Environmental
Research and
Consulting

November 28, 2018

Josie McKinley
Poseidon Water
5780 Fleet Street, Suite 140
Carlsbad, CA 92008

Re: Technical Memorandum: Copper Nickel Corrosion Estimates for the Proposed Huntington Beach Desalination Plant – Appendix IIIII

Dear Josie,

I am pleased to submit this final memorandum (memo) which estimates copper corrosion for the potential application of copper nickel wedgewire screens (WWS) for the proposed Huntington Beach Desalination Plant. The memo includes two appendices that review the available literature on copper nickel corrosion in seawater (Appendix 1) and monitoring data on copper in industrial water effluent (Appendix 2). The objective of the memo is to provide a preliminary response to the Santa Ana Regional Water Quality Control Board's request for data supporting the use of copper nickel WWS.

This memo was prepared jointly by TWB Environmental Research and Consulting (TWB), HDR, and Miller Marine Science & Consulting, Inc. (MMSC). TWB focused primarily on the literature review, HDR and MMSC focused primarily on the review of available monitoring data, and HDR estimated copper corrosion from the WWS.

I look forward to receiving your feedback on this draft memo. Please feel free to call with any questions or comments.

Sincerely,

Timothy W. Hogan
TWB Environmental Research and Consulting, Inc.

Executive Summary

Poseidon originally proposed to use copper nickel wedgewire screens (WWS) due to their increased resistance to biofouling. The CA State Lands Commission's (SLC) Final Supplemental Environmental Impact Report (FSEIR) subsequently identified the leaching of copper nickel as a potential ocean water quality risk, but that if Poseidon wishes to use copper nickel WWS, they must demonstrate that they do not pose a water quality risk. In the absence of a site-specific copper study demonstrating that copper nickel WWS would not pose a substantial risk to ocean water quality, the SLC FSEIR requires that the composition of the screens will be stainless steel. Poseidon is interested in maintaining copper nickel screens as an option due to their superior biofouling prevention performance. To that end, Poseidon retained TWB Environmental Research and Consulting (TWB), HDR, and Miller Marine Science & Consulting, Inc. (MMSC) to prepare this site-specific study evaluating the potential risk to ocean water quality associated with the use of copper nickel WWS.

TWB, HDR, and MMSC reviewed the available literature on copper nickel corrosion and prepared site-specific estimates of copper corrosion if copper nickel WWS were to be used for the proposed Huntington Beach Desalination Plant (HBDP).

The literature indicates that copper nickel WWS may corrode after initial installation in seawater, but that the corrosion rate would decrease quickly (within 12 months) in conjunction with the generation of the protective layer of corrosion byproducts on the metal's surface (Appendix 1).

Relative to the available environmental monitoring data, ambient copper concentrations in the Huntington Beach area are presently well below all indications of potential environmental impact or designated Ocean Plan Water Quality Objectives. Review of the two robust long-term datasets available in the vicinity of the Huntington Beach Generating Station (HBGS) (Appendix 2) found the copper contamination trend to be either stable or declining. In no case was copper identified as a potential threat to the health and vitality of the native marine ecology along the coast of Orange County

Based on the site-specific copper corrosion calculations, the data indicate that under all corrosion scenarios, the NPDES permit limits would always be met, whether meeting daily maximum (87 µg/L) or 6-month median (11 µg/L) targets. The calculations also illustrate that the majority of the copper is not coming from the screens, but instead from ambient copper concentrations that would be entering the plant. This is particularly true when considering published corrosion rates for longer-term studies (after 5 and 14 years of saltwater exposure). Lastly, corrosion rates that best represent conditions after multiple years of exposure to seawater (5 and 14 years per the literature) are likely to yield more accurate estimates of corrosion; conversely, using a corrosion rate associated with a 1-yr study is very conservative and will result in an overestimate of the long-term corrosion rate.

In the absence of a site-specific copper study, the SLC's FSEIR found that copper nickel WWS posed a potential risk to ocean water quality and that in order to utilize copper nickel WWS, Poseidon must demonstrate that it does not. The literature review (Appendix 1) demonstrates that copper nickel WWS offer superior protection against biofouling and operational uncertainty than WWS constructed of stainless steel. The site-specific copper nickel corrosion estimate provided herein demonstrates that the use of copper nickel WWS at the HBDP would not result in excessive leaching of copper and that expected copper concentrations in the HBDP discharge would comply with the receiving water requirements in the CA Ocean Plan.

Introduction

The CA State Lands Commission's (SLC) Final Supplemental Environmental Impact Report (FSEIR) found that the use of stainless steel wedgewire screens (WWS) for the proposed Huntington Beach Desalination Plant (HBDP) intake would not result in a significant and unavoidable impact to ocean water quality. Installing stationary stainless steel WWS would likely increase the number of offshore boat trips to maintain and inspect the WWS. Regarding copper nickel, SLC concluded, in the FSEIR, that "*some studies have shown screens fabricated of copper-nickel alloy provides the greatest resistance to biofouling (SWRCB 2015b), they also corrode more easily and the copper may leach into the water column, resulting in degraded water quality and potentially adversely affecting marine organisms*." However, in Applicant Proposed Measure 8 (Composition and Maintenance of Wedgewire Screens), Poseidon has reserved the right to use copper nickel WWS if they can demonstrate *"to the satisfaction of California State Lands Commission staff that the use of copper nickel alloy screens would not result in chemical leaching in excess of Ocean Plan Water Quality Objectives for Protection of Marine Life standards.*" Poseidon is interested in pursuing the use of copper nickel to minimize biofouling concerns and maximize operational reliability. Copper nickel is known to provide greater resistance to the accumulation of biofouling organisms; this is also noted in the FSEIR, "*some studies have shown screens fabricated of copper-nickel alloy provides the greatest resistance to biofouling*…"

With the SLC environmental review process completed, Poseidon will need to demonstrate to the satisfaction of the Santa Ana Regional Water Quality Control Board (Regional Board) that copper nickel WWS can comply with the receiving water quality requirements in the California Ocean Plan and are no more environmentally impactful than stainless steel WWS. To that end, Poseidon has asked TWB Environmental Research and Consulting (TWB), HDR, and Miller Marine Science & Consulting, Inc. (MMSC) to complete a review of available information on the topics of copper nickel corrosion in seawater and monitoring data on copper in industrial water effluent. In California, only one offshore submerged installation of a copper nickel WWS exists in the marine environment for the Charles E. Meyer desalination plant in Santa Barbara, California. As of November 2018, no violations of copper effluent limitations have been reported to or by the Central Coast Regional Water Quality Control Board, the agency with regulatory oversight of

the facility. As a follow-up step, HDR has estimated copper corrosion for the WWS proposed for HBDP.

Copper Corrosion Estimates For HB

Theoretical contributions of copper to solution through corrosion of 70-30 copper nickel WWS were estimated under a scenario in which the HBDP is operational and running with all 4 WWS in service; any corrosion that occurs would result in the direct leaching of copper into the surrounding ocean waters via the discharge. Three corrosion rates and three ambient copper concentrations were used. Details of these are provided in the following tables.

