in pH levels observed during recirculation compared with uncirculated waters, likely due to passivation of the CML surfaces.



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-20. CCPPs in Recirculated Waters - 1 Week, CML Pipe Loops

4.1.4 CU Pipes with Lead Solder and Brass Meters

Lead concentrations in the uncirculated test waters are shown in Figure 4-21. Lead concentrations were below 1 µg/L in all uncirculated waters. Separate, discrete samples were collected after a stagnation period from the brass meters and from the copper pipe with lead solder between the meters and the water tank.

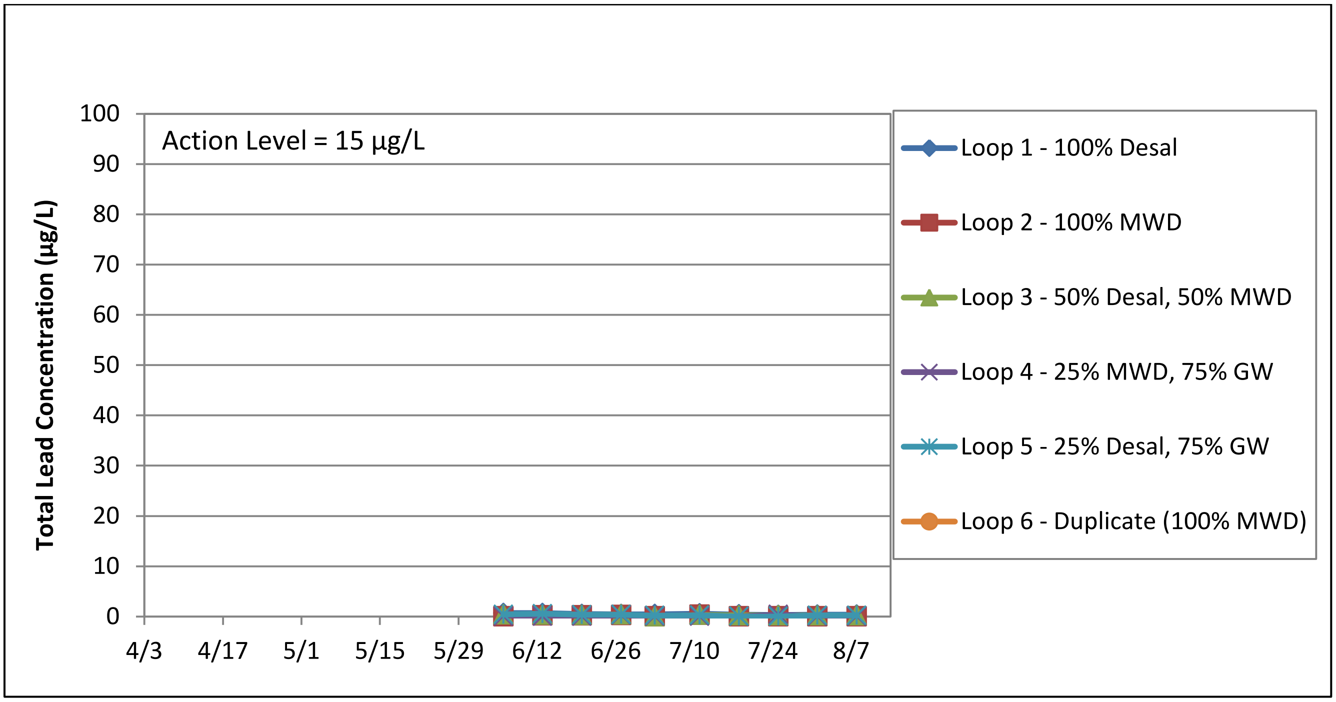


Figure 4-21. Lead Concentrations in Uncirculated Test Waters – Day 1, CU Pipe Loops

Total copper concentrations in uncirculated waters are shown in Figure 4-22. For all uncirculated waters, copper levels were below 7 µg/L.

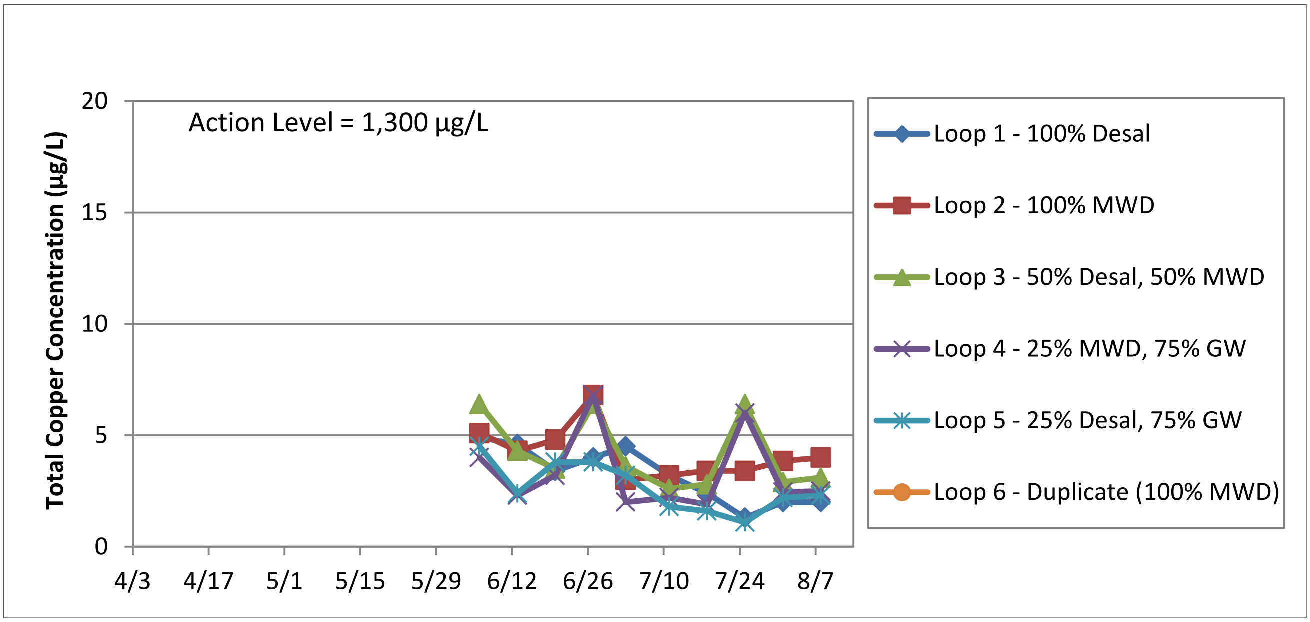


Figure 4-22. Copper Concentrations in Uncirculated Test Waters – Day 1, CU Pipe Loops

Zinc concentrations in uncirculated test waters supplied to the CU pipe loops are shown in Figure 4-23. Zinc levels in all uncirculated waters were below 10 µg/L.

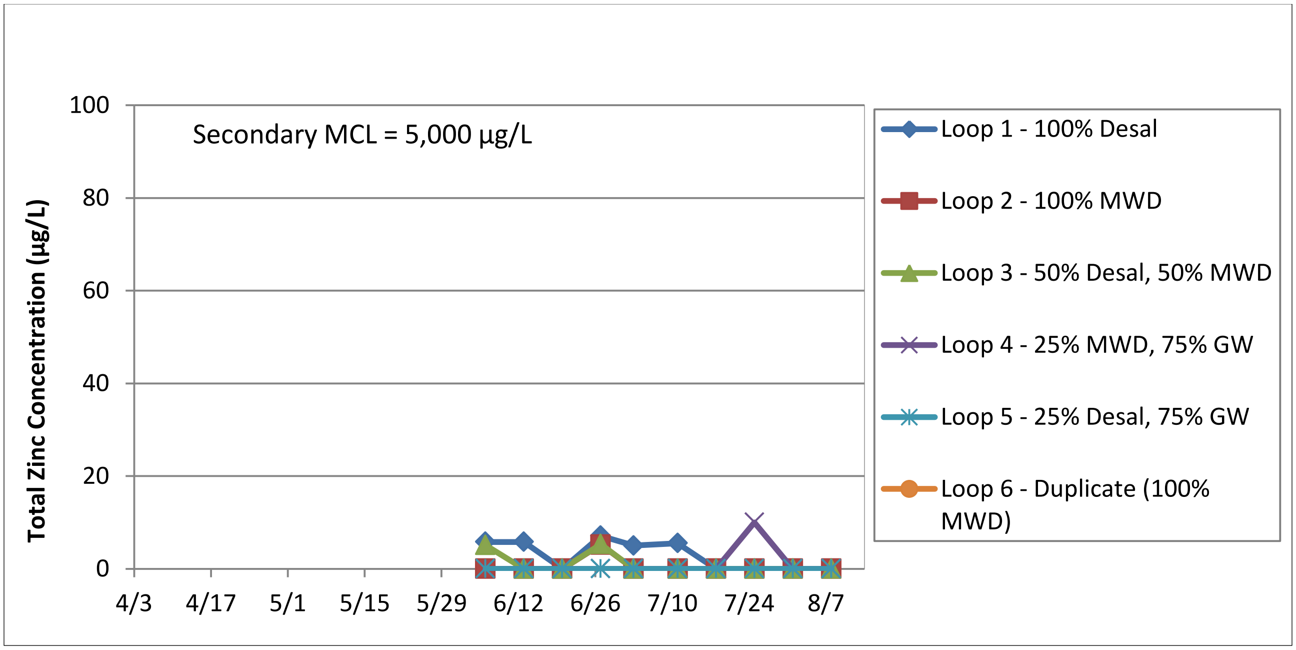
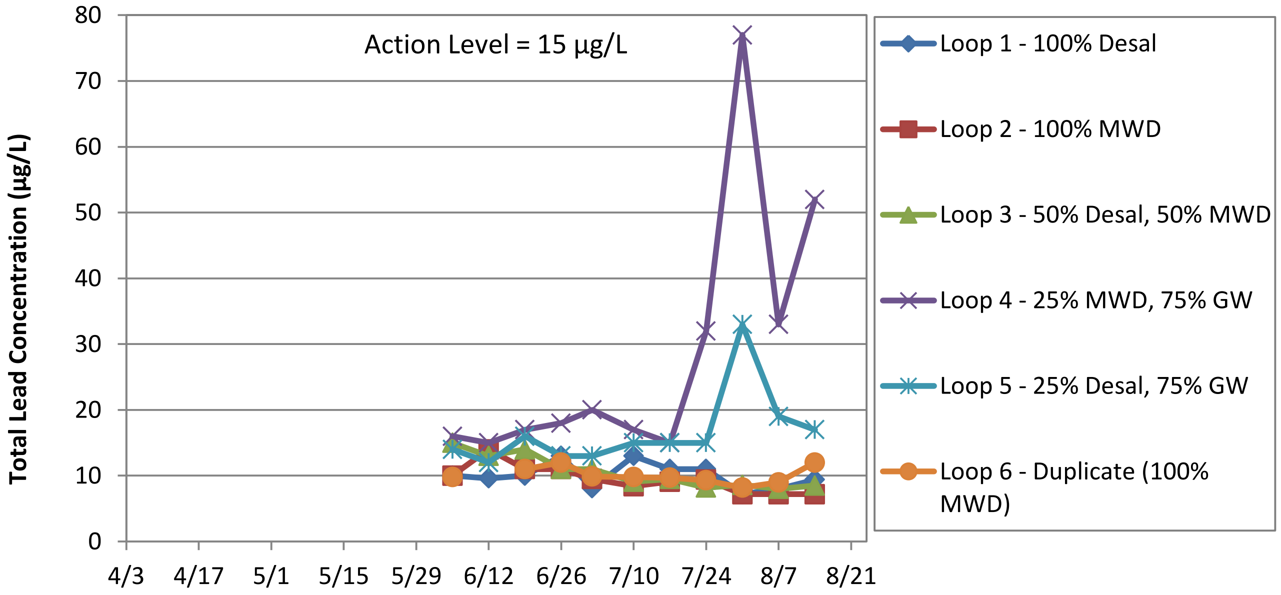


Figure 4-23. Zinc Concentrations in Uncirculated Test Waters – Day 1, CU Pipe Loops

4.1.4.1 Brass Meters

Figure 4-24 shows total lead concentrations in water collected from the brass meters installed at the end of the CU pipes. For the 100% Desal loop, lead concentrations ranged from 7.2 to 11 µg/L. Lead concentrations ranged from 7.2 to 14 µg/L for the 100% MWD loop. Similar levels were observed in samples from the duplicate loop and the 50% Desal/50%MWD blend loop.

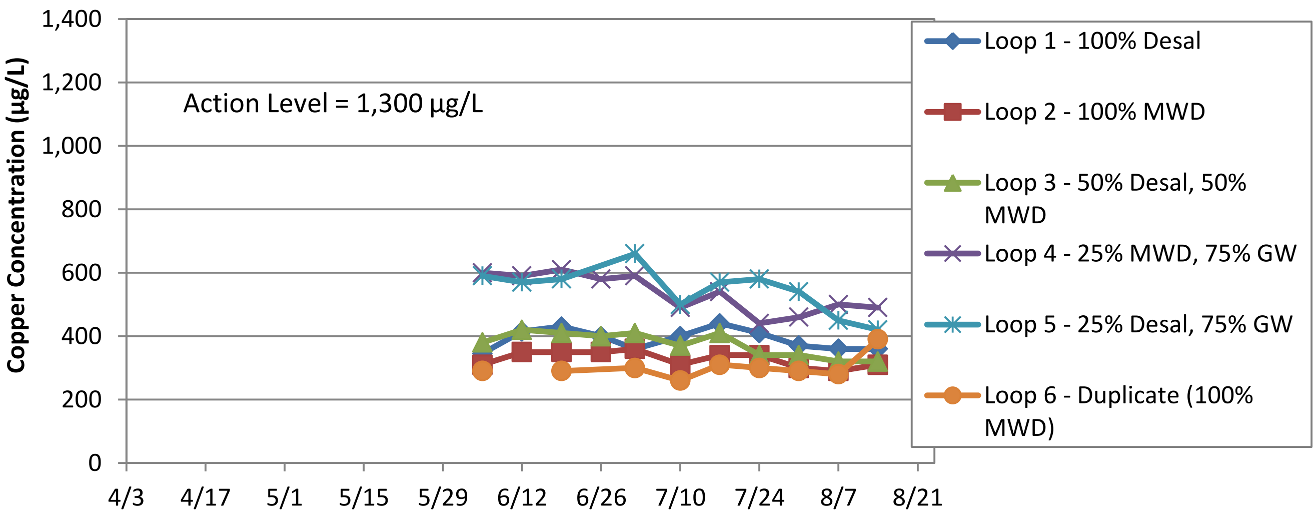
By contrast, the blends of 25% MWD/75% groundwater and 25% Desal/75% groundwater showed relatively high lead levels (up to 77 µg/L for Loop 4 and 33 µg/L for Loop 5). To investigate the cause of these higher levels, the duplicate loop (Loop 6) was switched to the blend of 25% MWD and 75% groundwater during the last week of the study. In this week, the lead level in the brass meter sample on Day 7 was 52 µg/L in Loop 4 compared to 12 µg/L in Loop 6. Additional samples collected post-study when all loops were operated with 100% MWD water showed lead concentrations of 15 µg/L in Loop 4 and 8.2 µg/L in Loop 6. It is unclear what caused the increase in lead from Loops 4 and 5, but results showed that the introduction of desalinated water into a groundwater blend did not cause higher concentrations than the 25% MWD/75% groundwater blend.



Loop 6 was switched from 100% MWD to 25% MWD/75% groundwater on 8/8/13.

Figure 4-24. Lead Concentrations in First Flush after Stagnation - Day 7, Brass Meters

Figure 4-25 shows total copper concentrations in first flush of water from the brass meters. Copper concentrations in the 100% Desal loop brass meter were between 270 and 380 µg/L. By comparison, the 100% MWD loop brass meter samples contained copper at levels of 150 to 180 µg/L. The duplicate 100% MWD loop samples contained copper between 190 and 230 µg/L. Similar copper results were observed for the 50% Desal/50% MWD loop. However, the 25% MWD/75% groundwater and 25% Desal/75% groundwater blends showed higher copper concentrations in the brass meter samples, possibly due to copper complexation with carbonate or natural ammonia in the groundwater (Edwards et al., 1996; Xiao et al., 2007; Shock, 1999). Switching the duplicate loop (Loop 6) to 25% MWD/75% groundwater during the last week of testing indicated that the water quality may have been responsible for the higher copper release, although the single data point is not conclusive. Overall, copper concentrations in all samples from brass meters were below the LCR Action Level of 1,300 µg/L.

