POSEIDON WATER

Appendix DD
Analysis of Potential for CDP Discharge to Cause Hypoxic Conditions

Renewal of NPDES CA0109223
Carlsbad Desalination Project

POSEIDON WATER

Analysis of Potential for Carlsbad Desalination Plant Discharge to Cause Hypoxic Conditions

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Introduction

The San Diego Water Board has requested that the owner/operator of the Carlsbad Desalination Plant (CDP), Poseidon Resources (Channelside) LP (Poseidon), provide additional information regarding the potential of the CDP discharge to create hypoxic (reduced oxygen) conditions in the Pacific Ocean.

Hypoxia, or oxygen depletion, is an environmental phenomenon where the concentration of dissolved oxygen in the water column decreases to a level that con no longer support living aquatic organisms. Hypoxia has been defined as a concentration of less than 2 mg/L.

The Ocean Plan states that the brine discharge shall not result in hypoxic conditions outside of the alternative brine mixing zone (chapter III.M.2.d.(2)(c)). The reason for these provisions is that the discharge of brine without adequate dilution could potentially create a hypoxic zone on the Pacific Ocean seafloor suffocating benthic aquatic organisms, such as fish and invertebrates. Based on these requirements, the Regional Water Board asked Poseidon to document whether the discharge would result in hypoxic conditions outside of the requested alternative Brine Mixing Zone (BMZ) of 200 meters. The following information is in response to this request.

To ensure the new proposed BMZ will not produce hypoxic conditions, Poseidon consulted with Michael Baker International to perform BMZ modeling and Amec Foster Wheeler to perform onsite and receiving water monitoring to demonstrate the discharge remains well within the limits for the D.O. concentration when released back into the ocean.

Dissolved Oxygen

The dissolved oxygen content (D.O.) present in a body of water is affected by the water's temperature, pressure, and salinity. The D.O. capacity of water decreases as temperature increases, decreases exponentially as salinity increases, and increases as pressure increases. In other words, warmer surface water can hold less oxygen in solution than colder, deeper water and saltwater holds about 20% less oxygen in solution than freshwater when other parameters are maintained. However, while colder, deeper water has increased D.O. capacity, microbial decomposition, the absence of atmospheric contact for diffusion, and reduced rates of photosynthesis typically result in D.O. levels below 100% saturation (Schulz, 2006).

Brine and Mixing

Brine is typically denser than ambient seawater and may form a brine layer (Shiau, 2004). Because of this segregation, a brine plume can form a physical barrier reducing the mixing between brine and ambient layers, and, depending on the characteristics of the two layers, result in anoxia or hypoxia in benthic organisms. Factors effecting the development of hypoxia include: stratification between ambient waters and the density layer, thickness of the layer, water depth, slope of the bottom, strength of wind, vertical velocity shear across the layer, and height of the surface waves. Depending on the mixing rates between layers, the D.O. supply to the density layer may be less than the net oxygen demand of the benthic fauna within the density layer causing D.O. to decrease over time and ultimately leading to hypoxia in the density layer. However, this is unlikely to occur with a well-designed discharge (Roberts, Jenkins, Paduan, Schlenk, & Weis, 2012). The use of flow augmentation like that at the CDP produces discharge salinities and D.O. levels near ambient conditions and prevents adverse effects to benthic communities (Phillips, 2012) (Roberts, Jenkins, Paduan, Schlenk, & Weis, 2012).

This is due in part to the design of the brine discharge system, which provides for maximum aeration prior to the discharge entering the ocean. As shown in Attachment C, the transit of the brine discharge from the reverse osmosis system to the Pacific Ocean presents multiple opportunities for reaeration of the discharge stream, including: (1) a vertical drop of 47.8 feet from top of reverse osmosis (RO) building to the brine pit; (2) a vertical drop of 13.08 feet in the drop structure; and (3) a vertical drop of 3.79 feet from the brine vault into the discharge channel. Total drop from the top of the RO building to the discharge pond is 64.67 feet. As a result, there is a significant amount of entrained air released when the combined CDP and EPS discharges surface in the discharge pond.

