Appendix C

Trussell Technologies
Technical Memorandum on
Boron Mitigation for Seawater Desalination
(Boron Removal Modeling)

Submitted as an Appendix to Attachment A of Irvine Ranch Water District's Comment Letter to Santa Ana Regional Water Quality Control Board Regarding the NPDES Permit Renewal for the Huntington Beach Seawater Desalination Project

November 26, 2019

TECHNICAL MEMORANDUM
Irvine Ranch Water District
Boron Mitigation for Seawater Desalination

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Subject: **Boron Mitigation for Seawater Desalination**

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1. Introduction

Poseidon Water is pursuing the development of the Huntington Beach Water Desalination Facility (HBWDF), with a design which would produce 50 million gallons per day (mgd) of drinking water. Orange County Water District (OCWD) has been considering a commitment to purchase and manage the desalinated seawater from the HBWDF and approved a nonbinding term sheet with Poseidon in July 2018. This latest term sheet references a Water Reliability Agreement (WRA) that was established between OCWD and Poseidon in 2015 that includes a proposed specification for the water quality that would be delivered by the HBWDF, 'Attachment A'. Previously, Trussell Technologies, Inc. (Trussell Tech) completed a study for OCWD evaluating the water quality and regulatory impacts of introducing desalinated seawater into OCWD's system, including the implications for the Orange County Groundwater Basin (OCGB) under various potential operational scenarios with desalinated seawater. Findings from this study were summarized in a report entitled "Review of Proposed Water Quality Requirements for the Huntington Beach Desalter" (Trussell Tech, 2016).

The Irvine Ranch Water District (IRWD) is interested in understanding the potential impact of the future use of desalinated seawater from the HBWDF on the water quality within the OCGB. The 2016 Trussell Tech report identified that boron has been accumulating in the OCGB related to the OCWD's Groundwater Replenishment System (GWRS), and that the use of desalinated seawater –

considering the proposed water quality – would substantially increase the rate of this boron accumulation.

The purpose of this technical memorandum (TM) is to provide an assessment of potential measures that could be implemented at the HBWDF to reduce the accumulation of boron in the groundwater supply. The TM provides a) a discussion of the State of the Science of boron removal from desalinated seawater, b) a review of boron removal strategies that have been implemented at existing seawater desalination facilities, and c) an evaluation of boron removal through modeling scenarios with varying operation of the Poseidon reverse osmosis (RO) design. In this analysis, the term sheet water quality goals for boron and certain other constituents, notably chloride, will be considered, as well as a lower boron water quality goal selected to be similar to the concentration contributed by the GWRS.

2. Background on Boron

Seawater is highly concentrated in dissolved minerals – often characterized by the bulk water quality parameter total dissolved solids (TDS). The dominant seawater minerals are summarized by typical concentration in Table 1. The RO membranes used in seawater desalination are very efficient in removing the most abundant minerals in seawater – namely, chloride, sodium, sulfate, and magnesium – that together account for more than 97% of the minerals present. However, boron is not as effectively removed via conventional RO, leaving elevated levels in the permeate in excess of conventional drinking water boron concentrations. Despite being efficiently removed via RO, the elevated background concentrations of chloride and sodium are sufficiently high, such that the residual levels in the permeate are still greater than corresponding levels in conventional drinking water. For these reasons, chloride, sodium, and boron are often treatment drivers for seawater desalination.

Table 1. Dominant minerals in seawater (Adapted from Millero, 2013; Assumes 25ºC and density of 1.025 Kg/L).

Mineral	mg/L
Chloride	19,837
Sodium	11,051
Sulfate	2,780
Magnesium	1,316
Calcium	422
Potassium	409
Bicarbonate	107
Bromide	69
Strontium	8.1
Boron	4.6
Fluoride	1.3

The state of California maintains a health-based Notification Level of of 1 mg/L for boron in drinking water. A lack of data on the occurrence of boron in drinking water supplies and its toxicology led to its inclusion on the United States Environmental Protection Agency (USEPA) second Drinking Water Contaminant Candidate List (CCL2). As a result of the CCL2 assessment, a proposed health advisory level of 6.7 mg/L (USEPA, 2008b) and a health reference level of 1.4 mg/L (USEPA 2008a) were established. Another result of this assessment was a decision by the USEPA not to establish an MCL for boron, as doing so offered no meaningful opportunity for health risk reduction (USEPA 2008c). The World Health Organization (WHO) established a guideline value of 2.4 mg/L for boron in drinking water in 2009 (WHO, 2009), representing an increase over its previous guideline value of 0.5 mg/L when health effect studies proved the higher level was appropriate (WHO, 2011). Nevertheless, the Notification Level of 1 mg/L remains in effect in California.

In addition to health considerations, the presence of elevated boron in drinking water raises horticultural concerns. Boron is essential for plant growth, but accumulation of boron associated with irrigation using water with a high concentration of boron can cause yellowing (‘chlorosis’, depicted in Figure 1) and even leaf death. These horticultural impacts are exacerbated by hot, more arid climates, where high rates of transpiration drive boron accumulation in the leaves.

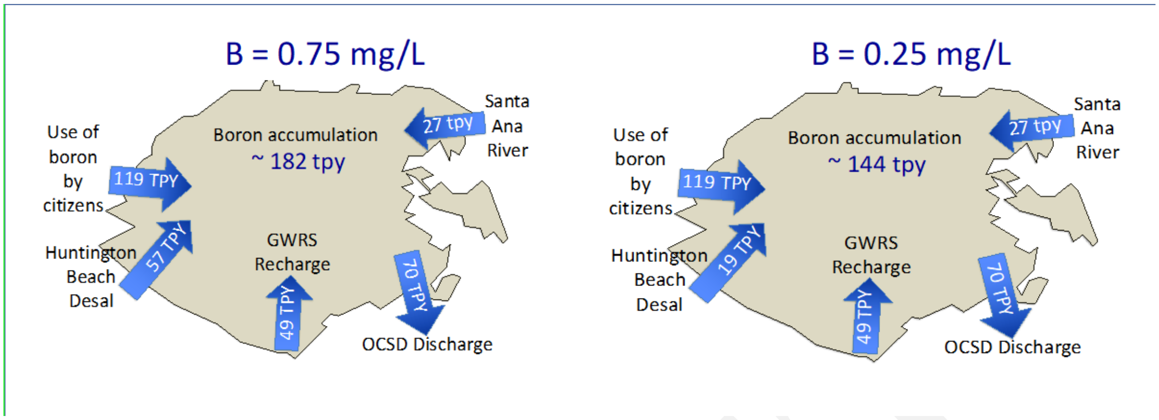
Figure 1. Chlorosis of leaves caused by excess boron

Two boron values have been put forth by Poseidon on Attachment A of their Water Reliability Agreement term sheet (included in this document as Appendix A). A mean value of 0.75 mg/L of boron is proposed, as well as a maximum boron value of 1.0 mg/L. While these values are in line with the California NL of 1 mg/L in drinking water, IRWD is concerned about the downstream fate of this boron.

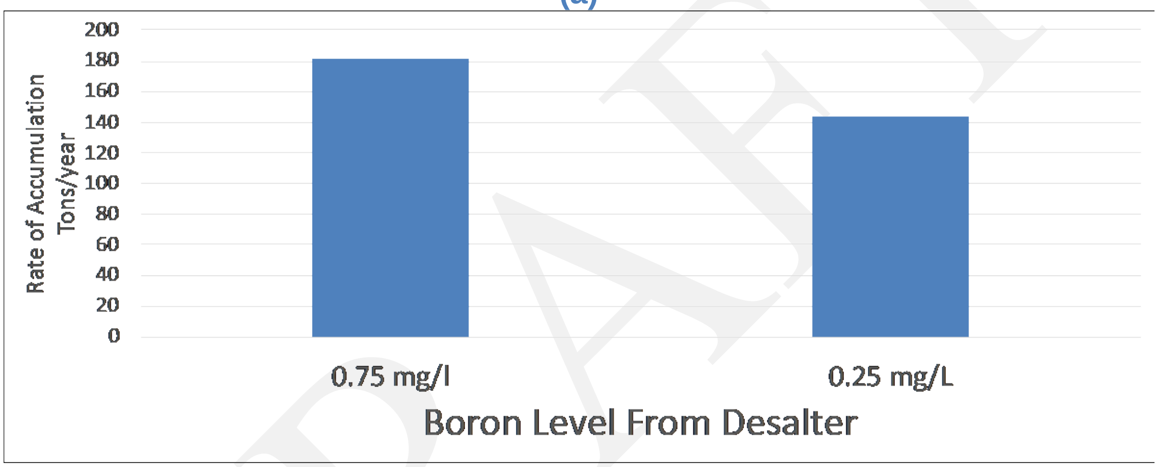
Trussell Tech provided an analysis of boron in the OCGB using mass balance approximations in the 2016 report (Trussell Tech, 2016). This new report represents inputs for two scenarios: (1) Contribution from HBWDF of 0.75 mg/L, which matches the term sheet; (2) a lower boron target of 0.25 mg/L that matches the concentrations contributed by the OCWD GWRS and by the flows in the Santa Ana River. Boron inputs to the OCGB are summarized in Figure 2a and reflect the following sources:

- Boron present within local water supplies and used at the household level (e.g. food, soaps/detergents) within the Santa Ana River Watershed is transferred to local domestic sewage systems. Boron is not removed through the wastewater treatment process, and the effluent is discharged to the Santa Ana River, bringing its average concentration to 0.25 mg/L. Assuming an average flow of 71 mgd for the river, this yields a contribution of 27 tons per year (TPY) to the OCGB.
- Water supplied by OCWD serves 2.5 million residents in north and central Orange County. Household use of boron is transferred to the domestic sewage that is conveyed by Orange County Sanitation District (OCSD). An increasing fraction of this sewage is purified at the GWRS (established in 2008) then applied to recharge basins to percolate into the OCGB. The purification process includes advanced treatment with RO, which – as referenced previously – is not efficient in removing boron. The future flow for the OCWD GWRS is used in the 2019 estimates – the average GWRS input to the basin is 130 mgd with an approximate boron concentration of 0.25 mg/L, contributing an additinoal 49 TPY to the OCGB.
- The amount of boron presently in OCSD's treated wastewater, or 119 TPY, is assumed to be contributed by local citizens (e.g. food, soaps, detergent, etc.)
- The HBWDF produces 50 mgd of desalinated seawater with an average boron concentration of 0.75 mg/L, or 57 TPY, most of which also enters the OCGB (left-hand side of Figure 2a).
- If the desalinated seawater from the HBWDF meets an average boron concentration of 0.25 mg/L (matching the boron concentrations of the GWRS and the SAR), its boron contribution would be reduced from 57 TPY to 19 TPY (right-hand side for Figure 2a).