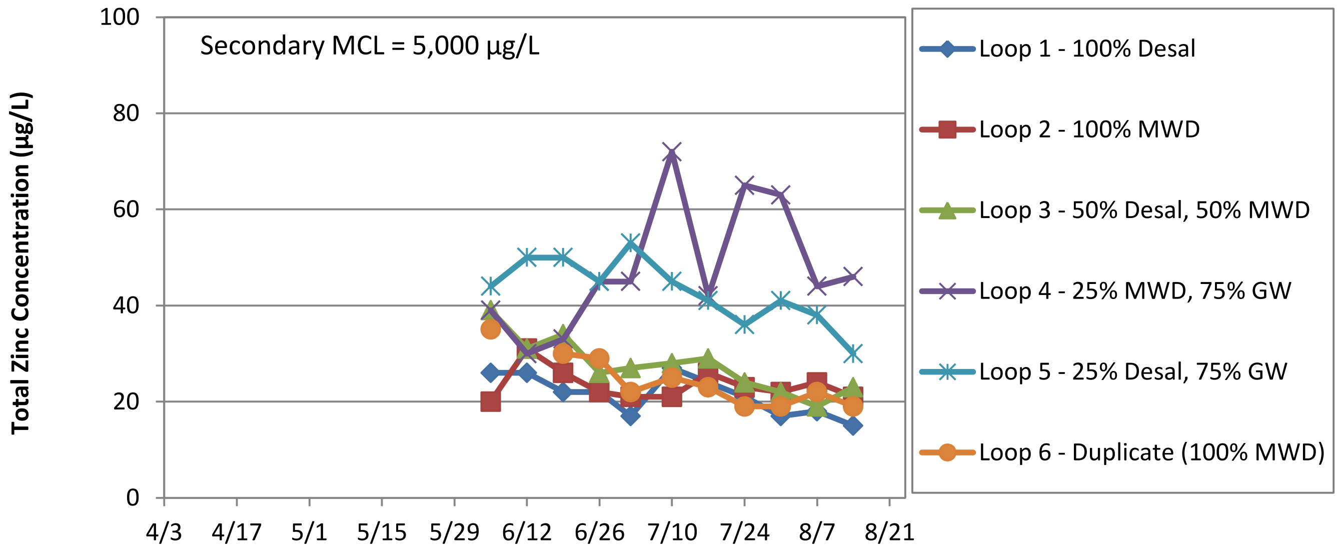


Loop 6 was switched from 100% MWD to 25% MWD/75% groundwater on 8/8/13.

Figure 4-25. Copper Concentrations in First Flush after Stagnation - Day 7, Brass Meters

Note: The copper result for Loop 5 on June 26, 2013, is not shown, as the 290 µg/L measurement was likely an analytical or sampling error considering the average copper concentration of 560 µg/L for this loop. The copper result for Loop 6 on July 26, 2013, is not shown, as the 590 µg/L measurement was likely an analytical or sampling error considering the average copper concentration of 301 µg/L for this loop.

Figure 4-26 shows zinc concentrations in the first–flush samples from brass meters after a stagnation period. Total zinc concentrations ranged from 15 to 27 µg/L for the 100% Desal loop and 20 to 31 µg/L for the 100% MWD loop. Similar zinc levels were observed for the other loops as well. Overall, zinc concentrations in water samples from all brass meters were well below the secondary MCL of 5,000 µg/L.



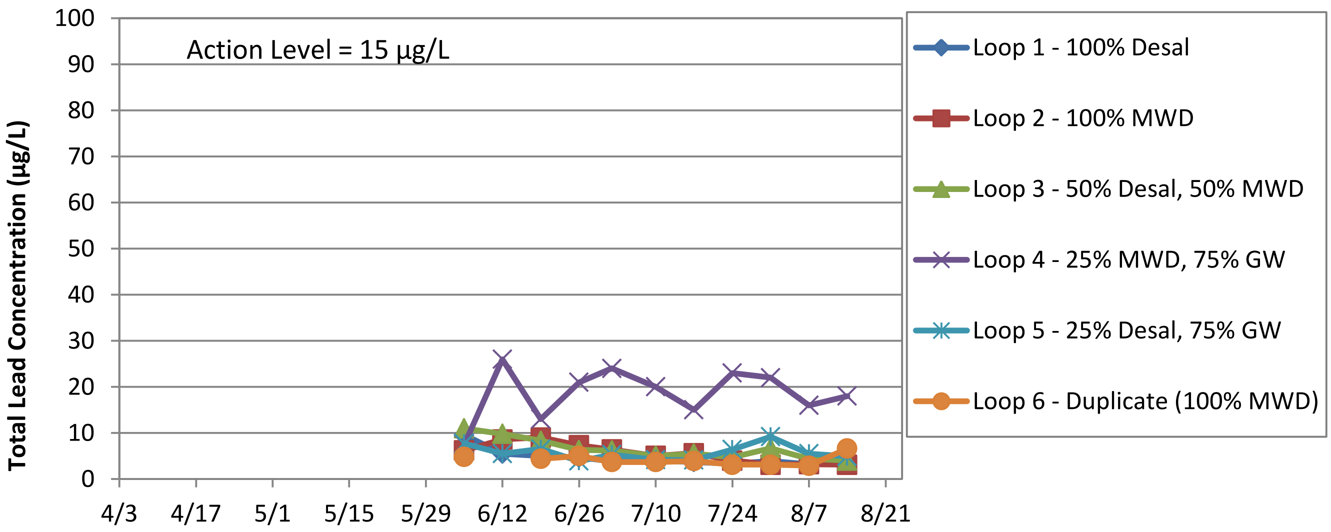
Loop 6 was switched from 100% MWD to 25% MWD/75% groundwater on 8/8/13.

Figure 4-26. Zinc Concentrations in First Flush after Stagnation - Day 7, Brass Meters

4.1.4.2 CU Pipes with Lead Solder

Total lead concentrations in the first-flush samples collected on Day 7 (i.e., water in contact with the copper pipe with lead solder) are provided in Figure 4-27. Total lead concentrations in the 100% Desal loop ranged from 3.2 to 9.6 µg/L, with an average of 4.6 µg/L. By comparison, the 100% MWD loop samples contained total lead between 3.1 and 9.0 µg/L, with an average of 5.6 µg/L. The duplicate 100% MWD loop samples contained total lead between 2.9 and 4.8 µg/L, with an average of 3.8 µg/L. Therefore, higher lead release was not observed for 100% Desal compared with 100% MWD water, and all lead concentrations were below the LCR Action Level of 15 µg/L.

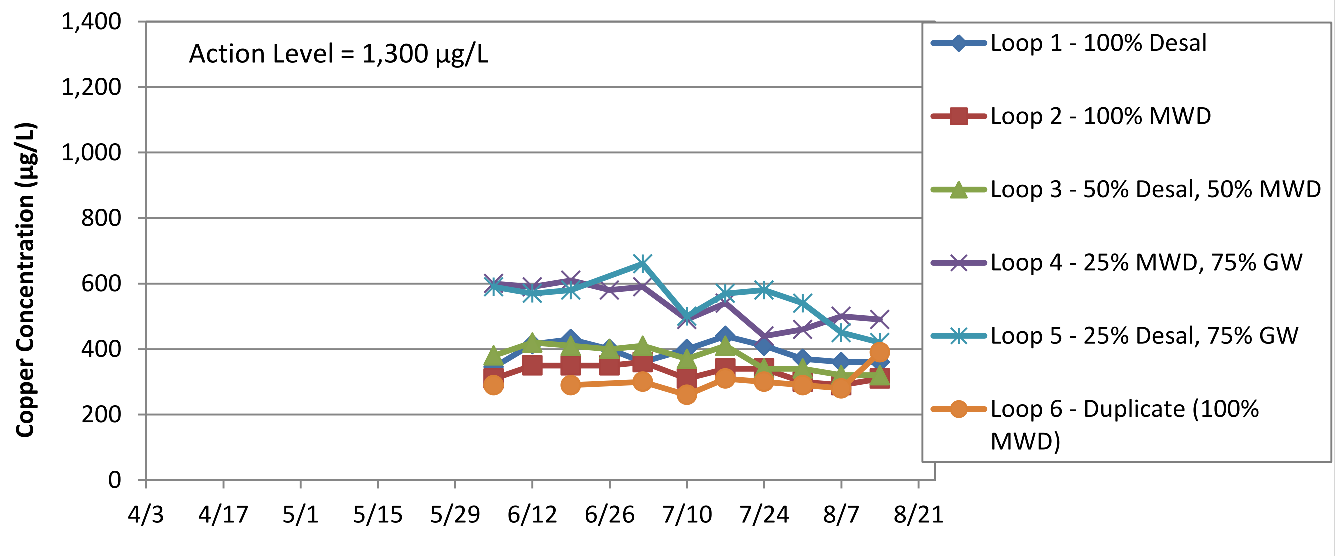
The blends of Desal with MWD and Desal with groundwater contained total lead at levels similar to the 100% Desal and 100% MWD loops. However, samples from the groundwater and MWD blend loop (Loop 4) showed higher total lead concentrations up to 26 µg/L with an average of 18.7 µg/L. To investigate the cause of higher lead release in Loop 4, the duplicate loop (Loop 6) was switched to the 25% MWD/75% groundwater blend during the last week of the study. The total lead concentration was 6.6 µg/L in the duplicate loop compared to 18 µg/L in Loop 4, indicating that variations in the pipe loops were partially responsible. To further investigate this question, a special set of samples was collected on September 12, 2013, after the study concluded when all loops were operated with 100% MWD water pending the final laboratory results. The total lead concentration in the first-flush sample taken from Loop 4 was 5.9 µg/L, compared to 2.7 µg/L from Loop 6. This finding indicates that the water quality of the MWD and groundwater blend may contribute to the higher lead leaching observed, in addition to variations in the loops, although the underlying reason is now known. No noticeable impact was observed for the other loops.



Loop 6 was switched from 100% MWD to 25% MWD/75% groundwater on 8/8/13.

Figure 4-27. Lead Concentrations in Composite Sample - Day 7, Copper Pipe with Lead Solder

Total copper concentrations in first-flush samples collected on Day 7 are shown in Figure 4-28. For the 100% Desal loop, copper concentrations ranged from 345 to 440 µg/L. Similar copper levels were observed in samples from the 100% MWD, the 50% Desal/50% MWD blend as well as the duplicate loop. Higher copper release was noted in the blends of groundwater with Desal and groundwater with MWD water, possibly due to higher alkalinity and/or the presence of higher ammonia concentrations. Overall, copper concentrations in all samples taken from the copper pipe loops were well below the LCR Action Level of 1,300 µg/L.



Loop 6 was switched from 100% MWD to 25% MWD/75% groundwater on 8/8/13.

Figure 4-28. Copper Concentrations in Composite Sample - Day 7, Copper Pipe with Lead Solder

Zinc concentrations in samples of stagnant water taken from the copper pipe are shown in Figure 4-29. In copper pipe samples, zinc concentrations ranged from 13 to 24 µg/L for the 100% Desal loop. Similar levels were observed for the other loops. Overall, zinc concentrations were well below the secondary MCL of 5,000 µg/L.

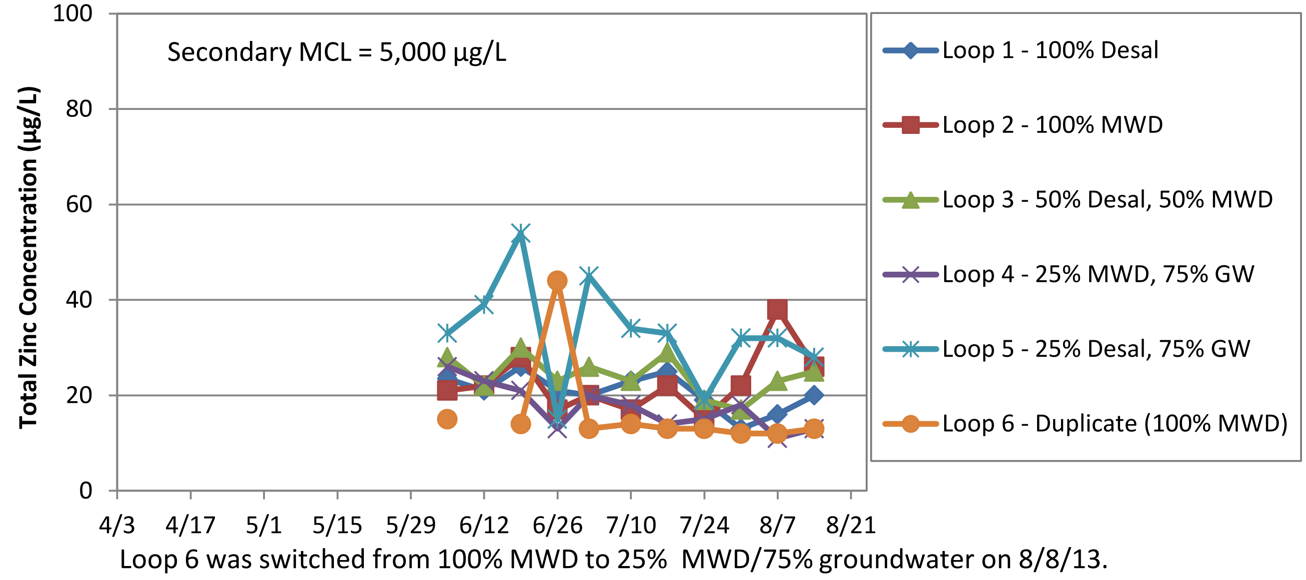


Figure 4-29. Zinc Concentrations in Composite Sample - Day 7, Copper Pipe with Lead Solder

4.1.5 Chloramine Stability

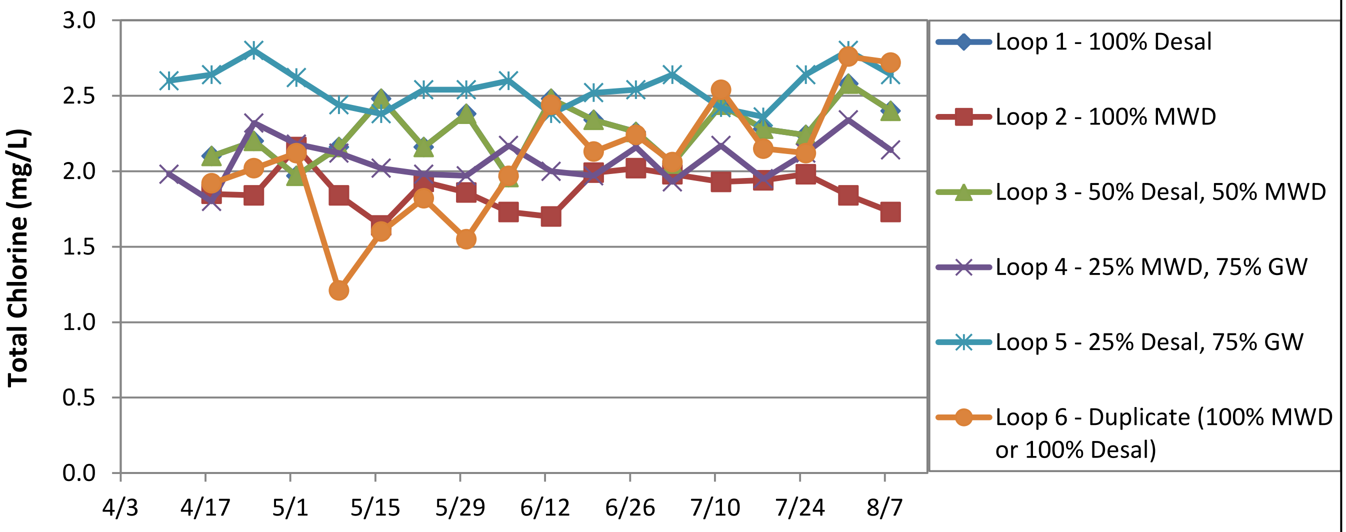
This section describes chloramine stability in the UCI, CML and CU pipe loops during the study. Total chlorine, total ammonia and nitrite were monitored on Day 1, Day 5 and Day 7 of each week for each pipe loop tank. Chloramines were boosted to meet the target chloramine concentration of 2.5 mg/L as Cl_2 on Day 5 beginning May 13, 2013.