The three 70-30 copper nickel corrosion rates are presented in Table 1 and described in more detail in the bulleted list below:

- Worst-case/conservative corrosion rate of 0.709 mil/yr. This assumes that bare metal continuously corrodes under uniform corrosion conditions without significant buildup of corrosion product. Uniform corrosion has potential to remove much more mass from a metal material than pitting, crevice, and other forms of localized corrosion that remove a relatively small volume of the material. The conservative assumption of uniform corrosion prior to formation of the protective layer would best mimic the first year that the screens are installed. Subsequent years (when protective layer is established) would experience significantly reduced rates of corrosion and subsequent release of copper. Tuthill (1987), for example, demonstrated that copper-nickel alloys experienced a 10-fold reduction in corrosion rates within three to seven years of exposure to seawater. Of the literature reviewed for this memo (Appendix 1), the highest corrosion rate found for 70-30 copper nickel material was 0.709 mil/yr (Table 1) for new 4-in by 4-in WWS sections submerged for 12 months without cleaning (Tetra Tech 2016).
- Additional corrosion rates derived from the relevant literature include
    - Corrosion rate of 0.10 mil/yr based on a five-year long field study conducted by Efird (1976).
    - Corrosion rate of 0.05 mil/yr based on a 14-year long field study conducted by Efird and Anderson (1975)

Table 1. Corrosion rates used for calculating copper leaching from 70-30 copper nickel WWS.

Corrosion Rate (mil/yr)	Note	Reference
0.709	From a one-year field study	Tetra Tech 2016
0.10	From a five-year field study	Efird 1976
0.05	From a 14-year field study	Efird and Anderson 1975

The three ambient copper concentrations were from data collected at the HBGS intake forebay. The minimum, maximum, and median values used are shown below in Table 2. In addition, copper estimates are presented using the Ocean Plan's 2 µg/l background copper value.

Table 2. Background copper concentrations (µg/L) as measured in forebay of HBGS.

Date	Concentration
12/15/2016	0.49
12/16/2016	0.93
12/17/2016	1.2
02/07/2017	8.3
Min	**0.49**
Median	**1.07**
Max	**8.3**

Table 3 presents the WWS details that were used in all of the copper leaching calculations.

Table 3. Wedgewire screen parameters used in corrosion calculations.

	Value	Units	Source of Information
Percent Copper	69.5	%	Vendor (Aqseptence Group)
Density of Material	0.323	lb/in^3	Vendor (Aqseptence Group)
Surface Area (per Screen)	4,010.4	ft^2	Vendor (Aqseptence Group)
Number of Screens (model Johnson T96HC)	4		Aqseptence Group Quotation Number/Date: 20047904, 01/23/2018

The water quality objectives against which the calculated results were compared are presented in Table 4. Only the Water Quality Objectives found in the active HBDP NPDES permit (R8-2012-0007) were used as these have applied the approved dilution factor to the Ocean Plan Table 1 base limits. Appendix F of the HBDP NPDES Permit indicates a 7.5:1 dilution factor.

Table 4. Water quality objective copper limits (µg/L) listed in the Huntington Beach Desalination Plant (HBDP) NPDES Permit (No. R8-2012-0007).

Water Quality Objective	HBDP Permit (µg/L)
Max Total Copper (6-Month Median)	11
Daily Maximum Copper	87
Instantaneous Maximum Copper	240

Methods

This operational scenario assumes that all 4 intake screens are in service and flow is being drawn into the HBDP. It represents what would theoretically happen if 70-30 copper nickel WWS were installed at the proposed HBDP. The three corrosion rates and three ambient copper concentrations used in the calculations are described above. The additional assumptions used for this scenario are explained below:

- The hydraulic zone of influence created by an operating WWS will result in all of the corroded copper entering the HBDP.
- All copper corroded remains in solution and is discharged as a component of the effluent. This assumption is conservative because it does not account for dissolved copper that passes through the film of cuprous oxide that has potential to precipitate out as $Cu_2(OH)_3Cl$ in seawater (Little et al. 1990). Dicopper chloride trihydroxide is a compound known that is a naturally occurring mineral as well as a metal corrosion product of copper alloys. It has fungicidal properties and is also a nutritional supplement for animals. When water is flowing from the ocean into the plant, this compound would precipitate out in the plant downstream of the intake and become a part of the sediment fraction that accumulates and is collected. The compound would be disposed of accordingly when such sediments are removed from the process equipment.

Table 1 presents the corrosion rates used in the calculations. These represent the theoretical corrosion rates of the 70-30 copper nickel screens over the first year, after 5 years, and after 14 years of service prior to consideration of screen maintenance and minimal corrosion product development on the metal (during the first year).

Table 2 provides the ambient copper concentrations used in the calculations.

Table 3 provides information on the material of the proposed WWS used for the calculations.

Table 5 provides information on the flow conditions used for the calculations.

Table 5. Intake and discharge volumes for the proposed Huntington Beach Desalination Plant (HBDP) in million gallons per day (MGD).

Flow Conditions	Intake Volume	Discharge w/ backwash	Desal Production
Daily Maximum	116.5	62.5	54
Approximate Annual Average	106.7	56.7	50

The equations used to derive the estimates are as follows:

- *Theoretical mass of copper released per day = (corrosion rate) x (surface area) x (density) x (% copper)*
- *Copper in discharge from the screens = (mass of copper released) / (volume of discharge)*
- *Background copper = (max, median, or min background concentration entering plant) x (intake volume) / (discharge volume)*
- *Total copper in discharge = (concentration from background copper) + (concentration from screens)*

Results

The calculated effluent total copper concentrations were compared against the HBGS NPDES Permit water quality objectives (Table 4). From these calculations, the theoretical total copper concentration in the discharge ranged from 1.0 to 20.1 µg/L. Under all corrosion scenarios (1st year, after 5 years, and after 14 years), when the median background copper value is applied (1.07 µg/L, Table 2), there are no exceedances of any of the HBDP NPDES Permit water quality objectives (Table 4). Likewise, when 2 µg/L of background copper are used (from the Ocean Plan's background copper value), all corrosion scenarios result in meeting the HBDP NPDES Permit water quality objectives (see Tables 6-8, last column).

Furthermore, when examining the data tables more closely, the "copper from screens" columns vs. the "copper in discharge" columns, illustrate that the majority of the copper is not coming from screens, but instead from ambient copper concentrations that would be entering the plant. The screens add an insignificant fraction of copper relative to the background ambient concentration. This is particularly true in the data after 5 and 14 years of saltwater exposure (Table 7 and Table 8). Over the first year, it is estimated that roughly 2 µg/L of copper would be contributed from the screens, and that this value would drop to 0.3 µg/L by 5 years, and 0.2 µg/L by 14 years of exposure to saltwater. The higher estimates of "Max Copper in Discharge" (ranging from 15.6 to 20.1 µg/L, Table 6 - Table 8) are largely derived from the maximum background copper value used (8.3 µg/L, Table 2) which appears to be anomalously high. With only 0.2 – 2 µg/L of copper contribution from the screens, the remaining contributions (15.4 to

17.9 µg/L) are the product of the concentration of background copper through the desalination process. Even with an anomalously high value for the max. background copper, the daily and instantaneous maximum permissible values (Table 4) are significantly higher than copper concentrations estimated to occur here.

It should be noted that based on the best available information, the calculations using the conservative 0.709-mil/yr corrosion rate will result in an overestimate of the long-term (after year one) in situ corrosion rate. Development of a corrosion product on the screen's surface will slow the corrosion rate, as evidenced by previous studies (Efird 1976; Efird and Anderson 1975). It is anticipated that with continued submersion in seawater, cuprous oxide formation followed by further oxidation to cupric hydroxychloride would develop a sufficiently thick protective layer to significantly slow corrosion processes and decrease the contribution of copper from the screens to well below 2 µg/L. Manual cleaning is not expected to be aggressive enough to disturb the protective layer. The frequency of manual cleaning will be dependent on the biofouling performance of the 70-30 copper nickel material, though anecdotal information relative to the performance of the 90-10 copper nickel WWS used at the Charles E. Meyer Desalination Plant in Santa Barbara indicates that biofouling has been almost non-existent since commissioning approximately nine months ago, and that manual cleaning has been unnecessary (B. Huber, Global Diving and Salvage, personal communication, January 17, 2018).

