Technical Memo: Brine Discharge Mortality Calculations for the Huntington Beach and Carlsbad Desalination Projects

Introduction

Poseidon Water (Poseidon) has developed conceptual discharge designs for each of their plants (Huntington Beach Desalination Plant [HBDP] and Carlsbad Desalination Plant [CDP]). Although the brine discharge approaches differ between the plants, the methods used to calculate the impacts are the same. Per section III.M.2.e of the Ocean Plan Amendment (OPA), the impacts that require mitigation are associated with the construction and operation of the intake and discharge structures after having first minimized intake and mortality of all forms of marine life through best available site, design, and technology. More specifically, in regards to the discharge method, section III.M.2.d.2.c of the OPA states "*The owner or operator must evaluate all of the individual and cumulative effects of the proposed alternative discharge method on the intake and mortality of all forms of marine life*". Generally, discharge-related impacts are parsed into two categories – construction-related impacts and operational impacts. Depending on the discharge method employed, mortality resulting from operational impacts can be comprised of the following components:

- mortality associated with elevated salinity in the brine mixing zone (BMZ); and
- mortality associated with shearing stress at the point of discharge; or
- mortality associated with intake-related entrainment– relevant for a flow augmentation approach

The objective of this technical memorandum (memo) is to describe the three components of the brine discharge mortality calculation and the methods used to estimate the mortality.

Brine Discharge Mortality Components

Construction Impacts

Per section III.M.2.e.1.c of the OPA, "*For construction-related mortality, the report shall use any acceptable approach approved by the regional water board for evaluating the mortality that occurs within the area disturbed by the facility's construction*."

The permanent loss of habitat resulting from construction of any of the discharge components is estimated using design drawings to determine the footprint impacted. These permanent construction impacts are limited to the seafloor. This conceptual design footprint is used in the mitigation calculation for the overall discharge-related marine life mortality. No modeling is required; rather the area permanently lost will be mitigated for.

Operational Impacts (Brine Mixing Zone)

Per section III.M.2.e.1.b of the OPA, "*For operational mortality related to discharges, the report shall estimate the area in which salinity* exceeds 2.0 parts per thousand above natural background salinity*".

The area in which the salinity exceeds the 2.0 ppt limit above ambient is estimated using the equation for calculating the area of a circle. If, for example, a discharge required the entire 100-m BMZ allowed to reduce the brine salinity to 2 ppt above ambient, the area would be calculated using $A = \pi r^2$. With a BMZ at 100 m, the area would be 3.14 x (100 m)^2 = 31,416 m^2 or 7.8 acres.

Section 8.5.1.2 of the SED provides the following guidance on how to calculate the area that exceeds the 2 ppt limit above ambient:

> *In order to estimate the amount of mortality that occurs as a result of the discharge, an owner or operator can model the facility's discharge to determine the area where salinity exceeds an established level above natural background salinity and mitigate for that area. For example, Figure 8-3 presents modeling data showing isohaline zones where salinity exceeds certain thresholds around a discharge. In this hypothetical example, the facility would be required to mitigate for the area in yellow to green (where salinity exceeds 2.0 ppt above natural background salinity).*

