Environmental Research and Consulting

May 9, 2017

Scott Maloni
Poseidon Water
17011 Beach Boulevard, Suite 900
Carlsbad, CA 92008

Re: Technical Memorandum: Response to SLC Request for Additional Turbulence Mortality Calculation

Dear Scott,

I am pleased to submit this memo responding to the State Land Commission's request for Poseidon to consider the merit of calculating turbulence mortality in the Huntington Beach Desalination Plant's diffuser using an equation derived from a method described by Dr. Phil Roberts. This memo was prepared jointly by TWB Environmental Research and Consulting (Tim Hogan) and Michael Baker International (Dr. Scott Jenkins).

The following are the principal conclusions:

- Upon careful review, the Roberts calculation method is inconsistent with State regulatory policy and contains several formulation errors which render it inappropriate for use.
- These inconsistencies and errors are most likely due to the fact that the proposed methodology for calculating diffuser impacts has not been subjected to the traditional regulatory rule making process.
- As a matter of public policy and regulatory compliance, the methodology for assessing diffuser impacts adopted by the State Water Resources Control Board represents the only regulatory guidance for assessing the turbulence mortality for multiport diffusers that has had the benefit of a comprehensive peer and public review process. Deviation from the approved guidance is not recommended until actual diffuser operating data becomes available, or the proposed model is adopted as a replacement of the existing guidance through an update of the Ocean Plan or similar rule making process.

Sincerely,

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

Introduction

Poseidon has proposed to construct the Huntington Beach Desalination Plant (HBDP) discharge by installing a multiport diffuser on the existing offshore discharge riser of the Huntington Beach Generating Station (HBGS). The Ocean Plan Amendment (OPA), at Chapter III.M.2.e.1.b, requires that the discharger estimate mortality that occurs due to shearing stress resulting from the facility's discharge. The Final Staff Report Including the Final Substitute Environmental Documentation (SED) provides guidance on how to estimate the turbulence mortality at the diffuser based on the total entrained volume of dilution water required to dilute the brine to the receiving water limitation (i.e., to within 2 ppt of ambient background salinity).

The State Land Commission (SLC) has requested that Poseidon consider the merit of conducting an additional calculation of turbulence mortality based on an alternative method described in a report prepared for the proposed CalAm Monterey Peninsula Water Supply Project (MPWSP). The alternative calculation method is described in Appendix D1 (Roberts 2016) of the Draft Environmental Impact Report/Environmental Impact Statement (DEIR/EIS) prepared by Environmental Science Associates. Appendix D1 was prepared by Dr. Philip Roberts, who also served as a member of the Expert Review Panel (ERP). The ERP was formed by the State Water Resources Control Board to:

> *…focus only on entrainment impacts and mitigation for desalination plants, <u>including potential impacts from discharge diffusers</u>* (emphasis added, Foster et al. 2013, pg 2).

Dr. Peter Raimondi (who also served on the ERP) was retained by the SLC to review information submitted by Poseidon relative to the HBDP. The SLC is preparing a Supplemental Environmental Impact Report for the HBDP in compliance with the California Environmental Quality Act. As a result, Dr. Raimondi, through the SLC, has issued a memorandum (memo) titled "*Procedure for calculating discharge entrainment volume having turbulent intensity sufficient to cause planktonic mortality*" which requests that Poseidon:

> *…calculate the realized entrainment volume using an equation derived from Roberts* (Raimondi 2017, pg 2)

"Roberts" refers to Appendix D1 (authored by Dr. Roberts; hereafter referred to as Roberts 2016) of the MPWSP DEIR/EIS report prepared by Environmental Science Associates. The detailed hydraulic computations by Roberts (2016) of the internal diffuser flow hydraulics diverge notably from the approach outlined in the SED.

The objectives of this memo are to:

1. provide a review of the calculation method presented in Roberts (2016): Appendix D1 of the MPWSP DEIR/EIS and

2. provide a review of the Ocean Plan requirements which establish the State Water Resources Control Board's regulatory requirements for calculating turbulence mortality.