Method and Analysis

Brine Mixing Zone Modeling

Poseidon consulted with HDR Engineering, Inc. to perform BMZ theoretical modeling based conservative assumptions and Amec Foster Wheeler to provide confirmation samples demonstrating that CDP discharge will remain above hypoxic D.O. concentrations when released back into the ocean. BMZ modeling was provided by Dr. Scott Jenkins of Michael Baker International to determine the dilution factor in the BMZ. Hypoxic conditions for this modeling were defined as a D.O. concentration depressed to less than 2 mg/L Ambient Seawater D.O. was conservatively selected from measured receiving water data at stations A10, A20, A30, and A50, approximately 7,000 feet northwest of the discharge site.

The proposed operating conditions for the CDP will have an intake flow of approximately 299 MGD with 1 MGD dedicated to the fish return system, 120 MGD pumped to the RO system and the balance of 178 MGD used for filter backwash (7 MGD) and dilution of the brine effluent (171 MGD). Of the 120 MGD pumped to the desalination plant, 60 MGD will become product water and the remaining 60 MGD will be the brine discharge. A simplified flow diagram can be seen below in Figure 1.

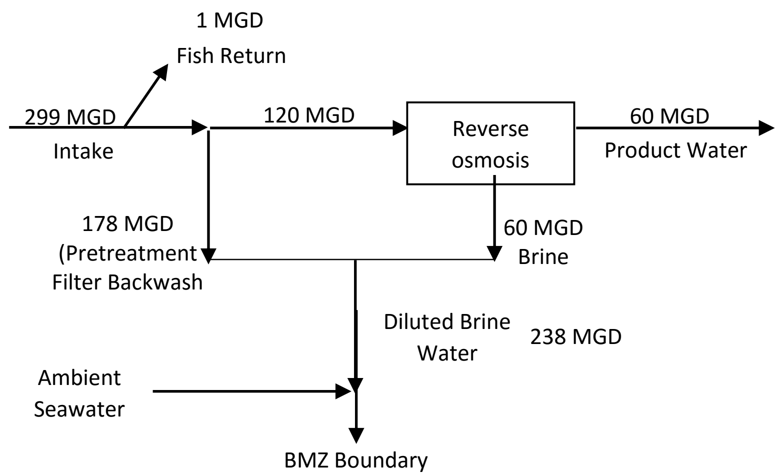


Figure 1. Flow diagram for the proposed upgraded Carlsbad Desalination Plant.

<u>Analysis of Worst Case Conditions</u>

In order to estimate the D.O. at the BMZ boundary, the D.O. of the blended dilution water of 178 MGD and the brine water of 60 MGD must be calculated. The D.O. of the brine discharge was conservatively assumed to be zero, which is highly unlikely given the multiple opportunities for aeration of the discharge on the way to the ocean. The D.O. of the dilution water used in the calculation was assumed to be the average of Poseidon's D.O. monitoring at the reference sampling station in the Pacific Ocean,[1] which is 8.30 mg/L. The D.O. concentration of the blended water was calculated by using the following mass balance equation:

$$Diluted\ Brine\ Water\ DO = \frac{(Backwash\ and\ Dilution\ Water\ Flow \times\ Ambient\ DO\ ) + (Brine\ Flow \times Brine\ DO)}{Diluted\ Brine\ Water\ Flow} \quad (1)$$

$$Diluted\ Brine\ Water\ DO = \frac{(178\ MGD\ \times\ 8.30\ \frac{mg}{L})\ + (60\ MGD\ \times\ 0.00 \frac{mg}{L})}{238\ MGD} = 6.21\ mg/L$$

Due to the assumption that the brine water D.O. concentration is zero, and therefore does not go through reaeration at the three vertical drop structures, the calculated blended water D.O. of 6.21 mg/L at the discharge channel is highly conservative.

