

APPENDIX E

Finished Water Compatibility Analysis

**Bay Area Regional Desalination Project (BARDP)
Pilot Study at Mallard Slough**

Subject: **Bench-Scale Study of BARDP Pilot Study Finished Water Quality and Compatibility Analysis**
Technical Memorandum

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The Bay Area Regional Desalination Project (BARDP) is currently performing a Reverse Osmosis (RO) Pilot Study for desalination of seawater and brackish water to supplement existing potable water supplies during droughts, emergencies, and maintenance-related facility outages. The finished water produced by the RO process at the desalination plant needs to be compatible with the existing supplies in the East Bay Municipal Water District (EBMUD) Mokelumne Aqueduct and the Contra Costa Water District (CCWD) Multipurpose Pipeline. Testing of the RO Train No. 1 permeate in January 2009 confirmed that the permeate water has a low pH value and is poorly buffered against pH changes, as expected for an RO permeate. Consequently, the water has strongly negative values of Calcium Carbonate Precipitation Potential (CCPP) and Langelier Saturation Index (LSI), indicating that the RO permeate is very corrosive and will require post-treatment stabilization prior to being discharged in the distribution system. In this bench-scale study, two post-treatment options were tested, including lime + carbon dioxide addition and a calcite filter. This memorandum describes the bench testing objectives, materials and methods, and results of the study.

1.0 Objectives

Bench-scale testing was conducted to test potential treatment techniques for the stabilization of BARDP Pilot RO permeate and ensure that the stabilized permeate was compatible with the existing water supplies. In addition, stabilized water was tested for its ability to maintain a disinfectant residual. Specifically, the main objectives of the testing were as follows:

1. Identify and test two post-treatment options for their effectiveness in stabilizing the RO permeate. Based on the Rothberg, Tamburini & Winsor (RTW) modeling and literature reports of desalinated water stabilization, target stabilized water quality parameters to yield a positive LSI and CCPP were:
 - Langelier Saturation Index (LSI): 0 – 1
 - Calcium Carbonate Precipitation Potential (CCPP): Positive, ideally between 4-10 mg/L as CaCO₃

- Alkalinity > 40 mg/L as CaCO₃
 - Calcium > 40 mg/L as CaCO₃ (16 mg/L as Ca)
 - pH value necessary to achieve positive LSI and CCPP (approximately 8.5 ± 0.5)
 - Turbidity < 1.0 NTU
2. Test the compatibility of the stabilized RO permeate with EBMUD Aqueduct and CCWD Multipurpose Pipeline water to assess whether these permeate water quality targets are sufficient with respect to the corrosion indices.
 3. Assess the stability of disinfectant residuals in stabilized RO permeate containing chloramines and in water blended with chloraminated CCWD water. DBP formation was also evaluated for the blended chloraminated water.
 4. Assess the stability of disinfectant residuals in stabilized RO permeate containing free chlorine and in water blended with chlorinated EBMUD water. DBP formation was also evaluated for the blended chlorinated water.

2.0 Materials and Methods

The bench-scale study was conducted from January 26, 2009 to February 2, 2009 in the on-site trailer laboratory at Mallard Slough. Two chemical treatment methods were tested for the stabilization of RO permeate water, including 1) liquid lime and carbon dioxide addition, and 2) a calcite filter with upstream acid addition and downstream caustic addition. Stabilized RO permeate water was then chlorinated or chloraminated to achieve disinfection residuals at levels similar to these in the EBMUD Aqueduct and CCWD Multipurpose Pipeline water, respectively. Finally, the disinfected and stabilized RO permeate water samples were blended with the EBMUD Aqueduct and CCWD Multipurpose Pipeline water to assess the disinfectant stability of the blends and DBP formation.

2.1 RO Permeate, EBMUD and CCWD Water Quality Analysis

RO permeate samples were collected from the RO Train No.1 effluent sampling port when needed. A five-gallon sample of RO permeate was collected on January 28, 2009, which was analyzed for water quality parameters, including pH, turbidity, conductivity, alkalinity, hardness, carbon dioxide, chloride, sulfate and TDS. CCPP and LSI values were calculated from the measured parameters using RTW modeling.

Two five-gallon samples were collected from the EBMUD Aqueduct #2 and CCWD Multiple Purpose Pipeline on January 28, 2009. The EBMUD sample was collected from the Bixler facility near Brentwood, California, and the CCWD sample from the treated effluent at the Randall-Bold Water Treatment Plant. The same water quality parameters were analyzed as for the RO permeate sample. The water quality analysis results are presented in the results section.

2.2 Liquid Lime Tests

Liquid lime tests were conducted on January 28th and 29th using the RO permeate sample collected on January 28, 2009. Sample bottles were placed on a stir-plate and the solutions were slowly mixed throughout the tests, as depicted in Figure 1. Liquid lime was used to increase alkalinity, hardness and pH levels in RO permeate; carbon dioxide gas was added simultaneously to reduce the pH and achieve the targeted range.

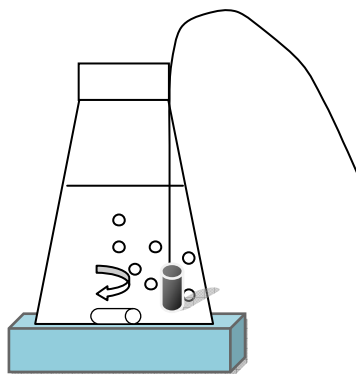


Figure 1. Schematic of Liquid Lime Test Apparatus

Preliminary tests were conducted to assess whether it was necessary to add carbon dioxide during lime addition to avoid calcium carbonate precipitation. In the preliminary tests, a dose of liquid lime (30 mg/L or 40 mg/L) was first added to a RO permeate sample, then pH and turbidity of the solution was monitored until stable. Following lime addition, visible calcium carbonate precipitation was observed in about 20 minutes, while turbidity gradually increased from around 1 NTU to around 14 NTU in 30 minutes; pH rose to 10.5 immediately following the lime dose. Based on these preliminary findings, carbon dioxide was added slowly during lime addition to avoid raising the pH too high and causing visible calcium carbonate precipitation in the liquid lime tests.