Review of Roberts (2016) Calculation Approach

Introduction

Section 6 of Roberts (2016) presents calculations estimating potential mortality to marine organisms as a consequence of exposure to turbulent shear (referred to herein as turbulence mortality) in discharges from the Monterey Regional Water Pollution Control Agency (MRWPCA) wastewater outfall offshore of Marina, California. The MRWPCA wastewater outfall utilizes a linear diffuser with 342 discharge ports, but only 129 are open along a 1024-ft long section, discharging at a depth of 104 ft. The study evaluates various combinations of brine and treated domestic effluent discharged into three synoptic current patterns of Monterey Bay: 1) the *upwelling* pattern, 2) the *oceanic* pattern, and 3) the *Davidson current* pattern. Zero current speed was assumed for all dilution calculations; however, all the turbulence mortality calculations are based on the upwelling current pattern assuming an ambient current of 5 cm/s.

Turbulence mortality calculations are based on the hypothesis that only those entrained organisms which are comparable to or smaller than Kolmogorov turbulence scales will suffer turbulence mortality (or sub-lethal injury). Kolmogorov scales are the small eddy sizes where the mechanical energy of turbulent fluctuations are dissipated into heat. Moreover, it is argued that incremental mortality due to the diffuser jets will only occur for regions where the Kolmogorov scales of the diffuser jets are shorter than the natural Kolmogorov scale in the ocean water mass near the diffuser. Therefore, the method for determining incremental turbulence mortality from diffusers *is not portable* because it relies on a highly site-specific parameter that is extremely difficult to measure. Walter et al. (2014) measured Kolmogorov scale ocean turbulence using Doppler velocimeters and fast-response conductivity-temperature sensors mounted on an underwater turbulence flux tower located in the far southern end of Monterey Bay, offshore of the Hopkins Marine Station in Pacific Grove. (This site is approximately 8.5 miles from the MRWPCA diffuser site and at a shallower depth). To our knowledge, no such direct measurements of Kolmogorov scale ocean turbulence in the nearshore environment exist anywhere else in California, and collecting such data would be a multi-year research effort, since nearshore ocean turbulence varies daily (even diurnally) with variations in winds, waves and currents, and is also highly depth dependent.

Roberts estimates turbulence mortality impacts of a linear diffuser by the following steps:

1. Assuming Kolmogorov turbulence length scales in receiving waters are the same as those found by Walter 8.5 miles away (from Walter et al. 2014) and comparing them

to the estimated size of the Kolmogorov scales in the diffuser jets (from eq. 9 applied to UM3 model results) for the various brine discharge scenarios to establish thresholds for the sizes of marine organisms that will suffer injury or mortality.

2. Estimating the total volumes where turbulence effects may be expected and express it as a fraction of the total volume of the BMZ. This is accomplished using UM3 model predictions of the dilution, distance to impact of the brine plume with the seabed, diameter of the plume at impact, and volume of the plume until impact. The volume of the plume until impact (Table 10, Column 11) is divided by the total volume of the BMZ from eq. (13) to give the volume of the Brine Mixing Zone ("BMZ") that could contain harmful turbulence at Kolmogorov scales.
3. Estimating the fraction of the ambient flow that passes over the diffuser that is entrained, and from this infer the fraction of marine organisms entrained by the diffuser. This is calculated beginning with the entrainment volume flux from eq. (20) using the brine discharge rate multiplied by the Cederwall dilution factor from eq. 3, multiplied by a factor of 1.4 (cf eq. (20) of Roberts 2016). The Cederwall dilution factor at the BMZ is derived in Table 7 column 7 under the assumption of *no ambient current*. The entrainment volume flux thus calculated from the Table 7 dilution factors is then divided by the BMZ flux from eq. (21) assuming the ambient currents are 5 cm/s. The ratio of these two factors (calculated from mutually exclusive assumptions of ambient current) gives the *Fraction of BMZ flux entrained* that appears in Table 10, column 17.
4. Estimating the total numbers of organisms entrained by the diffuser and the number that may be subject to mortality. The total number of organisms entrained is calculated by multiplying the count (from Table 11 column 4 and based on a one-day plankton sampling effort) times the discharge rate, multiplied by the Cederwall dilution factor (from Table 7 column 7), multiplied by a factor of 1.4 (cf eq. (20) of Roberts 2016), multiplied by 3,785.4 m^3/day per mgd to obtain the total numbers of organisms entrained per day in Table 11, column 7. Since the Kolmogorov turbulence length scales of the diffuser jets is less than 1 mm, and mortality is assumed under the Roberts hypothesis to only occur when the organisms are equal to or less than the Kolmogorov scales, the incremental mortality numbers in Table 11 column 8 are obtained by multiplying the only total numbers in column 7 whose size fractions contain a millimeter or less by the fraction of mortality, which is assumed to be 50%. As noted on pg 33 of Roberts (2016): *the fraction of them that actually die is uncertain*. Note, all the entries in column 8 for incremental mortality are exactly ½ the total numbers in column 7; or exactly ½ the percentage of the organism population that is equal to or less than 1 mm (the Kolmogorov scales)