Comparison to West Basin Calculations

A recent report released by West Basin Municipal Water District (Appendix 4B to the Draft Environmental Impact Report) contains a similar approach to assessing the potential release of copper from intake screens into the environment, including estimates for 70:30 and 90:10 copper nickel screens. The resulting corrosion calculations for 70:30 copper nickel from the West Basin report are provided at the bottom of Table 8 and illustrate a lower copper dissolution rate than what is estimated here for the proposed screens at HBDP. The differences in the approach to calculations between the two reports are briefly described below:

1) In the West Basin report, the corrosion rates cited in Efird and Anderson (1975) appear to have been accidently reversed for 90:10 and 70:30 copper nickel. This has been corrected in Table 8 of this report with the second West Basin row entitled "*West Basin adjusted calculations*."
2) In the West Basin report, the percentage of copper was not included in calculating the mass corroded. The second West Basin row ("*West Basin adjusted calculations*") illustrates a corrosion estimate with the percentage of copper accounted for.
3) Only the intake volume was considered in the West Basin report, vs. here, where the discharge volume is also considered, and subsequently concentrates the amount of copper released. West Basin estimates are recalculated to include the discharge volume and indicated in the last row of Table 8.
4) The West Basin report provides an estimate of how much copper could be released from the screens but does not account for additional copper that is present in ambient sea water. Consideration of ambient levels is accounted for here, in the last row of Table 8. This is relevant as the Ocean Plan does not allow for intake credits based on the

ambient levels of copper in the intake water. Effluent limits are based on the whole effluent, regardless of source.

5) The West Basin report only provides calculations using a 14-year corrosion rate (Efird and Anderson, 1975). This report also considers more conservative corrosion rates (up to 0.709 mils/year) to model what would happen in the first year, and at five years of corrosion. These estimates are provided in Table 6 and Table 7.

In comparing the overall differences between the calculations presented here and the calculations presented in the West Basin report, Table 8 illustrates that higher levels of copper are estimated to be released from the proposed HBDP copper nickel intake screens (0.1-0.2 µg/L vs. 0.04 µg/L for West Basin). This difference is largely attributed to the smaller surface area of the screens at West Basin. The values reported here are then further increased by ten-fold or greater, by accounting for the background copper levels originating from coastal seawater. Finally, this report considers the more conservative corrosion rates that are expected to occur in the first few years of operation (Table 6 and Table 7).

Table 6. Levels of copper released, estimated over first year using conservative corrosion assumptions (corrosion rate of 0.709 mils/year; Tetra Tech 2016).

Flow Conditions	Corrosion Rate	Mass of Copper Released	Intake Volume	Discharge Volume	Copper in Discharge from Screens	Max Copper in Discharge[1]	Median Copper in Discharge[1]	Min Copper in Discharge[1]	Copper in Discharge : Est. from O.P. background[2]
	mil/yr	*grams/day*	*MGD*	*MGD*	*µg/L*	*µg/L*	*µg/L*	*µg/L*	*µg/L*
Max Operation after 2020, w/Backwash	0.709	457	116.5	62.5	1.9	17.4	3.9	2.8	5.7
Max Operation after 2020, w/out Backwash	0.709	457	116.5	54	2.2	20.1	4.5	3.3	6.5
Annual Average[3], w/Backwash	0.709	457	106.7	56.7	2.1	17.7	4.1	3.1	5.9
Annual Average[3], w/out Backwash	0.709	457	106.7	50	2.4	20.1	4.7	3.5	6.7

[1] *Max, median, and min background copper values taken from HBGS forebay data (Table 2)*

[2] *Background copper value taken from the Ocean Plan's 2 µg/L*

[3] *Approximate value*

Table 7. Levels of copper released, estimated after 5 years of seawater exposure (corrosion rate of 0.10 mils/year; Efird, 1976).

Flow Conditions	Corrosion Rate	Mass of Copper Released	Intake Volume	Discharge Volume	Copper in Discharge from Screens	Max Copper in Discharge[1]	Median Copper in Discharge[1]	Min Copper in Discharge[1]	Copper in Discharge : Est. from O.P. background[2]
	mil/yr	*grams/day*	*MGD*	*MGD*	*µg/L*	*µg/L*	*µg/L*	*µg/L*	*µg/L*
Max Operation after 2020, w/Backwash	0.10	64	116.5	62.5	0.3	15.7	2.3	1.2	4.0
Max Operation after 2020, w/out Backwash	0.10	64	116.5	54	0.3	18.2	2.6	1.4	4.6
Annual Average[3], w/Backwash	0.10	64	106.7	56.7	0.3	15.9	2.3	1.2	4.1
Annual Average[3], w/out Backwash	0.10	64	106.7	50	0.3	18.1	2.6	1.4	4.6

[1] *Max, median, and min background copper values taken from HBGS forebay data (Table 2)*

[2] *Background copper value taken from the Ocean Plan's 2 µg/L*

[3] *Approximate value*

Table 8. Levels of copper released, estimated after 14 years of seawater exposure (corrosion rate of 0.05 mils/year; Efird and Anderson 1975).

Flow Conditions	Corrosion Rate	Mass of Copper Released	Intake Volume	Discharge Volume	Copper in Discharge from Screens	Max Copper in Discharge (w/ambient)[1]	Median Copper in Discharge (w/ambient)[1]	Min Copper in Discharge (w/ambient)[1]	Copper in Discharge : Est. from O.P. background[2]
	mil/yr	*grams/day*	*MGD*	*MGD*	*µg/L*	*µg/L*	*µg/L*	*µg/L*	*µg/L*
Max Operation after 2020, w/Backwash	0.05	32	116.5	62.5	0.1	15.6	2.1	1.0	3.9
Max Operation after 2020, w/out Backwash	0.05	32	116.5	54	0.2	18.1	2.5	1.2	4.5
Annual Average[3], w/Backwash	0.05	32	106.7	56.7	0.2	15.8	2.2	1.1	3.9
Annual Average[3], w/out Backwash	0.05	32	106.7	50	0.2	17.9	2.4	1.2	4.4
West Basin calculations (70:30)	**0.08[3]**	**8.3[5]**	**45.3**	**--**	**0.05[6]**	**--**	**--**	**--**	--
West Basin adjusted calculations (70:30)	**0.05[7]**	**3.6[8]**	**45.3**	**25.4[9]**	**0.04[10]**	**14.8**	**1.9**	**0.9**	3.6

[1] Max, median, and min background copper values taken from HBGS forebay data (Table 2)

[2] Background copper value taken from the Ocean Plan's 2 µg/L

[3] Approximate value

[4] Corrosion rate for 90:10 Copper Nickel from Efird & Anderson (1975)

[5] Total Metal Release (% Copper not accounted for)

[6] Discharge volume not accounted for in calculation

[7] Corrosion rate for 70:30 Copper Nickel from Efird & Anderson (1975)

[8] % Copper accounted for in calculation

[9] From DEIR project description ("the normal amount of flow to be discharged")

[10] Discharge volume accounted for in calculation

Conclusion

Poseidon originally proposed to use copper nickel WWS due to their increased resistance to biofouling. The SLC FSEIR subsequently identified the leaching of copper nickel as a potential ocean water quality risk, but that if Poseidon wishes to use copper nickel WWS, they must demonstrate that they do not pose a water quality risk. In the absence of a site-specific copper study demonstrating that copper nickel WWS would not pose a substantial risk to ocean water quality, the SLC FSEIR requires that the composition of the screens will be stainless steel. Poseidon is interested in maintaining copper nickel screens as an option due to their superior biofouling prevention performance. To that end, TWB, HDR, and MMSC prepared this site-specific study evaluating the potential risk to ocean water quality associated with the use of copper nickel WWS.