Based on the RO permeate sample water quality and RTW modeling, a dose of 30 mg/L liquid lime and 24 mg/L carbon dioxide addition resulted in a CCPP value of 2.41 mg/L and a LSI value of 0.42. Considering the EBMUD and CCWD water were corrosive with respect to these indices (as presented in the results section), a higher dose of liquid lime (i.e. 40 mg/L) was selected in the liquid lime tests to add more buffering capacity to the stabilized RO permeate while maintaining a reasonable lime dose.

A dose of 40 mg/L liquid lime was slowly added to the RO permeate sample while carbon dioxide was bubbled in at the same time. pH in the solutions was monitored closely during the tests. When the solution pH reached the range of 8.6 – 9.0, carbon dioxide addition was stopped and the stabilized sample was collected for further analysis, disinfection, and blending tests. Four batches of 1-liter RO permeate samples were run in the liquid lime tests to generate sufficient volume; these aliquots were blended together and used for subsequent tests. pH in the blended stabilized RO permeate dropped from the range of 8.6 – 8.9 to 8.43 in a couple of hours, so a

dose of 1.99 mg/L sodium hydroxide was added to the blend to increase the pH to yield positive LSI and CCPP indices (i.e., resulting in a pH of 8.88) prior to field analysis, collecting lab samples and disinfection tests. The stabilized RO permeate sample was analyzed for pH, turbidity, conductivity, alkalinity, hardness, carbon dioxide, chloride, sulfate and TDS.

2.3 Calcite Filter Tests

The calcite filter tests were conducted using the RO Train No. 1 permeate feed and a continuous flow-through calcite filter. Upstream of the calcite filter, pH was adjusted by acid addition to promote sufficient calcite dissolution. Figure 2 depicts the calcite filter system used in the tests. Sulfuric acid was used for pH adjustment of the RO permeate; note that a full-scale application would most likely use carbon dioxide for pH adjustment but acid was easier at this scale and for the short duration tests. An empty canister was used to provide sufficient mixing time of the acid and the RO permeate upstream of the calcite filter. The RO permeate pH was approximately 5.5 at the time of the tests. Two target pH levels in influent to the calcite filter were tested:

- pH 5.5 (ambient) – acid dose 0 mg/L
- pH 5.0 – sulfuric acid dose of 1.0 – 2.0 mg/L

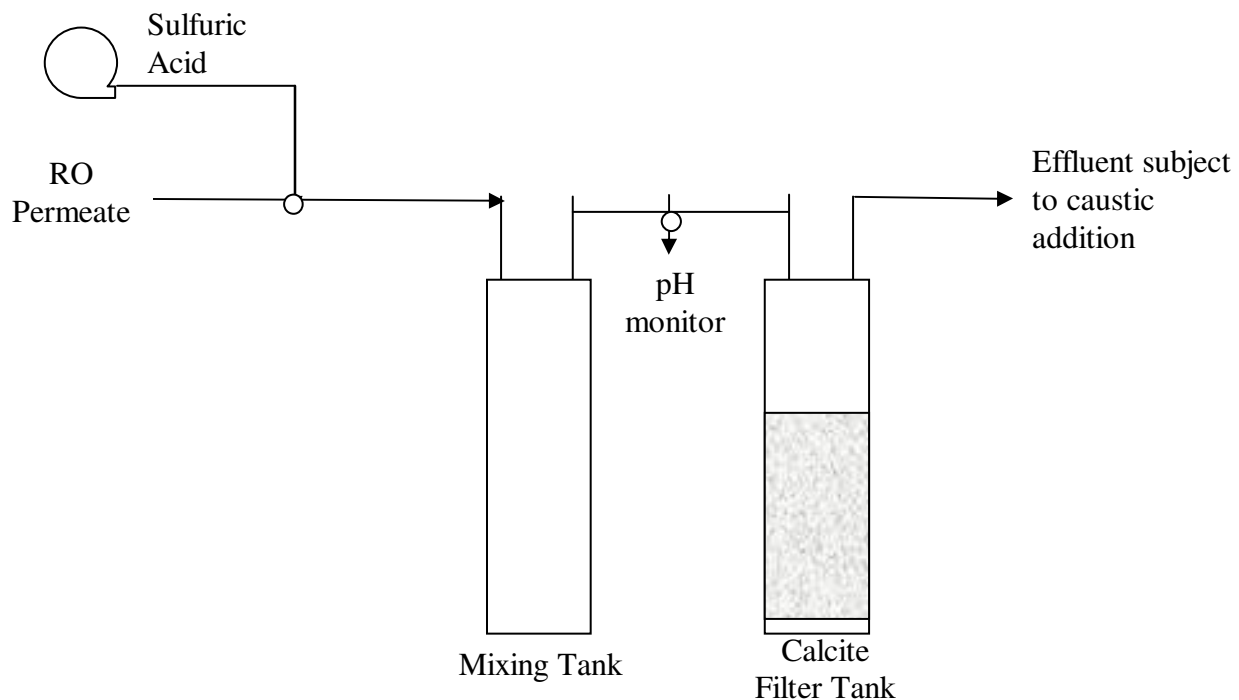




Figure 2. Photograph of the Calcite Filter Pilot System

Table 1 lists the specifications for the calcite filter and the operating conditions. The calcite filter consisted of the calcite Z White™ NSF from Imerys Performance Minerals (Marble Hill, GA). Fresh calcite was ordered directly from the manufacturer. Steel tanks from Culligan ordinarily used in ion exchange applications were used since no fiberglass reinforced tanks were readily available at the time of the tests.