The overall mass balance for boron accumulation in the OCGB with the HBDWF at 0.75 mg/L and 0.25 mg/L boron is summarized in Figure 2b.



(a)



(b)

Figure 2. Approximations of the boron mass balance in the Orange County Groundwater Basin (a) at boron concentration of 0.75 mg/L from the term sheet (left-side) vs. boron concentration of 0.25 mg/L, a lower boron target with desal concentration equal to GWRS concentration (right-side) (b) Summary of the overall mass balance boron contribution at 0.75 and 0.25 mg/L.

As shown in Figure 2a and 2b, with the HBWDF at 0.75 mg/L, the boron accumulation in the OCGB is increased by 57 TPY to approximately 182 TPY. If HBWDF operates at 0.25 mg/L, the overall boron accumulation is reduced to approximately 144 TPY. Thus, reducing the boron in the HBWDF in this manner reduces the overall accumulation in the OCGB by 38 TPY.

In order to provide perspective on the boron removal question, several existing seawater desalination facilities were reviewed (Trussell Tech, 2016) and that review indicated that the proposed boron levels presented in Attachment A of Poseidon's term sheet for the HBWDF are consistent with with boron specifications for many existing facilities. As shown in Table 2, the majority of the existing desalination facilities have water quality specifications for boron that are the same or higher than HBWDF.

Table 2. Critical Water Quality Specifications[1] for Existing Desalination Projects (Trussell Tech, 2016)

Date	Project	Country	Capacity mgd	2nd pass	Water Quality Specifications (mg/L)				
					TDS	Chloride	Bromide	Boron	Sodium
2003	Tampa (Phase 2)	USA	25	Partial	500	100	0.45	-	80
2005	Ashkelon	Israel	98	Partial	40[2]	20	-	0.4	-
2005	TUAS	Singapore	36	Full	415µS/cm	100	-	0.5	-
2006	Perth 1	Australia	33	Full	200	250	0.1	2	180
2007	Valdelentisco	Spain	36	None[3]	2,500µS/cm	250	-	1	-
2009	Gold Coast	Australia	33	Partial	220	50	0.1	1	-
2009	Sur	Oman	21	Partial	200-500	250	-	0.5	-
2009	Barcelona	Spain	53	Partial	-	100	-	1	-
2010	Sydney	Australia	66	Partial	115	40	0.1	1	-
2010	Fujairah 2	UAE	36	Partial	100-200	100	-	1	-
2011	Perth 2	Australia	66	Partial	200	-	0.1	2	-
2012	Melbourne	Australia	108	Full	120/140[4]	60	0.1	0.5	-
2015	Carlsbad[5]	USA	53	Partial	320/375/600	120/150/-	0.4/0.7/-	0.75[6]/1.0[7]/-	-
2016	Santa Barbara	USA	3	TBD	450	155	0.8	1.1	1109
2022 (est)	Monterey[8]	USA	9.6	Partial	-/500	60/100	0.3/0.5	0.5/0.7	35/60
-	WBMWD[9]	USA	-	Partial	450	100	0.3	0.5	-
-	HBWDF[8]	USA	56	TBD	*350/500*	*75/100[8]*	-	*0.75/1.0*	*60/80*
2008	GWRS[10]	USA	100	-	*54*	*7.5*	*0.01*	*0.26*	*9.6*

1 – Generally an average that cannot be exceeded. At Carlsbad, cannot be exceeded more then 50% of the time.
2 – before post treatment
3 – Substantial pH adjustment is used to enhance boron removal
4 – ≥ 120 mg/l for no more than 1800 minutes/month (4% of time); ≥ 140 mg/l for no more than 600 minutes per month (2% of time)
5 – central tendency (mean or median)/extreme (90%)/Maximum – Sodium Adsorption Ratio < 9 to 12;
6 – Allows for adjustments if the water temperature exceeds 73.4°C
7 – 95% of daily samples must be below 1.0 (can be exceeded no more than 18 days per year)
8 – Mean/maximum
9 – Criteria used for West Basin Municipal Water District's (WBMWD) Temporary Desal Demonstration Facility in Redondo Beach
10 – Average for 2014

It should be noted that some plants do have lower boron specifications, notably the Ashkelon plant in Israel. Those with boron specifications of 0.75 mg/L or less all have design provisions for treating all or a portion of the desalinated water with a 2nd pass of brackish water RO – usually called a “partial or full 2nd pass RO”. The treatment options for addressing boron are discussed in general within Section 3 and more specifically for 2nd pass RO within Section 4.

3. State of the Science for Boron Removal

An updated review of measures implemented by desalination plants to treat boron indicates that there have been no dramatic changes in boron treatment technologies since the publication of our earlier report to OCWD (Trussell Tech, 2016). There is no new technology in wide use at the full-scale. There are also no new technologies on the horizon at the full-scale.

As shown in Table 2 above, most full-scale facilities either rely on the level of boron treatment provided by single pass RO or use either partial 2nd pass RO or full 2nd pass RO to meet lower treatment targets. Many plants also take no specific steps to address boron and rely on meeting chloride targets to be suitably effective in boron control. It should be noted there is one facility in Israel that uses ion exchange for boron removal . There is also some research into boron chelating ion exchange resins that merits brief discussion. This section will address ion exchange and RO treatment of boron for seawater desalination.

3.1 Ion Exchange

There is one full scale facility that uses ion exchange to address boron in seawater desalination. Ion exchange is not commonly used for seawater desalination because it is not cost effective compared to 2nd pass RO. To be cost competitive, it is necessary to regenerate the ion exchange resins employed. This can be challenging at the scale of seawater desalination projects.

A promising technology that has been introduced by researchers at CalTech for the removal of boron from seawater at the research scale involves selective boron chelating ion exchange resins (Mishra et al., 2012). For this technology, the typical structural backbone of a boron selective resin is changed to a binding approach involving branched polyethylenimine (PEI) beads. This allows for an increase in binding capacity. Bench tests showed effective boron removal including for a seawater desalination feedwater. While promising, this technology is nowhere near ready for deployment at the full-scale.

3.2 Reverse Osmosis

As indicated in Table 2, the most common way of improving treatment performance in general – and specifically for boron removal – is the installation of 2nd pass RO using brackish water membranes. Because the permeate from the 1st pass SWRO is nearly dead soft (i.e., contains no divalent ions) and has almost no total organic carbon (TOC), both the recovery and the design flux in 2nd pass systems can be very high. Often the pH in the 2nd pass feed is also adjusted using caustic (NaOH) to improve the removal of boron by converting it to the ionized form. This pH adjustment is straightforward to accomplish given the low alkalinity and reduced buffer capacity of SWRO product water.

More recently, designs segregate the permeate from the first and second half of vessels in the first stage of SWRO treatment, using the better quality permeate from the lead elements directly and sending the permeate from the tail elements through the 2nd pass RO.

The Poseidon project in Carlsbad reportedly uses a four-stage cascade process patented by IDE, the plant's designer (Gasia et al. 2015). This patent is a further enhancement of the permeate split idea where the poorer quality permeate from the second half of the first stage is further polished through a 2nd pass containing a cascade of four RO stages where removal of TDS and other contaminants can occur through a flexible combination of different membrane types working at different pH levels (Figure 3). Where boron removal is concerned, this design is state-of-the-art. The desalination project in Monterey, CA will also use a simplified version of this concept.

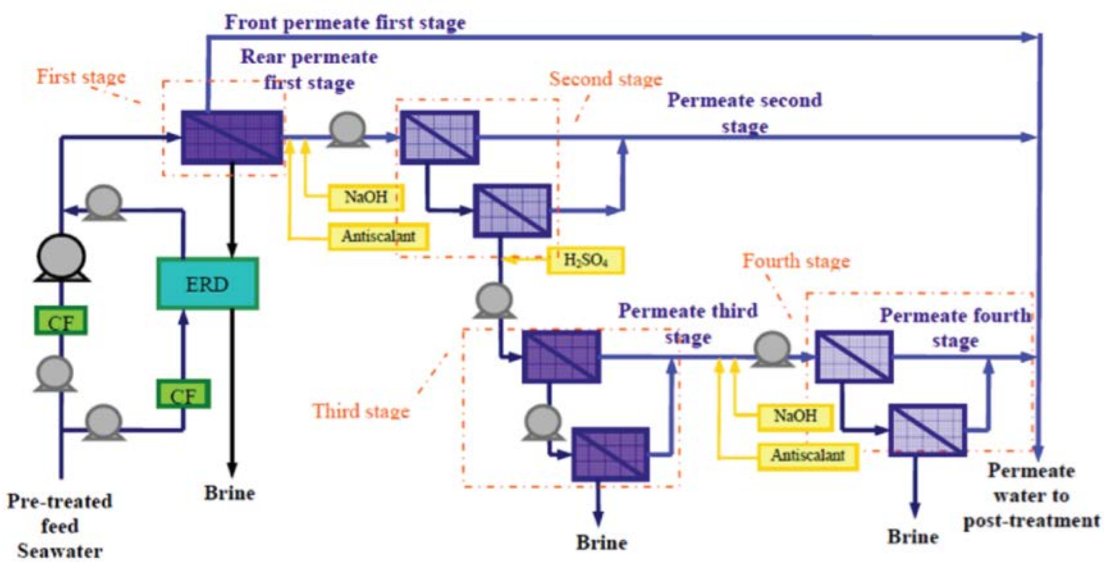


Figure 3. Diagram of IDE's patented 4 Stage Cascade Process (Adapted from Gasia, 2015)

Most RO manufacturers also offer tighter membranes, which can meet lower boron objectives in a single pass, but generally these membranes are not seeing a lot of use as they also lead to higher operating pressures, higher energy requirements, and higher operating costs.