The literature indicates that copper nickel WWS may corrode after initial installation in seawater, but that the corrosion rate would decrease quickly (within 12 months) in conjunction with the generation of the protective layer of corrosion byproducts on the metal's surface (Appendix 1).

Relative to the available environmental monitoring data, ambient copper concentrations in the Huntington Beach area are presently well below all indications of potential environmental impact or designated Ocean Plan Water Quality Objectives. Review of the two robust, long-term datasets available in the vicinity of the HBGS (Appendix 2) found the copper contamination trend to be either stable or declining. In no case was copper identified as a potential threat to the health and vitality of the native marine ecology along the coast of Orange County.

The site-specific estimated copper corrosion calculations indicate that under all corrosion scenarios, the NPDES permit limits would always be met, whether meeting daily maximum (87 µg/L) or 6-month median (11 µg/L) targets. The calculations also illustrate that the majority of the copper is not coming from screens, but instead from ambient copper concentrations that would be entering the plant. This is particularly true in the data after 5 and 14 years of saltwater exposure (Table 7 and Table 8). Lastly, corrosion rates that best represent conditions after multiple years of exposure to seawater are likely to yield more accurate estimates of corrosion; conversely, using a corrosion rate associated with a 1-yr study will result in an overestimate of the long-term corrosion rate.

In the absence of a site-specific copper corrosion study, the SLC's FSEIR found that copper nickel WWS posed a potential risk to ocean water quality and required that Poseidon "*demonstrates to the satisfaction of California State Lands Commission staff that the use of*

copper nickel alloy screens would not result in chemical leaching in excess of Ocean Plan Water Quality Objectives for Protection of Marine Life standards. Such demonstration must be based on data that have been reviewed and approved by the State and Regional Water Boards' staff and California Coastal Commission staff."

The literature review (Appendix 1) demonstrates that copper nickel WWS offer superior protection against biofouling and operational uncertainty that WWS constructed of stainless steel. The copper nickel corrosion estimate provided herein demonstrates that the use of copper nickel WWS at the HBDP would not result in excessive leaching of copper and that expected copper concentrations in the HBDP discharge would comply with the receiving water requirements in the CA Ocean Plan.

References

Efird, K. 1976. The Interrelation of Corrosion and Fouling of Metals in Seawater. NACE Corrosion, Ontario, April 1975.

Efird, K. and D.B. Anderson. 1975. Seawater Corrosion of 90-10 and 70-30 Cu-Ni: 14 Year Exposures. Materials Performance, November 1975.

GHD. 2018. West Basin Municipal Water District, Ocean Water Desalination Project: Literature Review on Long Term Corrosion and Biofouling Resistance of Copper Nickel Alloys and Stainless Steels for Marine Applications.

LaQue, F.L. and W.F. Clapp. Relationships Between Corrosion and Fouling of Copper-Nickel Alloys in Sea Water. Journal of the Electrochemical Society 87(1): 103-125.

Little, B., P. Wagner, R. Ray, and M. McNeil. 1990. Microbiologically Influenced Corrosion in Copper and Nickel Seawater Piping Systems. MTS Journal 24(3): 10-17.

Long, E.R., D.D. MacDonald, S.L. Smith, and F.D. Calder. 1995. Incidence of Adverse Biological Effects within Ranges of Chemical Concentrations in Marine and Estuarine Sediments. Environmental Management 19(1): 81-97.

MBC Applied Environmental Sciences. 2017. National Pollutant Discharge Elimination System, 2016 Receiving Water Monitoring Report, AES Huntington Beach L.L.C. Generating Station, Orange County, California. Prepared for AES Huntington Beach L.L.C.

Melwani, A.R., D. Gregorio, J. Jin, M. Stephenson, K. Maruya, D. Crane, G. Lauenstein, and J.A. Davis. 2013. Mussel Watch Monitoring in California: Long-term Trends in Coastal Contaminants and Recommendations for Future Monitoring, SFEI Contribution #685, San Francisco Estuary Institute, Richmond, California.

Michel et al., 2011. An Assessment of the Biofouling Resistance and Copper Release Rate of 90-10 Copper-Nickel Alloy. NACE Corrosion 2011 Conference &Expo, Paper No. 11352.

Tetra Tech. 2016. Final Intake Biofouling and Corrosion Study. West Basin Ocean Water Desalination Demonstration Facility Intake Biofouling and Corrosion Study. Prepared for the West Basin Municipal Water District, January 13, 2016.

Tuthill, A.H. 1987. Guidelines for the Use of Copper Alloys in Seawater. Materials Performance 26(9):12-22.

Appendix 1:
Literature Review of Copper Nickel Corrosion

Copper Nickel Corrosion

The corrosion resistance of copper nickel in seawater is related to the formation/retention of the surface film which acts as a protective layer (Michel et al. 2011; Tuthill 1987). First, a cuprous oxide film forms, followed by a second oxidation reaction between copper ions and seawater which creates a second oxide layer (cuprous hydroxide or cuprous hydroxychloride). The second layer is thick and porous and is considered the barrier for diffusion of copper ions into the surrounding seawater. The second layer is loosely attached to the underlying cuprous oxide layer. When fouling organisms attach to the outer layer, they can be detached readily without disturbing the bottom layer of cuprous oxide (Figure 1.1).

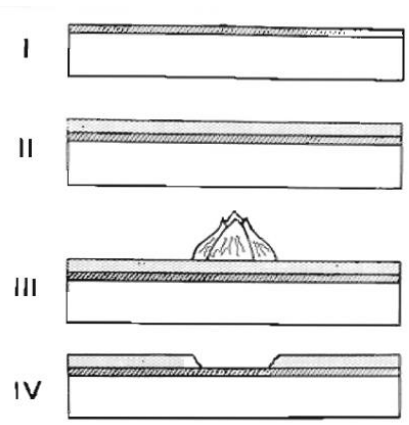

Figure 1.1. Sequence of corrosion film formation on copper-based alloys. I. Initial formation of a protective Cu_2O film; II. Subsequent hydrolysis of Cu_2O to a loose $Cu(OH)_2 \cdot 3CuCl_2$ film; III. Fouling attachment to the $Cu(OH)_2 \cdot 3CuCl_2$ film; IV. Removal of the fouling organism leaving the Cu_2O film intact (figure from Efird 1976).

The composite protective layer for 90-10 copper nickel is 4,440 angstroms thick (0.44 microns or 0.0173 mils) and has been shown to form quickly upon initial exposure to seawater (Figure 1.2; Tuthill 1987). The generation rate of the protective layer, therefore, can generally be considered inversely correlated to the corrosion rate.