Table 1: Properties and Operating Conditions of Z White™ Calcite Filter	
Media Properties	
Mesh Size	1% Plus 40, 7% Minus 20 (i.e., between 0.84-2.0 mm)
% CaCO ₃	95
Specific Gravity	2.7
Solid Density (lb/gal)	22.7
Bulk Density (packed, lb/ft ³)	105
Filter Properties	
Unit	Steel Tank
Filter Height (in)	36
Filter Diameter (in)	9
Calcite Media Bed Depth (in)	18
Calcite Quantity (cf, lbs.)	0.66 cf, 70 lbs.
Sieve Size on Effluent (mm)	0.20
Operating Conditions	
Permeate Flow Rate (gpm)	0.5
Filter Loading Rate (gpm/ft ²)	3

Empty Bed Contact Time (min)	10
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The calcite filter was operated at each pH level until pH stabilized for at least 15 minutes. The filter effluent samples were collected and analyzed for pH, turbidity, conductivity, alkalinity, hardness, carbon dioxide, chloride, sulfate and TDS. Sodium hydroxide solution was added to increase the filter effluent pH to achieve positive CCPP and LSI values. CCPP and LSI values were calculated from the measured parameters using RTW modeling.

2.4 Disinfection and Blending Tests

Although blending ratios have not yet been determined, for this testing we assumed that BARDP finished water will be blended with EBMUD Mokelumne Aqueduct water at a ratio of 1:2 and with CCWD Multipurpose Pipeline treated water at a ratio of 1:1. The stabilized RO permeate was chlorinated or chloraminated to match the disinfectant residuals in the EBMUD or CCWD water, respectively. Subsequently, the disinfected RO permeate was blended with the EBMUD or CCWD water. Due to time constraints and since both treatment options yielded similar water quality, only the RO permeate stabilized using liquid lime treatment was disinfected and blended with EBMUD and CCWD. The following disinfectant stability tests were performed in amber glass bottles and stored at room temperature.

2.4.1 EBMUD

Stabilized RO permeate water was chlorinated to match the concentration in the Mokelumne aqueduct water. However, the current concentration observed was 0.05 mg/L. Limited data from 1999-2000 indicate a typical chlorine concentration of 0.2 mg/L in the EBMUD aqueduct; therefore, a free chlorine residual of 0.2 mg/L was selected as the target disinfectant concentration in the stabilized RO permeate. Hypochlorite was added to the EBMUD sample collected on January 28, 2009 to boost the free chlorine residual to 0.2 mg/L.

Chlorine residuals in the stabilized RO permeate were analyzed after one and two hours. After two hours, disinfected stabilized RO permeate and EBMUD water were blended at a ratio of 1:2. The blended water was analyzed for pH, turbidity, conductivity, alkalinity, hardness, carbon dioxide, chloride, sulfate and TDS. CCPP and LSI values were calculated from the measured parameters using RTW modeling.

DBP formation in the blend of stabilized BARDP water and EBMUD water was determined 24 hours after blending by sending samples to the contract laboratory. In addition, EBMUD water held on-site (from the time of collection to the time of 24-hour DBP sample collection for the blend) was sampled for DBPs to provide information on the relative proportion that EBMUD water contributed to the DBP levels in the blend.

2.4.2 CCWD

For CCWD, stabilized RO permeate was blended with treated water from the Multipurpose Pipeline. Treated CCWD water from this plant was chloraminated; consequently, two disinfection scenarios were tested:

- Chloramination: Addition of 2.5 mg/L of sodium hypochlorite followed by 0.5 mg/L of ammonia (as nitrogen). The ammonia was added approximately 5 minutes after chlorine addition.
- Superchloramination: Addition of 4.5 mg/L of sodium hypochlorite followed by the addition of 0.5 mg/L of ammonia (as nitrogen). It was anticipated that this will yield a stable residual of approximately 2.5 mg/L with a Cl₂: NH₃-N ratio of 5:1 within several hours of contact time, based on our previous experience with chloramination of seawater RO permeate. However, the superchloramination results suggested that the RO permeate was breakpoint chlorinated at the dose of 4.5 mg/L chlorine and this chlorine-to-ammonia ratio, as presented in the results section. Therefore, RO permeate disinfected at these concentrations was not blended with EBMUD or CCWD water. Instead, the previous (2.5 mg/L chlorine dose) sample was used.

Total chlorine residuals were analyzed over a period of two hours, with total chlorine and total ammonia residuals measured after one and two hours from chloramine dosing. After two hours, disinfected stabilized RO permeate and CCWD water was blended at a ratio of 1:1. The blended water was analyzed for pH, turbidity, conductivity, alkalinity, hardness, carbon dioxide, chloride, sulfate and TDS. CCPP and LSI values were calculated from the measured parameters using RTW modeling.

DBP formation potential in the blend of stabilized BARDP water and CCWD water was determined 24 hours after blending by sending samples to the contract laboratory. In addition, CCWD water held on-site (from the time of collection to the time of 24-hour DBP sample collection for the blend) was sampled for DBP analysis to provide information on how much the CCWD water contributed to the DBP levels in the blend.

2.5 Analytical Methods

The analytical methods for the measurement of various water quality parameters during the performance of the bench-scale testing are listed in Table 2. Analyses for chloride, sulfate, TDS, total trihalomethanes (TTHM) and haloacetic acids (HAA5) were performed by TestAmerica Laboratories (Irvine, California). In addition, hardness and total alkalinity were analyzed for some samples by the lab as a quality control on field methods.

Parameter	Method
pH	Standard Method 4500-H+
Conductivity	Standard Method 2510- B
Turbidity	Standard Method 2130 or EPA Method 180.1

Alkalinity	Hach Method 8203
Calcium Hardness	Hach Method 8204
Carbon Dioxide	Hach Method 8205
Total Chlorine	Hach Method 8167
Free Chlorine	Hach Method 8021
Total Ammonia	Hach Method 8155
Chloride*	EPA 300.0
Sulfate*	EPA 300.0
Total Dissolved Solids*	SM 2540C
Hardness*	SM 2340B
Total Alkalinity*	SM 2320B
TTHM*	EPA 524.2
HAA5*	EPA 552.2

* Lab analyses

2.6 QA/QC Procedures

Quality assurance and quality control of the experimental equipment, added chemicals, and measured water quality parameters were maintained during the bench-scale testing. All analytical instruments were calibrated prior to use. The glassware was appropriately cleaned prior to being used in the testing. At least one test condition from both the liquid lime and the calcite filter experiments were performed in duplicate to gauge the reproducibility of the experimental technique.