5. Estimating the upper bound for the fraction of entrained organisms subject to mortality equal to: *(Fraction of BMZ flux entrained) x (Fraction of organisms <1mm) x (Fractional mortality)*, where:

   Fraction of BMZ flux entrained = Entrainment Volume / BMZ flux (from Table 10, column 17)
   Fraction of organisms < 1mm is based on the idea that only organism this small are subject to mortality from turbulence (natural Kolmogorov scale near the diffuser is about 1 mm)
   Fractional Mortality = the percentage of organisms <1mm that die as a result of such turbulence (calculation assumes 50% survival, but no basis for this assumption has been provided)

General Comments

There are no direct measurements of turbulence mortality in the bio-engineering literature to support the hypothesis that only those entrained organisms which are comparable to or smaller than Kolmogorov turbulence scales will suffer injury or mortality. Roberts claims on p. 34, "*Experimental evidence suggests that the main turbulence effect is caused by small-scale eddies, known as the Kolmogorov scales…*" However, the literature he cites is his own (Foster et al. 2013), where he re-interprets the experimental literature in terms of dissipation rates that he calculated from idealized relations and subsequently links to Kolmogorov scales. All published measurements of sub-lethal and lethal injury in turbulent flows are reported in terms of the mean velocity, the mean strain rate, or total shear stress. The notion that the small-scale Kolmogorov eddies are somehow more damaging to juvenile fish and ichthyoplankton appears to be based on the fact that most of the dissipation of turbulent energy into heat occurs at the Kolmogorov eddy scales; but it has been incorrectly presumed that strain rates and shear stresses are also largest at these small eddy scales. This confusion arises over the fact that energy and energy dissipation are two different properties of a turbulent flow. Experimental measurements and theoretical work on properties of turbulent flow show that almost all the turbulent energy is concentrated at the large eddy scales of the energy spectra (distribution of energy vs eddy size), see Grant et al. (1962). The structure of the turbulence at these large eddy scales is determined by the mean flow of the jet, $\bar{u}$, which supplies the energy for turbulence formation, and it is the size of these large eddies, l, that control the turbulent diffusion of momentum and the size of the eddy diffusivity $\varepsilon = l^2 \left| \frac{\partial \bar{u}}{\partial r} \right|$, and ultimately the size of shear stress that injures the organisms. On the other hand, the Kolmogorov Hypothesis is based on the small-scale eddies being decoupled from the mean flow, and completely independent of the large energy-containing eddies

(Kolmogorov, 1941). While an energy dissipation spectra (distribution of energy dissipation vs eddy size) may peak at the Kolmogorov eddy scales (Heisenberg 1948; Kovasznay 1948), energy dissipation does not directly injure or kill juvenile fish or ichthyoplankton, because the heat evolved through turbulent energy dissipation causes a negligible change in water temperature, owing to the high heat capacity of water. Finally, juvenile fish or ichthyoplankton entrained into a turbulent jet will simultaneously be exposed to all sizes of turbulent eddies across the energy spectra, and it is impossible to separate the injurious effects of one size of eddy from another. If the Roberts hypothesis were correct, then it leads to some insensible conclusions. Per eq. (9) the Kolmogorov eddy size increases with decreasing velocity. If injury only occurs when the organism is equal to or less than the Kolmogorov scale, then lower velocity diffusers would harm a larger fraction of the ichthyoplankton population. All that is actually known and reported in the bio-engineering literature are injury and mortality statistics relative to the mean flow properties (velocity, strain rate or shear stress) and it is the largest turbulent eddies containing almost all the turbulent energy that determine the turbulent shear stress. The most comprehensive such study in the bio-engineering literature is Nietzel et al. (2004) who related lethal and sub-lethal injury to the mean strain rates in prototype scale diffuser jets under laboratory-controlled conditions involving 10 cm juvenile salmon in a flume at the Pacific Northwest National Laboratory. If the Roberts hypothesis were valid, these juveniles would have suffered no injury. Instead injuries such as ruptured eye balls and gills were reported.