High water velocities and associated shear effects can contribute to the loss of the protective layer, as can the presence of fine debris/sediment in the water (Tuthill 1987). This phenomenon is referred to as erosion-corrosion. However, these risks are more of a concern in power plants where copper nickel is used as a condenser tube material and velocities can be high (i.e., over 5 ft/sec). For a WWS designed for a through-slot velocity of 0.5 ft/sec or less and for an intake location that has low suspended solids in the feedwater, these risks can be considered sufficiently low.

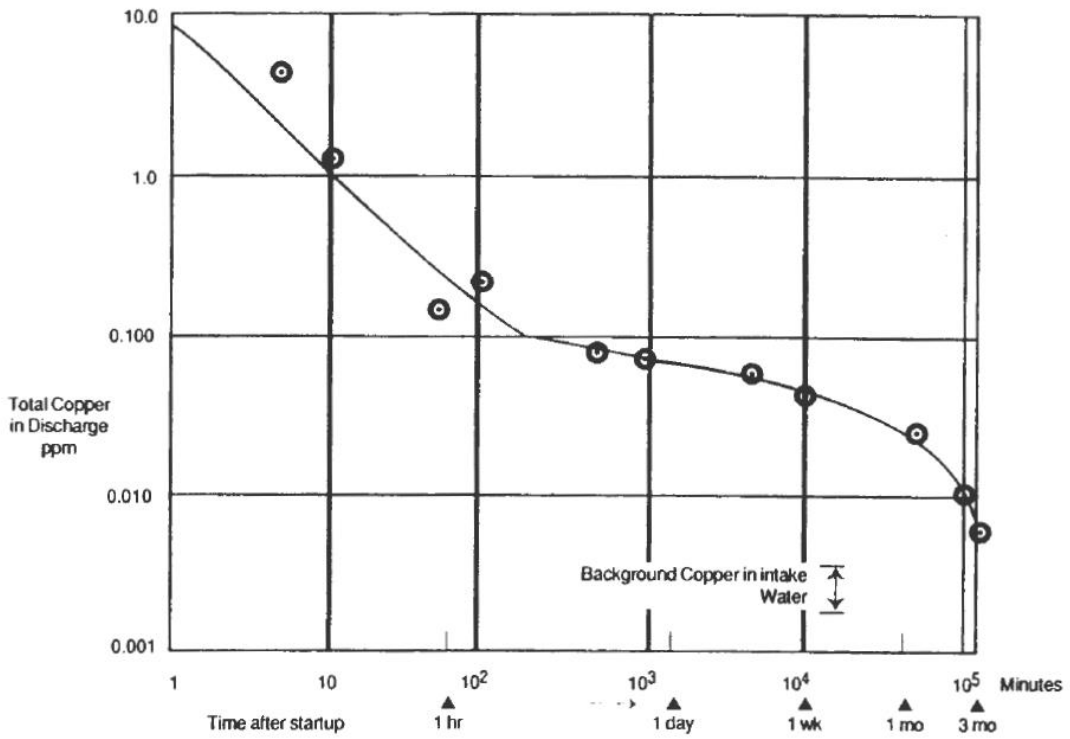

Figure 1.2. Rate of protective layer formation measured as delta of copper in effluent compared to influent (figure from Tuthill 1987). Note the rapid decrease in copper in the effluent to 1/100th of initial concentration after one hour and to near background concentration after three months.

Tuthill (1987) notes that previous studies (Efird and Anderson 1975) demonstrated that the corrosion rate for 90-10 and 70-30 copper nickel decreases as the protective layer develops, citing that the rate is about 0.5 mils/yr after one year of exposure and 0.05 mils/yr after three to seven years of exposure (considered the long-term steady state) (Figure 1.3). Tuthill (1987) also notes that although using short-term corrosion data may be appropriate for making comparisons among various materials, it can be very misleading when estimating material service life since corrosion rates can be high initially and decrease quickly over time.

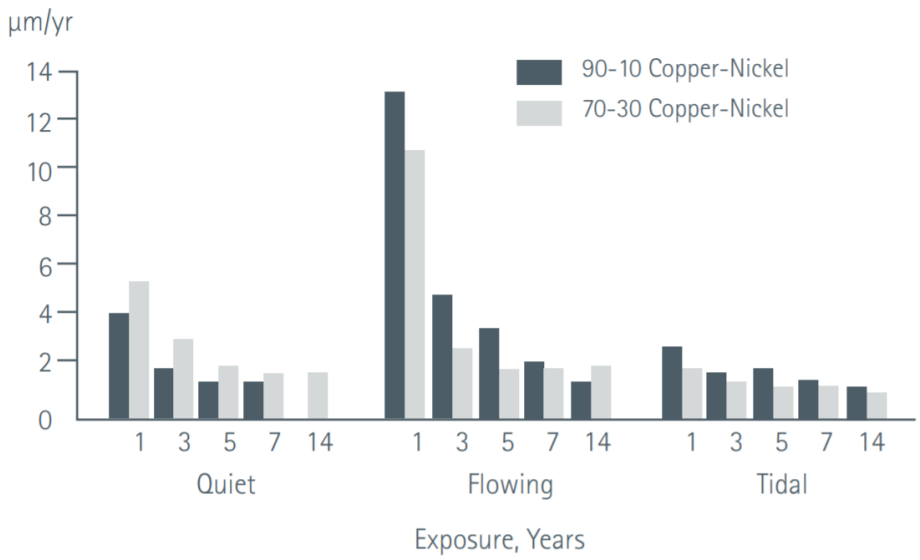

Figure 1.3. Long-term corrosion rate of 90-10 and 70-30 copper nickel in seawater under various flow conditions (figure from Efird and Anderson 1975).

Copper Leaching

While corrosion rates are measured directly by weighing coupons pre- and post-exposure, leaching rates are not typically measured directly; rather, they are derived (calculated) from corrosion rates.

In Michel et al's (2011) review of the study done by Efird and Anderson (1975), he states:

"*Trying to assess leaching data from these results raises a variety of issues. Should the corrosion rates used for design or assessments be taken from initial years or be taken from the stabilized rates? Logically, the corrosion rate should represent the number of years that the alloy in any application is intended for service. Also, data is often taken from weight loss measurements after the films have been removed by acid cleaning. As the films are a permanent feature of the corrosion and biofouling resistance in service, would removing them make the rates calculated overly high and misleading?*

From the above, it can be seen, how complicated it is to provide sensible leaching data from corrosion rates in sea water as the corrosion rate is influenced by time of exposure, flow rate, temperature and final method of measurement. In other offshore corrosion evaluations of a range of alloys, short term ranking tests become a means of assessing this and very often deceptively become perceived as the actual data indicative of rates in the field. Often these might be evaluated in artificial sea water as this is one method of producing a reproducible environment conveniently and cheaply without the many interactions of the natural

environment. However, it is apparent for copper-nickel that both the corrosion and biofouling resistance are so closely tuned to the reaction of the surface with the biological and chemical ingredients of natural live sea water that this could be grossly undervaluing the alloy and misleading."

The above excerpt agrees with Tuthill's (1987) position that short-term corrosion studies can be misleading, suggesting that corrosion rates should be relative to a steady-state that has been reached after the metal has developed its protective layer. Additionally, although a controlled laboratory study with artificial seawater may be well-suited to identify corrosion rates in the absence of external factors that cannot be controlled in a field study, the results will not accurately represent real-world conditions.