Huntington Beach and Carlsbad are both Poseidon plants, so it is useful to look at Carlsbad. At Carlsbad, the pH is increased to convert boron to an ionized form prior to a partial 2nd pass. The annual water quality report of one of the purveyors that receives desalinated water from the Carlsbad plant, Vallecitos Water District (VWD), indicates that the plant runs with approximately 1/3 of the RO permeate from the 1st pass being sent through the partial 2nd pass to reduce chloride and boron. VWD annual Consumer Confidence Reports (CCRs) on water quality from local sources for 2017 and 2018 list boron levels for the Carlsbad Treatment Plant (VWD, 2018 and 2019).

2017	Boron	0.59 (avg)	0.33-0.95 mg/L
2018	Boron	0.61 (avg)	0.37-0.92 mg/L

The average boron levels meet the HBWDF term sheet boron goal (Appendix A), but they are substantially above the basin boron goal of 0.25 mg/L that is under evaluation.

4. Huntington Beach Desalter Impacts

Building on a modeling approach implemented for the previous assessment of the HBWDF water quality (Trussell Tech. 2016), modeling was completed to understand a range of boron mitigation options via 2nd pass RO configurations. As described in the previous report (Trussell Tech, 2016), the RO modeling was completed using TorayDS™ and inputting feed seawater quality to demonstrate the expected change in water quality parameters of interest through varying operational conditions involving 2nd pass RO. The model was set up to understand the impact of 2nd pass RO treatment in a simplified way and not to suggest specific vendors or designs. The RO design configuration is shown on Figure 4. The TorayDS™ model from Toray Industries was used to model the performance, where a 1st pass RO with partial 2nd pass treatment was used, without 2nd pass concentrate recycle. The 1st pass RO was modeled as a seawater reverse osmosis (SWRO) system, whereas the 2nd pass RO was modeled as a brackish water reverse osmosis (BWRO) system. Model parameters are further detailed in Table 3.

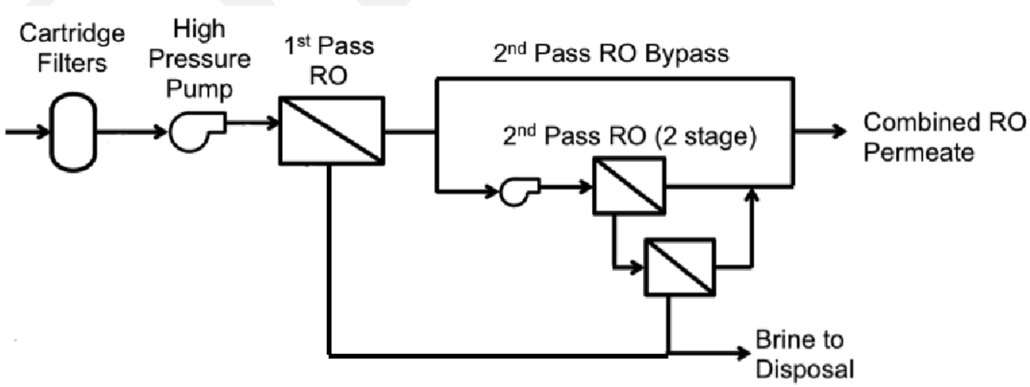


Figure 4. RO Design Configuration for Modeling

Table 3. 1st and 2nd Pass RO System Design Assumptions

Parameter	Units	Value
Combined RO System		
Total Product Flowrate	gpm	1110
Total Product Flowrate	MGD	1.6
1st Pass (SWRO) Membrane System		
Maximum Flux Rate	gfd	Varies, depending on configuration of partial 2nd pass
Recovery	%	45
Number of Pressure Vessels Per Train	no.	70
SWRO Membrane Element Diameter	in	8
SWRO Membrane Elements per Vessel	no.	7
SWRO Membrane Surface Area per Element	sf	400
SWRO Membrane Age	yr	5
SWRO Fouling Factor	-	0.77
SWRO Salt Passage Increase	%/yr	7.0
1st Pass Feed pH	-	8.3
2nd Pass (BWRO) Membrane System		
Maximum Flux Rate	gfd	Varies, depending on configuration of partial 2nd pass
Recovery	%	85
BWRO Membrane Element Diameter	in	8
BWRO Membrane Elements per Vessel	no.	7
BWRO Membrane Surface Area per Element	sf	400
BWRO Membrane Age	yr	5
BWRO Fouling Factor	-	0.77
BWRO Salt Passage Increase	%/yr	7.0
2nd Pass RO Feed pH	-	10.0

4.1 Summary of Water Quality Goals

The water quality goals for the combined RO permeate are summarized in Table 4. These include the term sheet water quality goals and the basin boron goal.

Table 4 - Water Quality Goals for the Combined RO Permeate

Parameter	Units	
Water Quality Goals from Draft Term Sheet (Appendix A)		
Term Sheet Conditions		**Average (Mean)**
Total Dissolved Solids (TDS)	mg/L	350
Boron	mg/L	0.75
Chloride	mg/L	75
Sodium	mg/L	60
Basin Boron Goal[a]		
Boron	mg/L	0.25

[a]Meeting a boron goal of 0.25 mg/L will also be explored by varying fraction 2nd pass RO to consider impact of a lower boron goal on the basin water quality that is identical to the concentration of boron input into the basin from the GWRS and the SAR.

4.2 Modeling conditions for 2nd pass RO treatment

Feed water temperature can influence the design and operation of a desalination plant. Previous RO modeling of the HBWDF (Trussell Tech, 2016), included scenarios using elevated seawater temperatures related to operations using the discharge from a nearby powerplant, AES HB power station. Recent regulatory changes have resulted in a shift away from 'once-through-cooling' systems for power plants. As a consequence, a Subsequent Environmental Impact Report (SEIR) was certified including provisions for HBWDF to operate as a "stand-alone" facility, independent of discharge from AES (Poseidon HB Desalination website, 2019). Due to this anticipated change, the impact of the power plant discharge on feed water temperature was not included in the current report.

Table 3 summarizes the parameters used in the model.

Two temperature scenarios were considered in the current modeling evaluation of the HBWDF water quality, both based on temperature data from the nearby Newport Beach Pier over the period of 2010 through 2015 (Figure 5). The first case is the most important for operations, as it is intended to represent normal operations once the plant is built, while the second case represents the worst-case scenario, using maximum seawater temperature. The method for determining these temperatures is described in detail in the previous report for OCWD (Trussell Technologies, 2016).

This exercise based on historical data is useful to demonstrate the effect of different temperatures. It should be noted that it would also be interesting to consider the effect of climate change on temperatures into the future (over 30 years, for example) on both the average and maximum boron levels, but this analysis was beyond the scope of this TM. The two temperature cases are summarized below:

- **Case 1 –** Normal Operations using ambient seawater at 63ºF, based on the average temperature measured from the nearby Newport Beach Pier (2010-2015)
- **Case 2 –** Operations on warm seawater at 74ºF, using the maximum monthly average temperature (2010-2015 Newport Beach Pier data) as the 'worst-case' scenario for boron removal.

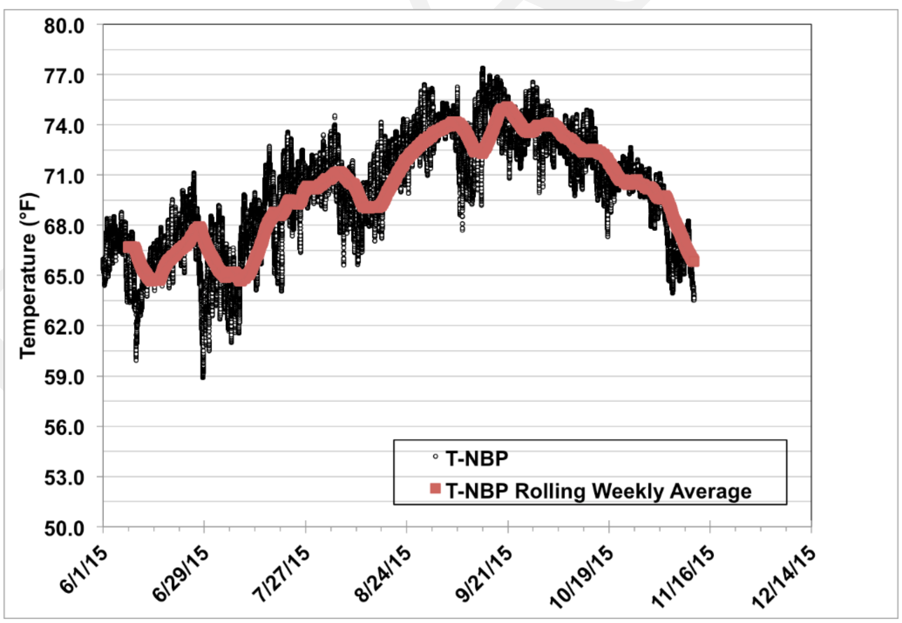


Figure 5. Temperature Data from SCCOOS for Newport Beach Pier for Summer/Fall 2015.