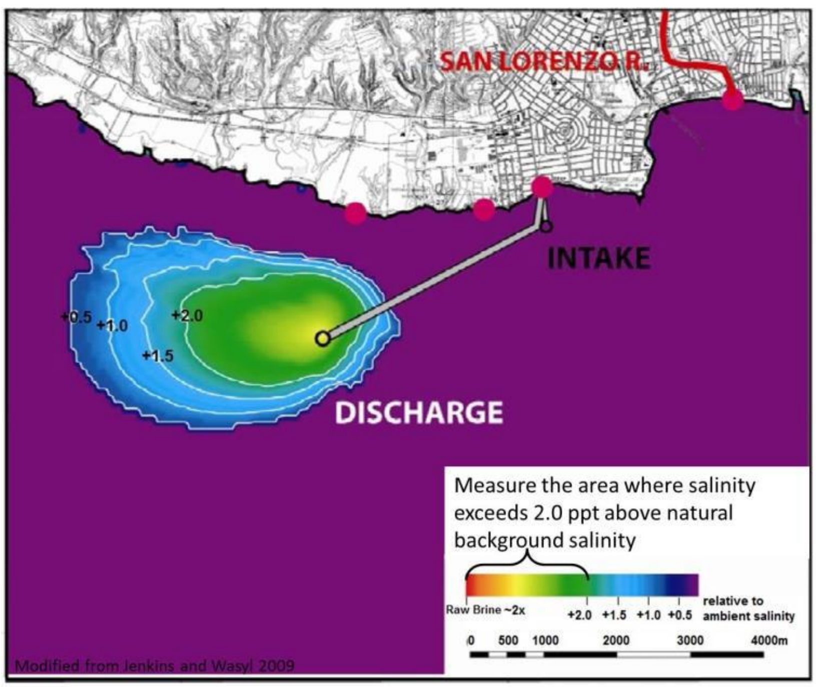

Figure 1. Brine discharge salinity concentrations ppt relative to ambient seawater. Modified from Jenkins and Wasyl 2009.

In addition, relative to the HBDP, Poseidon received the following guidance on the BMZ calculation from the Santa Ana Regional Water Quality Control Board (Proposed Poseidon

Water Huntington Beach Desalination Project, Application for California Water Code Section 13142.S{b) Determination: Request for Additional Information, dated October 31, 2016):

> *These estimates shall be based on the area in which salinity exceeds 2.0 parts per thousand above natural background salinity, and an ETM/APF analysis is not an appropriate approach for this estimate…..The area shall be calculated horizontally from each discharge point.*

Based on the explicit language in the OPA and the above Water Board staff guidance, the BMZ calculation for the two Poseidon projects represents a two-dimensional area - the footprint of the seafloor where the salinity exceeds 2 ppt above ambient. The area of the BMZ with salinity greater than 2 ppt above ambient has been determined by modeling done by Michael Baker International (Dr. Scott Jenkins).

Operational Impacts (Shear-Related)

Justification for Use of the Empirical Transport Model for Estimating Shear-related Mortality

Per section III.M.2.e.1.b of the OPA, "*The report shall use any acceptable approach approved by the regional water board for evaluating mortality that occurs due to shearing stress resulting from the facility's discharge*"

According to this language, the Regional Water Quality Control Board (RWQCB) is requesting supporting documentation for the approach used for evaluating mortality that occurs due to shearing stress resulting from the facility's discharge. This section of the memo provides the documentation requested for use of the Empirical Transport Model (ETM) method for this purpose.

Entrainment relative to a discharge diffuser refers to secondary entrainment of ambient organisms in the ocean water entrained into the diffuser jets. Early life stages of ambient organisms near the operating diffuser will be entrained into the brine plume and a proportion of those organisms will suffer mortality from high levels of shear. The Substitute Environmental Documentation (SED) states in section 8.6.2.2.1 that "*organisms that are entrained into the brine discharge may experience high levels of shear stress for short durations, which is thought to cause some mortality*." As cited in the SED, modeling results from Foster et al. (2013) indicated that "*23 percent of the total entrained volume of dilution water may be exposed to lethal turbulence*." and more specifically, the State Water Resources Control Board (SWRCB 2014) states in the SED that "*we assume that larvae in 23 percent of the total entrained volume of diffuser dilution water are killed by exposure to lethal turbulence*".