3.0 Results

3.1 Water Quality: RO Permeate (unstabilized), EBMUD, and CCWD

Table 3 lists the water quality analysis results for the RO permeate, EBMUD Aqueduct #2 and CCWD Multiple Purpose Pipeline samples, all of which were collected on January 28, 2009. As expected, RO permeate had low pH, alkalinity and calcium hardness. CCPP and LSI values based on the field measurements were -14.4 and -5.6, respectively, which suggest that RO permeate would be very corrosive to many pipeline materials. EBMUD Aqueduct #2 water had low alkalinity and hardness. The CCPP and LSI values based on the field measurements suggest that EBMUD water would be considered corrosive. CCWD Multiple Purpose Pipeline water had moderate alkalinity and hardness values, but CCPP and LSI values based on the field measurements suggest that CCWD water would also be considered corrosive due to the pH.

Parameter	RO Permeate	EBMUD Aqueduct #2	CCWD Multi-Purpose Pipeline
pH	5.76 [†]	7.83	7.71
Free Chlorine (mg/L)	N/A	0.05	N/A
Total Chlorine (mg/L)	N/A	N/A	2.78
Total Ammonia (mg/L as N)	N/A	0.01	0.44
Turbidity (NTU)	0.12	0.31	0.16
Conductivity (µS/cm)	255	55.9	911
Alkalinity (mg/L as CaCO ₃)	1.2 (Lab: <5.0 [^])	18 (lab: 18)	76 (lab: 78)
Calcium Hardness (mg/L as CaCO ₃)	1.6 (Lab: <5.0 [^])	20 (lab: 10)	66 (lab: 55)
Carbon Dioxide (mg/L as CO ₂)	17 [^]	Not Tested	Note Tested
Total Hardness* (mg/L as CaCO ₃)	2.9 [^]	13	120
Chloride (mg/L)*	27 [^]	2.3	110
Sulfate (mg/L)*	1.1 [^]	1.3	68
Total Dissolved Solids* (mg/L)	24 [^]	48	380
CCPP (mg/L) at 25 °C	-14.4	-3.7	-3.1
LSI at 25 °C	-5.6	-1.2	-0.3

[†] RO permeate - pH during the calcite filter test on January 30th and 31st was lower, ranging from 5.50 to 5.65.

[^] Lab analyses were conducted for RO permeate on a sample collected January 31, 2009.

*Lab analyses; for CCPP and LSI calculations, field analyses were used where available because they comprised a complete data set for each water tested.

N/A – not applicable

3.2 Liquid Lime Tests

Table 4 lists the water quality parameters for the stabilized RO permeate in the liquid lime tests. The stabilized RO permeate had alkalinity and calcium hardness values of 50 mg/L as CaCO₃, for a liquid lime dose of 40 mg/L (with CO₂ addition). Based on the measured parameters, CCPP and LSI values were 4.2 and 0.5, respectively, which met the desired targets and suggested that the liquid lime stabilized RO permeate would not be corrosive. Note that pH dropped significantly in the stabilized RO permeate within three hours after CO₂ addition was finished. In this study, a dose of 1.99 mg/L sodium hydroxide was added to the RO permeate stabilized by the liquid lime test to increase pH from 8.43 to 8.88.

Parameter	Stabilized RO Permeate Using 40 mg/L Liquid Lime and Carbon Dioxide[#]
pH	8.88 [†]
Turbidity (NTU)	0.44
Conductivity (µS/cm)	322
Alkalinity (mg/L as CaCO ₃)	50
Calcium Hardness (mg/L as CaCO ₃)	50
Carbon Dioxide (mg/L as CO ₂)	5
Chloride (mg/L)*	43
Sulfate (mg/L)*	1.5
Total Dissolved Solids (mg/L)*	110
CCPP (mg/L) at 25 °C [‡]	4.2
LSI at 25 °C [‡]	0.5

The dose of carbon dioxide could not be measured. Based on RTW modeling, stabilized RO permeate with a liquid lime dose of 40 mg/L would result in a similar water quality as observed using a carbon dioxide dose of approximately 30 to 40 mg/L.

† pH in four batches of stabilized RO permeate varied from 8.6 to 9.0, depending on the dose of carbon dioxide, which was difficult to control precisely in small batch samples. The four stabilized RO permeate samples were blended for further testing. pH in the blend dropped to 8.43 in approximately three hours. Sodium hydroxide was added to the blend to adjust pH to 8.88 before field and lab analysis.

* Lab analyses

[‡] Based on a final pH of 8.88.

3.3 Calcite Filter Tests

Table 5 lists the water quality analysis results for stabilized RO permeate in the calcite filter tests with and without upstream sulfuric acid for pH adjustment. The stabilized RO permeate with pH adjustment had an alkalinity of 40 mg/L as CaCO₃ and calcium hardness of 36 mg/L as CaCO₃. The stabilized RO permeate without pH adjustment was slightly lower in alkalinity and had a similar calcium hardness. In both cases, calcite filter effluents needed additional pH adjustment (e.g. sodium hydroxide addition) after the calcite filter to achieve positive CCPP and LSI values. For the stabilized RO permeate generated with upstream acid addition, CCPP and LSI values were 2.39 mg/L and 0.41, respectively. For the stabilized RO permeate without acid, CCPP and LSI values were 2.59 mg/L and 0.44, respectively. Thus, both stabilized RO permeate with and without acid had similar CCPP and LSI values as long as pH was increased after the calcite filter.