Case Study – Francis L. LaQue Corrosion Laboratory, Wrightsville, North Carolina

Efird (1976) completed a five-year long field study in which five metal coupons were exposed to ambient seawater at Wrightsville Beach in North Carolina. The metals tested were carbon steel, 5086-0 aluminum, Electrolytic Tough Pitch (ETP) copper (CA 110; nearly 100% copper), 90/10 copper nickel (CA 706), and 70/30 copper nickel (CA 715). The coupons were submerged 18 inches below the surface from a floating dock. Metals were inspected for fouling community development at 3, 9, 18, 36, 48, and 60 months. At the completion of the five-year study period, the coupons were cleaned of biofouling and weighed to determine corrosion rates.

Table 1.1 presents the corrosion rates and estimated metal ion leaching rates for ETP copper and the two copper nickel alloys. ETP copper had a corrosion and leaching rate that was three times higher than the copper nickel alloys. Efird (1976) noted, however, that there was no significant difference in its resistance to fouling. This would seem to indicate that the presence of the protective layer on the metals (common to the ETP copper and the copper nickel alloys) conferred the fouling resistance and not the concentration of copper ions released from the metal. Efird (1976) also referred to a previous study he conducted (Efird and Anderson 1975) in which copper nickel coupons were exposed to seawater for 14 years, noting the following:

"*This concept was further substantiated by a removal in another experiment where 70-30 Cu-Ni panels had been exposed in seawater for 14 years, with corrosion rates of 0.05 mpy* (mils/yr)*, were only slightly fouled as shown in Figure 11. This is in conflict with the leaching theory for fouling resistance of copper-base alloys in seawater, which requires a minimum corrosion rate of 0.7 mpy* (mils/yr) *to prevent fouling (LaQue and Clapp 1945).*"

Table 1.1. Corrosion rates, estimated copper leaching rates, and fouling resistance of copper and copper nickel alloys exposed to seawater for five years (data from Efird 1976).

Material	Corrosion Rate (mils/yr)	Metal Ion Leaching Rate ($\mu g/cm^2/day$)	Fouling Observations
Copper	0.3	18.6	Minimal fouling after 4 years and approximately 70% fouled after 5 years
70-30 copper nickel	0.1	6.2	Minimal fouling after 4 years and approximately 70% fouled after 5 years
90-10 copper nickel	0.1	6.2	Minimal fouling after 4 years and approximately 70% fouled after 5 years

Figure 1.4 and Figure 1.5 present the biofouling progression on the 90-10 and 70-30 coupons, respectively, during the five-year study period. Based on the qualitative photographic data in these figures, the accumulated biofouling could become a concern for a WWS with a 1-mm slot width somewhere between 18 and 48 months of exposure. It is important to note, however, that the nature of fouling on a 1-mm WWS which is designed to pass flow through it is fundamentally different from fouling on a flat, unslotted coupon since biofouling organisms will grow at a higher rate in a flowing environment where planktonic food is constantly being supplied to the organisms. The recent corrosion and fouling studies conducted by the West Basin Municipal Water District (WBMWD) included testing of WWS material (Tetra Tech 2016), though the study duration was only one year. See below for more information on the WBMWD study results.

Figure 1.4. Five-year sequence of fouling on 90-10 copper nickel in seawater. Top left to right: 3, 9, and 18 months. Bottom left to right: 36, 48, and 60 months.

Figure 1.5. Five-year sequence of fouling on 70-30 copper nickel in seawater. Top left to right: 3, 9, and 18 months. Bottom left to right: 36, 48, and 60 months.

Case Study – West Basin Intake Biofouling and Corrosion Study

The screen corrosion and biofouling study conducted by WBMWD differed from previous copper nickel corrosion studies in that multiple metal sample forms were used (1-in by 3-in coupons, 4-in by 4-in plates, and 4-in by 4-in sections of 2-mm slot width WWS). The use of WWS samples provides data that is more representative of an actual seawater intake. Limitations of the study included that it was of relatively short duration (12 months) and that it was conducted under passive conditions (i.e., no flow through the screening material).

The test coupons and WWS sections were deployed on four replicate PVC test racks (Figure 1.6). The test racks were attached to the grating of the non-operating Redondo Beach Generating Station intake structure. One test rack was removed every three months (approximately) to assess biofouling and corrosion (via sample weight loss).

Figure 1.6. Coupon and screen test rack (photo from Tetra Tech 2016).

In addition to the coupon and WWS samples mounted on the test rack, test plates (4-in by 4-in) were enclosed in mesh bags and deployed on a separate PVC test rack inside the coarse grating of the Redondo Beach Generating Station intake structure to simulate corrosion in a low flow (essentially stagnant) environment. The plates remained submerged for the entire

12-month study period and were retrieved for corrosion and biofouling assessment at the end of the study.

The results of the corrosion analyses are summarized in Table 1.2. The Z Alloy screen section had the highest average corrosion rate (1.772 mils/yr) over the 12-month study period, with the 90-10 copper nickel screen section corroding at essentially the same rate (1.732 mils/yr; Table 1.2). Their quarter by quarter corrosion rates were also very similar (Figure 1.7). All other materials and sample types experienced low corrosion rates. Corrosion rates for the Z Alloy and 90-10 WWS sections decreased substantially between the first quarter and second quarter assessments, with no appreciable change in the corrosion rate after the third quarter assessment (Figure 1.7). These results agree with previous research summarized above that documented a rapid decrease in corrosion rates of copper nickel after the first few months of exposure to seawater.

It is notable that the WWS sections of Z Alloy and 90-10 copper nickel had significantly higher corrosion rates than the same materials in their coupon and plate forms (Figure 1.7). These results indicate that the WWS sections may have a greater tendency to corrode than flat coupon or plate samples perhaps attributable to the increased surface exposed to seawater. Tetra Tech (2016) noted that the difference seen in the 90-10 materials may be attributable to different suppliers of the WWS section versus the coupon and plates samples, but also noted that all of the Z Alloy samples (coupons, WWS sections, and flat plates) came from a single vendor and still experienced significantly differing corrosion rates.

Table 1.2. Corrosion rates of the four metals tested (in coupon, WWS section, and plate forms) after 12 months of seawater exposure at the Redondo Beach Generating Station intake structure (data from Tetra Tech 2016).

Metal	Sample Type	Surface Area (in^2)	Maximum Pitting Depth over 364 Days (mils)	Overall Average Corrosion Rate (mils/yr)
2205 Duplex SS Uncoated	1-in by 3-in Coupon	8.2	1.38	0.0004
	WWS section	96.7	< 20	0.001
	4-in by 4-in Plate	33.9	< 20	0.002
2205 Duplex SS with Foul-Release Coating	1-in by 3-in Coupon	8.2	1.3	0.039
	WWS section	96.7	< 20	0.039
	4-in by 4-in Plate	34.6	< 20	0.039
70-30 Copper Nickel (CDA 715)	1-in by 3-in Coupon	8.2	1.57	0.472
	WWS section	65	< 20	0.709
	4-in by 4-in Plate	34.4	< 20	0.315
90-10 Copper Nickel (CDA 706)	1-in by 3-in Coupon	8.2	11.45 (94.3 wide)	0.669
	WWS section	79.1	< 20	1.732
	4-in by 4-in Plate	34.1	< 20	1.142
Z Alloy	1-in by 3-in Coupon	8.2	0.47	0.236
	WWS section	96.3	< 20	1.772
	4-in by 4-in Plate	36.6	< 20	0.232