Specific Comments

1. Equation (20) is dimensionally incorrect. It is stated that eq. (20) represents, "*total volume entrained into the jets*", but the left-hand side of eq. (20) has units of volume/time. Equation (20) actually represents volume flux.
2. The calculation *Fraction of BMZ flux entrained* = Entrainment Volume / BMZ flux (from Table 10, column 17) involves mutually exclusive assumptions. The entrained volume is calculated from a dilution factor based on zero ambient current. The BMZ flux is calculated from an assumption that the ambient current is not zero, but equal to 5 cm/s.
3. The calculation of upper bound of the incremental turbulence mortality impact using the un-numbered equation on p. 33 produces a division by zero (singularity) for zero ambient currents. The un-numbered equation on p. 33 is based on eq. (21) which converges to zero for zero mean current, resulting in the division by zero singularity. Equation 21 is fundamentally corrupted because it neglects the volume flux into the BMZ by the diffuser-induced entrainment flows, which must occur in order to produce dilution within the BMZ volume. (Note, new fluid must continually enter the BMZ to produce dilution of a continuous discharge). If this term were added to eq. (21), then the un-numbered equation on p. 33 for the fraction of entrained organisms passing

over the diffuser would not converge to infinity for zero ambient currents; but rather converge to 1.0. This in turn, would produce a result for the upper bound of the incremental turbulence mortality impact at zero ambient current that is the same as the incremental mortality numbers in Table 11 column 8 (or exactly ½ of the total number of organisms less than or equal to 1mm in size), where the Table 11 numbers are based on dilution factors at zero current.

4. The flux plane in eq. (21) is also formulated incorrectly. The BMZ volume as represented by eq. (13) is a rectangular volume 1024 ft X 656 ft. X 104 ft with two half cylinders of radius 328 ft. attached to both ends. Therefore, the flux plane is actually $(L+w)H$ not $(L+2w)H$.
5. There appears to be quite a bit of obscuration over the value of the dilution factor. Table 7 lists dilution factors from both the UM3 model and the Cederwall algorithm and then Table 10 lists the UM3 dilution factor but does not use that value to calculate the Fraction of BMZ flux entrained in column 17 of Table 10. Instead, column 17 is calculated from the Cederwall value in Table 7 after multiplying it by a factor of 1.4 to calculate the Fraction of BMZ flux entrained in the last column of Table 10. Since all the turbulence mortality calculations are normalized to the BMZ volume, then the average dilution at the BMZ is simply known from conservation of mass, and from the definition of terms in the OPA, which states dilution is:

$$Dm = \frac{S_b(x=0) - S_b(x=BMZ)}{S_b(x=BMZ) - S_o}$$

Where $S_b(x=0)$ is the brine salinity at the point of discharge; $S_b(x=BMZ)$ is the brine salinity at the BMZ and S_0 is the ambient ocean salinity.

Review of Codified Language Supporting the 23% Calculation Approach

The SLC is interested in developing the most robust record of analysis to illustrate that all means to evaluate potential environmental impacts to state-owned land and associated biota have been applied. Further, Poseidon understands that the SLC's California Environmental Quality Act (CEQA) assessment does not limit staff from investigating alternative turbulence mortality calculation methodologies when those models may provide new or better information. However, the inherent assumption that each alternative calculation method has undergone the same magnitude of peer review and vetting is not met for this new calculation method. Rather, the calculation method described in Roberts (2016) was part of a proposed project-specific submittal for a proposed seawater desalination project in Monterey Bay that has not completed the CEQA process nor demonstrated compliance with the OPA. As such, without a similar level of peer review and public vetting, applying this alternative calculation method to the HBDP is inappropriate. Instead, it is more defensible to use the existing guidance in the SED on how to calculate turbulence mortality as it has undergone independent review by multiple subject matter experts.