The field testing results suggest that the calcite filter with and without acid generated similar water quality results with slightly higher alkalinity for the lower pH influent water. However, the results were based on a relatively low pH level in raw RO permeate at the time of testing. According to MWH field monitoring results, RO permeate exhibited pH values ranging from 5.0 to 7.0 during pilot testing. Based on experience elsewhere (Blute et al. 2008), it is expected that pH adjustment would be required if the pH of the RO permeate was higher than 5.6.

Parameter	Stabilized RO Permeate with Acid prior to Calcite Filter[^]	Stabilized RO Permeate without Acid prior to Calcite Filter
pH in mixing tank effluent	4.86	5.65
pH in calcite filter effluent	7.87 [†]	8.21
Final pH with post NaOH addition	8.88 [#]	8.97 ^{##}
Turbidity (NTU)	0.39	0.27
Conductivity (µS/cm)	187.1	181.6
Alkalinity (mg/L as CaCO ₃)	40 (lab: 40)	35 (lab: 38)
Calcium Hardness (mg/L as CaCO ₃)	37 (lab: 35)	36
Carbon Dioxide (mg/L as CO ₂)	10	Not Tested
Total Hardness (mg/L as CaCO ₃)*	38	Not Tested
Chloride (mg/L)*	27	27
Sulfate (mg/L)*	3.9	2.5
Total Dissolved Solids (mg/L)*	82	82
CCPP (mg/L) at 25 °C [‡]	2.39	2.59
LSI at 25 °C [‡]	0.41	0.44

[^] The acid dose was approximately in the range of 1.0 – 2.0 mg/L H₂SO₄, which can only be estimated due to the low accuracy of the acid pump at low frequency and stroke length settings.

[†] pH in a sample was measured as 8.12 after the sample was collected and sit for approximately three hours.

[#] 1.8 mg/L NaOH was added to increase pH from 8.12 to 8.88.

^{##} 1.5 mg/L NaOH was added to increase pH from 8.21 to 8.97.

* Lab analyses

‡ Based on the final pH values with NaOH

3.4 Disinfection and Blending Tests

Stabilized RO permeate in liquid lime tests was chlorinated and chloraminated to match the disinfectant in EBMUD Aqueduct #2 and CCWD Multiple Purpose Pipeline waters, respectively. The disinfected RO permeate was blended with EBMUD at a ratio of 1:2 or CCWD water at a ratio of 1:1.

3.4.1 Chlorination of Stabilized RO Permeate

A chlorine dose of 0.3 mg/L added to stabilized RO resulted in an initial free chlorine residual of 0.25 mg/L, which then decreased to 0.18 mg/L in one hour and 0.16 mg/L in two hours, as shown in Figure 3.

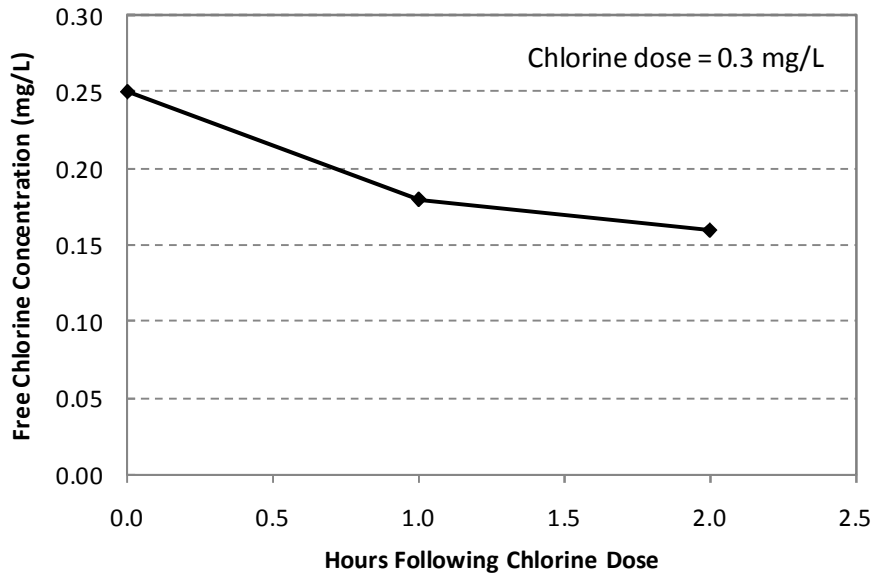


Figure 3. Free Chlorine Degradation Curve for Stabilized RO Permeate

3.4.2 Chloramination of Stabilized RO Permeate

A chlorine dose of 2.5 mg/L and ammonia dose of 0.5 mg/L were added to chloramine stabilized RO permeate. Figure 4 shows the total chlorine degradation curve. Total chlorine was 2.76 mg/L immediately following the chloramination, which decreased to 1.88 mg/L in one hour and 1.54 mg/L in two hours. Total ammonia was 0.34 mg/L as N one hour following chloramination, lower than the initial dose of 0.5 mg/L. It was possible that a portion of ammonia was converted to nitrogen gas in reactions of bromide with ammonia and chlorine as discussed below.