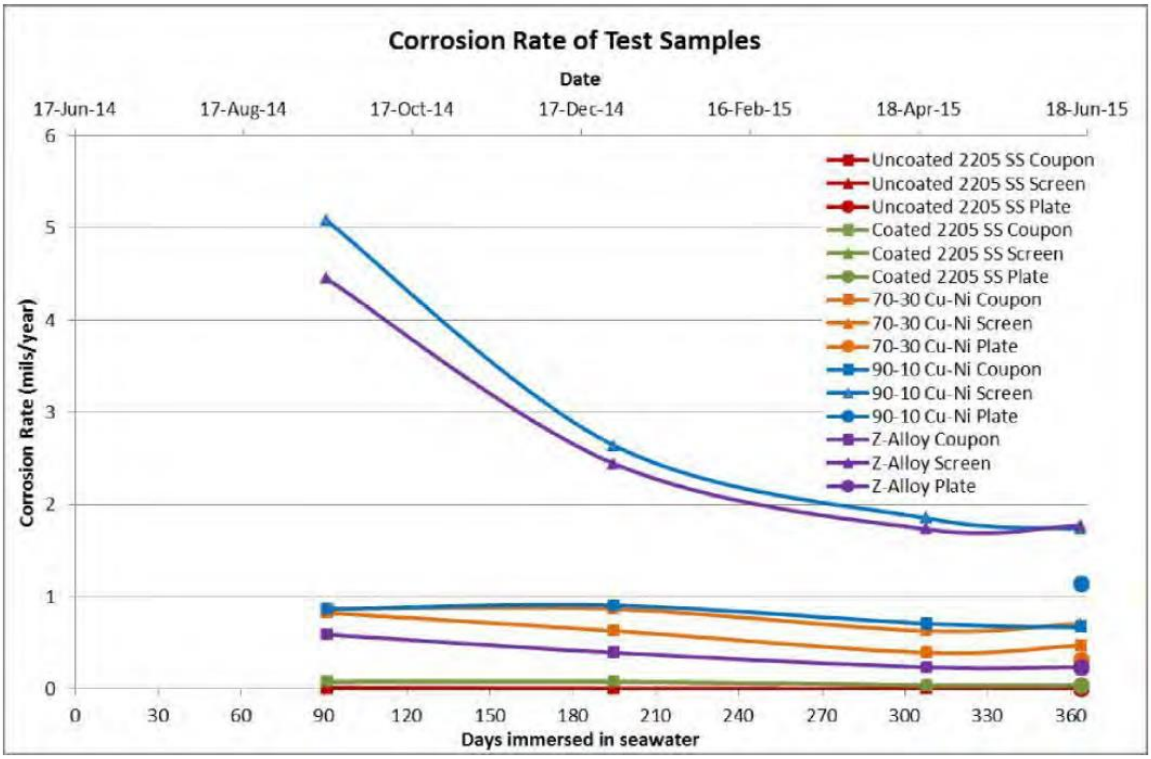

Figure 1.7. Corrosion rates of the four metals tested (in coupon, WWS section, and plate forms) after 12 months of seawater exposure at the Redondo Beach Generating Station intake structure (figure from Tetra Tech 2016).

Tetra Tech (2016) concluded that the corrosion rates were higher in this study than those given in the literature they reviewed. However, the corrosion rates cited for copper nickel came from Efird and Anderson (1975) which was a long-term study conducted over 14 years, so the results are difficult to compare.

Appendix 2:
Copper Monitoring Data

Existing environmental monitoring for copper in the Huntington Beach area indicates ambient concentrations in the coastal ecosystem are well below levels of concern. Levels of concern are defined as either Effects Range Low (Long et al. 1995) for sediment metal concentrations or as water quality objectives included in adopted National Pollutant Discharge Elimination System (NPDES) Permits. In addition to sediments and effluent monitoring, bioaccumulating filter feeding organisms like mussels (*Mytilus* spp.) are routinely tested to monitor copper levels in the aquatic environment (Melwani et al. 2013). These bioaccumulation data are available through the National Oceanic and Atmospheric Administration (NOAA) Mussel Watch program. California also has the State Mussel Watch Program, but all Orange County monitoring stations are in bays and harbors rather than along the open coast. The NOAA Mussel Watch (NMW) program has two monitoring locations along the open coast of Orange County: the jetty at Anaheim Bay and the jetty at Newport Bay. These two sites are approximately eight miles upcoast and downcoast, respectively, from the Huntington Beach Generating Station (HBGS) outfall, the proposed site of the HBDP.

The most recent offshore environmental survey results for copper from NPDES-required monitoring for HBGS (MBC 2017) were reviewed and compiled in Table 2.1. In each case, the most recent data available indicates copper levels well below the testing matrix level of concern. For sediments, this is the Effects Range Low and for effluent, these were the water quality objectives listed in the HBGS NPDES permit (Order No. R8-2014-0076). NOAA-sponsored research evaluated contaminant concentrations likely to impact aquatic life. From this research, scientists were able to categorize copper (and other contaminants) concentrations likely to cause adverse biological effects. Those concentrations compiled from the various independent studies that were in the lower 10th percentile were designated as the Effects Range Low, or the lowest category designated. Concentrations below the Effects Range Low were considered to estimate conditions where biological effects would be rarely observed (Long et al. 1995). In each analysis conducted near the HBGS discharge (Station 1D) and at the NPDES permit-specified reference stations (Stations CUA and DC), the sediment copper concentrations were in the Effects Range Low (Table 2.1). Over the last few years, copper concentrations at all stations sampled in compliance with the HBGS NPDES permit have declined to a slightly lower level than earlier in the 32-year sampling program (Figure 2.1). Likewise, effluent monitoring data retrieved from the HBGS electronic self-monitoring reports (eSMR) available on the California Integrated Water Quality System (CIWQS; http://ciwqs.waterboards.ca.gov/ciwqs/readOnly/CiwqsReportServlet?inCommand=reset&reportName=esmrAnalytical) indicate that the HBGS effluent was also well below the prescribed water quality objectives.

Data from the NMW for Orange County were downloaded from the California Environmental Data Exchange Network (CEDEN; http://ceden.waterboards.ca.gov/AdvancedQueryTool).

These data were only available for the 1985-2010 period. Melwani et al. (2013) reviewed these data as well and noted that in southern California, most coastal copper concentrations were stable or declining. Only in the bays and harbors were copper concentrations increasing. At the two NWM sites on the Orange County coastline, copper concentrations at one site had no significant trend when results were plotted over time (Newport Beach jetty; Figure 2.2), while the other station's copper concentrations significantly declined over time (Anaheim Bay) per Melwani et al. (2013).

The Santa Barbara (Charles E. Meyer) Desalination Plant discharges brine through the El Estero Wastewater Treatment Facility ocean outfall after mixing with the existing wastewater effluent. The Santa Barbara Desalination Plant is currently the only facility in California withdrawing seawater through copper nickel alloy screens along the open coast. Start-up testing began in May 2017 at the Santa Barbara Desalination Plant with full operation commencing shortly thereafter. Therefore, publicly available effluent monitoring data relevant to the potential addition of copper to the effluent is insufficient to parse out copper-nickel screen sourced copper and those concentrations contributed by the wastewater effluent. However, the publicly available electronic self-monitoring reports (eSMRs) for El Estero WWTP (where the Santa Barbara desal discharge is co-mingled) show effluent concentrations well below permit and Ocean Plan respective limits (6-month median, daily, instantaneous). Copper concentrations (and NPDES permit effluent limitations) in the effluent from El Estero WWTP are provided in Table 2.2. To date, the Central Coast Regional Water Quality Control Board has not determined the effluent from El Estero WWTP to be out of compliance with respect to copper effluent limitations. Therefore, no Notice of Violation has been issued based on copper concentrations in the effluent.