Six different scenarios each were considered for Case 1 (63ºF) and Case 2 (74ºF), varying the portion of RO permeate from the 1st pass used as the feed water for 2nd pass RO treatment (Table 5) . The modeled flows to the 2nd pass RO included 0%, 20%, 40%, 60%, 80%, and 100% of the 1st pass RO permeate. Table 6 shows the configuration of the 2nd pass RO vessels for each train used with the TorayDS™ model, and the corresponding membranes used for each pass are indicated in Table 7. The SWRO membranes are high pressure membranes aimed at addressing the high levels of salts in the seawater. The BWRO membranes for the 2nd pass RO are low pressure, as the quality of the 1st pass RO permeate is significantly higher.

Table 5. Parameters Varied for RO Modeling

Parameter	Case 1	Case 2
Brief Case Description	Normal Operations on Ambient Seawater	Normal Operations on Warm Seawater from Power Plant Condenser
Feedwater Temperature	63 °F	74 °F
Percent 2nd Pass[1]	0%, 20%, 40%, 60%, 80%, 100%	0%, 20%, 40%, 60%, 80%, 100%

[1]Six RO model runs were performed for each case with different 2nd pass

Table 6. 2nd Pass Vessel Configuration per Train for Case 1 and Case 2.

Parameter	No. of Vessels[1] (Stage 1:Stage 2)
0% 2nd Pass	N/A
20% 2nd Pass	4:2
40% 2nd Pass	8:4
60% 2nd Pass	12:6
80% 2nd Pass	18:9
100% 2nd Pass	22:11

[1]Seven elements per vessel

Table 7. Membrane Model and Characteristics

Manufacturer	Model	Characteristics
Toray	TM 820 V – 400	SWRO, High Permeability, High Pressure, 400 sf (I pass)
	TM 720 – 400	BWRO, High Rejection, Low Pressure, 400sf (II pass)

4.3 RO Modeling Results

As shown on Figure 4, with a partial 2nd pass, a portion of the 1st pass RO permeate is fed to the 2nd pass and another portion bypasses the 2nd pass and is later blended with the 2nd pass permeate to produce the combined RO product water. The RO bypass is taken from the lead part of the RO 1st pass elements and is of higher water quality; whereas the tail end elements that feed the 2nd pass are at lower water quality.

4.3.1 Permeate (Product Water)

Table 8 shows the combined product water permeate concentrations for Case 1 (T=63 °F). RO modeling results are shown for constituents of interest TDS, boron, chloride, bromide, and sodium. As discussed, chloride, boron, and sodium are most likely to be the controlling constituents. TDS and bromide are included as they are important constituents with respect to desalination water quality. For the combined RO product water, 0% 2nd pass RO treatment showed significantly higher chloride concentration than the water quality goals (85 mg/L). All the other scenarios (20-100% 2nd pass RO treatment) for combined RO product water showed results that meet all the water quality goals.

As expected, boron removal increases as the fraction of 2nd pass RO increases. At 0% 2nd pass, boron is at 0.57 mg/L, with improvements to 0.42, 0.31, and 0.23 mg/L, 2nd, at 20%, 40%, and 60%., respectively, 2nd pass RO.

Table 8. RO Modeling Results for Case 1 (T=63°F): Normal Operations on Ambient seawater. Combined RO Product Water

Constit-uent	Fraction of Flow through the 2nd Pass						Term Sheet	Basin Boron Goal
	0%	20%	40%	60%	80%	100%		
	Quality (mg/L)							
TDS	148	98	67	42	21	3	≤ 350	
Boron	0.57	0.42	0.31	0.23	0.16	0.10	≤ 0.75	0.25
Chloride	85	57	38	24	12	2	≤ 75	
Sodium	52	35	23	15	7	1	≤ 60	
Bromide	0.30	0.20	0.13	0.08	0.04	0.01	n.a.	
	does not meet Term Sheet							
	meets basin boron goal							

Table 9 shows the same combined product water permeate concentrations for Case 2 (T=74 °F). For the combined RO product water, 0% 2nd pass RO treatment showed significantly higher chloride and sodium concentrations than the term sheet water quality goals (116 and 71 mg/L, respectively). All the other scenarios (20-100% 2nd pass RO treatment) for combined RO product water showed results that meet all the water quality goals. Boron exceeded the term sheet water quality goal to a lesser degree at 0% 2nd pass, to be discussed below.

Boron concentrations at 0% and 100% 2nd pass RO scenarios were 0.81 mg/L, exceeding the term sheet average of 0.75 mg/L. Similarly, the combined RO product without 2nd pass (0% 2nd pass scenario) resulted in a boron concentration of 0.81 mg/L. Further, chloride and sodium concentration of the combined RO product exceeded water quality goals for the 0% 2nd pass scenario.

Focusing on boron for this TM, it is again shown that as expected, boron removal increases as fraction 2nd pass RO increases. At 0% 2nd pass, boron is at 0.81 mg/L for Case 2, with improvements to 0.59, 0.44, 0.33, and 0.24 mg/L, respectively, at 20%, 40%, 60%., and 80%, respectively, 2nd pass RO.

The results highlight the importance of 2nd pass RO treatment, particularly in summer periods, where occasional maximum temperatures can be expected. Notably, Case 2 is most useful for designing to assure the plant meets the term sheet on days when this maximum temperature occurs. Case 2 is not representative of normal operations during majority of the year, where seawater temperature is expected to be lower than 74 °F.

Table 9. RO Modeling Results for Case 2 (T=74°F): Operations on warm seawater during maximum monthly average temperature. Combined RO Product Water

Constit-uent	Fraction of Flow through the 2nd Pass						Term Sheet	Basin Boron Goal
	0%	20%	40%	60%	80%	100%		
	Quality (mg/L)							
TDS	201	129	86	53	28	5	≤ 350	
Boron	0.81	0.59	0.44	0.33	0.24	0.16	≤ 0.75	0.25
Chloride	116	74	49	31	16	2.7	≤ 75	
Sodium	71	46	30	19	9.8	1.8	≤ 60	
Bromide	0.40	0.26	0.17	0.11	0.06	0.01	n.a.	
(yellow)	does not meet Term Sheet							
(blue)	meets basin boron goal							

When targeting 0.25 mg/L boron, it was observed from the RO modeling (Table 8 and Table 9, respectively) that 60% 2nd pass RO achieves 0.23 mg/L boron for Case 1 (T=63°F) and that 80% RO achieves 0.24 mg/L boron for Case 2 (T=74°F).

Table 10 compares Case 1 and Case for the different 2nd pass scenarios considered. The results show that temperature made a significant difference in water quality. However, to meet all water quality goals on the Term Sheet for combined RO product water, including chloride, at least 20% 2nd pass RO treatment was required for both Case 1 and Case 2. Chloride was found to be the limiting constituent for design consideration for the Term Sheet for both Case 1 and Case 2. Overall, application of combined RO product water with 20% or more 2nd pass RO treatment can ensure that all Term Sheet water quality goals are maintained, even during high temperature seasons.

When considering the more stringent basin boron water quality goal of 0.25 mg/L, the following observations can be made. At the 20% 2nd pass RO treatment required to meet the Term Sheet water quality targets, the boron level for Case 1 (T=63°F) is 0.42 mg/L and the boron level for Case 2 (T=74°F) is 0.59 mg/L, as shown in Table 9. Both levels exceed the water quality goal of 0.25 mg/L under consideration to meet a greater level of protection for the basin. To achieve the goal of 0.25 mg/L boron, a 60% 2nd pass will be needed for Case 1 (T=63°F) and an 80% 2nd pass will be needed for Case 2 (T=74°F), as shown in Table 9.

This represents an increase of 20% 2nd pass to 60% 2nd pass for Case 1 (T=63°F), when considering the Term Sheet water quality target of 0.75 mg/L boron compared with the 0.25 mg/L water quality goal under evaluation to provide additional protection to the basin. This represents an increase of 20% 2nd pass to 80% 2nd pass for Case 2 (T=74°F), when considering the Term Sheet water quality target of 0.75 mg/L boron compared with the 0.25 mg/L boron water quality goal under evaluation to provide additional protection to the basin.

Table 10. Comparison of RO Modeling Results for Case 1 and Case 2: Combined RO product water. Model conditions where term sheet goals are not met are highlighted yellow. Model conditions where basin boron goal is met are highlighted light blue.

Constituent	Fraction of flow through 2nd pass												Term Sheet	Basin Boron Goal
	0%		20%		40%		60%		80%		100%			
	Temperature (°F)													
	63	74	63	74	63	74	63	74	63	74	63	74		
	Quality (mg/L)													
TDS	148	201	98	129	67	86	42	53	21	28	3	5	≤ 350	
Boron	0.57	0.81	0.42	0.59	0.31	0.44	0.23	0.33	0.16	0.24	0.10	0.16	≤ 0.75	0.25
Chloride	85	116	57	74	38	49	24	31	12	16	2	2.7	≤ 75	
Sodium	52	71	35	46	23	30	15	19	7	9.8	1	1.8	≤ 60	
Bromide	0.30	0.40	0.20	0.26	0.13	0.17	0.08	0.11	0.04	0.06	0.01	0.01	n.a.	

(yellow)	does not meet Term Sheet
(light blue)	meets basin boron goal

4.3.2 Concentrate (Brine Disposal)

The RO concentrate composition changes as the fraction of flow through 2nd pass increases.   Table 11 shows the 1st pass RO concentrate, 2nd pass RO concentrate, and the combined RO concentrate as a function of fraction of flow through the 2nd pass. Table 11 shows the feed and concentrate flow for the RO model. It is observed from Table 11 that there is a small trend downward in the RO concentrate boron concentration as fraction of flow through the 2nd pass increases, from 8.62 mg/L at 20% 2nd pass and 8.31 mg/L at 60% 2nd pass at 63°F. . A similar trend was observed for the other constituents studied. The limited change in the concentrations of the constituents of interest and the downward trend in concentrations as the fraction through the 2nd pass increases suggests there will not be regulatory challenges associated with the change in ocean discharge water composition. Likewise, the seawater intake is not expected to be affected by adding the 2nd pass for boron treatment. The 1st pass RO membranes will be the same, with or without the 2nd pass RO. Additional RO concentrate concentrations at varying fraction of flow through 2nd pass are shown in the Appendix B (Table B-1).