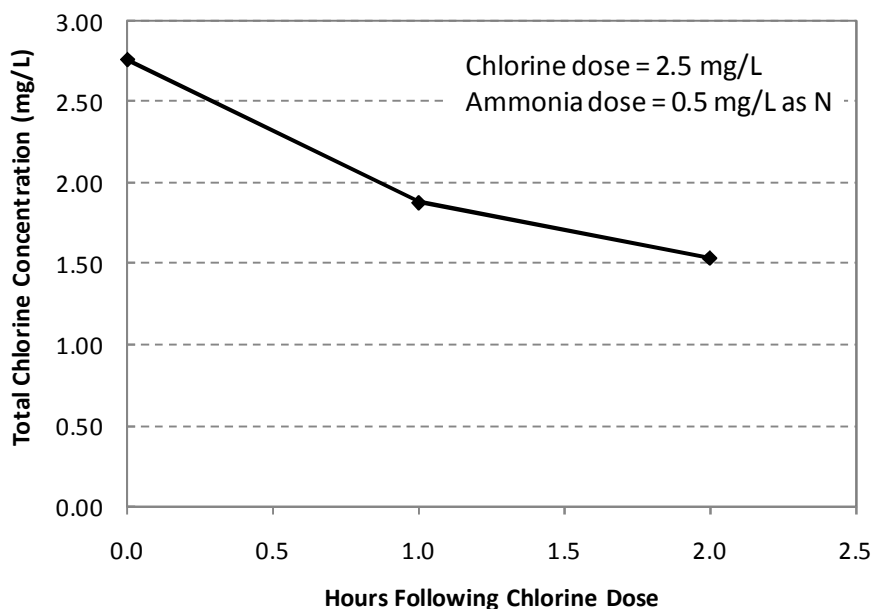


Figure 4. Total Chlorine Degradation Curve for Stabilized RO Permeate

In a previous study, superchloramination was necessary to achieve a desired total chlorine residual due to the presence of bromide in RO permeate generated from seawater. Bromide in chloraminated water complicates system chemistry by reacting with chloramine species to form bromamines. Bromamines are capable of accelerating monochloramine decay as catalysts for chloramine decomposition (Vikesland et al., 2001). The net result is chloramine decay catalyzed by bromide as follows, which assumes nitrogen gas is the primary oxidized nitrogen containing product.



A chlorine dose of 4.5 mg/L and an ammonia dose of 0.5 mg/L were added to superchloramine RO permeate in an attempt to reduce the rapid chloramine decay. This approach was successful in three other studies of RO permeate stabilization (Blute et al. 2008; Loveland and Means, 2005; Chao et al. 2004). In this study, total chlorine was measured as 3.60 mg/L immediately following chloramination, but the concentration decreased to 1.37 mg/L in one hour. Total ammonia after the first hour was 0.00 mg/L and a measurement of free chlorine equaled total chlorine, confirming that the sample was breakpoint chlorinated. The results suggest a chlorine dose of 4.5 mg/L Cl_2 with 0.5 mg/L $\text{NH}_3\text{-N}$ is too high of a ratio for the BARDP RO permeate sample. Combined with the chloramination results of 2.5 mg/L chlorine dose, the proper chlorine dose to achieve a total chlorine residual of 2.5 mg/L with a 4-hr residence time should be between 2.5 mg/L and 4.5 mg/L. Additional testing is recommended to further evaluate the optimal dose.

3.4.3 EBMUD and Stabilized RO Permeate Blending

A chlorine dose of 0.3 mg/L was added to the EBMUD water sample to reach a target chlorine residual of 0.2 mg/L that was typical of historical data provided to us. Following chlorine addition, the free chlorine concentration was 0.34 mg/L, which suggested that the EBMUD water did not have significant chlorine demand. At the time of blending, the stabilized RO permeate had a free chlorine residual of 0.16 mg/L (i.e., 2 hours after receiving a dose of 0.3 mg/L).

Table 6 presents water quality of the EBMUD and stabilized RO permeate blend. The blend had a pH value of 7.50, which was lower than the pH in stabilized RO permeate (8.88) and the EBMUD sample (7.83). The reason for the pH decrease is unclear; RTW modeling of the blended waters predicted a pH of 8.55. Alkalinity and calcium hardness were 28.0 and 22.8 mg/L as CaCO₃, respectively, which were expected due to the low alkalinity in EBMUD water. CCPP and LSI values were -5.4 mg/L and -1.3, respectively, which suggest the blend of EBMUD and RO permeate at a ratio of 2:1 had a tendency to be corrosive. Even if the pH was 8.55, the CCPP and LSI values were modeled to be -1.2 and -0.2, respectively. This tendency toward corrosive conditions is due to the composition of the EBMUD water (i.e., low alkalinity and calcium). A pH of nearly 9.2 would be needed to yield positive LSI and CCPP values for the EBMUD water quality. Results shown in Tables 3 and 4 and modeled results of the blend indicate that the addition of stabilized RO permeate should cause an increase in the LSI and CCPP values (and hence a tendency toward less corrosive conditions).

Table 6. Water Quality of Blended EBMUD Water and Stabilized RO Permeate (Blend Ratio = 2:1)			
Parameter	EBMUD Aqueduct #2	Stabilized RO Permeate Using 40 mg/L Liquid Lime and CO₂	Blend of EBMUD and RO Permeate
pH [‡]	7.83	8.88	7.50
Free Chlorine (mg/L)	0.34	0.16	0.22
Turbidity (NTU)	0.31	0.44	0.26
Conductivity (µS/cm)	55.9	322	131.4
Alkalinity (mg/L as CaCO ₃)	18	50	28
Calcium (mg/L as CaCO ₃)	20	50	23
Carbon Dioxide (mg/L)	Not Tested	5	7
Chloride (mg/L)*	2.3	43	18
Sulfate (mg/L)*	1.3	1.5	1.3
Total Dissolved Solids (mg/L)*	48	110	56
CCPP (mg/L) at 25 °C [‡]	-3.7	4.2	-5.4
LSI at 25 °C [‡]	-1.2	0.5	-1.3

* Lab analyses

‡ A pH lower than either blended waters was observed in bench testing. RTW modeling of the blend indicates that pH should be 8.55, yielding CCPP and LSI values of -1.2 and -0.2, respectively.

3.4.4 CCWD and Stabilized RO Permeate Blending

The total chlorine residual in the CCWD water sample degraded from 2.78 mg/L at the time of sampling to 2.20 mg/L at the time of blending. A chlorine dose of 0.5 mg/L was added to the CCWD water sample to boost chlorine to the original level. Following chlorine addition, the total chlorine residual was measured as 2.44 mg/L. The chloraminated stabilized RO permeate contained a total chlorine concentration of 1.54 mg/L and a total ammonia concentration of 0.34 mg/L as N at the time of blending (i.e., 2 hours after initial dosing).