Further dilution of the blended water occurs after it is discharged to the Pacific Ocean as the water travels 200 meters to the BMZ boundary. Based on Dr. Scott Jenkins's findings from the Note on the Zone of Initial Dilution in a Quiescent Ocean Due to Discharges of Concentrated Seawater from the Carlsbad Desalination Project (Jenkins, 2016), the 238 MGD brine water is diluted by a factor of 3.31 between the discharge channel and the edge of the BMZ during the worst case month mixing conditions, meaning that there is an additional 788 MGD (238 MGD x 3.31) of background seawater that further dilutes the blended water as it flows to the edge of the BMZ. The following mass balance equation was used to compute the D.O. of the fully diluted brine water at the edge of the BMZ:

$$Discharge\ D.O. at\ BMZ = \frac{(Diluted\ Brine\ Water\ Flow \times Diluted\ Brine\ Water\ DO\ )\ + (Ambient\ Seawater\ Flow \times Ambient\ DO)}{(Diluted\ Brine\ Water + Ambient\ Seawater\ Flow)} \quad (2)$$

$$Brine\ Discharge\ D.O. at\ BMZ = \frac{(238\ MGD\ \times\ 6.21 \frac{mg}{L})\ + (788\ MGD\ \times\ 8.30 \frac{mg}{L})}{1026\ MGD} = 7.81\ mg/L$$

Based on the most conservative assumptions, the D.O. concentration of the fully diluted brine water at the edge of the BMZ of a 200-meter radius is 7.81 mg/L, or 0.49 mg/L below the natural background ocean D.O. level of 8.30 mg/L; which is well above the 2 mg/L threshold for the onset of hypoxic conditions. While this modeling was informative, direct field testing of discharge water from the plant will provide a more accurate assessment of the potential for the proposed discharge to create hypoxic conditions at outside the BMZ.

[1] The average of the semi-annual monitoring of D.O. at Stations A-10, A-20, A-30, A-40, and A-50 in the second half of 2015, and the first and second halves of 2016.

Field Testing of D.O. Concentrations in Brine Discharge

Analysis of Current Operating Conditions

In order to verify the current discharge flow does not create hypoxic conditions at the edge of the BMZ, the dissolved oxygen content was measured throughout multiple locations onsite and offshore of the Carlsbad Desalination Plant on August 2, 2016. Onsite monitoring consisted of measuring multiple parameters, including dissolved oxygen concentration, temperature, and salinity, of the brine as it traveled from the reverse osmosis membranes to the discharge pond. Attachment A shows the locations of each onsite monitoring location in the CDP. The offshore monitoring locations corresponded to the receiving water monitoring stations described in Poseidon Resources' NPDES permit for receiving water monitoring. A description of each of these sites can be seen in Attachment B.

The collected measurements of each onsite and offshore sampling location is provided below in Table 1. All receiving water measurements were recorded at the surface level of the ocean. There is a decrease in D.O. as the brine moves through CDP, but once the brine has mixed with the dilution water and reaches the discharge pond the D.O. has increased back to a value relatively similar to the measured D.O. of the intake on Agua Hedionda Lagoon (M-INF).

Table 1. Surface water onsite and offshore monitoring results of the Carlsbad Desalination Plant.

Site No.	Sampling Locations	Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (mg/L)
1	Intake Lagoon	25.6	33.1	7.58
2	Intake Pump Station (IPS)	25.7	34.1	6.98
3	Brine Pit	26.6	58.3	6.01
4	Brine Vault	28.2	59.4	5.01
5	Discharge Pond	25.6	38.1	7.36
6	A-00*	24.9	33.09	7.86
7	A-40	24.9	32.95	8.33
8	C-10	24.8	33.0	8.28
9	C-20	24.8	32.99	8.28
10	C-30	24.9	33.0	7.95
11	D-10	24.8	32.97	8.26
12	D-20	24.9	32.94	7.95
13	D-30	24.8	32.97	7.75
14	D-50	24.9	32.94	7.96
15	E-10	24.7	32.50	8.15
16	E-20	24.8	32.94	7.73
17	E-30	24.9	33.12	7.89

* Site IDs A-10, A-20, and A-30 are the same locations as Site A-00 as described in Attachment A.