As a complement to the pipe loop tests, MWD performed bench-scale testing for similar source water blends under controlled conditions. Results are presented in Appendix 2. Two extremes are offered: Bench-scale testing provides controlled conditions (pH, temperature, clean glassware) and pilot-scale testing provides impacts from pipes (but is more extreme than would occur in a distribution system).

UCI Pipes

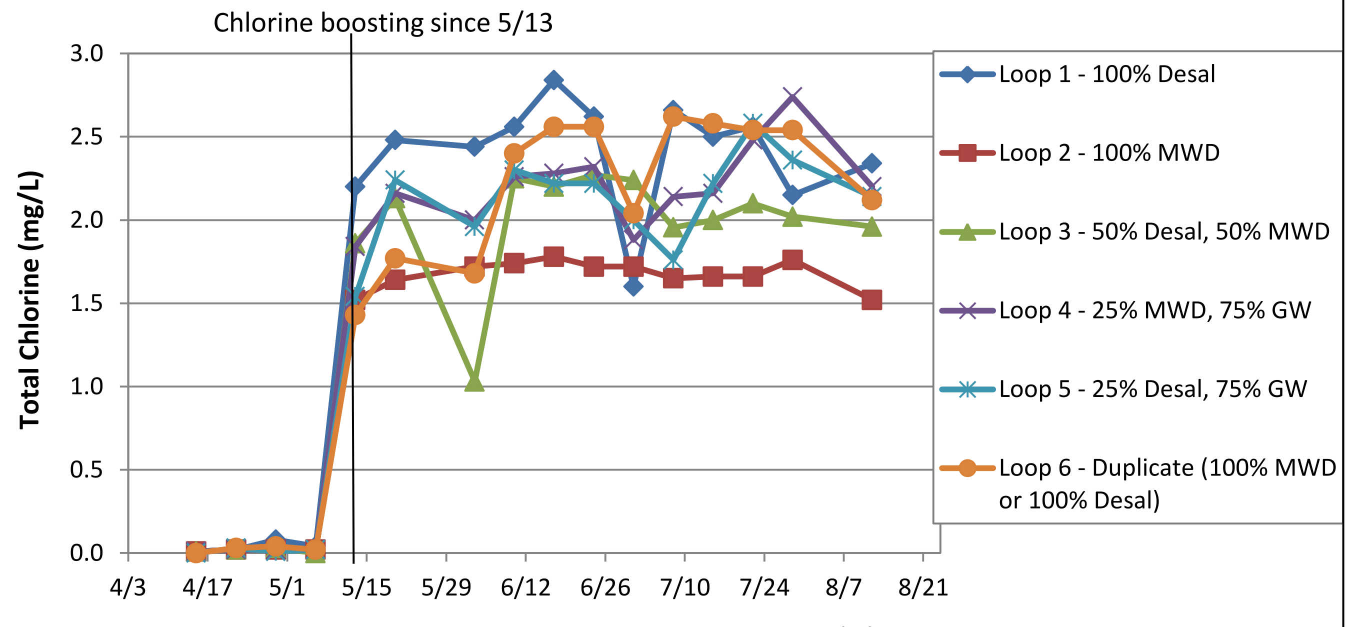
Total chlorine concentrations in the UCI pipe loop tanks on Day 1, Day 5 and Day 7 are shown in Figure 4-30, Figure 4-31 and Figure 4-32, respectively. Total chlorine concentrations in the water samples taken from the UCI pipe loop tanks were typically non-detect (< 0.02 mg/L) on

Day 5 for all the pipe loops, as shown in Figure 4-31 (before May 13, 2013). Extensive deposits and biogrowth in the pipes were hypothesized to exert a significant chloramine demand. Starting on May 13, 2013, total chlorine was boosted to the target levels on Day 5. Even with chlorine boosting, total chlorine loss occurred in the UCI pipe loops by Day 7, especially for Loops 4 and 5 that had high ammonia concentrations which resulted in nitrification. The other loops (1, 3, and 6) showed higher chlorine residuals with the chlorine boosting on Day 5. Note the pipe loop test with water recirculated for seven days do not represent real conditions in a distribution system. The chlorine loss observed in the pipe loop test does not reflect the same chlorine loss would be expected in a distribution system. However, results showed that the 25% MWD/75% GW blend and the 25% Desal/75% GW blend are the mostly likely to lose chlorine, followed by the other water qualities in UCI pipes.



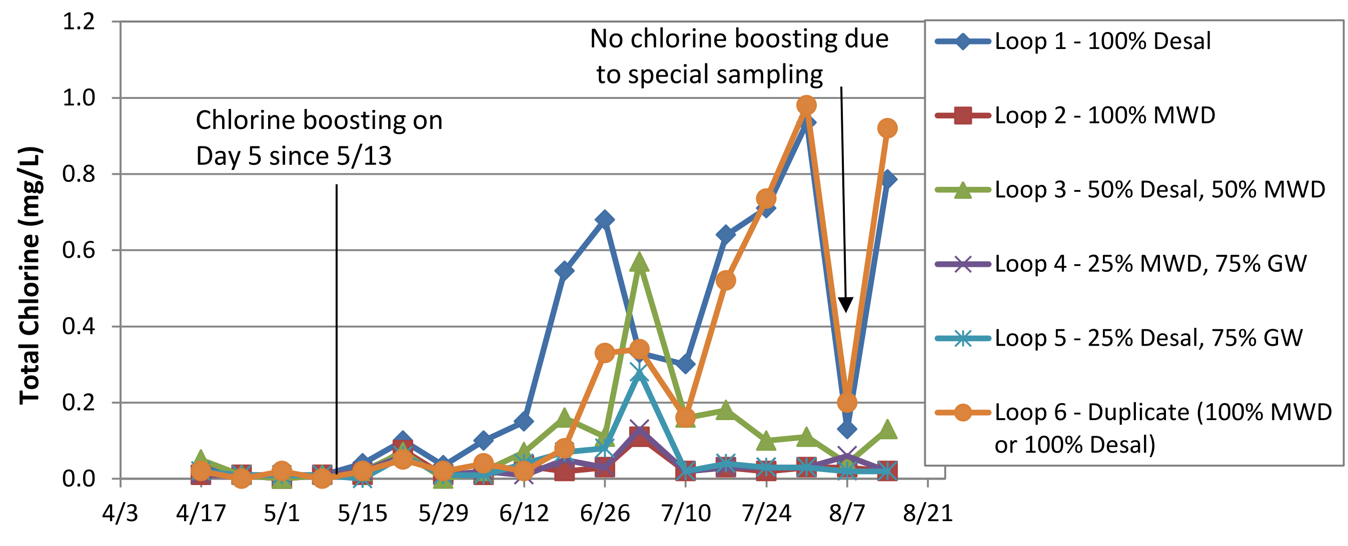
Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-30. Total Chlorine Concentrations in Uncirculated Water - Day 1, UCI Pipe Loops



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

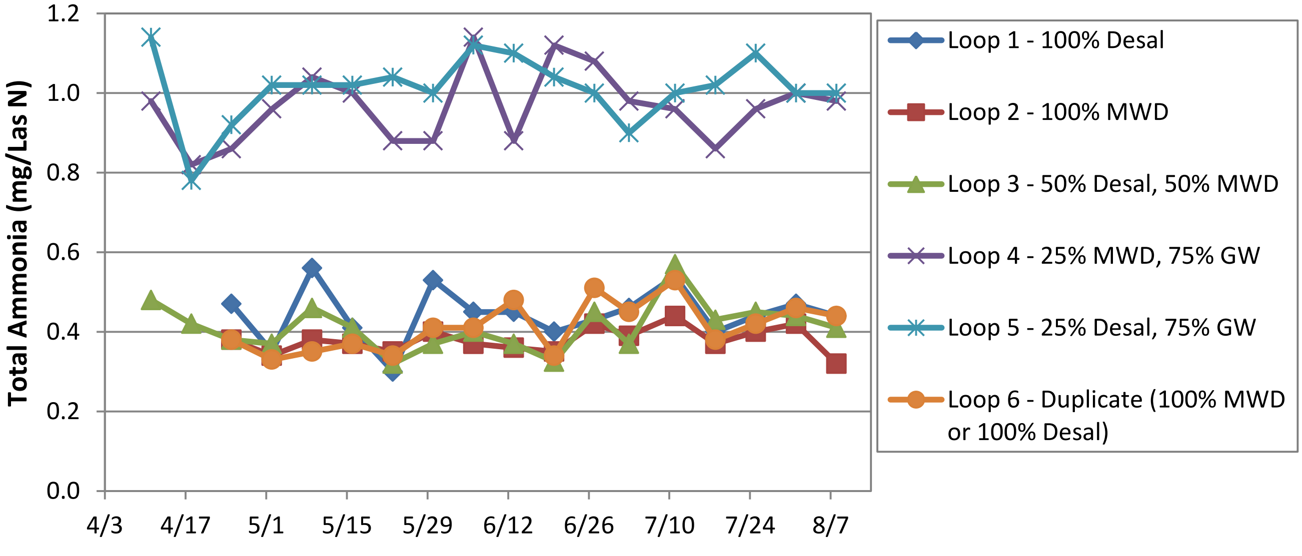
Figure 4-31. Total Chlorine Concentrations in Recirculated Water - Day 5, UCI Pipe Loops



Loop 6 was switched from 100% MWD to 100% desal on 6/6/13.

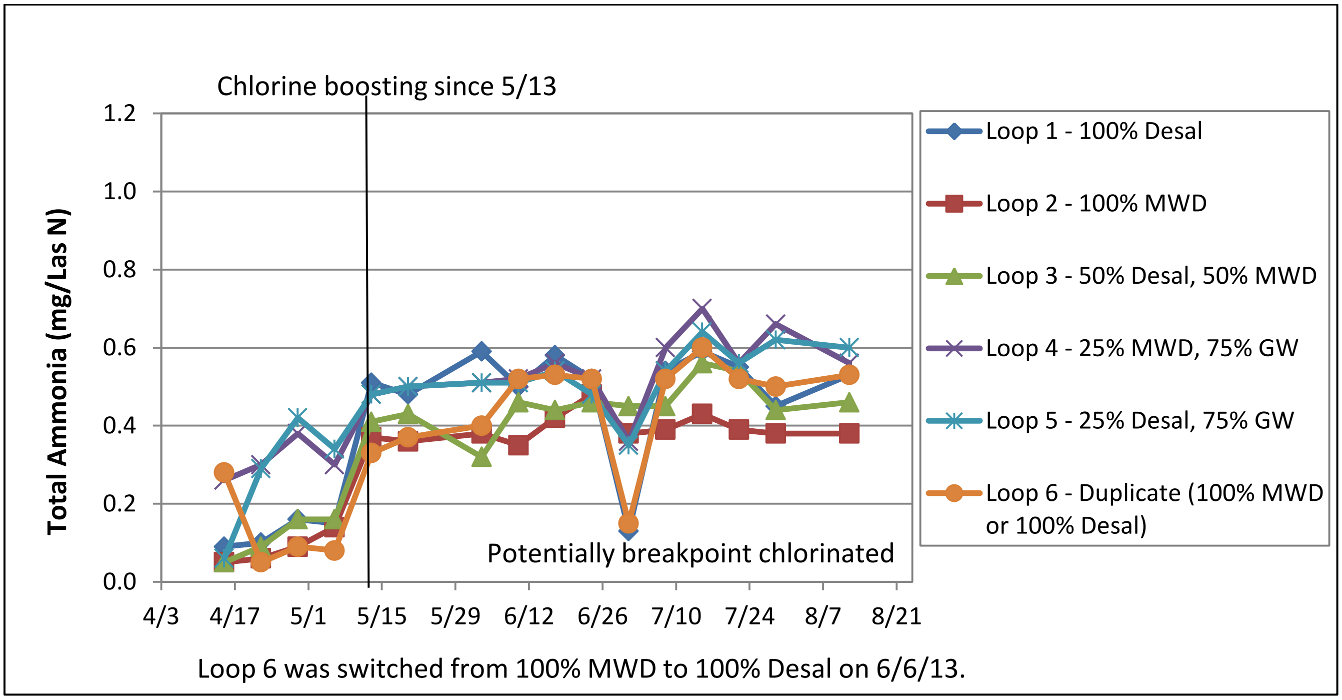
Figure 4-32. Total Chlorine Concentrations in Recirculated Water - Day 7, UCI Pipe Loops

Total ammonia concentrations in the UCI pipe loop tanks on Day 1, Day 5 and Day 7 are shown in Figure 4-33, Figure 4-34 and Figure 4-35, respectively. The blends of groundwater with MWD water and groundwater with Desal (Loops 4 and 5) contained high ammonia levels due to naturally-occurring ammonia in the groundwater. The high levels of natural ammonia in the blends (approximately 0.8 to 1.1 mg/L NH_3-N) together with a total chlorine residual of 2.5 mg/L meant that free ammonia remained in the waters for the groundwater blend loops. Ammonia loss was observed, from 0.8 – 1.1 mg/L NH_3-N on Day 1 to 0.12 - 0.24 mg/L NH_3-N on Day 7 in the first four weeks without boosting on Day 5. Increasing nitrification was observed as the study progressed through the summer, as indicated by the concentrations of nitrite measured in the test waters (0.32 – 0.33 mg/L NO_2-N in Week 5). Total ammonia loss continued even with chlorine and ammonia boosting on Day 5, which was attributed to nitrification.



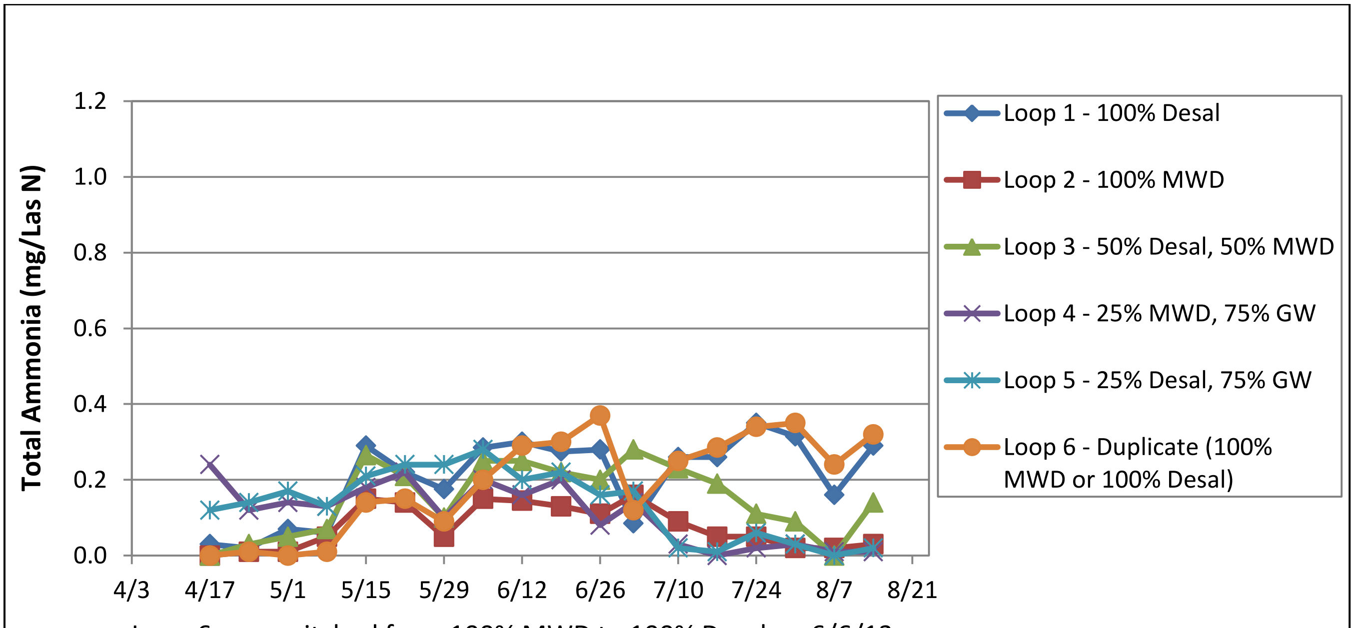
Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-33. Total Ammonia Concentrations in Uncirculated Water - Day 1, UCI Pipe Loops



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-34. Total Ammonia in Recirculated Water - Day 5, UCI Pipe Loops