The SED also provides guidance on how to calculate shear-related mortality. Section 8.5.1.2 (Discharge-related mortality) states, "*However, until additional data is available, we assume that larvae in 23 percent of the total entrained volume of diffuser dilution water are killed by exposure to lethal turbulence. The actual percentage of killed organisms will likely change as more desalination facilities are built and more studies emerge.*"

This is, therefore, a calculation which takes into account the volume of ambient water required to dilute the brine to the target salinity (35.5 ppt). Organisms in the ambient water used for dilution are synonymous to the organisms in the ambient water drawn into the intake. In each case, a proportion of those at risk of mortality will be lost.

Section 8.5.1.1 (Intake-related mortality) of the SED provides similar guidance on the use of ETM/Area of Production Foregone (APF) for calculating the marine life mortality associated with intake flows. The Expert Review Panel (ERP) recommended that ETM/APF (over other modeling approaches) be used to calculate mitigation for a number of reasons. Many components of Section 8.5.1.1 are common to the use of ETM/APF at either the intake or discharge. Table 1 provides a description of how certain excerpts from the SED support the use of ETM/APF for the calculating the mortality of organisms due to diffuser shear.

Table 1. How excerpts describing the use of ETM/APF for intake mortality relate to the use of ETM/APF for shear-related mortality in a diffuser jet.

Excerpts from Section 8.5.1.1	How it relates to ETM/APF use at discharge
The first step in determining an APF is to develop an ETM that determines the spatial area containing the organisms at risk of intake entrainment.	The source water body also must be delineated for the discharge. In the case of the discharge, the source water body is the ambient ocean water that is entrained into the brine jet emerging from the diffuser port.
The ETM also determines proportional mortality (Pm), or the percentage of the larval organisms or propagules in the source water body that are expected to be entrained at a desalination facility's intake	When applied to the diffuser, ETM similarly estimates proportional mortality of organisms in the source water body. However, for a diffuser, the APF is only calculated for 23% of the total flow required to meet the salinity limit, not 100% of the flow.
The source water body (acreage) and the average annual Pm (percentage) are then multiplied together to calculate the APF.	When applied to the diffuser, APF is calculated by multiplying the average Pm for each taxon by its estimated source-water area.

Regarding the application of the ETM/APF method for the diffuser, the APF is the product of multiplying the average Pm for each taxon by its estimated source-water area. The taxa selected for analysis represent a wide range of habitat preferences and life history strategies. Therefore, after splitting the taxa into two groups (estuarine and open coast) based on their predominant habitat affinity, consistent with Dr. Raimondi's approach, the average APF and standard error was calculated by habitat. The average plus 95% confidence interval APF was calculated using the NORM.INV function in MS-Excel substituting standard error for standard deviation as suggested by Dr. Raimondi. See the Attachments[1] (previously submitted) for additional information on how the discharge APF was calculated for the CDP and the HBDP.

The basic dynamics of how flow is drawn into an intake are indistinguishable from how flow is drawn into a diffuser discharge; however, the means by which the ambient flow is withdrawn are different in each case. For intake flows, ambient water is withdrawn; for a diffuser plume,

[1] Carlsbad Desalination Facility: Entrainment Analysis for Dilution and Discharge Options, July 27, 2015; and Huntington Beach Desalination Facility: Diffuser Discharge Analysis, March 2016.

ambient water is drawn in due to the momentum flux of the discharge (Foster et al. 2013). Figure 2 depicts how ambient flow is withdrawn at an intake and into a discharge diffuser.