While modeling analysis of the BMZ used the most conservative value for the D.O. content of the brine (0.00 mg/L), CDP onsite data collection allowed for a more accurate assessment of brine D.O. to be used for the determination blended water D.O. content. Since monitoring locations A-00, A-10, A-20, A-30, and A-40 are so far away from CDP's discharge, the data collected on August 2, 2016 at these sites were averaged and referenced as natural ocean water measurements for the area around CDP. Using this methodology, the natural background seawater D.O. concentration was determined to be 8.10 mg/L. Comparison of the background ocean D.O. content of 8.10 mg/L to the measured D.O. value at the discharge pond of 7.36 mg/L indicates a 9.1% dissolved oxygen depression in the discharge pond. Furthermore, the discharge water continues to be diluted even more as it moves towards the boundaries of the BMZ, allowing for the oxygen content in the water to increase. Equation 2 was used to compute the expected D.O. at the BMZ along the seafloor, where D.O. concentrations would be more likely to be impacted by the discharge. The following mass balance equation was used to compute the D.O. of the fully diluted brine water at the edge of the BMZ:

$$Brine\ Discharge\ D.O. at\ BMZ =$$

$$\frac{(Diluted\ Brine \times Blended\ D.O.)\ + (Background\ Seawater \times Dilution\ D.O.)}{Diluted\ Brine\ Water}$$

$$Brine\ Discharge\ D.O. at\ BMZ = \frac{(252\ MGD\ \times\ 7.36\frac{mg}{L})\ + (834\ MGD\ \times\ 8.10\frac{mg}{L})}{1086\ MGD} = 7.92\ mg/L$$

The diluted brine flow was calculated to be 252 MGD by averaging the combined CDP and Encina Power Station (EPS) discharge flow over the time frame the onsite monitoring data were collected. As previously noted, the dilution factor at the BMZ during the worst case month is 3.31; therefore, the background seawater flow was calculated to be 834 MGD (252 MGD x 3.31). From these calculations, the dissolved oxygen concentration at the seafloor increases to 7.91 mg/L at the edge of the BMZ, which is a 2.2% depression from the natural ocean water D.O. of 8.10 mg/L.

Analysis of Proposed Operating Conditions

The CDP's proposed operating conditions corresponds with an increase in discharge flow and a decrease in dilution flow, which can be seen in Figure 1. To demonstrate the proposed operating conditions will not result in hypoxic conditions, the same calculated natural ocean as D.O. concentration of 8.10 mg/L and the brine vault D.O. of 5.01 mg/L were used to calculate the blended water D.O. under the proposed operating conditions. This background seawater D.O. value and the new proposed flows were input into equation 1 to obtain the D.O. content of the combined brine, backwash, and dilution water discharge in the discharge pond under the proposed operating conditions.

$$Blended\ Water\ D.O. = \frac{(178\ MGD\ \times\ 8.10\frac{mg}{L})\ + (60\ MGD\ \times\ 5.01\frac{mg}{L})}{238\ MGD} = 7.32\ mg$$

Under these operating conditions, the D.O. of the combined CDP and dilution water in the discharge pond is 9.6% lower than the D.O. in the ocean and 3.4% lower than the D.O. in Agua Hedionda Lagoon. Furthermore, the combined brine, backwash, and dilution water discharge continues to be diluted even more as it moves towards the boundaries of the BMZ, allowing for the oxygen content in the water to increase. Equation 2 was used to compute the D.O. of the combined discharge at the edge of the BMZ based off onsite monitoring data collected:

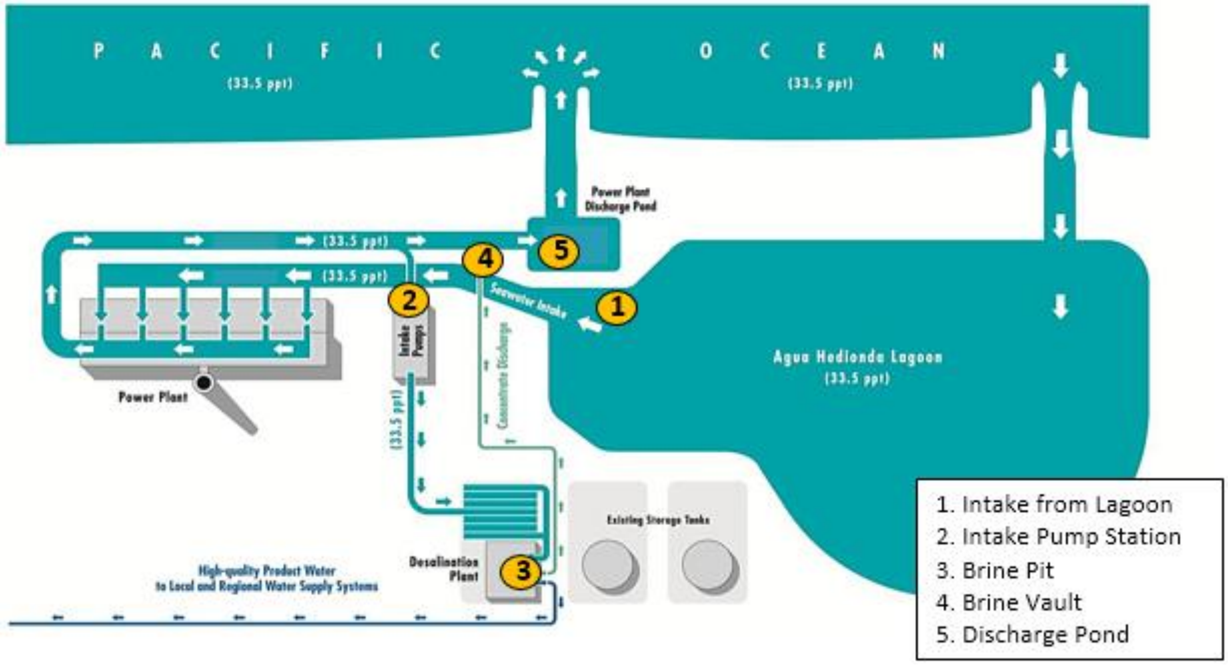
$$Brine\ Discharge\ D.O.at\ BMZ = \frac{(238\ MGD\ \times\ 7.32\frac{mg}{L})\ +(788\ MGD\ \times\ 8.10\frac{mg}{L})}{1026\ MGD} = 7.92\ mg/L$$

After the discharge water is mixed in the BMZ of 200 meters, the dissolved oxygen concentration increases to 7.92 mg/L, which is a 2.2% depression from the natural ocean water D.O. of 8.10 mg/L.

Conclusion

The analysis presented above supports a conclusion that hypoxic conditions are not present under existing operating conditions, and are not expected to be present outside the 200 meter BMZ under the proposed operating conditions. This conclusion is based on the worst case month mixing conditions within the BMZ. In the highly unlikely event that the D.O. concentration in the brine discharge was zero, the analysis predicted the D.O. concentration along the bottom of the ocean at the BMZ would be 0.49 mg/L, or 5.9% lower than the D.O. of the in the receiving water. When actual field measurements of the D.O. in the brine vault, discharge pond and the receiving water reference sites are used to predict the D.O. at the outside edge of the BMZ, the analysis predicted a 0.18 mg/L, or 2.2% depression of D.O. content along the bottom of the ocean at edge of the proposed BMZ under both the current operating conditions and the proposed operating conditions.