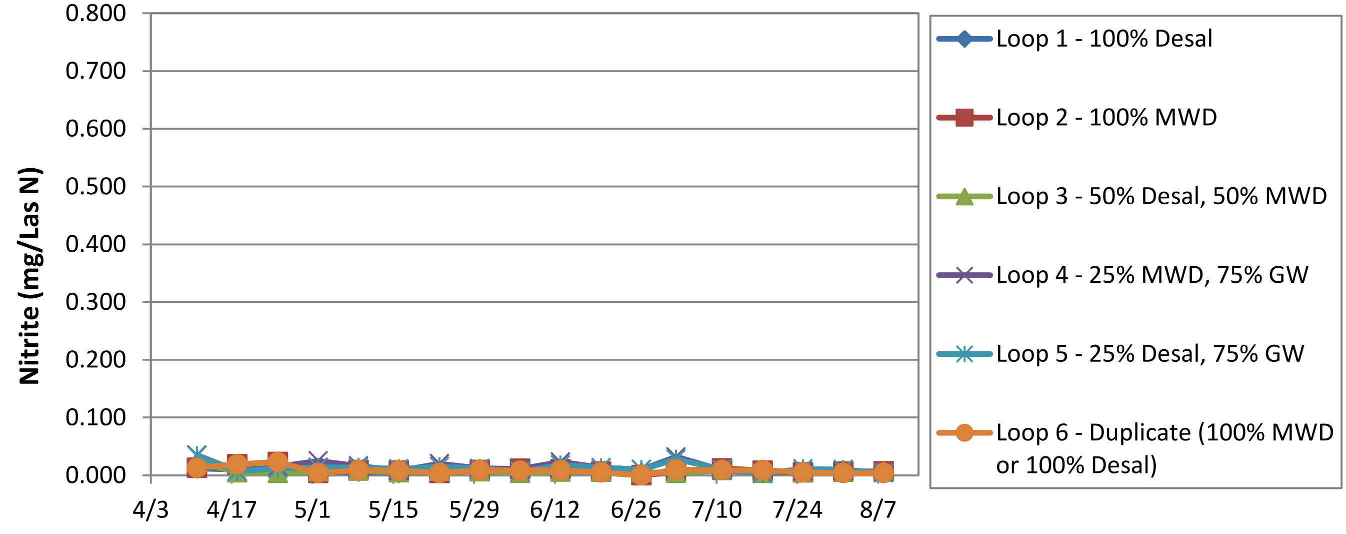


Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-35. Total Ammonia in Recirculated Water - Day 7, UCI Pipe Loops

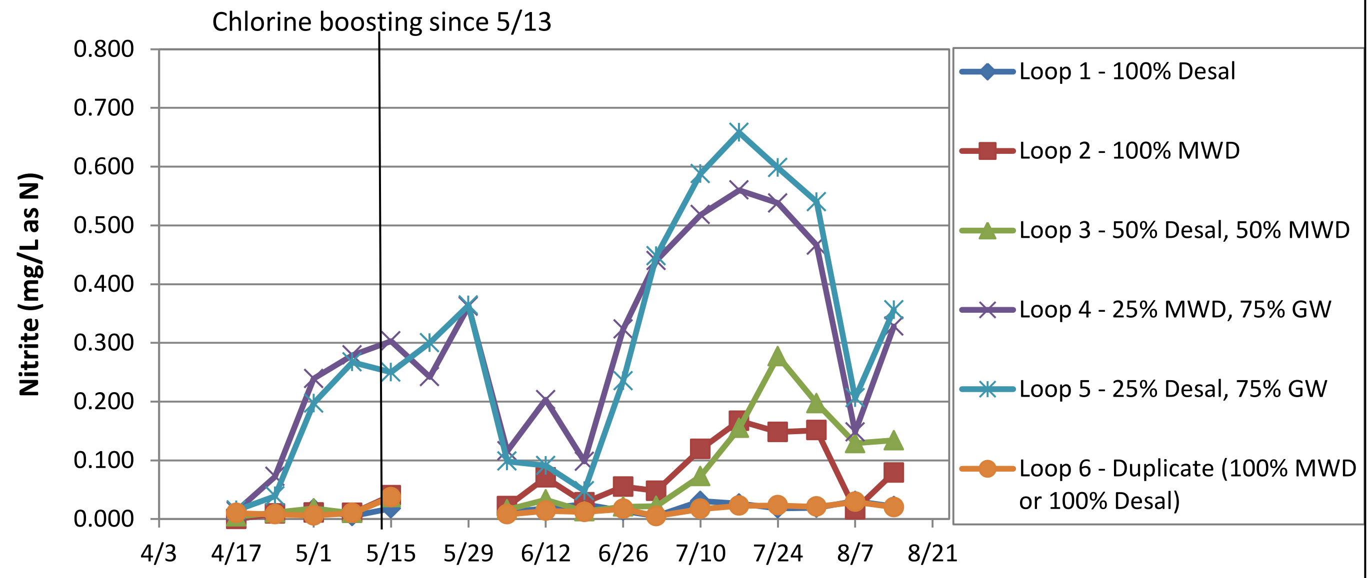
Nitrite concentrations in the UCI loop tanks on Day 1 are shown in Figure 4-36 and on Day 7 in Figure 4-37. Little if any nitrite was present in uncirculated test waters on Day 1, which were typically below 0.010 mg/L as N. Nitrite levels rose in all loops on Day 7 compared to Day 1, especially in Loops 4 and 5. Chlorine boosting on Day 5 helped to reduce nitrite levels (by comparing nitrite levels on Day 5 before boosting and the levels on Day 7), although a trend of increasing nitrite concentrations by Day 7 and throughout the study proved the development of nitrification in the pipes.

Jar testing was conducted to see if the chlorine loss observed in the pipe loop tanks was caused by ammonia oxidizing bacteria residing in the pipe tuberculation or in the test water. During Week 4, uncirculated water from the 6 loops on Day 1 were collected and held in amber glass bottles on the site at ambient air temperature. The jar samples were tested for total chlorine, total ammonia and nitrite on Day 1 and Day 7, for comparison with the uncirculated and recirculated waters in the pipe loops. Total chlorine concentrations in the jars were much higher than in the recirculated waters on Day 7 (Figure 4-38). Total ammonia concentrations did not change substantially in the jars over the seven days, while ammonia dropped in the pipe loop recirculated waters (Figure 4-39). Large differences in nitrite concentrations were also observed between the water held in the jars and the water recirculated through the pipe loops for loops 4 and 5 containing groundwater blends (Figure 4-40). The total chlorine, total ammonia and nitrite results indicate that chlorine loss in the UCI loops was mostly caused by nitrification occurring (due to high free ammonia) or beginning in the pipe deposits rather than from the test water.



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-36. Nitrite Concentrations in Uncirculated Water - Day 1, UCI Pipe Loops



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-37. Nitrite Concentrations in Recirculated Water - Day 7, UCI Pipe Loops

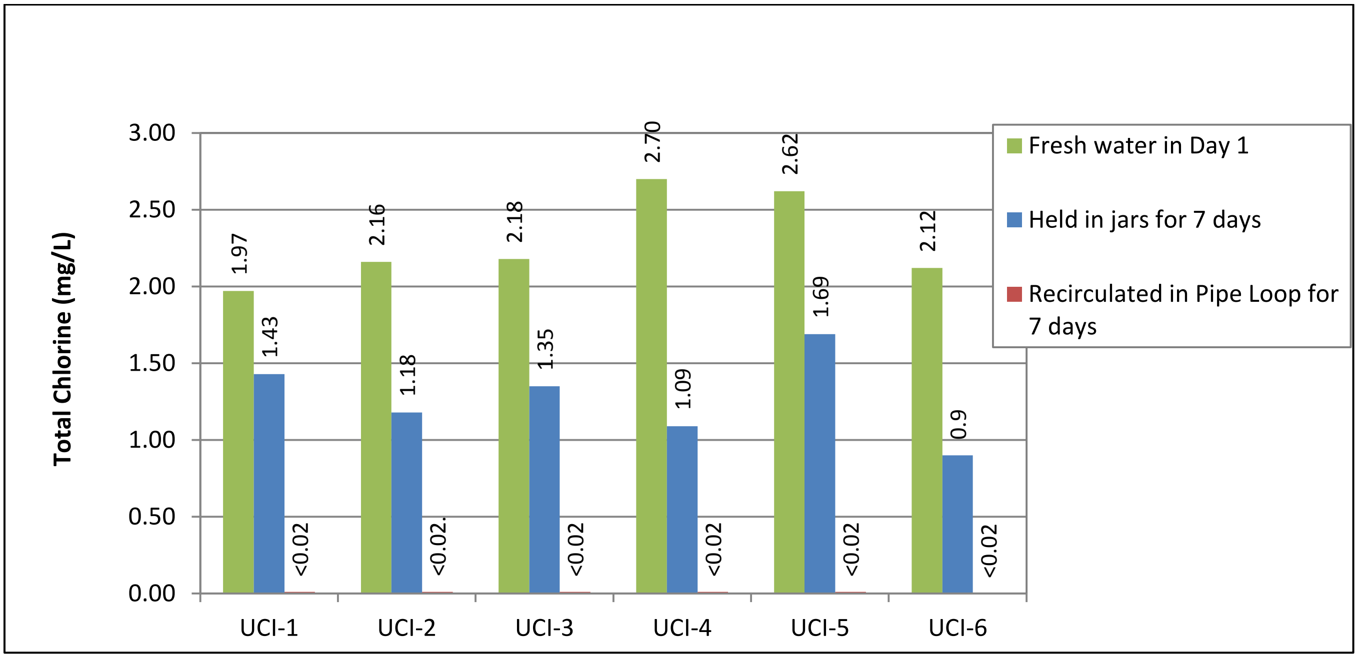


Figure 4-38. Comparison of Total Chlorine in UCI Loop Tanks and Jars – Week 4

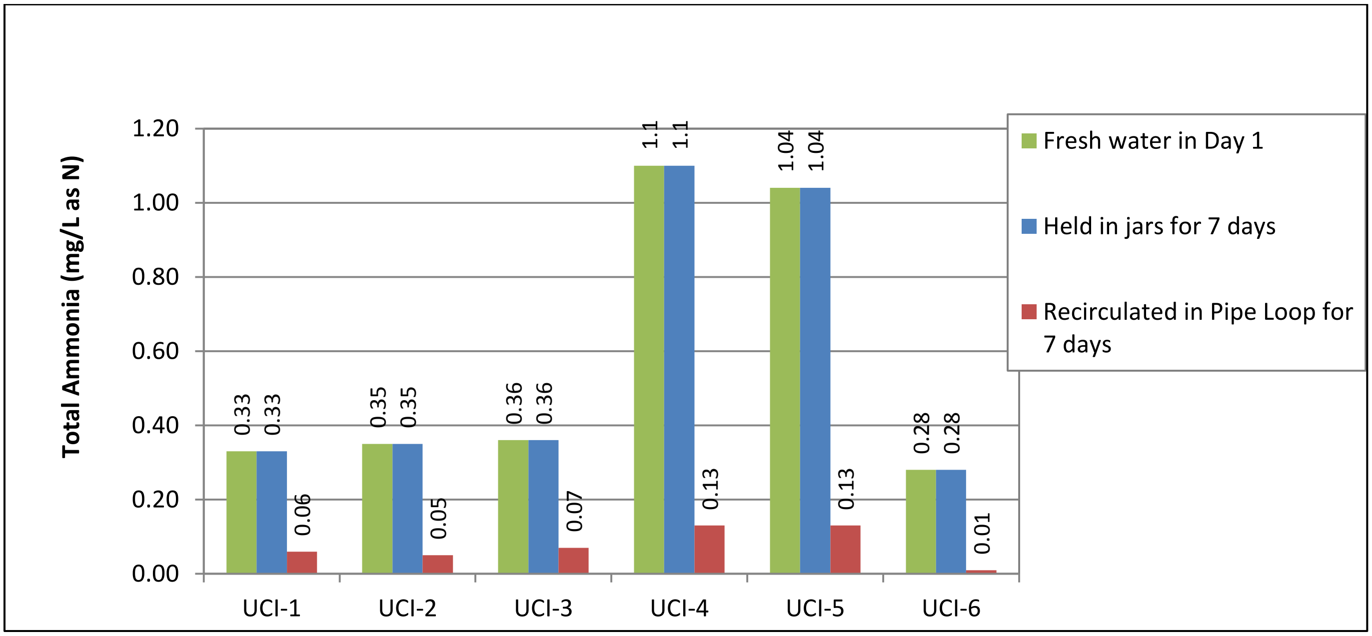


Figure 4-39. Comparison of Total Ammonia in UCI Loop Tanks and Jars – Week 4

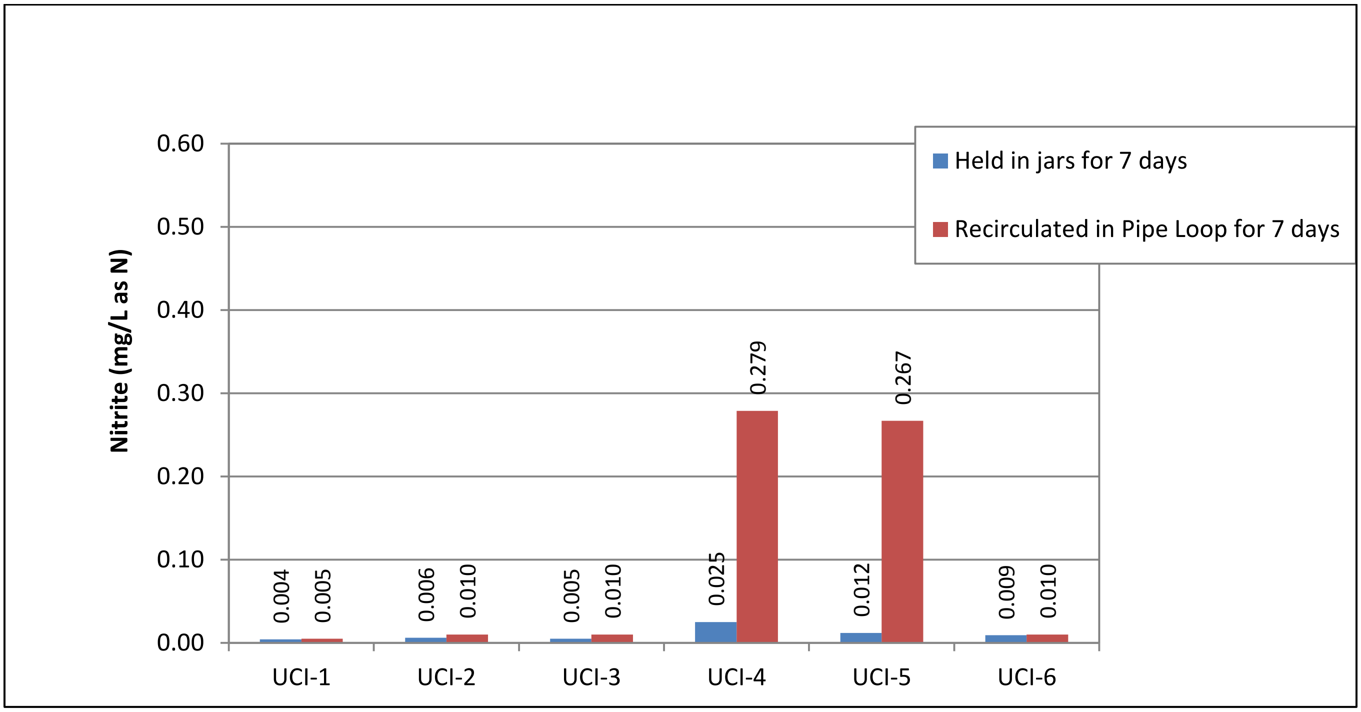
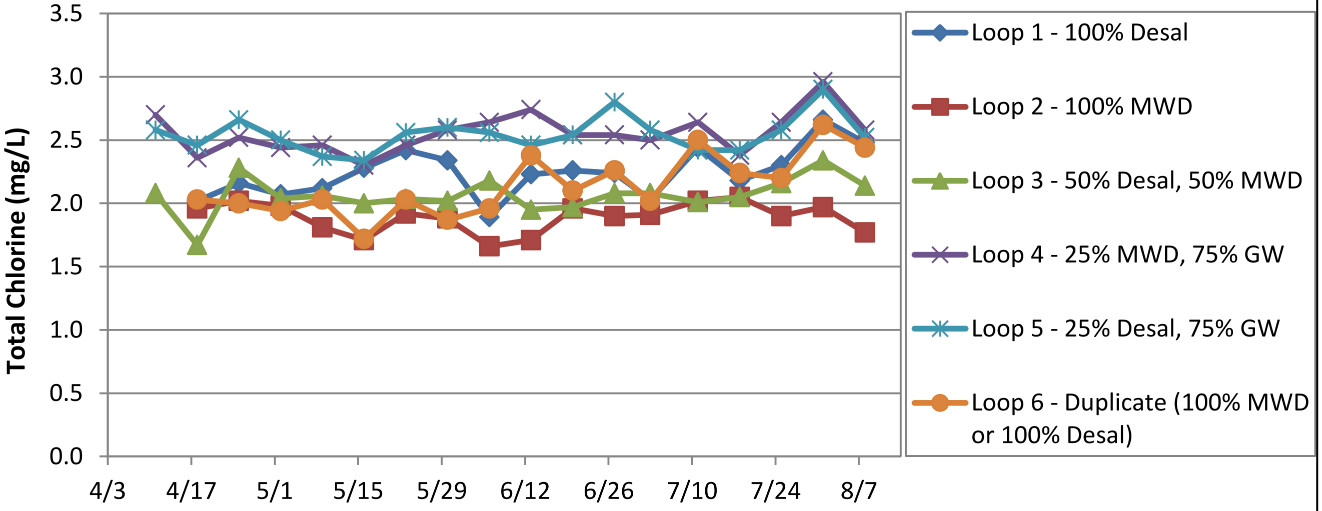