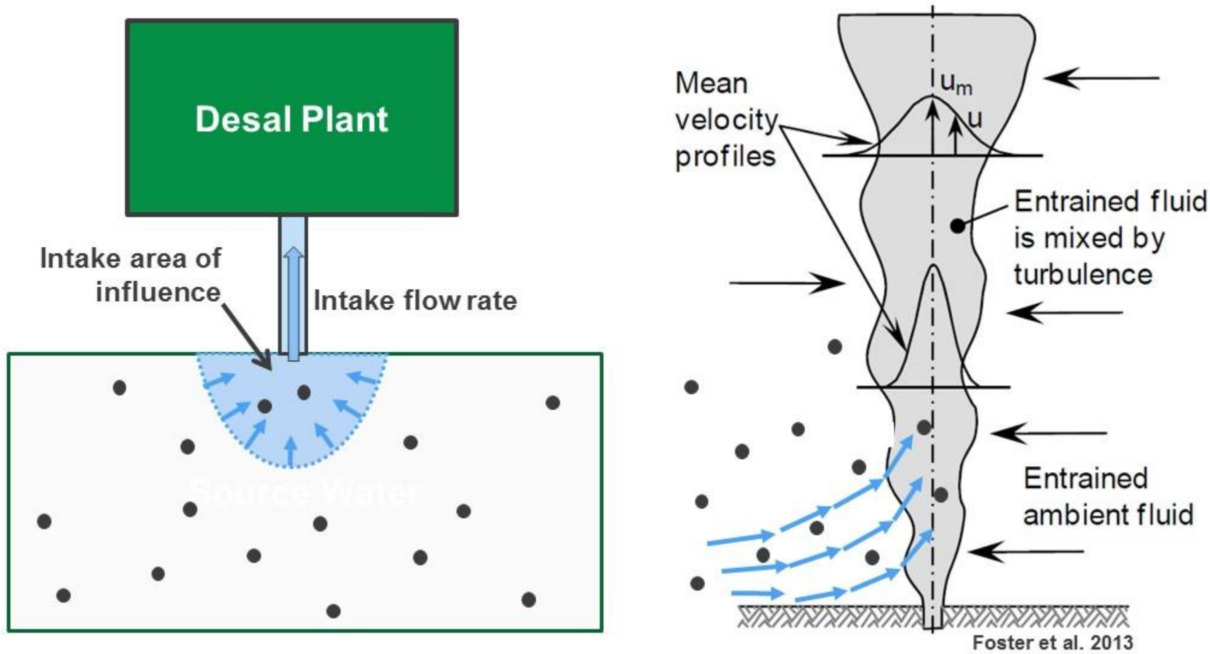

Figure 2. Conceptual schematics of how ambient flow (and passive marine life) is drawn into a) a desalination intake and b) a desalination discharge diffuser. Blue arrows indicate ambient water flow and black dots represent passive marine organisms.

Proportional loss, in each case, represents the number of organisms in the ambient water that are lost due to the operation of the system component. Whether the organisms are lost to entrainment due to intake pumping or to entrainment of dilution flow in brine plume is immaterial; the outcome is the same. Calculating the proportional loss follows the same sequence of steps:

- Delineation of the source water body within which organisms are susceptible to entrainment.
- Calculation of the proportional loss of susceptible organisms to the intake or discharge
- Calculation of the area that could have produced that larvae based on larval age, current speed, and current direction
- Calculation of the acreage required to offset this loss.

Operational Impacts (Intake-Related)

Note that to estimate marine life mortality at the CDP which has proposed to use flow augmentation, the same ETM approach was used as described above for calculating the shear-related losses. No such calculation was done for the HBDP since it is proposing to use a discharge diffuser, not flow augmentation. See the Attachments (previously submitted) for additional information on how the discharge APF was calculated for the CDP and the HBDP.

ETM/APF Methodology for Estimating Shear-related Mortality and Mitigation Acreage

The OPA states a preference for entrainment assessment using ETM with its results converted to habitat area equivalent to the production lost to entrainment using the Area of Production Foregone (APF). The term "source water" is used in both model descriptions, but it has model-specific definitions and applications; discussed below.

Empirical Transport Model based on Steinbeck et al. (2007)

Based on the models originally developed by Boreman et al. (1978 and 1981) with a later revision by MacCall et al. (1983), the ETM provides a method to evaluate entrainment relative to the larval source susceptible to entrainment. This method represents an alternative to more traditional demographic models that rely on extensive life history information for entrained taxa to support converting entrained abundances to adult equivalent individuals. In some areas, demographic models are sufficiently supported by life history data. California taxa are poorly understood with minimal life history information available (Miller et al. 2011). Therefore, entrainment studies since at least 2000 in California have increasingly relied on the ETM.