Table 11 - RO concentrate concentrations of TDS, boron, chloride, sodium and chloride when targeting 0.75 mg/L boron at 63°F and 74°F (20% 2nd Pass) and when targeting 0.25 mg/L boron at 63°F (60% 2nd pass) and 74°F (80% 2nd pass)

Stream	RO Concentrate Concentration (mg/L)				
	TDS	Boron	Chloride	Sodium	Bromide
20% 2nd Pass (corresponds to 0.75 mg/L boron target) at 63°F					
1st Pass RO	61000	8.63	33600	18700	117
2nd Pass RO	1860	5.42	983	663	3.41
Combined RO	59500	8.55	32800	18300	114
20% 2nd Pass (corresponds to 0.75 mg/L boron target) at 74°F					
1st Pass RO	60900	8.43	33500	18700	117
2nd Pass RO	2620	7.74	1420	935	4.93
Combined RO	59500	8.41	32800	18300	114
60% 2nd Pass (corresponds to 0.25 mg/L boron target) at 63°F					
1st Pass RO	61000	8.63	33600	18700	117
2nd Pass RO	1360	3.99	690	483	2.39
Combined RO	56900	8.31	31300	17400	109
80% 2nd Pass (corresponds to 0.25 mg/L boron target) at 74°F					
1st Pass RO	60800	8.42	33500	18700	116
2nd Pass RO	1590	4.88	828	571	2.87
Combined RO	55500	8.11	30600	17000	106

The flow distribution for the varying fraction of flow in the various streams is shown in Table 12. As discussed above, the RO recovery for the seawater RO membranes used for the 1st Pass RO is 45%. The recovery for the brackish water RO membranes used for the 2nd pass RO is 85%. The overall recovery ranges is 44% at 20% 2nd pass and 40% recovery at 100% 2nd pass. The decrease in recovery is observed in the increase in concentrate (brine) flow when the fraction of feed to the 2nd pass RO is increased, as shown in the "combined concentrate (brine)" row in Table 12. Additional RO concentrate flows at varying fraction of flow through 2nd pass are shown in the Appendix B (Table B-2).

Table 12 - Feed and Concentrate Flows Used in RO Model, As Well As Recovery when targeting 0.75 mg/L boron at 63°F and 74°F (20% 2nd Pass) and when targeting 0.25 mg/L boron at 63°F (60% 2nd pass) and 74°F (80% 2nd pass)

Component	Fraction of Flow through 2nd Pass RO		
	20%[a]	60%[b]	80%[c]
	Flow (gal/min)		
Feed Flow	2540	2710	2810
Lead Element 1st Pass RO Permeate / 2nd Pass RO Bypass	916	488	252
Tail Element 1st Pass RO Permeate / 2nd Pass RO feed	229	732	1010
2nd Pass RO Permeate	195	622	858
Combined Product water (permeate)	1110	1110	1110
Concentrate (brine) flow (gal/min)			
1st Pass	1400	1490	1550
2nd Pass	34.4	110	152
Combined	1430	1600	1700
Recovery (%)			
1st Pass RO Recovery	45%	45%	45%
2nd Pass RO Recovery	85%	85%	85%
Overall Recovery	44%	41%	40.%

[a]Corresponds to 0.75 mg/L boron target
[b]Corresponds to 0.25 mg/L boron target at 63°F
[c]Corresponds to 0.25 mg/L boron target at 74°F

5. Summary of Findings

Elevated levels of boron in seawater are only moderately-well removed by seawater RO, resulting in boron concentrations that are significantly greater than conventional drinking water sources. A mass balance on boron was conducted to estimate boron accumulation in the OCGB under differing conditions. Sources of boron included input from use of boron by citizens, contribution from the HBWDF, GWRS recharge input, OCSD discharge output , and Santa Ana River input. The accumulation estimate was made for two different HBWDF boron contribution scenarios: (1) 0.75 mg/L boron from the Term Sheet and (2) 0.25 mg/L boron matching the GWRS discharge concentration. The boron accumulation estimated by the mass balance was 182 tpy for the 0.75 mg/L scenario and 144 tpy for the 0.25 mg/L scenario.

The inefficient removal of boron through both seawater desalination and downstream advanced treatment through the GWRS is expected to result in increased accumulation of boron in the groundwater basin, compounding the existing accumulation related to the GWRS. These cumulative impacts downstream of the use of desalinated drinking water, present a unique and long-term challenge for utilities like IRWD that use groundwater from the OCGB. However, it is possible to introduce treatment measures or optimizations that would promote improved boron removal from the HBWDF to decrease the ultimate accumulation of boron in the OCGB.

The primary boron removal treatment strategies include the following:

- **2nd Pass RO:** The permeate from all or part of the 1st pass RO can be sent to additional RO stages to increase the removal of boron (and other constituents). By elevating the pH – typically using NaOH (caustic) - the boron removal is further enhanced. This is the most common method currently employed for boron removal at existing desalination facilities. There are many variations on this process, including a cascading design by IDE with up to four stages that is expected to be used for the HDWDF, based on Poseidon's use of this design at the Carlsbad Desalination Facility.
- **Ion exchange:** As discussed in the boron treatment section above, ion exchange has been considered for boron treatment for seawater desalination facilities. This includes the use of boron chelating resins, which are not in use in an existing seawater desalination facility. There is only one facility discussed in this report using ion exchange. A challenge posed by the use of ion exchange is regeneration or replacement of the resin, once exhausted. For this reason, the evaluation focused on 2nd pass RO.

Considering the use of the IDE cascading 2nd pass RO design at Poseidon's nearby Carlsbad Desalination Facility, a similar design provision is expected for the HBWDF. With this in mind, Trussell Tech completed RO modeling to understand the impact of variable operation of 2nd pass RO for removing boron. The modeling considered two temperature conditions – 63ºF to represent the average ocean water temperatures measured at the Huntington Beach site between 2010 and 2015, and 74ºF to represent the maximum ocean water temperature from the same data set.

Boron rejection through RO decreases with increasing water temperature. In addition to temperature, the modeling considered a range of operating conditions for the 2nd pass RO feed, including 0, 20, 40, 60, 80, and 100% of the 1st pass permeate. Results from these modeling efforts are summarized in Table 13. The results showed that feed water temperature made a significant difference in boron rejection. In order to meet all term sheet water quality goals in combined RO product water, including chloride, at least 20% 2nd pass treatment was found necessary. At 63°F, 60% 2nd pass was sufficient to achieve the basin boron goal of 0.25 mg/L. At 74°F, RO modeling demonstrated 80% 2nd pass would be required to achieve the basin boron goal of 0.25 mg/L. Put another way, under average conditions (63°F), meeting the chloride requirement in Appendix A would necessitate a 20% 2nd pass, but seeking to meet a boron limit of 0.25 mg/L would necessitate a 60% 2nd pass under those same conditions.

Table 13. Comparison of RO Modeling Results for Case 1 (T=63°F) and Case 2 (T=74°F): Combined RO product water

Constit-uent	Fraction of flow through 2nd pass												Term Sheet	Basin Boron Goal
	0%		20%		40%		60%		80%		100%			
	Temperature (°F)													
	63	74	63	74	63	74	63	74	63	74	63	74		
	Quality (mg/L)													
Boron	0.57	0.81	0.42	0.59	0.31	0.44	**0.23**	0.33	0.16	**0.24**	0.10	0.16	≤ 0.75	0.25
Chloride	85	116	57	74	38	49	24	31	12	16	2	2.7	≤ 75	

(yellow)	does not meet Term Sheet
(blue)	meets basin boron goal

Depending on the design implemented at HBWDF and the ultimate boron concentration desired, boron levels could be significantly lower than the levels defined in the Attachment A term sheet (Appendix A). The accumulation of boron in the OCGB is a long-term issue influenced by HBWDF operations, as well as household boron use, the water quality in the Santa Ana River, and the GWRS.

It is instructive to present results at 50 mgd RO product water (combined RO permeate), which is the size of the HBWDF. The RO feed, RO concentrate (Brine), and RO permeate (Product) flows determined based on RO modeling and presented in Table B-2 are scalable to 50 mgd RO product water. The flows do not depend on temperature. A breakdown of the flow versus percent second pass is provided in Figure 6.

As shown in Figure 6, the RO feed flow varies from 111 to 131 mgd as percent second pass varies from 0% to 100% in increments of 20%. The RO brine flow varies from 61.3 mgd to 80.6 mgd over the same increment in percent second pass. As mentioned earlier, RO product water flow is set at a constant target of 50 mgd.

It is important to note that the trends in concentration, discussed below, are influenced by observing that the RO model was run with the RO product water flow target of 50 mgd. This influences the trends observed for the both RO feed flow and RO brine flow, as well as the concentration of the constituents of interest in the brine. Additional discussion of these trends is provided in Appendix C.