Figure 4-40. Comparison of Nitrite in UCI Loop Tanks and Jars – Week 4

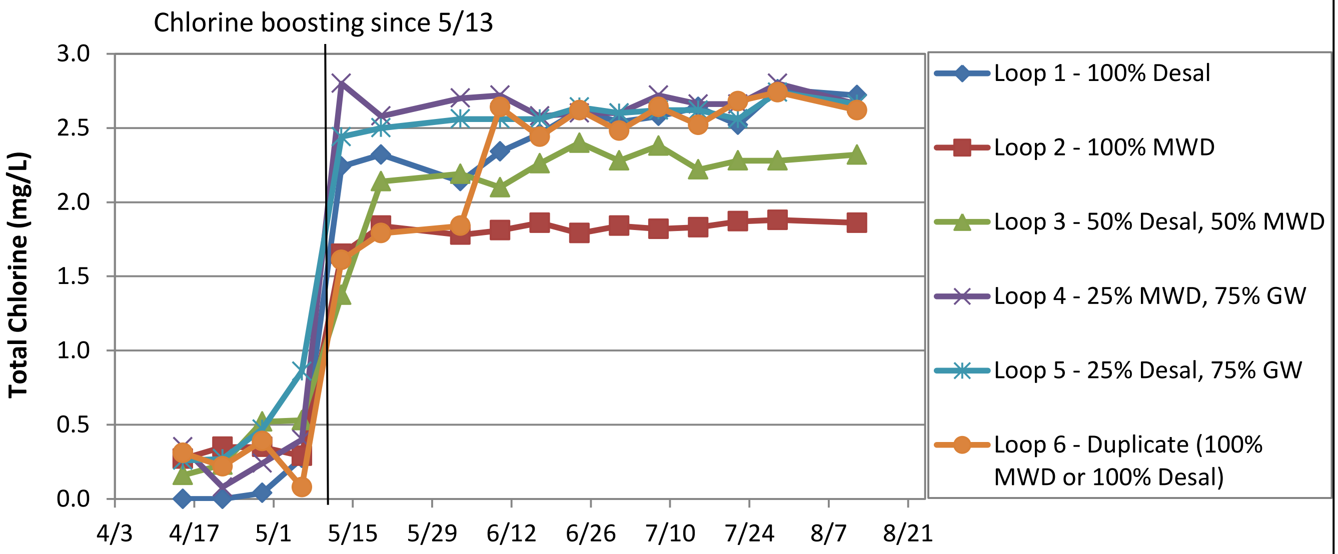
CML Pipes

Total chlorine concentrations in the CML pipe loop tanks on Day 1, Day 5 and Day 7 are shown in Figure 4-41 through Figure 4-43. High chlorine loss was observed on Day 5 (before chloramine boosting on May 13, 2013, shown on Figure 4-42) compared to the levels in uncirculated waters on Day 1 (Figure 4-41). Total chlorine was boosted to target levels on Day 5 beginning on May 13, 2013, and acceptable chlorine residuals were maintained through Day 7 in subsequent weeks.



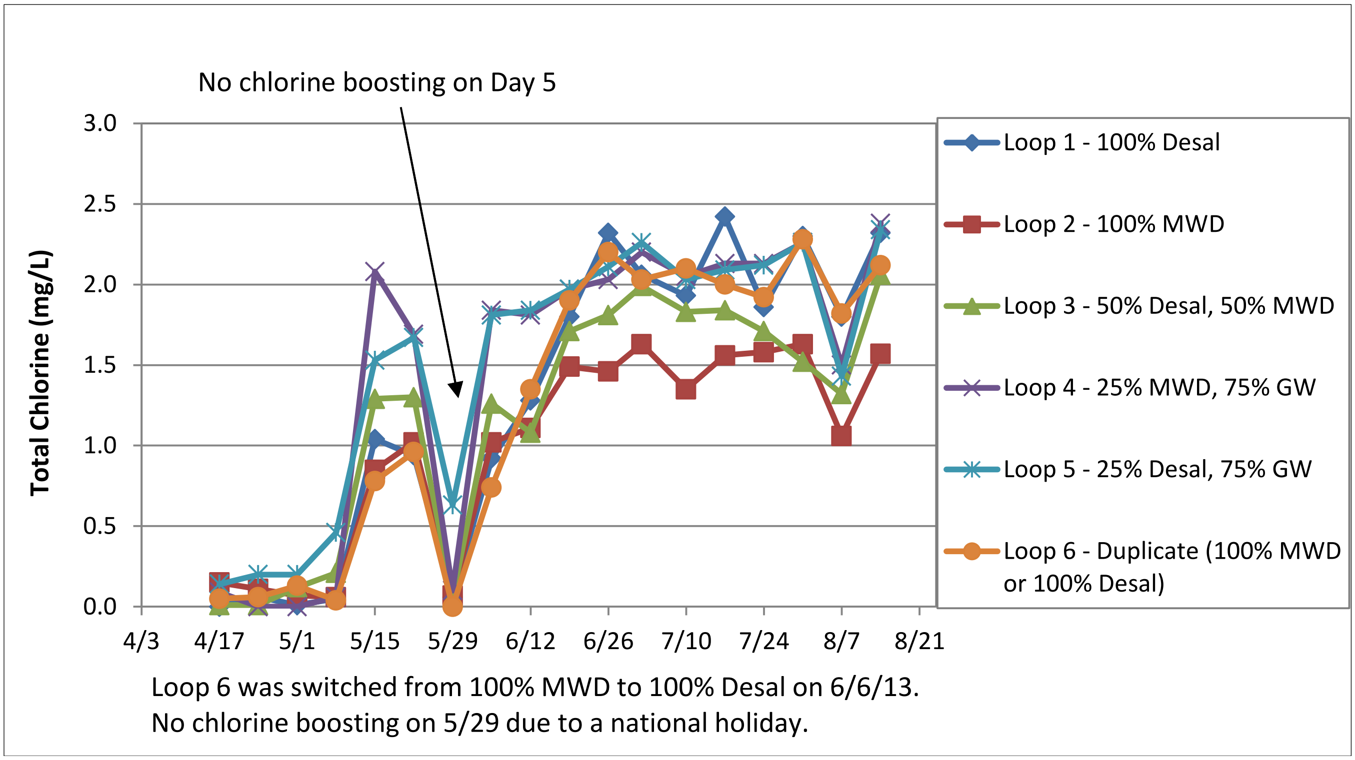
Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-41. Total Chlorine in Uncirculated Water - Day 1, CML Pipe Loops



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

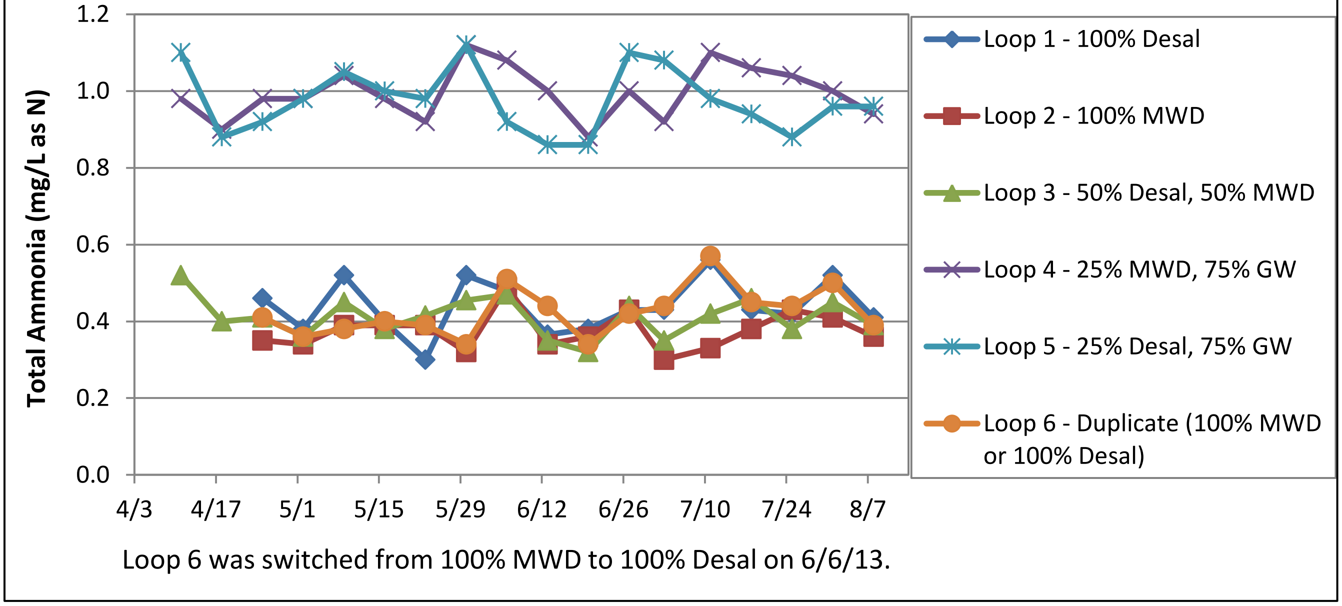
Figure 4-42. Total Chlorine in Recirculated Water - Day 5, CML Pipe Loops



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.
No chlorine boosting on 5/29 due to a national holiday.

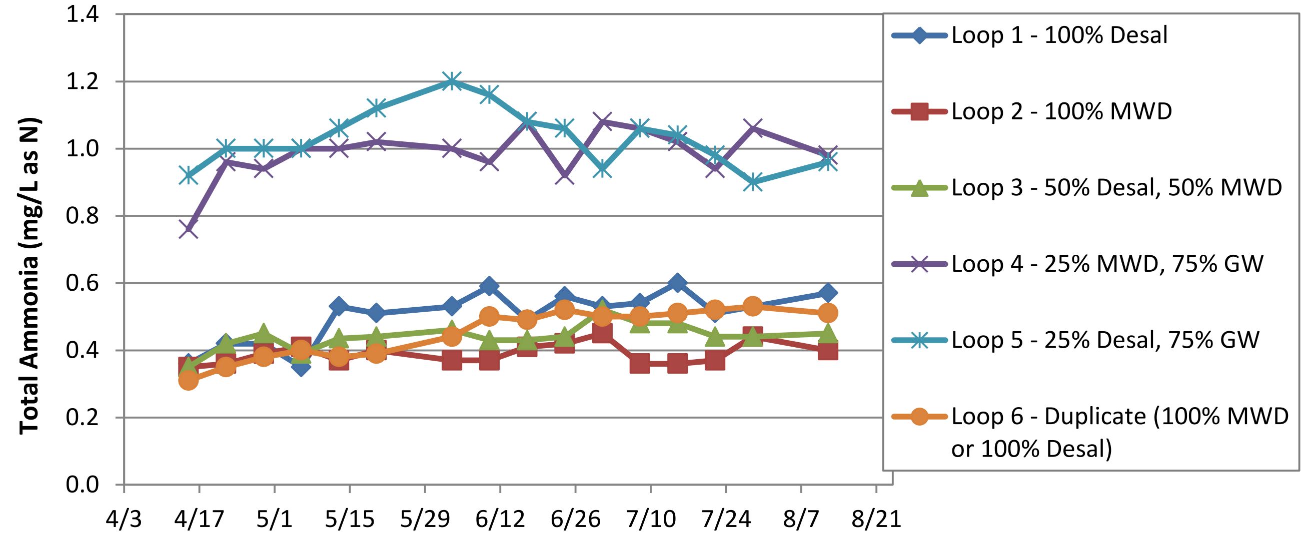
Figure 4-43. Total Chlorine in Recirculated Water - Day 7, CML Pipe Loops

Total ammonia in the CML pipe loop tanks on Day 1, Day 5, and Day 7 are shown in Figure 4-44 through Figure 4-46, respectively. For all loops, a large ammonia loss was not observed on Day 5 compared to Day 1, so no ammonia addition was needed to boost the chloramine concentration. Ammonia concentrations were stable through Day 7. In addition, nitrite concentrations on Day 7 were typically below 0.010 mg/L as N (data not shown), showing that there was no nitrification in the CML pipes. Therefore, the chlorine loss observed on Day 5 was caused by chlorine demand from the pipe material and demand in the water rather than nitrification. This finding also indicates that biofilms in the tuberculation within the UCI pipe was responsible for the nitrification, rather than the test waters, as the water qualities were initially the same for both the UCI and CML pipe loops.



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-44. Total Ammonia in Uncirculated Water - Day 1, CML Pipe Loops



Loop 6 was switched from 100% MWD to 100% Desal on 6/6/13.

Figure 4-45. Total Ammonia in Recirculated Water - Day 5, CML Pipe Loops

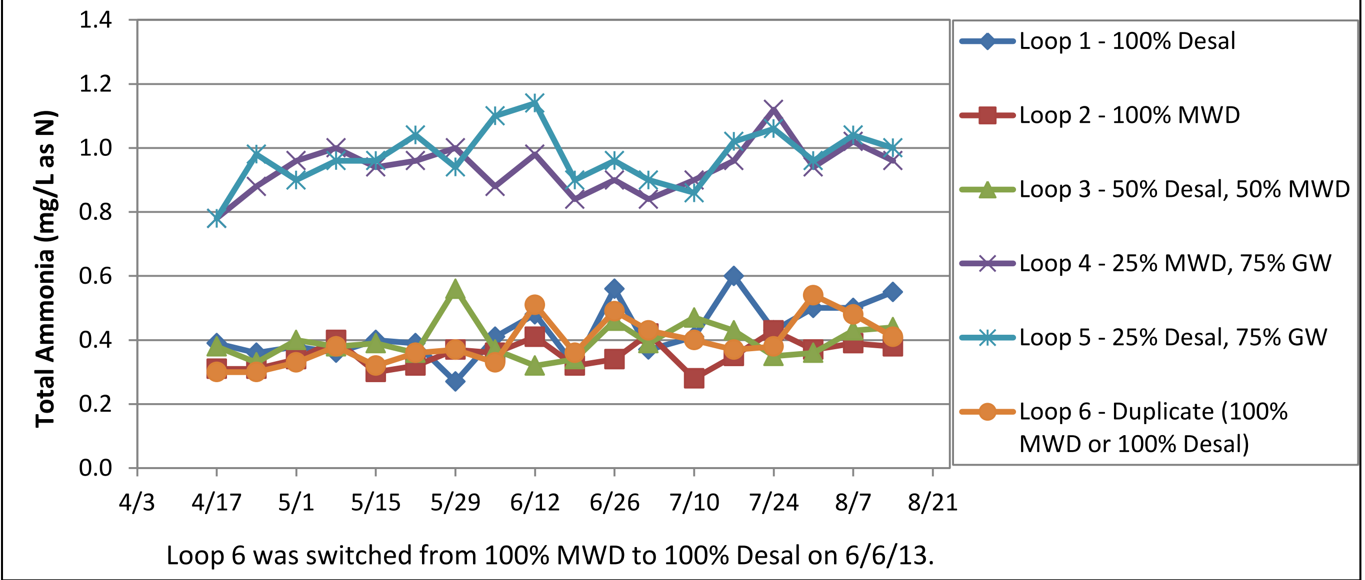
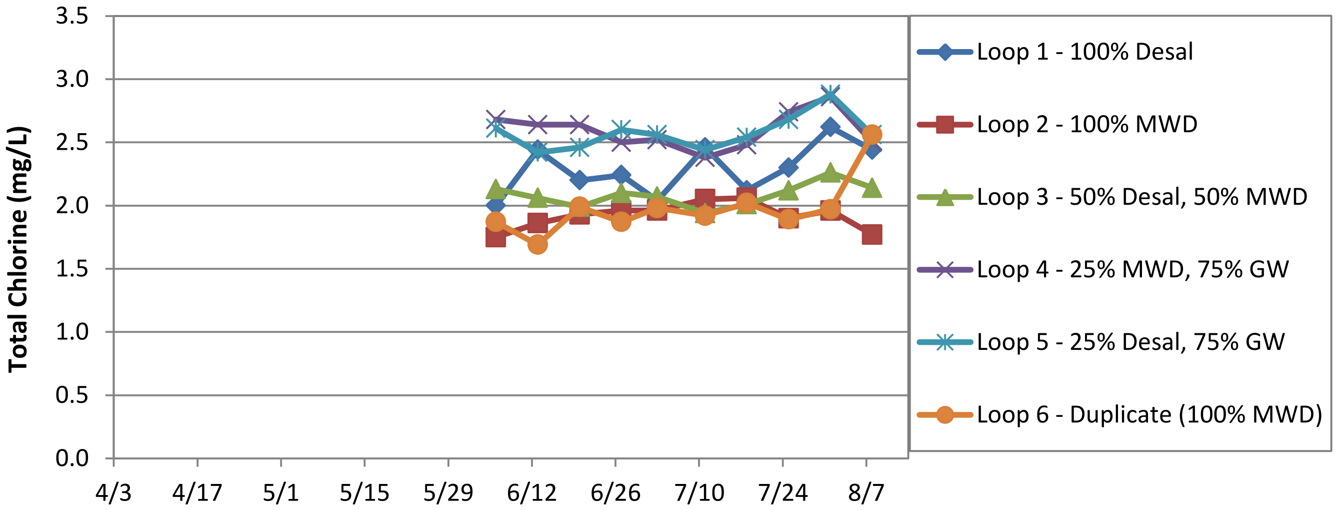