The ETM relies on sampling the source larval population that could be entrained on the day of sampling, sampling near the intake structure to estimate the entrained larval abundance, and the estimated age of the entrained larvae. From these data, the ETM reports a proportional mortality, or the proportion of the larvae susceptible to entrainment that were entrained and lost to the environment (assuming 100% entrainment mortality). Additional parameters are used in the model, but source water population abundance, entrainment, and estimated larval age are the three dominant inputs to the model. These ETM parameters, or required pieces of information, are discussed in greater detail below.

Source water for the ETM is defined as the area of the waterbody from which the intake is drawing water that contains larvae susceptible to entrainment in the intake while sampling at the intake is underway. Usually, this means the area in which a single larva could transit to the intake and be entrained during a 24-hour period. The source water is designated based on available hydrodynamic and biological characteristics of the waterbody. For offshore submerged intakes or intakes in a tidally flushed lagoon, ambient coastal current measurements are needed to accurately characterize the source water area. Specific attention to current speed and direction is paid when delineating the source water area. While the currents are predominantly in one direction for coastal sites, incorporating areas up and downcurrent of the intake is useful to capture periods of current reversal and also to document the amount of larvae in the source water that may be entrained (still upcurrent of the intake) and may have been, but were not, entrained (downcurrent of the intake). Ideally, recent current measurements are available from the site or near the site to determine the applicable source water area. Once defined, the source water area should be subdivided into reasonably uniform areas based on water volume within the area to determine sampling blocks. The volume is derived through data on area and nominal seafloor depths underlying the area. A plankton sampling station within each area is needed to accurately characterize the plankton present in the source water. These samples are standardized to the volume of water filtered through the net while sampling as measured by a calibrated flow meter installed in the mouth of the net.

Common practice in California has been to sample near the intake structure rather than within the plant after the water has been drawn through the offshore intake structure. Plankton nets induce a high level of drag in the water requiring considerable power to pull through the water. Near an operating power plant intake with a velocity cap designed to increase the lateral intake velocity so juvenile and adult fish will sense it better with their lateral line system, sampling nets needed to be deployed outside the hydraulic zone of influence to avoid the net being caught in the intake flow. Concerns over potential predation on the plankton by filter-feeding animals lining the intake conduit discouraged using in-plant sampling. Therefore, oblique tows from near the bottom to the surface are conducted to catch plankton as close to the intake structure as can be safely achieved.. Entrainment sampling results are also standardized to the water volume filtered through the net as measured by the integrated flow meter. A proportion entrained is derived by dividing the entrainment value by the total estimated larval density in the source water.

A representative subset of larvae is measured by taxa to estimate the median age of the area's larvae. This is entered into the ETM to account for variability in larval size and age, both of which naturally influence mortality rates as older/larger larvae typically suffer less mortality than smaller/younger larvae. Estimated larval age is a key parameter to estimate larval daily survival.

The ETM equations are (from Steinbeck et al. 2007):

1. Proportional Entrainment (PE)

On each sampling day i, the conditional entrainment mortality can be expressed as follows:

$$PE_i = \frac{E_i}{N_i}, \qquad (18)$$

where

E_i = total numbers of larvae entrained during a day during the i^{th} survey; and

N_i = numbers of larvae at risk of entrainment, that is, abundance of larvae in the sampled source water during a day during the i^{th} survey.

Estimated Source Water larval density:

$$N_i = V_S \cdot \overline{\rho}_{N_i} , \tag{19}$$

where

V_S = the static volume of the source water (N); and

$\overline{\rho}_{N_i}$ = the average larval concentration in the source water during the i^{th} survey.