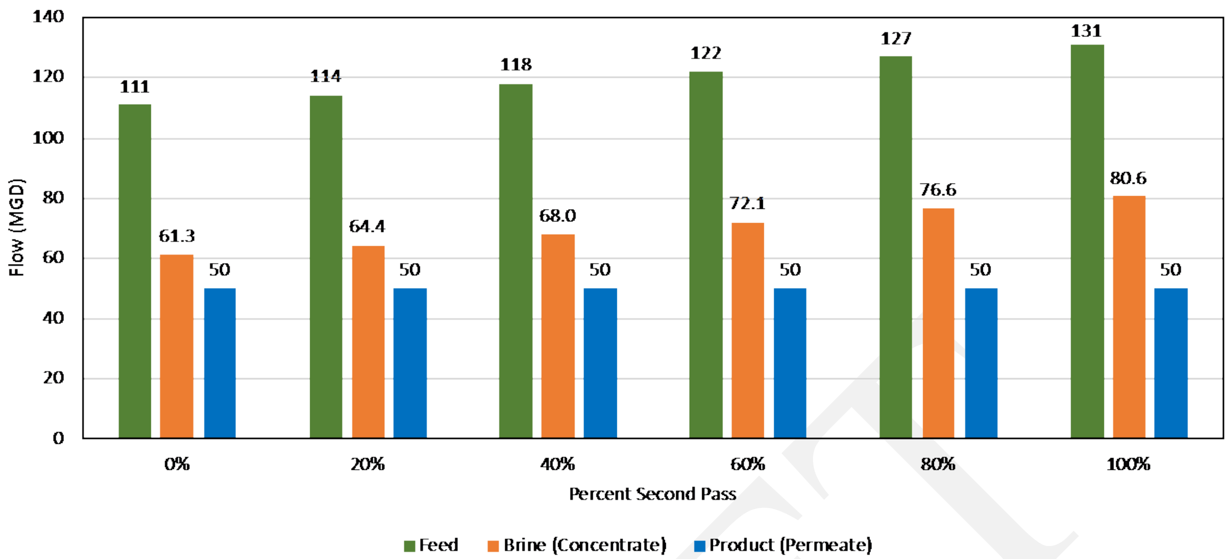


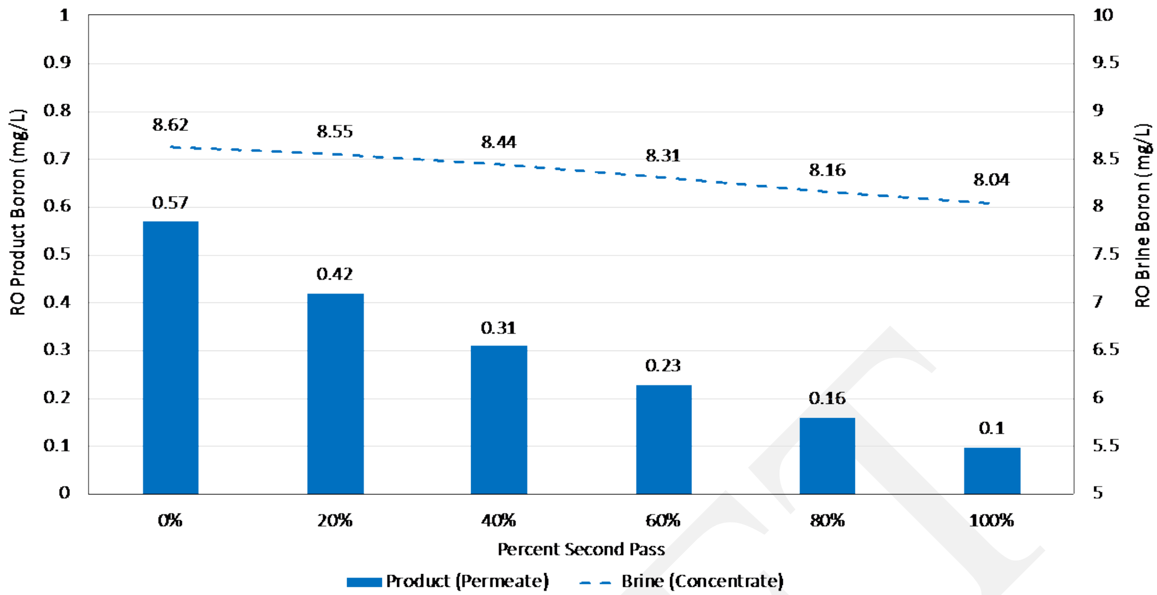
Figure 6 – Flow versus Percent Second Pass for the HBWDF at 50 mgd RO product water

Based on RO modeling and data presented in Table 10 and Appendix B, Table B-1, product and brine water concentrations versus percent second pass as a function of temperature can be plotted. The results for boron are shown in Figure 7. The results for chloride are shown in Figure 8. The results for TDS are shown in Figure 9.

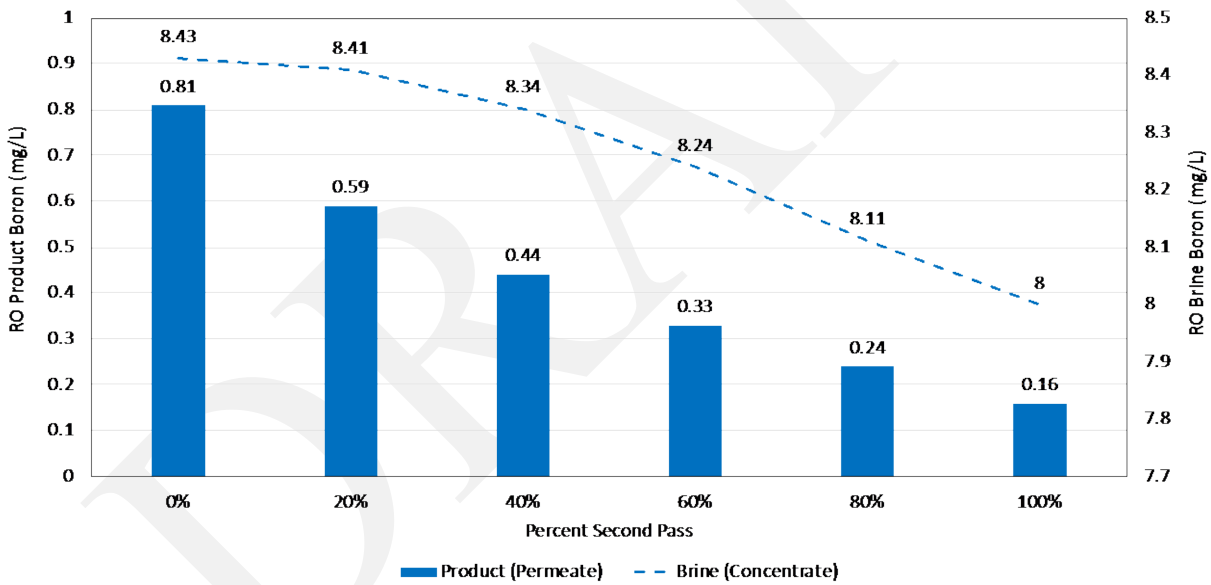
From Figure 7 it is observed over a percent second pass range from 0% to 100% at a temperature of 74°F that RO product water boron concentration trends downward from 0.57 to 0.10 mg/L and that RO brine water boron concentration trends downward from 8.62 to 8.04 mg/L. For the boron target of 0.25 mg/L and 80% second pass that would be required to meet the boron target at 74°F, discussed above, it is observed from Figure 7 that RO brine water boron concentration would be equal to 8.11 mg/L.

From Figure 8 it is observed over a percent second pass range from 0% to 100% at a temperature of 63°F that RO product water chloride concentration trends downward from 85 to 2.0 mg/L and that RO brine water chloride concentration trends downward from 33,600 to 30,000 mg/L. For the boron target of 0.25 mg/L and 80% second pass that would be required to meet the boron target at 74°F, discussed above, it is observed from Figure 8 that RO brine water chlorine concentration would be equal to 30,600 mg/L.

From Figure 9 it is observed over a percent second pass range from 0% to 100% at a temperature of 63°F that RO product water TDS concentration trends downward from 148 to 3.0 mg/L and that RO brine water TDS concentration trends downward from 61,000 to 54,400 mg/L. For the boron target of 0.25 mg/L and 80% second pass that would be required to meet the boron target at 74°F, discussed above, it is observed from Figure 9 that RO brine water TDS concentration would be equal to 55,500 mg/L.

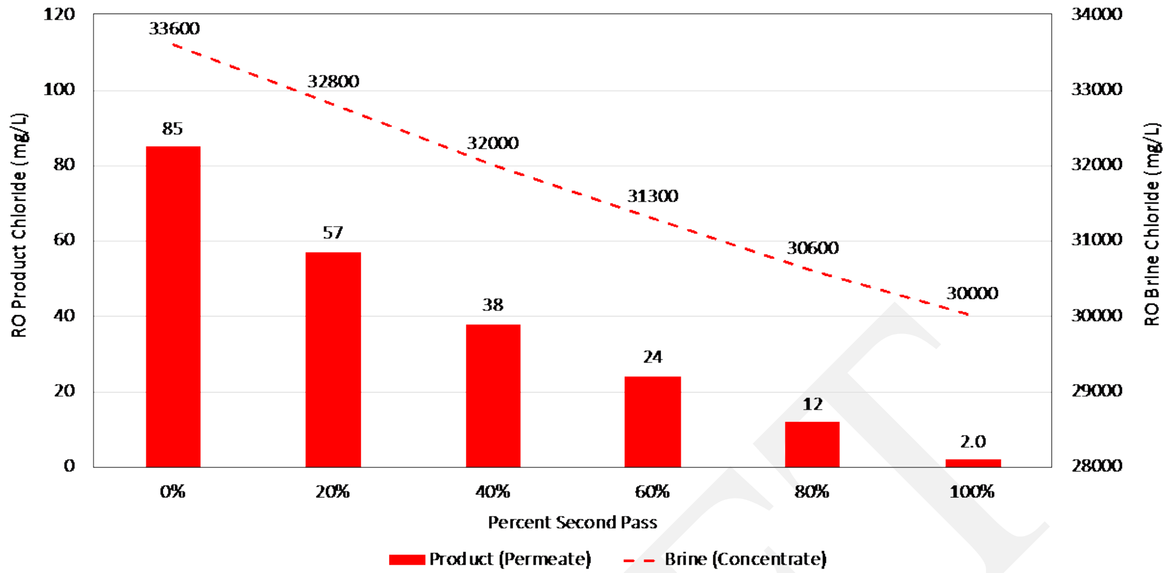


(a)