Figure 4-46. Total Ammonia in Recirculated Water - Day 7, CML Pipe Loops

CU Pipes

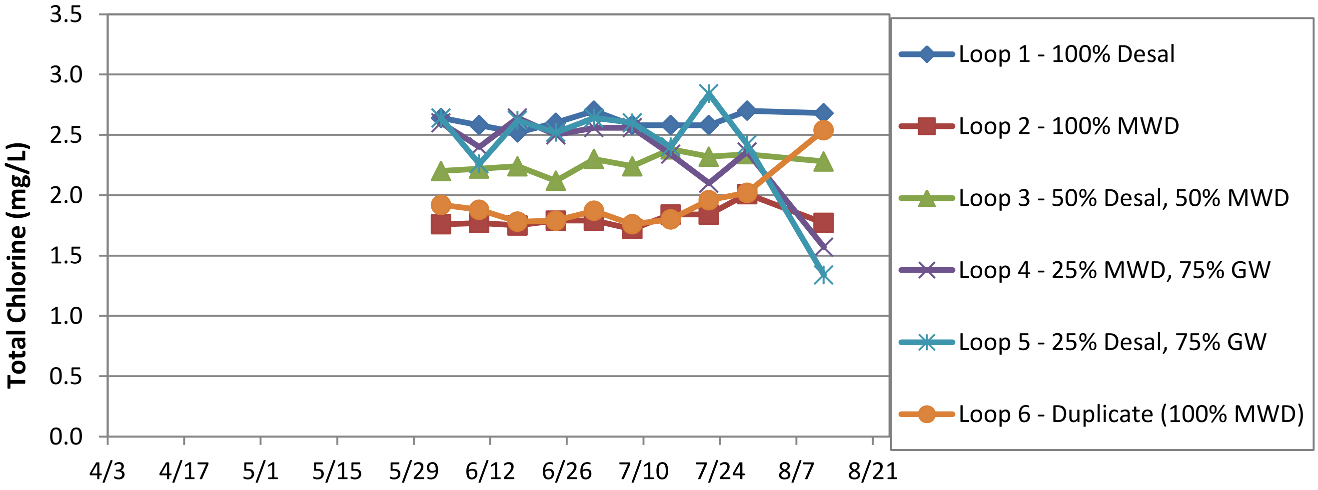
Total chlorine concentrations in the CU pipe loop tanks on Day 1 and Day 5 are shown in Figure 4-47 and Figure 4-48, respectively. For the CU pipe loops, water was not recirculated like UCI and CML loops. Instead, water from the tanks flowed through the copper pipe loops out to waste twice a day. Therefore, the chlorine loss observed in samples collected from the tanks represented chlorine demand in the tanks and water, not the pipes. The blends of groundwater with MWD and Desal water (Loops 4 and 5) showed a high degree of total chlorine loss by the end of study, which was likely due to nitrification as indicated by increases in nitrite and decreases in ammonia concentrations.

Total chlorine levels in first-flush samples taken from test waters in contact with the copper pipes on Day 7 are shown in Figure 4-49. The first-flush samples were composite samples from copper pipe (excluding brass meters) as brass meter samples had limited volume and were used to monitor metals release. A high degree of chlorine loss was observed in the first-flush samples compared to chlorine concentrations in uncirculated waters. The chlorine loss range was 1.3 – 1.8, 1.5 – 1.9, 1.3 – 1.9, 2.2 – 2.8, 1.5 – 2.8, 1.4 – 1.9 for Loops 1 through 6, respectively. The chlorine loss in Figure 4-49 represents chlorine demand by the copper pipes/brass meters during the stagnation periods, compared with the tank (Figure 4-47 and Figure 4-48). New copper pipe is also known to cause chloramine decay. In addition, more chlorine loss was noted for Loops 4 and 5, which was likely caused by nitrification.



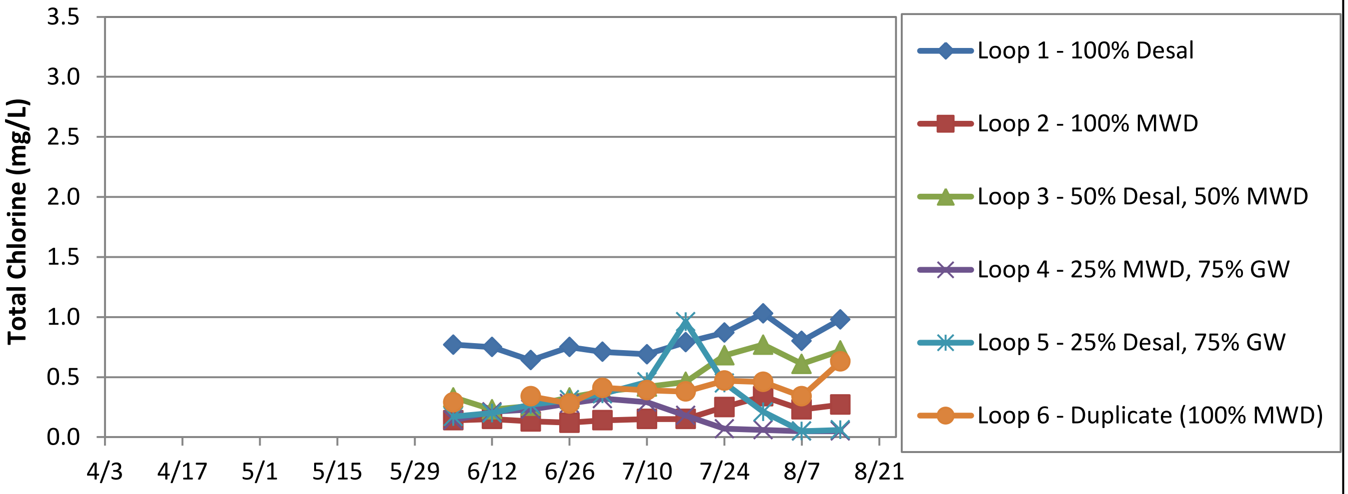
Loop 6 was switched from 100% MWD to 25% MWD/75% groundwater on 8/8/13.

Figure 4-47. Total Chlorine in CU Loop Tanks on Day 1



Loop 6 was switched from 100% MWD to 25% MWD/75% groundwater on 8/8/13.
Lower chlorine residual for Loops 4 and 5 on 8/12 due to fast chlorine consumption by nitrification.

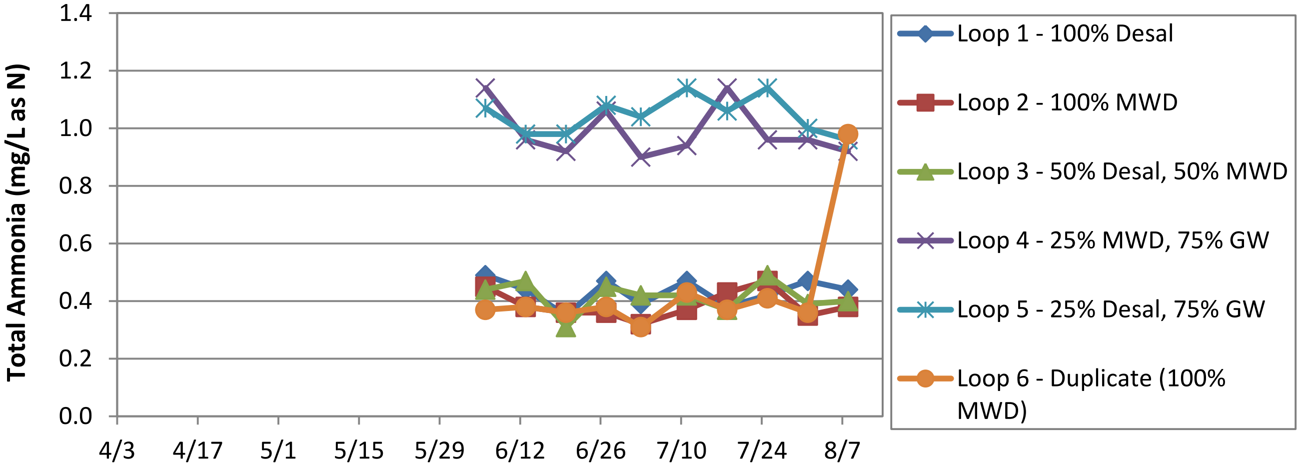
Figure 4-48. Total Chlorine in CU Loop Tanks on Day 5



Loop 6 was switched from 100% MWD to 25% MWD/75% groundwater on 8/8/13.

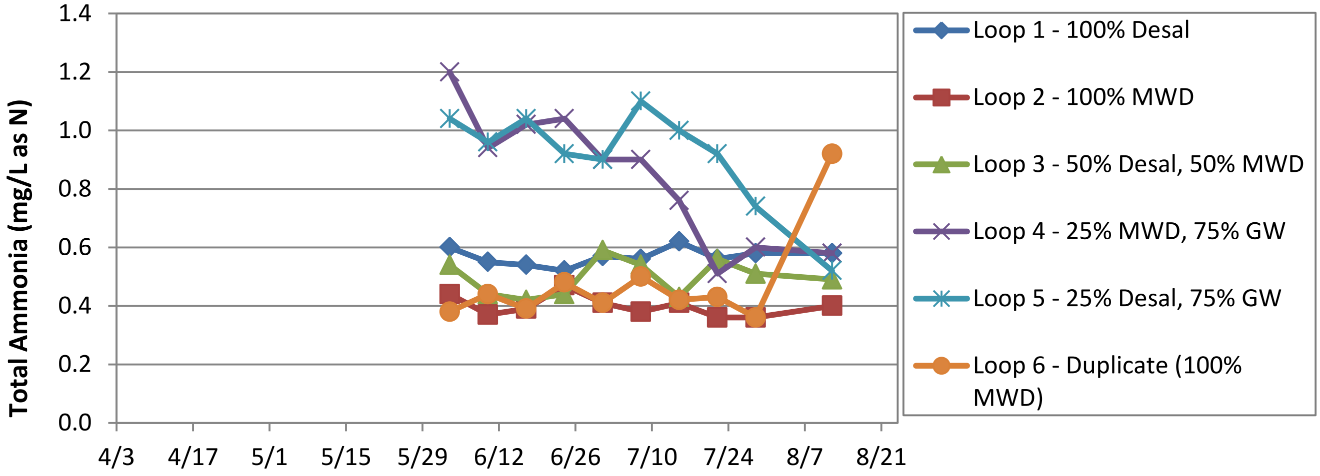
Figure 4-49. Total Chlorine in First Flush from CU Pipes on Day 7

Figure 4-50 and Figure 4-51 show total ammonia concentrations in the copper pipe loop tanks on Day 1 and Day 5, respectively. Total ammonia levels in the blends of 25% MWD/75% groundwater and 25% Desal/75% groundwater (Loops 4 and 5) strongly decreased from Day 1 to Day 5. Typically, ammonia was not added to the pipe loop tanks for Loops 4 and 5 on Day 5 due to the high naturally-occurring ammonia levels in groundwater. Figure 4-52 shows total ammonia concentrations in the first-flush samples from copper pipes on Day 7. Total ammonia levels in first-flush samples for all loops decreased compared to Day 5, particularly in the groundwater blend loops (Loops 4 and 5). Nitrite concentrations in first-flush samples in Loops 4 and 5 were up to 0.528 and 0.728 mg/L NO_2-N, respectively, suggesting severe nitrification occurred in these loops in the last 2 months of the study period (Figure 4-53; loops with groundwater). Nitrification was likely due to accumulation of AOB and warmer temperatures. This finding is consistent with the prevalence of free ammonia in the groundwater, which served as a good source for ammonia oxidizing bacteria.



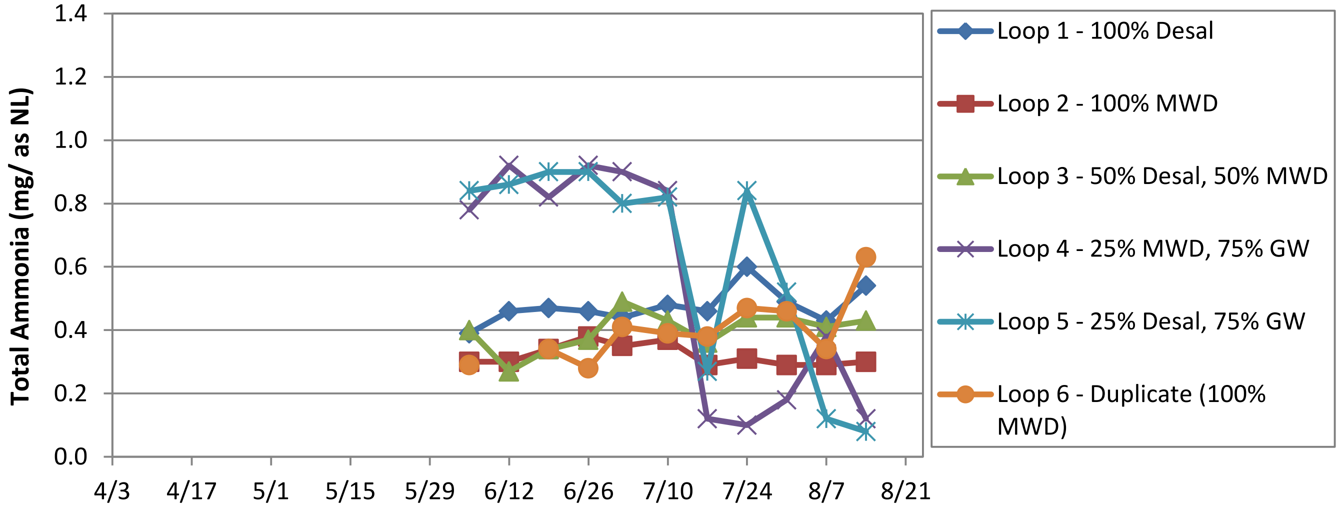
Loop 6 was switched from 100% MWD to 25% MWD/75% groundwater on 8/8/13.