These are plugged into the final ETM:

$$P_M = 1 - \sum_{i=1}^{n} f_i (1 - P_S PE_i)^d , \tag{21}$$

where

PE_i = estimate of proportional entrainment for the ith survey (i = 1,...,n);

P_S = proportion of sampled source water to total estimated source water;

f_i = annual proportion of total larvae hatched during the ith survey; and

d = estimated number of days that the larvae are exposed to entrainment.

The ETM produces a proportional mortality, or Pm, that is later used in the APF, described below.

Area of Production Foregone

The APF is a method of converting abstract ideas of the proportional mortality caused by an intake to a more readily comprehended currency of habitat. Perhaps the chief reason this model was developed and is now preferred is (from Steinbeck et al. 2007):

> *It is based on the idea that losses from environmental impacts can usually only be estimated from a group of species and that the true impact results from the sum of direct and indirect losses attributable to the impact. The use of APF allows for the estimation of both the direct and indirect consequences of an impact and provides a currency (that is, habitat acreage) that may be useful for understanding the extent of compensation required to offset an impact. …*
>
> *In APF the concern is more that each taxon is representative of other taxa that are either unsampled (most invertebrates, plants and holoplankton) or not analyzed (the vast majority of fish). In APF, the average loss across taxa then represents the average loss across all entrained organisms.*

The APF is derived from a subset of taxa, but the habitat estimates resulting from the calculation relate to more than just the taxa used in the analysis. As noted in the above quote, using the APF better accounts for entrainment impacts to all forms of marine life than the ETM alone by virtue of deriving a habitat area that can be easily translated to mitigation. Habitat mitigation such as restoration, in lieu of direct stocking an individual taxon such as releasing hatchery reared fish, provides ecosystem services replacing the ecosystem services lost to entrainment.

Source water area or habitat is also used in the APF, but with a different definition. The APF source water is the area encompassing available habitats where the larvae could have been spawned. Calculating the APF involves current speed and direction monitoring to determine the actual net distance water was transported in any block of time (day, month, year, etc.). This estimated area is multiplied by the Pm derived by the ETM. The product of this equation is the APF, or the estimated area needed to replace the lost production.

Discussion of BMZ and Shear-related Impacts

Poseidon has approached the calculation of operational discharge impacts with the understanding that the BMZ and shear-related impacts represent separate phenomena and should therefore be calculated separately. The BMZ can be conceptualized as a static zone within which the salinity can always be expected to be above the 2 ppt limit.

Relative to a discharge diffuser, the zone in which high shear will be present can be conceptualized similarly. It is a fixed zone that occurs in the water column. However, the organisms that will be exposed to the lethal shear are being transported with the ambient dilution water being drawn into the turbulent jet generated by the operating diffuser. The calculation of the shear-related impacts must reflect the understanding that the organisms being exposed to the high shear are being passively transported into the injurious zone from the surrounding source water area that is significantly more expansive than the area contained within the BMZ. In this sense, the loss of organisms in the 23% of the dilution volume entrained is no different from the loss of organisms in the volume entrained at an intake (i.e., in both instances the entrained organisms are a subset of a much larger population residing in the source water body extending up gradient from the intake or diffuser and are subject to 100% mortality).

Figure 3 and Figure 4 below illustrate how the shear-related calculation differs from the BMZ calculation.