Table 7 presents water quality of the blend of CCWD water and RO permeate. Alkalinity and calcium hardness levels were in the expected range between the corresponding values in the RO permeate and CCWD water. CCPP and LSI values of the blend were -2.8 mg/L and -0.3, respectively, suggesting that the blend of CCWD water and RO permeate at a ratio of 1:1 had a tendency to be corrosive. Like EBMUD water, CCWD water also exhibited negative LSI and CCPP values prior to blending with stabilized RO permeate. pH contributes strongly to these negative values; an increase to even 8.1 could result in positive corrosion indices. RTW blend modeling predicted a blend pH of 8.26, which would result in an LSI of 0.1 and CCPP of 0.3. The reason for the lower than predicted pH is unclear at this time. Nevertheless, introduction of stabilized RO permeate lessened the corrosivity of the water compared with 100% CCWD water.

Parameter	CCWD Multi-Purpose Pipeline	Stabilized RO Permeate Using 40 mg/L Liquid Lime and CO₂	Blend of CCWD and RO Permeate
pH	7.71	8.88	7.77
Total Chlorine (mg/L)	2.44	1.54	1.42
Total Ammonia (mg/L as N)	0.44	0.34	0.16
Turbidity (NTU)	0.16	0.44	0.27
Conductivity (µS/cm)	911	322	516
Alkalinity (mg/L as CaCO ₃)	76	50	67
Calcium (mg/L as CaCO ₃)	66	50	56
Carbon Dioxide (mg/L)	Not Tested	5	13
Chloride (mg/L)*	110	43	80
Sulfate (mg/L)*	68	1.5	32
Total Dissolved Solids (mg/L)*	380	110	250
CCPP (mg/L) at 25 °C	-3.1	4.2	-2.8
LSI at 25 °C	-0.3	0.5	-0.3

* Lab analyses

The blend of CCWD water and stabilized RO permeate had a total chlorine concentration of 1.42 mg/L, which was lower than the chlorine residuals in the RO permeate (1.54 mg/L) and CCWD

water (2.44 mg/L). The total ammonia concentration in the blend was 0.16 mg/L as N, which was much lower than total ammonia levels in the RO permeate (0.34 mg/L) and CCWD water (0.44 mg/L), indicating that some breakpoint chlorination occurred during blending.

3.4.5 DBP Formation

Figure 5 presents TTHM formation results for blends of EBMUD water with stabilized RO permeate, and CCWD water with stabilized RO permeate (using a 24-hour hold time). The blend of free chlorinated EBMUD water and stabilized RO permeate had a TTHM concentration of 26 µg/L, which was slightly higher than the TTHM level (23 µg/L) in EBMUD water. The proportion of individual trihalomethane species shifted in the blend to include more brominated DBPs due to the influence of bromide in the RO permeate.

The chloraminated blend of CCWD water and stabilized RO permeate yielded a TTHM concentration of 20 µg/L, which was lower than the TTHM concentration of 34 µg/L in CCWD water. These results suggest that stabilized RO permeate had lower TTHM formation compared with CCWD water. TTHM concentrations in the blends of EBMUD water with stabilized RO permeate, CCWD water with stabilized RO permeate, EBMUD and CCWD water were well below the primary maximum contaminant level (MCL) of 80 µg/L.

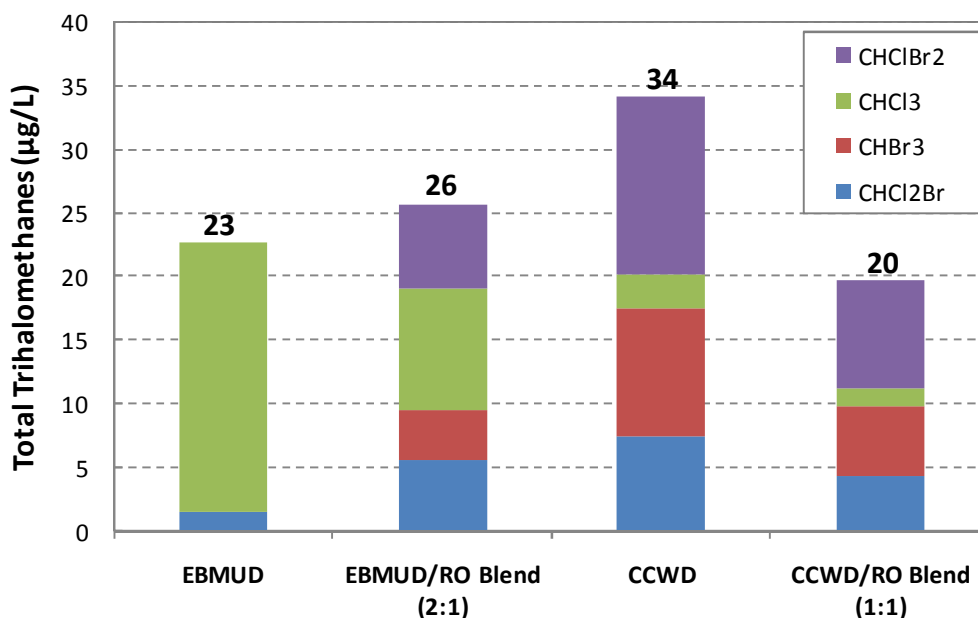


Figure 5. TTHM Formation in EBMUD, CCWD, EBMUD/RO and CCWD/RO Blend
 CHCl₂Br – Bromodichloromethane; CHCl₃ – Chloroform; CHBr₃ – Bromoform;
 CHClBr₂ - Dibromochloromethane

Figure 6 shows HAA5 results for EMBUD, CCWD water, and the blends of chlorinated EBMUD water with stabilized RO permeate, and chloraminated CCWD water with stabilized RO permeate

(using a 24-hour hold time). The HAA5 concentration in the blend of EBMUD with stabilized RO permeate was 8.6 µg/L, slightly higher than that in EBMUD water. The blend of CCWD water with stabilized RO permeate had an HAA5 concentration of 4.4 µg/L, lower than that of CCWD water. The addition of stabilized RO permeate to the EBMUD blend increased the HAA5 levels due to reactions of organic matter with free chlorine, whereas chloramination of the stabilized RO permeate before blending with CCWD water caused a decrease in the total HAA5 level in the blend. Overall, HAA5 concentrations in the blends of EBMUD with RO permeate, CCWD with RO permeate, EBMUD water, and CCWD water were all well below the primary MCL of 60 µg/L.