Figure 4-50. Total Ammonia Concentrations in CU Loop Tanks on Day 1



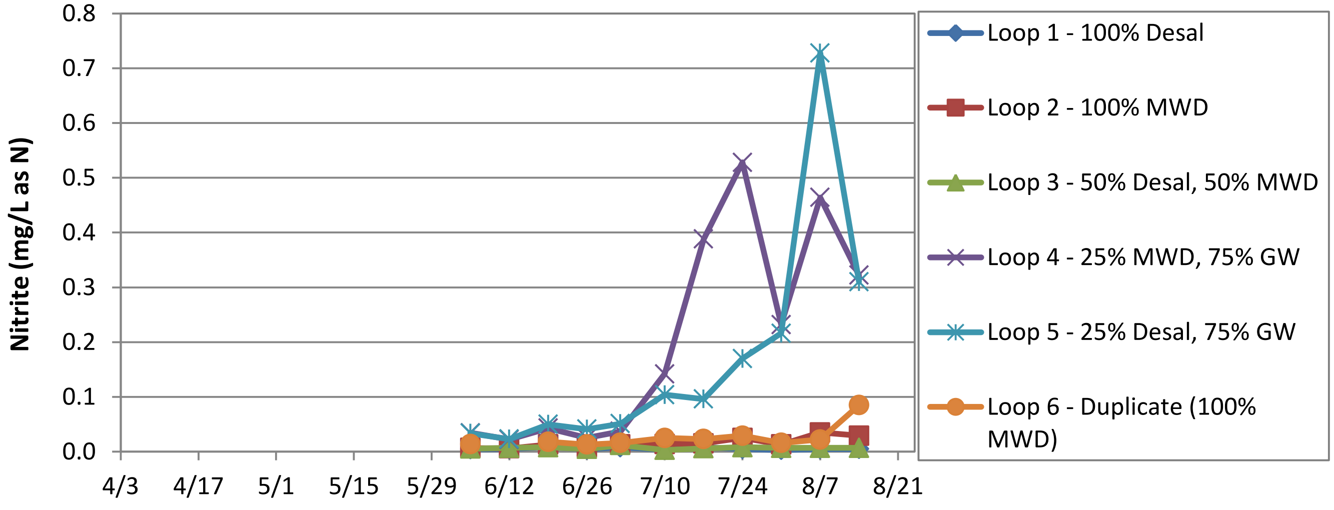
Loop 6 was switched from 100% MWD to 25% MWD /75% groundater on 8/8/13.

Figure 4-51. Total Ammonia Concentrations in CU Loop Tanks on Day 5



Loop 6 was switched from 100% MWD to 25% MWD/75% groundwater on 8/8/13.

Figure 4-52. Total Ammonia Concentrations in First Flush Samples from CU Pipes on Day 7



Loop 6 was switched from 100% MWD to 25% MWD/75% groundwater on 8/8/13.

Figure 4-53. Nitrite Concentrations in First Flush Samples from CU Pipes on Day 7

4.1.6 Disinfection Byproducts

Disinfection byproducts (TTHM, HAA5 and NDMA) were analyzed in the second-to-last week of the pipe loop study for the UCI and CML pipe loops. Uncirculated test waters on Day 1 (8/1/13) and recirculated waters on Day 7 (8/7/13) were sampled. DBP testing was not performed on the CU pipe loops as the results from the CML and UCI pipes were expected to be representative.

As a complement to the pipe loop tests, MWD performed bench-scale testing of DBP formation for similar source water blends under controlled conditions. Results are presented in Appendix 2.

UCI Pipes

Figure 4-54 and Figure 4-55 show TTHM and HAA5 results for samples taken from the UCI pipe loops. For 100% Desal water, very little TTHM and HAA5 were found in the uncirculated test waters or recirculated waters. The 100% MWD loop showed TTHM and HAA5 concentrations below the regulatory levels of 80 µg/L for TTHM and 60 µg/L for HAA5. This difference was anticipated, as MWD water is treated surface water containing more organic carbon (including disinfection byproduct precursors), compared with Desal which contains low concentrations of TOC. Similarly, the blends of 50% MWD/50% Desal and 25% MWD/75% groundwater resulted in TTHM and HAA5 concentrations that corresponded to the ratio of the water blends. The 25% Desal/75% groundwater blend contained low TTHM (13 µg/L) and HAA5 (3.7 µg/L) concentrations on Day 1, which decreased after seven days of recirculation. The results indicate that TTHM and HAA5 concentrations are well below the regulatory limit.

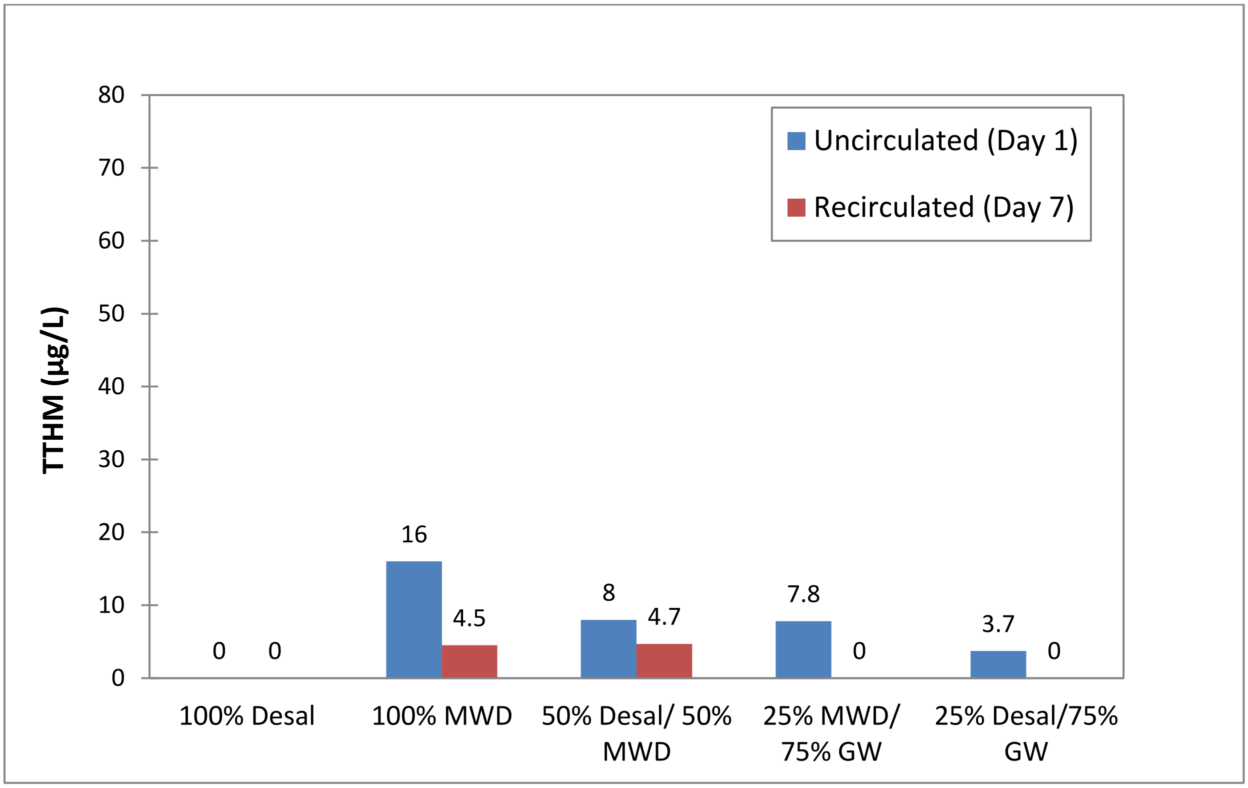


Figure 4-54. TTHM Concentrations in Water - UCI Pipe Loops

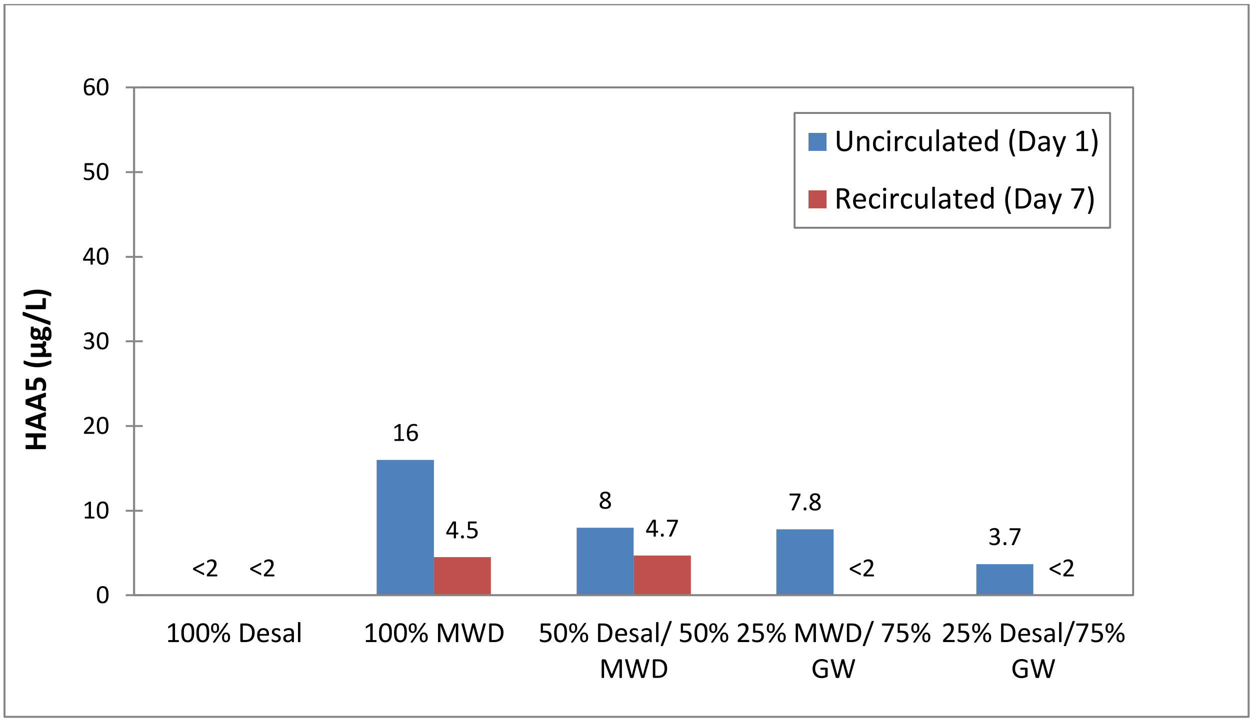


Figure 4-55. HAA5 Concentrations in Water - UCI Pipe Loops

Figure 4-56 shows NDMA results for samples taken from the uncirculated test waters and water recirculated through the UCI pipe loops. The Desal water samples showed low concentrations of NDMA in both uncirculated water (2.7 ng/L) and recirculated water after 6 days (5.6 ng/L). The higher NDMA level in recirculated water than in uncirculated water indicated NDMA formation over time, with levels remaining below the Notification Level of 10 ng/L.

Water samples taken from the Desal/groundwater blend in the UCI pipe loop showed non-detect NDMA concentrations (< 2 ng/L), showing little NDMA formation in the groundwater. The blend of MWD and groundwater showed lower NDMA concentrations compared with 100% MWD water.

Overall, the NDMA concentrations for all pipe loops were below the current Notification Level of 10 ng/L in California. The results indicate that Desal is not expected to increase NDMA concentrations when introduced into a distribution system or when blended with MWD water or groundwater.

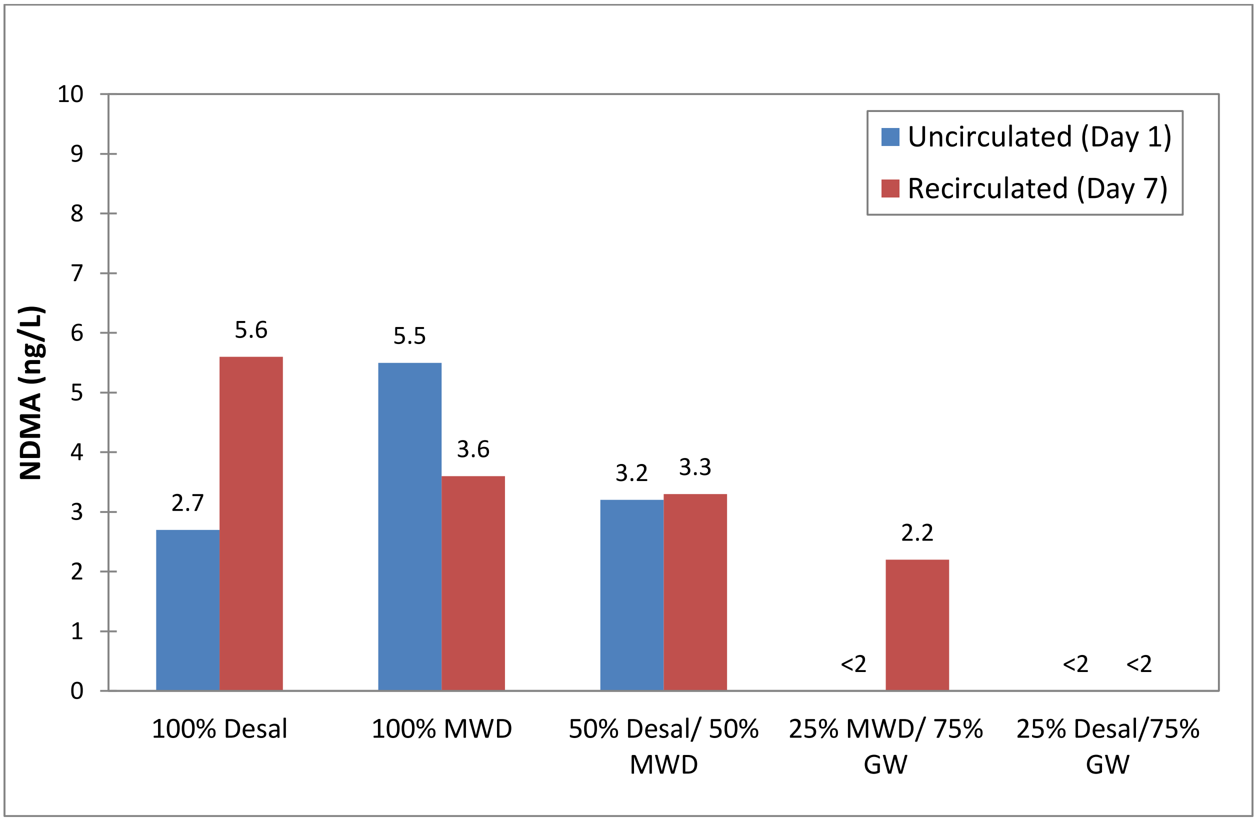


Figure 4-56. NDMA Concentrations in Water Samples - UCI Pipe Loops

CML Pipes

Figure 4-57 and Figure 4-58 show TTHM and HAA5 results for water samples taken from the CML pipe loops. Similar to the UCI pipe results, very low TTHM and HAA5 concentrations were observed in the Desal water. The 100% MWD water loop as well as blends of 50% MWD/50% Desal and 25% MWD/75% groundwater showed higher TTHM and HAA5 concentrations compared with the Desal water loop. Overall, the TTHM and HAA5 concentrations for all CML pipe loops were below the regulatory limits of 80 μg/L for TTHM and 60 μg/L for HAA5.