Table 2.1. Copper concentrations reported by the Huntington Beach Generating Station in National Pollutant Discharge Elimination System permit-required monitoring.

Source	Location	Matrix	Concentration	Units	Limit	Source
HBGS	Discharge	Sediment	3.24	mg/dry kg	34[a]	MBC 2017
HBGS	Upcoast Control	Sediment	4.46	mg/dry kg	34[a]	MBC 2017
HBGS	Downcoast Control	Sediment	2.29	mg/dry kg	34[a]	MBC 2017
HBGS	Discharge 001	Effluent	3.1	ug/L	240[b]	eSMR 1/4/17
HBGS	Discharge 001	Effluent	3.1	ug/L	87[c]	eSMR 1/4/17
HBGS	Discharge 001	Effluent	DNQ	ug/L	11[d]	eSMR 1/31/17
HBGS	Discharge 001	Effluent	4.62	ug/L	240[b]	eSMR 4/4/17
HBGS	Discharge 001	Effluent	4.62	ug/L	87[c]	eSMR 4/4/18
HBGS	Discharge 001	Effluent	3.86	ug/L	11[d]	eSMR 4/30/17
HBGS	Discharge 001	Effluent	1.86	ug/L	240[b]	eSMR 7/10/17
HBGS	Discharge 001	Effluent	1.905	ug/L	87[c]	eSMR 7/10/17
HBGS	Discharge 001	Effluent	3.27	ug/L	11[d]	eSMR 7/31/17
a = Effects Range Low (Long et al. 1995)						
b = Order No. R8-2014-0076 Instantaneous Maximum						
c = Order No. R8-2014-0076 Daily Maximum						
d = Order No. R8-2014-0076 6-Month Median Maximum						
DNQ = Did not quantify						

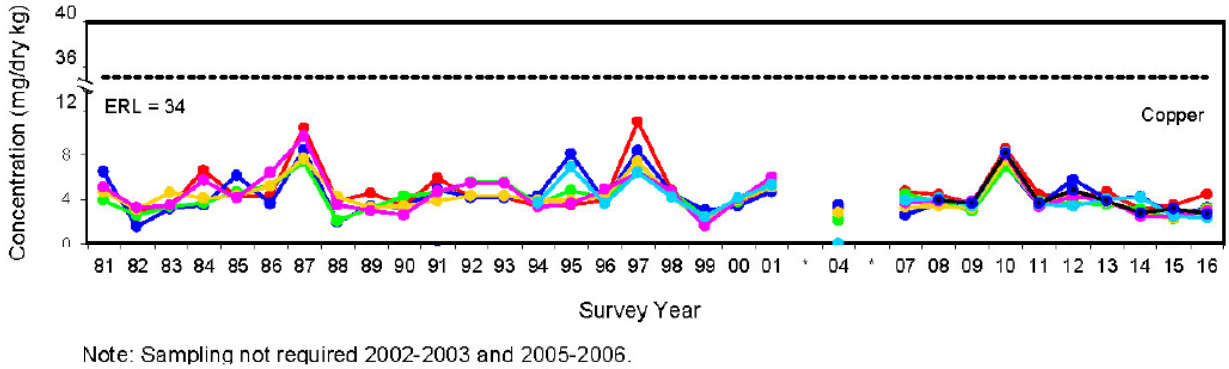

Figure 2.1. Annual sediment copper concentrations and the Effects Range Low (ERL) reported for the Huntington Beach Generating Station, 1981-2016 (figure from MBC 2017). Each colored line represents one of the six sampling stations.

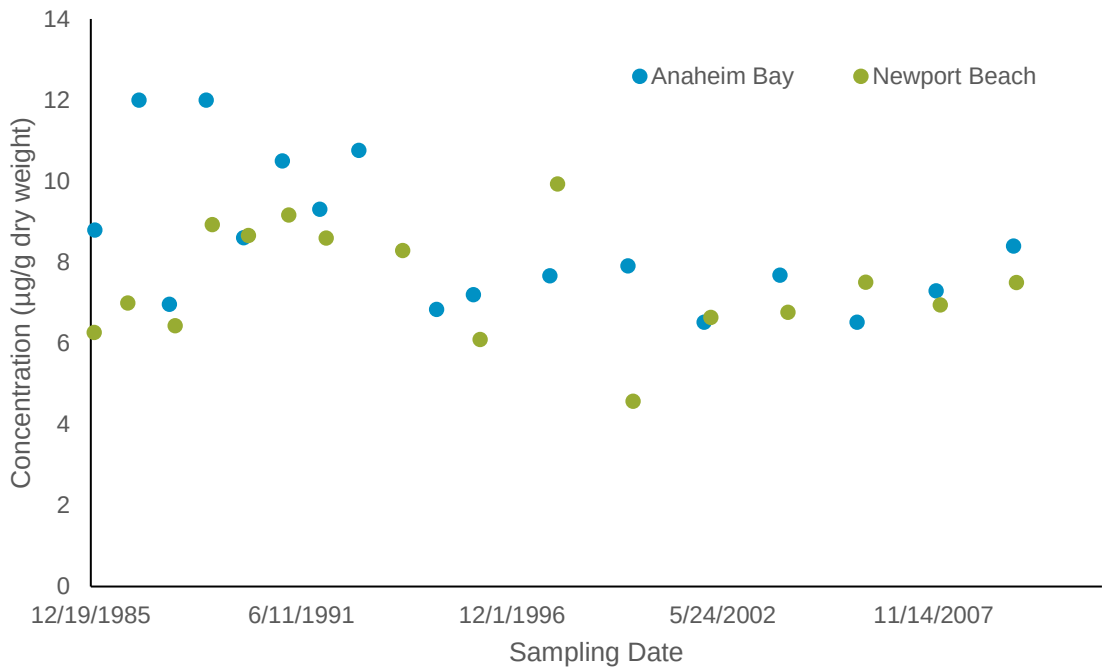

Figure 2.2. Concentration of copper in mussels collected from the jetties at Anaheim Bay and Newport Bay, 1985-2010. Data are from the National Oceanic and Atmospheric Administration National Mussel Watch.

Table 2.2. El Estero Wastewater Treatment Facility effluent sampling results for copper (data are from the California Integrated Water Quality System electronic Self-Monitoring Report).

Sampling Date	Description	Location	Parameter	Calculated Method	Result (ug/L)	Eff Lim (ug/L)
Data below are from the El Estero WWTP effluent before desalination brine is introduced						
09/13/2017	Pre-commingling	EFF-001A[1]	Copper, Total	Instantaneous	91.2	3,390
12/31/2017	Pre-commingling	EFF-001A[1]	Copper, Total	6-Month Median	91.2	123
Data below are from the El Estero WWTP effluent after desalination brine is introduced						
03/04/2017	Mingled with brine	EFF-001B[2]	Copper, Total	Instantaneous	11.6	1,262
06/13/2017	Mingled with brine	EFF-001B[2]	Copper, Total	Instantaneous	7.61	1,262
12/12/2017	Mingled with brine	EFF-001B[2]	Copper, Total	Instantaneous	11.3	1,262
12/31/2017	Mingled with brine	EFF-001B[2]	Copper, Total	6-Month Median	11.3	47

[1] Location is within the El Estero WWTP effluent stream upstream of brine introduction.
[2] Location is within the El Estero WWTP effluent stream downstream of brine introduction.