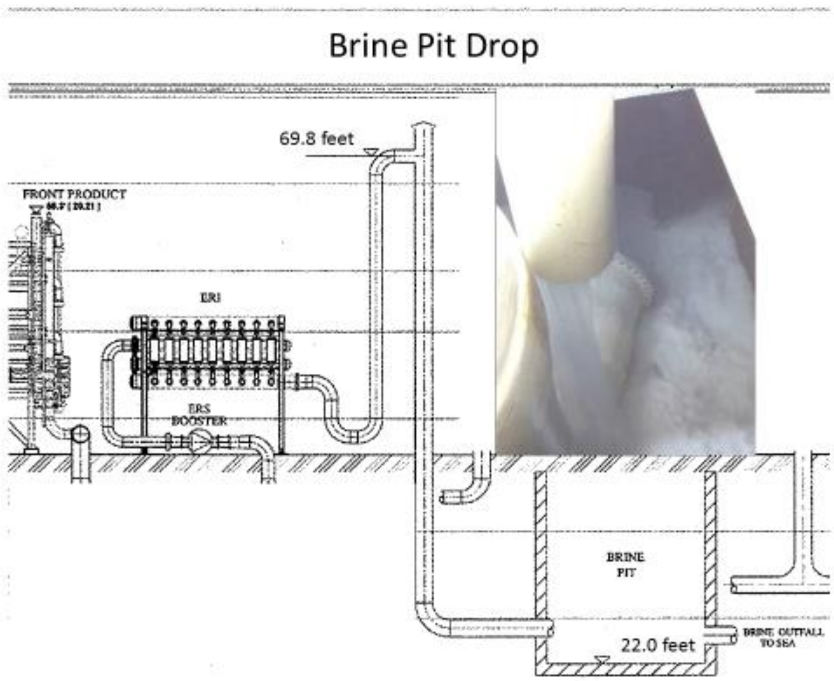
Attachment A: Onsite Monitoring Locations



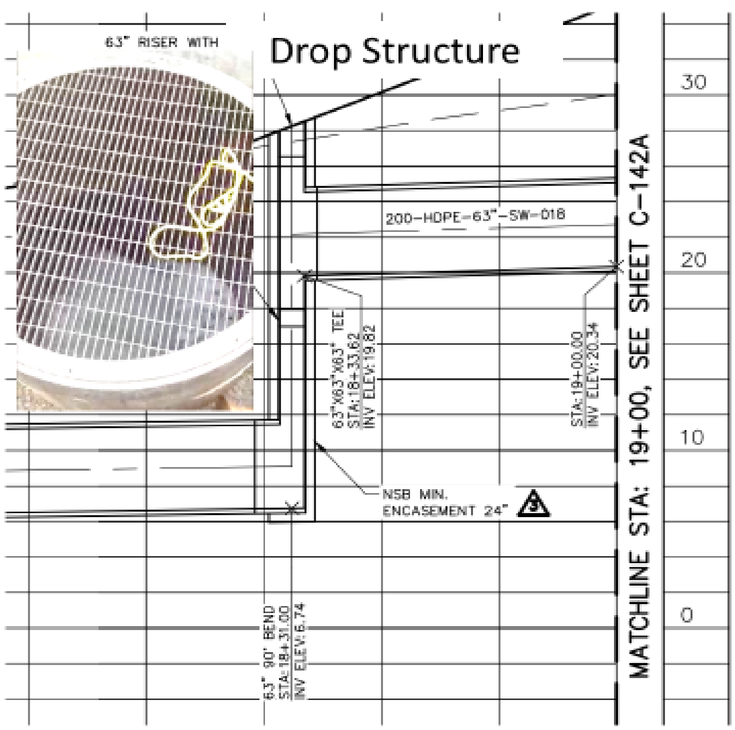
Attachment B: Offshore Monitoring Locations