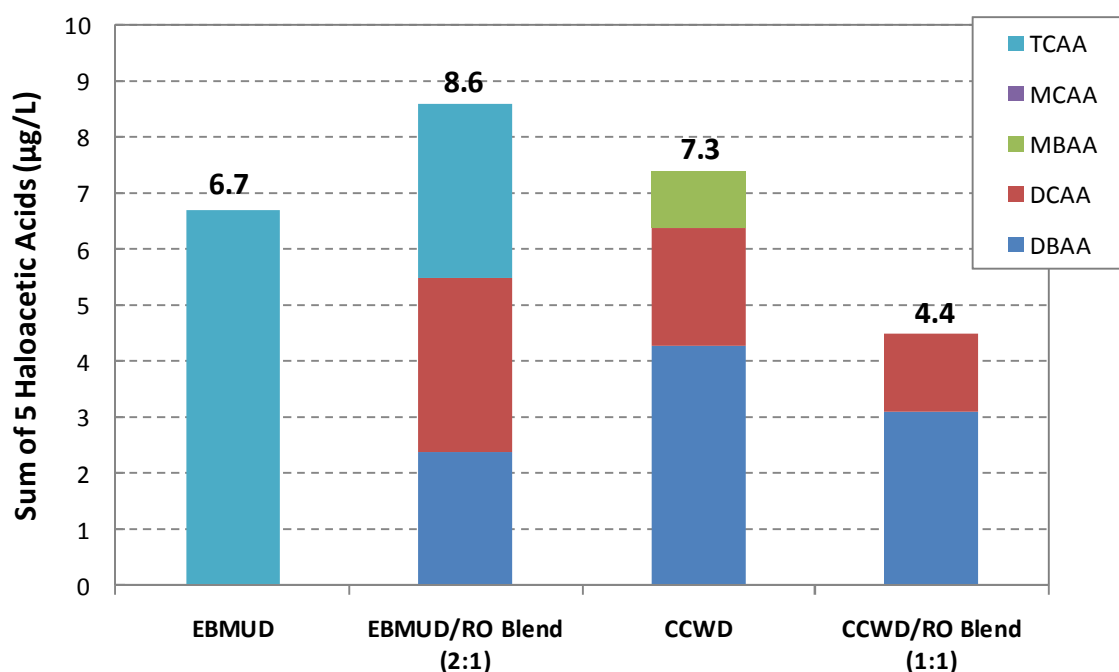


Figure 6. HAA5 Formation in EBMUD, CCWD, EBMUD/RO and CCWD/RO Blend
 TCAA - Trichloroacetic Acid; MCAA - Monochloroacetic Acid; MBAA - Monobromoacetic Acid;
 DCAA - Dichloroacetic Acid; DBAA - Dibromoacetic Acid

4.0 Conclusions and Recommendations

This bench-scale study tested liquid lime with carbon dioxide and a calcite filter as stabilization treatment options for finished water (i.e. RO permeate) of the BARDP pilot study. The study results showed that both options were able to sufficiently stabilize RO permeate to achieve the water quality targets.

RO permeate treated with liquid lime and carbon dioxide yielded alkalinity and hardness at levels of 50 mg/L as CaCO₃, a CCPP value of 4.2 mg/L and a LSI value of 0.5. Visible turbidity

formation was observed due to calcium carbonate precipitation when liquid lime was added first with subsequent carbon dioxide due to a high interim pH. Turbidity formation was lessened to acceptable levels by simultaneously adding liquid lime and carbon dioxide.

RO permeate treated with a calcite filter resulted in alkalinity and hardness at levels of 40 mg/L as CaCO₃, a CCPP value of 2.4 mg/L and a LSI value of 0.4. pH depression prior to calcite filtration may be necessary to yield sufficient calcite dissolution (i.e., alkalinity and calcium) depending on RO permeate pH.

Chlorination tests of stabilized RO permeate showed that a chlorine dose of 0.3 mg/L resulted in a free chlorine residual of 0.16 mg/L within two hours. Initial chloramination results of stabilized RO permeate indicate that a chlorine dose between 2.5 mg/L and 4.5 mg/L is needed to reach a target total chlorine residual of 2.5 mg/L. Further testing is necessary to determine the exact total chlorine dose since the superchloramination method shown to be effective elsewhere at the dose tested was too aggressive in this case (resulting in breakpoint chlorination). In addition, significant decreases in total chlorine and total ammonia concentrations were observed when CCWD water was blended with chloraminated RO permeate during the bench-scale study. The reasons for this were unknown; more detailed source water blending analysis would be required to determine whether this behavior would be expected at full scale.

Blends of EBMUD water with stabilized RO permeate and CCWD water with stabilized RO permeate exhibited negative CCPP and LSI values. This occurred because both EBMUD and CCWD water were shown to have negative CCPP and LSI values due to low calcium, alkalinity, and pH in EBMUD water and low pH in CCWD water. In contrast, stabilized RO permeate (produced by either method tested) had positive corrosion index values. Blending with stabilized RO permeate could not compensate for the negative CCPP and LSI values of EBMUD and CCWD water. However, stabilized RO permeate should drive the LSI and CCPP values to less corrosive values.

For the time period (24 hrs) and residuals tested (0.3 mg/L free chlorine or 2.5 mg/L chloramines), RO permeate caused a slight increase in DBPs with free chlorine compared when blended with EBMUD water and a decrease in DBPs with chloramines when blended with CCWD water. Overall, DBPs in the blends were well below the primary MCLs for TTHM and HAA5.

5.0 References

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