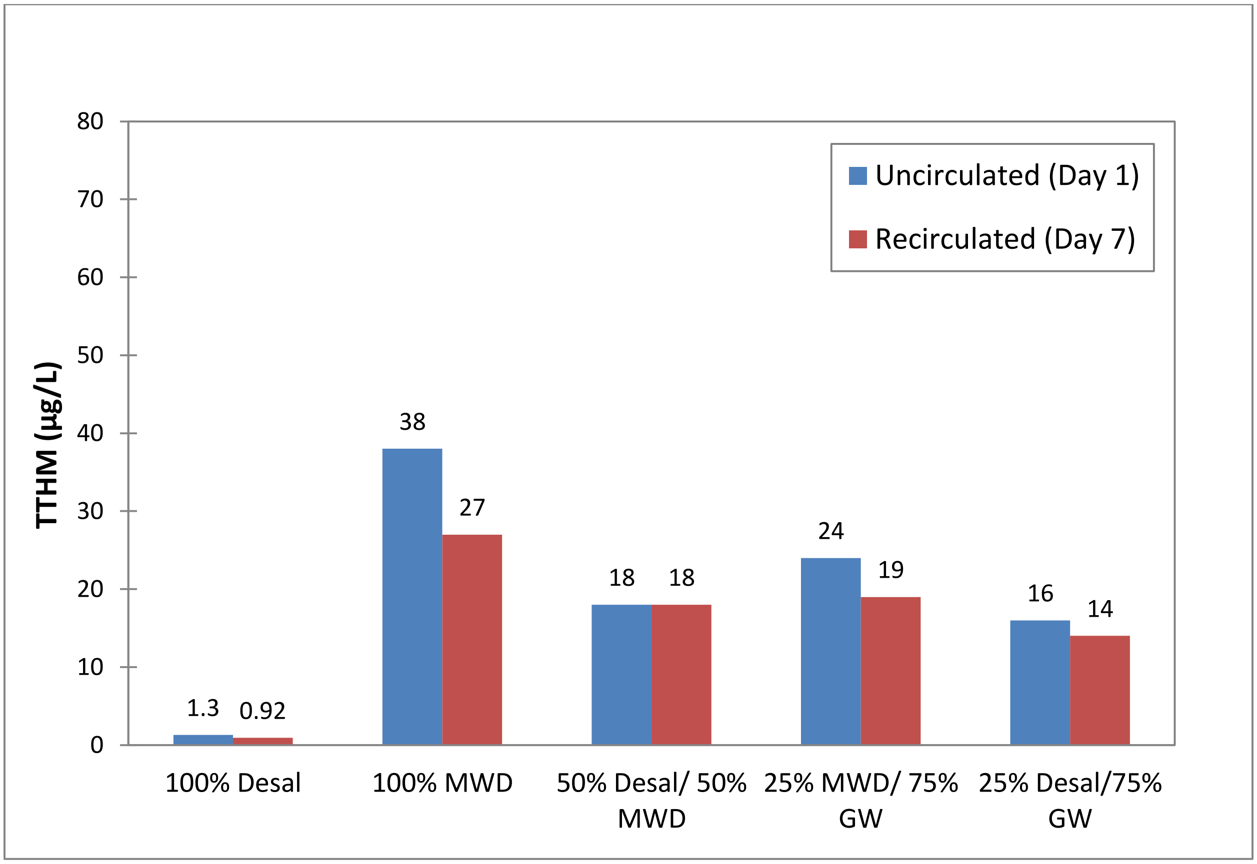


Figure 4-57. TTHM Concentrations in Water - CML Pipe Loops

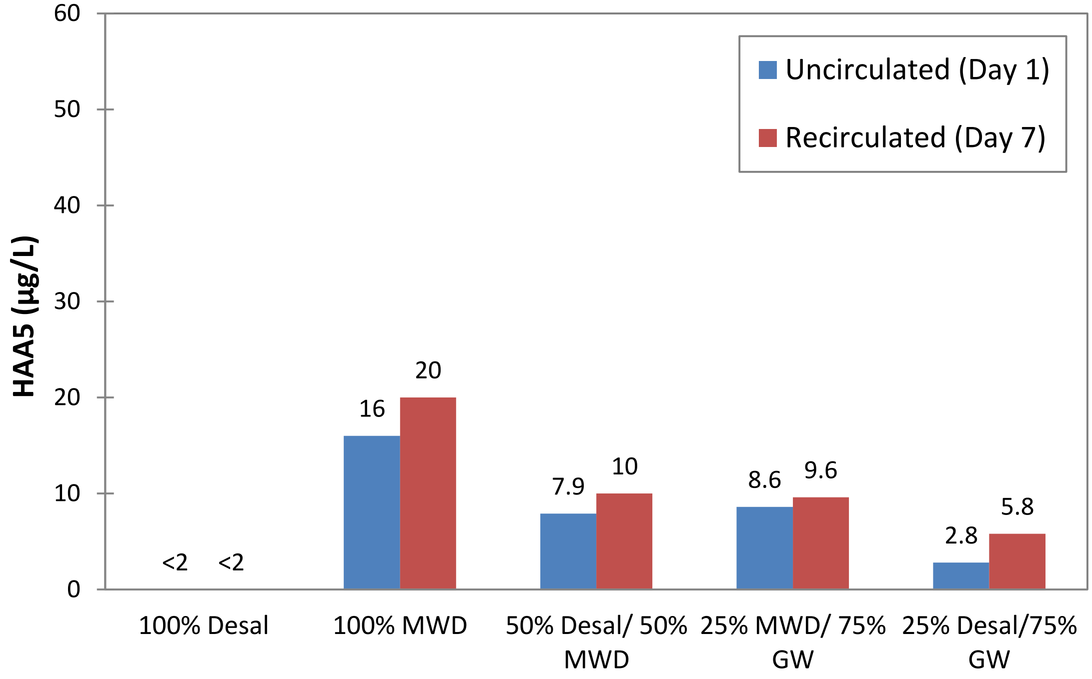


Figure 4-58. HAA5 Concentrations in Water - CML Pipe Loops

NDMA results for the water samples taken from the CML pipe loops are shown in Figure 4-59. Similar to the results from the UCI pipe loops, NDMA was detected in recirculated 100% Desal water. However, NDMA was not detected in the uncirculated Desal water for the CML pipe loops. For the 100% MWD loop, NDMA was detected in both uncirculated and recirculated samples. The blend of Desal and MWD water contained slightly lower NDMA levels than in MWD water alone. Lower NDMA levels were measured in the recirculated groundwater blends than in the recirculated Desal water. Overall, the results for the CML pipe loops were similar to the trends observed for the UCI pipe loops, with concentrations below the Notification Level of 10 ng/L.

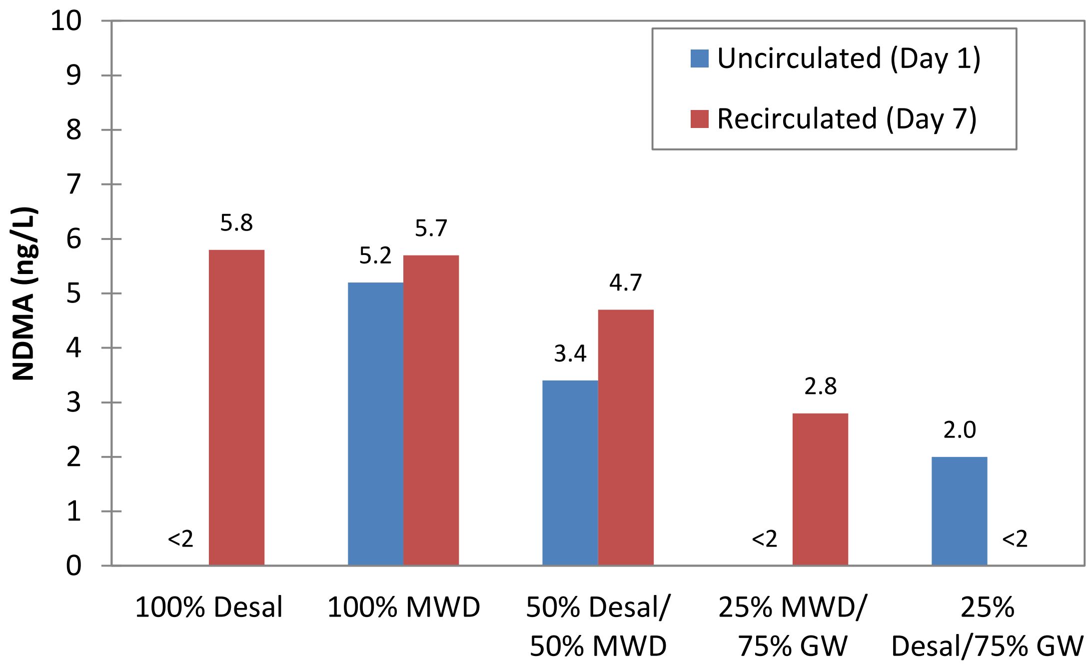


Figure 4-59. NDMA Concentrations in Water - CML Pipe Loops

4.1.7 Taste and Odor

Taste and odor analysis was performed by Hazen and Sawyer trained FPA panelists. One set of uncirculated water samples was collected on July 19, 2013, and analyzed for taste and odor. At the end of the week, the recirculated water samples from UCI and CML pipes were collected on July 25, 2013, and analyzed for odor only (i.e., not taste due to concerns with potential bacterial presence).

Table 4-1 summarizes the taste and odor results. Taste and odor intensities are scaled from 0 to 12 (non-detect to strong), as described in Standard Method 2170. An intensity rating of 4 indicates that some customers will notice the odor/flavor and may voice concern to their water provider. If more than half of the FPA panelists recognize the same taste or odor characteristic, the intensity is the average of the intensities rated by the panelists. If less than half of the FPA panelists recognize the same taste or odor, no intensity is given and these taste/odor are listed as notes.

FPA testing showed that the uncirculated Desal water was odor free with a slight bitter taste. The Desal and MWD blend had a slight chlorine odor and a slight dry-mouth feel. By comparison, the uncirculated MWD water had a slight mineral/salty taste and a slight earthy/musty smell, in addition to chlorine. Earthy and musty taste and odor are often associated with algae in surface water. The blend of groundwater with MWD or Desal water also had a very slight earthy and musty odor. Overall, the uncirculated waters did not have strong taste or odor and are not expected to cause customer complaints.

For recirculated samples, a very slight chlorine odor was detected in the Desal water sample taken from the UCI pipe loop. Earthy and musty odors were observed, but MIB and geosmin levels were low in MWD water during July (i.e., ND to 2 μg/L MIB and 2 to 4 μg/L geosmin). Plastic odor was recognized for three CML samples, which was likely due to the contribution of PVC pipes as a component of the pipe loops.

Table 4-1. Taste and Odor Results for Uncirculated and Recirculated Water

Sample	Uncirculated Water		UCI Recirculated Water	CML Recirculated Water
	Odor Descriptor and Intensities	**Flavor Descriptor and Intensities**	**Odor Descriptor and Intensities**	**Odor Descriptor and Intensities**
100% Desal	**Odor Free** Notes: chlorine, plastic	**Bitter 3** Notes: chlorine, salty, drying	**Chlorine 2** Notes: odor free	**Odor Free** Notes: chlorine
100% MWD	**Chlorine 3** **Earthy/musty 3** Notes: plastic	**Mineral/salty 3** **Chlorine 3** Notes: dry mouthfeel	**Earthy/musty 3** Notes: chlorine, medicine, odor free	**Chlorine 2** Notes: metallic, earthy/musty
50% Desal/ 50% MWD	**Chlorine 3** **Earthy/musty 4** Notes: plastic	**Dry Mouth feel 3** Notes: mineral/salty, chlorine, bitter	**Odor Free** Notes: chlorine, iron, medicine, earthy/musty	**Plastic 4** Notes: chlorine
25% MWD/75% groundwater	**Earthy/musty 2** **Sulfide 2** Notes: chlorine, metallic	N/A	**Earthy/musty 2** Notes: sulfur, odor free	**Plastic 3** Notes: odor free
25% Desal/75% groundwater	**Earthy/musty 2** **Sulfide 2** Notes: chlorine	N/A	**Odor Free** Notes: earthy, sulfur	**Plastic 6** Notes: none

Note: Odor and flavor intensity scales from 0 to 12. “0” represents taste or odor free and “12” represents the strongest intensity. An intensity rating of 4 usually means that some customers will notice the odor/flavor and may call.
N/A – not analyzed.

4.2 Bench-Scale Study

The bench-scale study results are documented in Appendix 2.

5. Conclusions and Recommendations

The Desal was effectively stabilized to obtain the target alkalinity and calcium levels using calcite contactors with pH reduction upstream. The target water quality parameters established for the Desal through the literature review and utility survey were consistently achieved as detailed in Table 5-1.

Table 5-1. Target Quality for Stabilized Desalinated Ocean Water

Constituent	Target Concentration
Alkalinity	65 – 80 mg/L as $CaCO_3$
Calcium[≠]	> 65 mg/L as $CaCO_3$
pH	8.2 ± 0.2
CCPP	Between 0 and 10 mg/L as $CaCO_3$
LSI	Between 0 and 0.5
Total Chlorine Residual	2.5 mg/L
Total Ammonia	0.5 mg/L as N

Due to the high pH used in the OWDDF second pass RO for boron control, a large acid dose was needed to reduce pH before the calcite contactors. The average sulfuric acid dose used during the study was 82 mg/L, which is above the NSF maximum usage level for sulfuric acid of 50 mg/L. Alternative approaches to reduce pH upstream of the calcite contactor, such as a combination of CO_2 and sulfuric acid, or another means of adding minerals to the desalinated ocean water such as lime and CO_2 need to be considered for full-scale application. CO_2 and lime were tested at bench-scale and also effectively achieved the stabilized water quality targets.

Pipe loop testing was performed using UCI, CML, and CU pipe loops for an operational period of 4 months with 5 water qualities (100% Desal, 100% MWD, 50% Desal/50% MWD, 25% MWD/75% groundwater, and 25% Desal/75% groundwater).

For highly tuberculated UCI pipe loops, pilot testing data showed that 100% Desal or Desal blends tested did not result in higher iron release than 100% MWD water. Given the variability in the pipe loop deposits, the concentrations observed in the water were considered to be similar. CCPP values in recirculated water were positive for all test waters (except one occasion for 100% Desal during the stabilization period). Results showed that 100% Desal water and blends of 50% Desal/50% MWD and 25% Desal/75% groundwater did not cause higher total iron or manganese release compared with 100% MWD water.

For the CML steel pipe loops, aluminum and pH were monitored as primary indicators of cement mortar dissolution. Throughout the testing, aluminum concentration in the recirculated waters were below the secondary MCL of 200 µg/L. pH increases were observed initially for all loops since the pipe surfaces were unsealed, although the degree of increase was much less than observed in prior testing when water was not sufficiently stabilized (Blute et al., 2008). After this period, pH stabilized around 8.5 -8.6, slightly above pH levels in uncirculated waters. CCPP values in recirculated waters remained positive and were slightly higher than in the uncirculated test water due to the pH increases. Overall, each of the waters tested, including stabilized desalinated ocean water, were found to be non-aggressive toward the CML pipes.

For the CU pipe loops, lead concentrations in the first-flush samples taken from the brass meters and copper pipes with lead solder after a stagnant period were below the Action Level of 15 µg/L for 100% Desal and 100% MWD water. Levels were higher in one of the loops supplied with 25% MWD and 75% groundwater, which was found to be primarily a result of variations in the brass meter, and secondarily due to impacts of the groundwater. The desalinated ocean water alone or in blends did not show an increased tendency to leach lead from lead solder or brass meters. Copper and zinc concentrations in the stagnant water were well below the Action Level of 1,300 µg/L for copper and secondary MCL of 5,000 µg/L for zinc for both copper pipe segments and the brass meters.

The impact of desalinated ocean water on total chlorine residuals was investigated in this study both in the pilot-scale pipe loop testing and at a bench-scale in the laboratory by MWD (Appendix 2). The UCI pipes contained substantial tuberculation that appeared to be mainly iron and manganese deposits, which are consistent with elevated levels of these constituents in the groundwater. High chlorine loss was observed for all UCI loops as a result of water chlorine demand and pipe tuberculation, accompanied by nitrification (i.e., a loss of ammonia and increase in nitrite were observed). Typically, chlorine residual became less than 0.3 mg/L after recirculation for seven days for all the pipe loops. Nitrification was most severe in the groundwater blend pipe loops due to the presence of high levels of free ammonia. No corrosion-related outcomes of nitrification, such as a decrease in pH, were observed in the pipe loop study indicating that the water was sufficiently buffered.

By comparison, less chlorine loss was observed in the CML pipe loops, with little evidence of nitrification. High chlorine loss (ranging from 1.3 to 2.8 mg/L for the 6 loops) was also noted in CU pipe loop first-flush samples, compared to uncirculated waters. New copper pipe is also known to cause chloramine decay, and severe nitrification occurred in the groundwater blends in the later study period (although a noticeable drop in pH was not observed).

Pilot testing showed that disinfection by products, including TTHM and HAA5, were very low in 100% Desal – both uncirculated and recirculated waters. No increase in TTHM or HAA5 was observed for blends compared to the proportion of DBPs measured in the baseline water quality. Low levels of NDMA (up to 5.8 ng/L) were detected in both uncirculated and recirculated 100% Desal waters, which were similar to NDMA levels measured in 100% MWD water.

In sum, the introduction of desalinated ocean water (both with appropriate calcium, alkalinity, and pH levels, and stabilized chloramine residual) and blended water tested into a range of typical and representative potable water distribution system and household plumbing materials did not cause negative impacts on water quality, corrosion or disinfection in the pilot tests. The tested desalination water quality targets, determined by an extensive literature review and desalination plant survey, were shown to be protective of the distribution system and household plumbing materials.

6. References

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Appendix 1

Ocean Water Desalination Water Quality Integration Study
Pipe Loop Design, Installation and Testing Plan
Final Updated 5/8/2013

Appendix 2

Ocean Water Desalination Water Quality Integration
Bench-Scale Study
May 2014