Monitoring Location Name	Monitoring Location Description	Depth (ft)
A-00	7,000 feet upcoast (northerly) of the discharge channel in the surf zone	Surface
A-10	7,000 feet upcoast (northerly) of the discharge channel in the surf zone	10 feet (at mean lower low water, or MLLW)
A-20	7,000 feet upcoast (northerly) of the discharge channel in the surf zone	20 ft (MLLW)
A-30	7,000 feet upcoast (northerly) of the discharge channel in the surf zone	30 ft (MLLW)
A-40	7,000 feet upcoast (northerly) of the discharge channel, 3400 ft. offshore	Surface
C-10	1,000 feet upcoast (northerly) of the discharge channel, 521 ft. offshore	Surface
C-20	1,000 feet upcoast (northerly) of the discharge channel, 956 ft. offshore	Surface
C-30	1,000 feet upcoast (northerly) of the discharge channel, 2,000 ft. offshore	Surface
D-10	Normal to the discharge channel, 565 ft. offshore	Surface
D-20	Normal to the discharge channel, 1,129 ft. offshore	Surface
D-30	Normal to the discharge channel, 1600 ft. offshore	Surface
D-50	Normal to the discharge channel, 2,800 ft. offshore	Surface
E-10	1,000 feet downcoast (southerly) of the discharge channel, 652 ft. offshore	Surface
E-20	1,000 feet downcoast (southerly) of the discharge channel, 1,086 ft. offshore	Surface
E-30	1,000 feet downcoast (southerly) of the discharge channel, 2,000 ft. offshore	Surface

Attachment C: CDP Features Showing Aeration

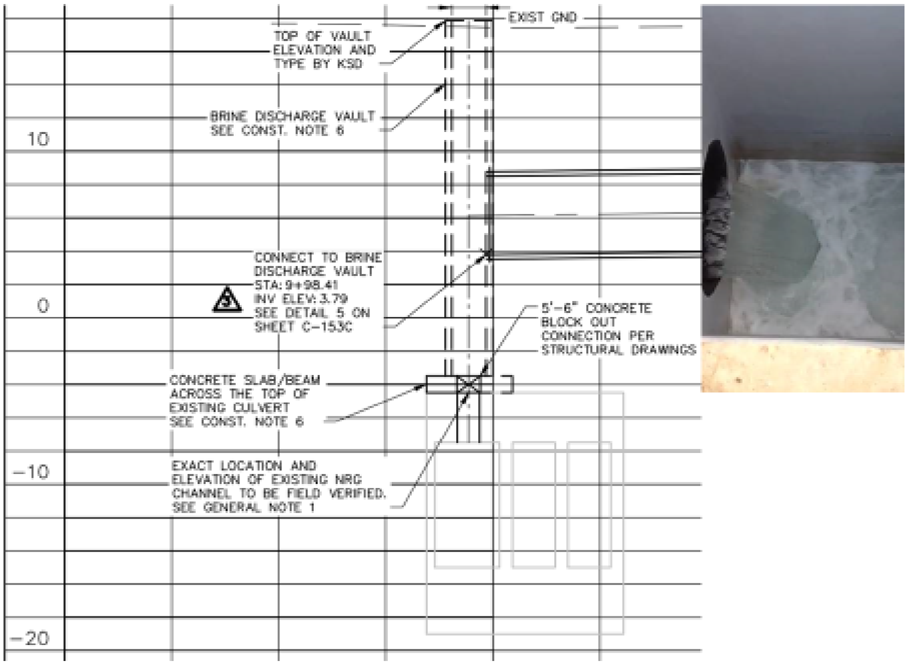


Aeration in the Brine Pit



Aeration in the Drop Structure

Brine Vault Drop



Aeration in the Brine Vault

Aeration in the Discharge Pond