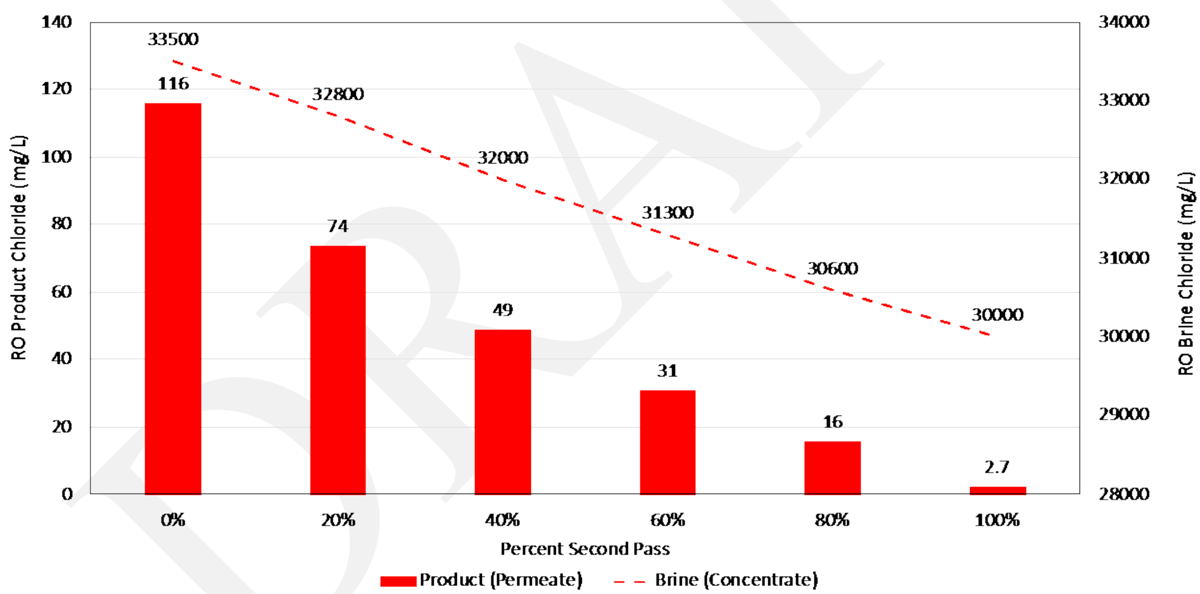


(b)

Figure 7 – RO Product and RO Brine Water Boron vs. Percent Second Pass (a) T=63°F, (b) T=74°F

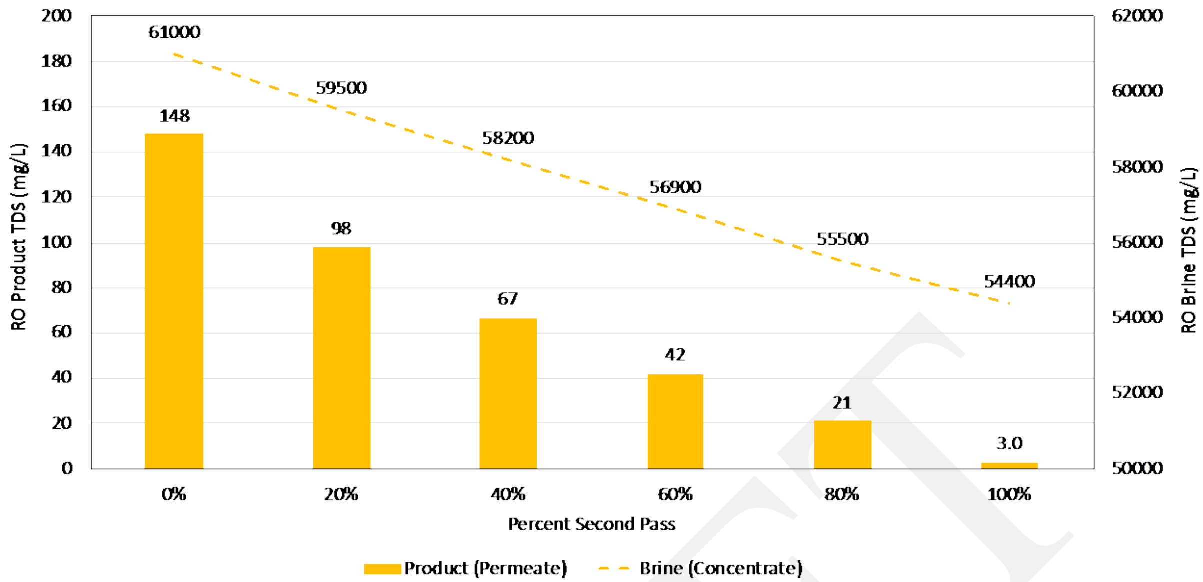


(a)

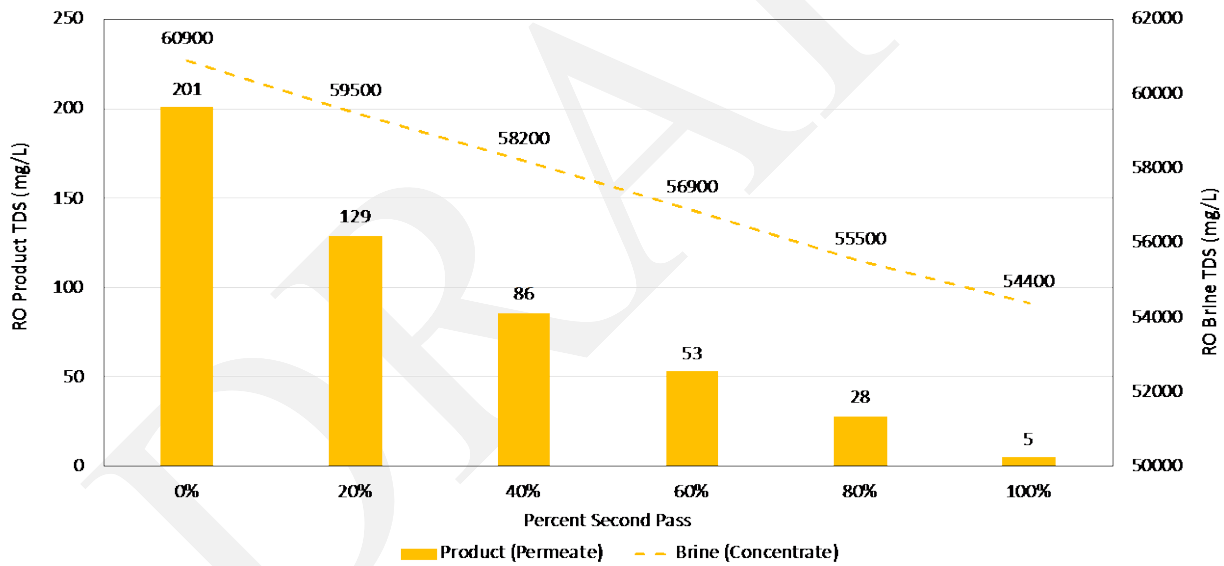


(b)

Figure 8 – RO Product and RO Brine Water Chloride vs. Percent Second Pass (a) T=63°F, (b) T=74°F



(a)



(b)

Figure 9 – RO Product and RO Brine Water TDS vs. Percent Second Pass (a) T=63°F, (b) T=74°F

6. References

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Appendix A – Water Quality Specifications for the HBWDF from 'Attachment A' to the Water Reliability Agreement Term Sheet signed by Poseidon and OCWD

Water Reliability Agreement Term Sheet
Attachment A

Quality Parameter	Analytical Method[1]	Sampling		Units	Mean[3]	Maximum[4]
		Sampling Period[2]	Sample Frequency			
Total Dissolved Solids	2540C	One year	Weekly Grab	mg/L	350	500
Chloride	4110B	One year	Weekly Grab	mg/L	75	100
Boron	3120B	One year	Weekly Grab	mg/L	0.75	1.0
Turbidity	2130B	Daily	Continuous[5]	NTU	0.5	1.0
DBP – THM[6]	5710C	One Year	Weekly Grab	μg/L	80% of maximum contaminant level ("MCL")	90% of MCL
DBP – HAA[6]	5710D	One Year	Weekly Grab	μg/L	80% of MCL	90% of MCL
DBP – NDMA[6]	521	One Year	Weekly Grab	μg/L	80% of NL	Notification Level (0.010 μg/L)
Temperature	2550	One Year	Daily Grab	°F	74	85
pH	4500	Daily	Continuous[5]	pH units	7.0-8.0	>6.5,<8.5
Sodium	200.7	One Year	Weekly Grab	mg/L	60	80
Calcium	200.7	One Year	Weekly Grab	mg/L	20	<20
Magnesium	200.7	One Year	Weekly Grab	mg/L	TBD	TBD
Sodium Adsorption Ratio	Footnote (7) below	One Year	Monthly	none	5	6

1. All methods taken from Standard Methods On-Line, published by APHA, AWWA, and WEF or current EPA methods.
2. Sample period - concentration limits are calculated for this period.
3. Mean – not to exceed (or go below for certain of the Quality Parameter) the average over the Sampling Period.

Water Reliability Agreement Term Sheet
Attachment A

4. Maximum Concentration Limit - cannot be exceeded at any time with the exception of Temperature which cannot exceed the Maximum over a 30 day average.

5. Continuous analysis - values at 15 minute intervals used in all calculations.

6. Disinfection By-Product (DBP) Formation tests will be used to determine compliance with THM and HAA requirements for the samples collected at the compliance point.

   Product Water is to be collected for the DBP tests and held with no modifications in a water bath. The following describes the test conditions:

   (a) pH: No adjustment to collected sample.
   (b) Temperature: Same as Product Water at time of collection ± 3°C.
   (c) Total Cl_2 residual at test end: No adjustment to collected sample.
   (d) Sample to be quenched and analyzed at the end of this period.
   (e)

7. The formula for calculating sodium adsorption ratio is:

$$\text{S.A.R.} = \frac{Na^+}{\sqrt{\frac{1}{2}(Ca^{2+} + Mg^{2+})}}$$

where sodium, calcium, and magnesium are in milliequivalents/liter.