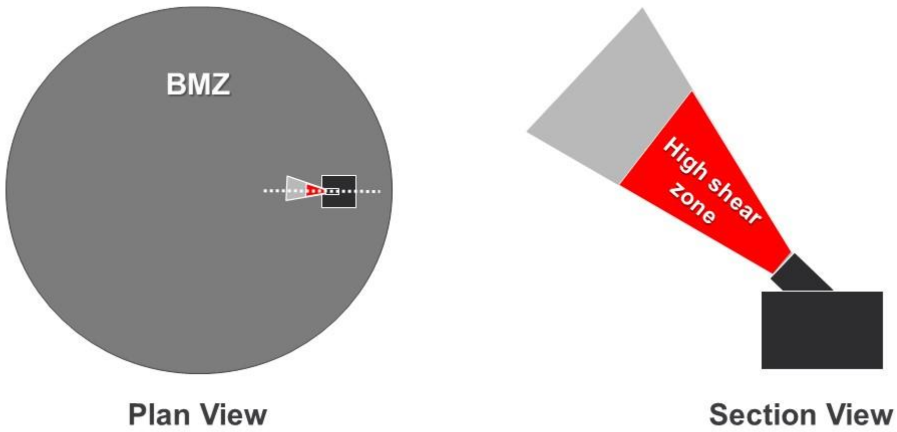

Figure 3. Conceptual schematic of the BMZ (left) and high shear zone of the discharge diffuser (right).