Appendix B – Tables of Water Quality and Flow

Table B-1 RO concentrate concentrations at 63°F and 74°F for 1st pass RO concentrate, 2nd pass RO concentrate, and combined RO concentrate for varying fraction of flow through the 2nd pass

Fraction of Flow through 2nd Pass	63 °F	74 °F	63 °F	74 °F	63 °F	74 °F
	RO Concentrate TDS (mg/L)					
	1st Pass		2nd Pass		Combined	
0%	61000	60900	NA	NA	61000	60900
20%	61000	60900	1860	2620	59500	59500
40%	61000	60900	1550	2120	58200	58200
60%	61000	60900	1360	1820	56900	56900
80%	60900	60800	1210	1590	55500	55500
100%	61000	60900	1120	1460	54400	54400
	RO Concentrate Boron (mg/L)					
0%	8.62	8.43	NA	NA	8.62	8.43
20%	8.63	8.43	5.42	7.74	8.55	8.41
40%	8.63	8.43	4.55	6.46	8.44	8.34
60%	8.63	8.43	3.99	5.6	8.31	8.24
80%	8.62	8.42	3.51	4.88	8.16	8.11
100%	8.62	8.43	3.24	4.49	8.04	8
	RO Concentrate Chloride (mg/L)					
0%	33600	33500	NA	NA	33600	33500
20%	33600	33500	983	1420	32800	32800
40%	33600	33500	802	1140	32000	32000
60%	33600	33500	690	959	31300	31300
80%	33500	33500	606	828	30600	30600
100%	33600	33500	555	753	30000	30000
	RO Concentrate Sodium (mg/L)					
0%	18700	18700	NA	NA	18700	18700
20%	18700	18700	663	935	18300	18300
40%	18700	18700	552	760	17800	17800
60%	18700	18700	483	651	17400	17400
80%	18700	18700	432	571	17000	17000
100%	18700	18700	400	525	16700	16700

	RO Concentrate Bromide (mg/L)					
0%	117	117	NA	NA	117	117
20%	117	117	3.41	4.93	114	114
40%	117	117	2.78	3.94	111	111
60%	117	117	2.39	3.32	109	109
80%	116	116	2.1	2.87	106	106
100%	117	117	1.92	2.61	104	104

Table B-2 -Feed and Concentrate Flows Used in RO Model, As Well As Recovery.

Component	Fraction of Flow through the 2nd Pass					
	0%	20%	40%	60%	80%	100%
	Flow (gal/min)					
Feed Flow	2470	2540	2620	2710	2810	2900
Lead Element 1st Pass RO Permeate / 2nd Pass RO Bypass	2470	916	709	488	252	0
Tail Element 1st Pass RO Permeate / 2nd Pass RO feed	0	229	472	732	1010	1310
2nd Pass RO Permeate	0	195	402	622	858	1110
Combined Product water (permeate)	1110	1110	1110	1110	1110	1110
	Concentrate (Brine) flow (gal/min)					
1st Pass	1360	1400	1440	1490	1550	1600
2nd Pass	0	34.4	70.9	110	152	196
Combined	1360	1430	1510	1600	1700	1790
	Recovery (%)					
1st Pass RO Recovery	45%	45%	45%	45%	45%	45%
2nd Pass RO Recovery	-	85%	85%	85%	85%	85%
Overall Recovery	45%	44%	42%	41%	40.%	38%

Appendix C
Implications of Flow Target on Process Flows

All water quality parameters were not varied during the model runs other than flow, discussed below. The feed concentrations of boron, chloride, and TDS, for example, were maintained at the same level throughout the different scenarios modeled. In the case of flow, the combined treated water RO flow from the plant was set at a target of 50 mgd. This combined treated water RO flow was held constant at 50 mgd in all the model runs. However, the flow of the feed water to produce a set amount of product water (permeate), i.e. 50 mgd, was increased with increasing percent second pass treatment (Figure 6) to produce 50 mgd.

The results shown on Figures 7 - 9 capture the effect of this increased feed water inflow at a set influent water quality, by showing a decline of all constituents' concentration in both product water and brine with an increase in second pass RO treatment. For example, the feed boron concentration used for the RO model is 5.0 mg/L for all scenarios, while the feed inflow increased from 111 to 131 mgd as the portion of the water treated with second pass RO increased from 0% to 100%, respectively. Consequently, boron concentration in both product water and brine declined. However, the removal rate of boron from the product water increased with more water treated by second pass RO. The boron removal rate increased from 94.9% at 0% second pass treatment to 99.2% at 100% second pass RO treatment. These trends are accounted for in the model based on a mass balance around the treatment process.

The implications of the method of addressing the flow target are illustrated on Figures C-1 and C-2. Figure C-1 shows flow and boron concentrations as a function of percent second pass for the RO feed, the RO product (permeate), and the RO brine (concentrate). For the feed, a constant boron concentration was used while, as discussed, the flow increases with increasing percent second pass. For the RO product water, the flow was held constant at 50 mgd, as discussed, while the boron decreased with increasing percent second pass. For the RO brine water, the flow increased with increasing percent second pass while the boron concentration decreased with increasing percent second pass due to the fact the RO product water was held constant at a 50 mgd target and the implications. The overall boron removal as a function of percent second pass is presented in Figure C-2. From Figure C-2, it is observed that boron removal increases with increasing percent second pass, as expected.

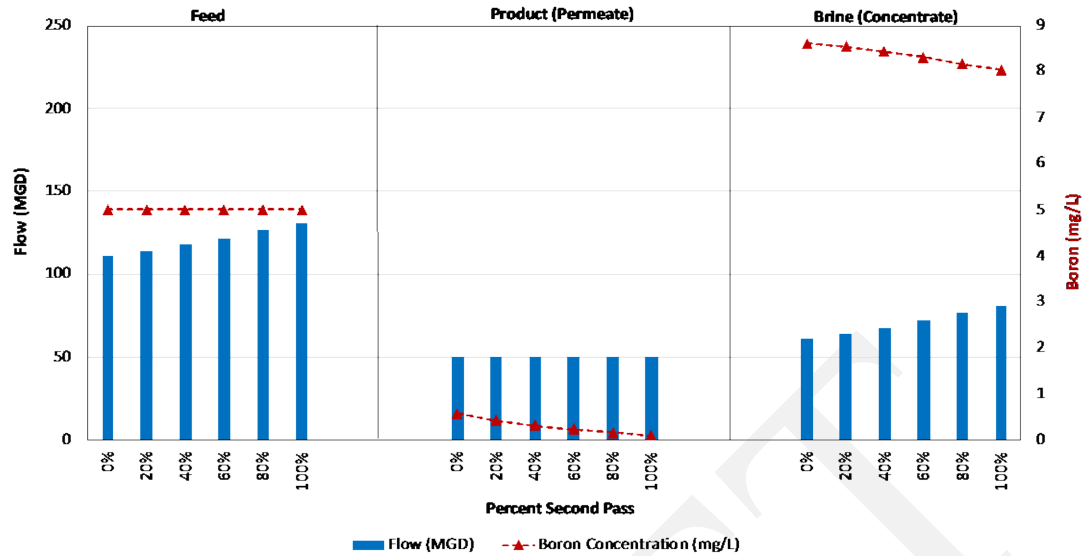

Figure C-1 Flow and Boron Concentration vs. Percent Second Pass for RO feed, RO Product (permeate) and RO Brine (Concentrate).

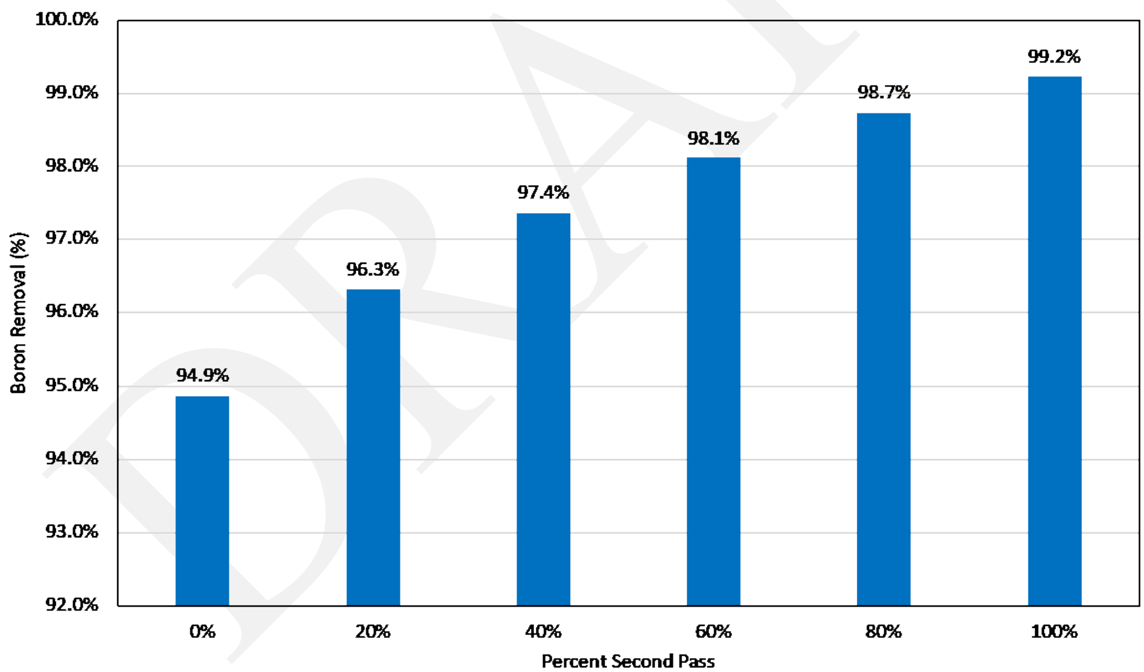

Figure C-2 Overall Percent Boron Removal vs. Percent Second Pass