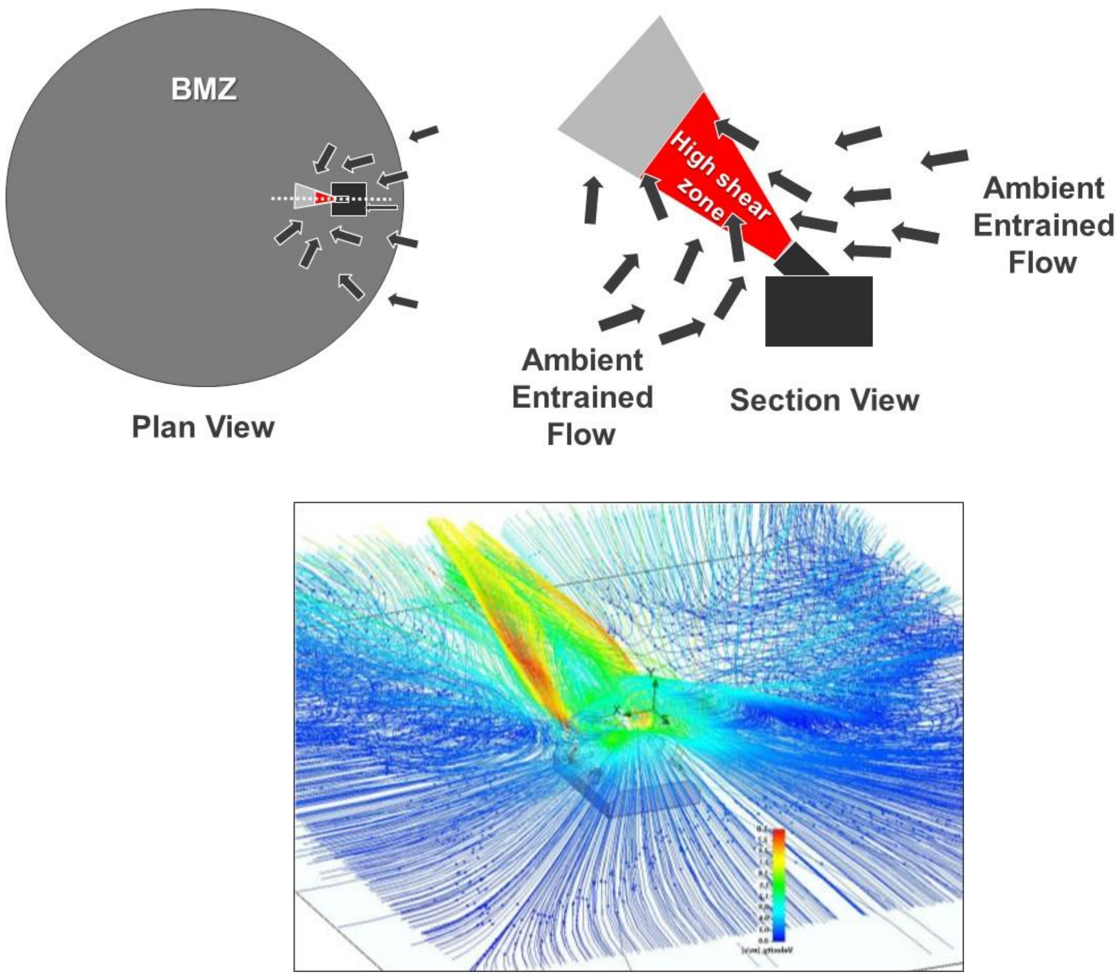

Figure 4. Conceptual schematic (top left and right) of ambient flow being drawn into a discharge diffuser’s turbulent jet from the receiving water body and results from a numerical model (bottom) with flow streamlines illustrating the same phenomenon for a diffuser at the HBDP.

Based on the above, the BMZ should not be counted since it overlaps with source water bodies of the diffuser and/or intake (in the case of the CDP which draws flow augmentation water for dilution). Rather, for both the CDP and the HBDP, the BMZ occurs within the source water body that is also impacted by the intake (flow augmentation at the CDP) or the diffuser (at HBDP). Therefore, since mitigation is already included for the impacts associated with the intake (flow augmentation) and/or the diffuser, including mitigation for the BMZ impact would constitute duplicative mitigation. Conversely, it is correct to include only the intake (flow augmentation) or diffuser (shear-related) impact in the calculation of discharge mortality as it adequately accounts for the impact within the BMZ as well. Therefore, the BMZ APF can be eliminated from the overall discharge-related mortality estimate.

Conclusion

Per the OPA, the discharge impacts that require mitigation are associated with the construction and operation of the discharge structures after having first minimized intake and mortality of all forms of marine life through best available site, design, and technology. This memo describes Poseidon's methods for calculating mortality associated with the brine discharge approach for their projects. The three individual components to each discharge mortality calculation include construction-related impacts, impacts associated with the BMZ, and impacts associated with high shearing stress at the point of discharge.

This memo provides support for the use of ETM for estimating shear-related impacts associated with a diffuser. In addition, it provides an evaluation of why the BMZ component of the overall discharge-related mortality calculation can be eliminated since this is accounted for in the mitigation calculation for the intake (flow augmentation) or diffuser (shear-related).

References

Boreman, J., C. P. Goodyear, and S. W. Christensen. 1978. An empirical transport model for evaluating entrainment of aquatic organism by power plants. US Fish Wildl. Ser. FWS/OBS-78/90, Ann Arbor, MI.

Boreman, J., C. P. Goodyear, and S. W. Christensen. 1981. An empirical methodology for estimating entrainment losses at power plants sited on estuaries. Transactions of the American Fisheries Society. 110: 253-260.

Foster, M.S., G.M. Cailliet, J. Calloway, K.M. Vetter, P. Raimondi, and P.J.W. Roberts. 2013. Desalination Plant Entrainment Impacts and Mitigation. Final report submitted to MarielaPaz Carpio-Obeso, Ocean Standards Unit, State Water Resources Control Board (SWRCB) in fulfillment of SWRCB Contract No. 11-074-270, Work Order SJSURF 11-11-019.

MacCall, A. D., K. R. Parker, R. Leithiser, and B. Jessee. 1983. Power plant impact assessment: A simple fishery production model approach. Fishery Bulletin 81(3): 613-619.

Miller, E.F., C.T. Mitchell, D.J. Pondella, and S. Goldberg. 2011. Life history parameters of common southern California marine fishes. PIER Final Project Report prepared for the California Energy Commission. CEC-500-2011-008.

Steinbeck, J., J. Hedgepeth, P. Raimondi, G. Cailliet, and D. Mayer. 2007. Assessing power plant cooling water intake system environmental impacts. Consultant Report prepared for the California Energy Commission. CEC-700-2007-010.

Attachments -
Discharge APF Calculations for CDP and HBDP

Appendix K -
Entrainment Analysis

Appendix T - Memo -
Poseidon HBDF Diffus