The OPA and SED were developed in a very thoughtful, inclusive, and comprehensive manner as evidenced by this excerpt from the executive summary of the SED:

> *The process to develop the Desalination Amendment was assisted by the formation of expert review panels, an interagency workgroup, and extensive stakeholder outreach that provided the State Water Board with many concepts and recommendations to consider in the development of the proposed amendment.* (SWRCB 2015, pg 11-12)

Similarly, the SED underscores the importance of a comprehensive peer review process when new science-based rules are developed:

> *In 1997, section 57004 was added to the California Health and Safety Code (Senate Bill 1320-Sher) which requires external scientific peer review of the scientific basis for any rule proposed by any board, office or department within Cal/EPA. Scientific peer review is a mechanism for ensuring that regulatory decisions and initiatives are based on sound science. Scientific peer review also helps strengthen regulatory activities, establishes credibility with stakeholders, and ensures that public resources are managed effectively. The scientific and technical information supporting Desalination Amendment underwent external scientific peer review in June of 2014 by the following reviewers….* (SWRCB 2015, pg 31)

Development of the OPA and SED took approximately eight years, beginning on June 26, 2007 with a scoping meeting and ending with the adoption of the OPA and SED on May 6, 2015. Since the adoption of the OPA and SED two years ago, these documents have formed the basis around which desalination project proponents have developed compliance strategies. As such, Poseidon used the guidance provided in the SED to develop a compliance plan to ensure implementation of the best available site, design, technology, and mitigation measures feasible to minimize the intake and mortality of all forms of marine life. Relative to estimating turbulence mortality at the diffuser, Poseidon relied on the guidance provided in section 8.5.1.2 of the SED (with the reasonable expectation that the guidance would be relied on to make a regulatory determination):

> *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*. (SWRCB 2015, pg 85-86)

This assumption of 23% was derived from the October 9, 2013 ERP report titled "*Desalination Plant Entrainment Impacts and Mitigation*" (Foster et al. 2013). The analysis provided by Roberts and Mead-Vetter (2013) in Appendix 1 to this report clearly provides this conclusion:

> *Therefore, the volume of water that is entrained for dilution that is subject to relatively high turbulence intensities and shear stresses is about 23 to 38% of the total entrained volume.* (Roberts and Mead-Vetter 2013 [Appendix 1, pg iii] in Foster et al. 2013)

The SED subsequently incorporated the lower percentage (23%) as follows:

> *Foster et al. (2013) modeled shearing stress from multiport diffusers and reported that larvae in 23 percent of the total entrained volume of dilution water may be exposed to lethal turbulence for 10 to 50 seconds.* (SWRCB 2015, pg 85)

Based on the information from Foster et al. (2013) and Roberts and Mead-Vetter (2013) and its subsequent incorporation into the SED at section 8.5.1.2, the use of 23% of the total entrained dilution flow is appropriate for calculating turbulence mortality at the diffuser. Furthermore, since no new "*empirical data showing the level of mortality caused by multiport diffusers*" (SWRCB 2015, pg 85) are presented, the use of an alternative calculation method is unsupported per the SED language.

The calculation method proposed by Roberts (2016) has yet to undergo the thoughtful, inclusive, and comprehensive peer review process that all the supporting documentation did during the development of the OPA and SED. As a matter of policy and permitting streamlining, therefore, the prevailing regulatory guidance is that which has been comprehensively peer reviewed and ultimately codified in the SED; no other calculations are warranted until such time as new empirical data become available and are peer-reviewed.

Lastly, the calculation method proposed by Roberts (2016) conflicts fundamentally with the calculation method proposed by Roberts and Mead-Vetter (2013) in Appendix 1 of Foster et al. (2013). Though much of the hydraulic theory presented is common to both reports by Dr. Roberts, there is an inherent conflict in using the same hydraulic theory to derive two different calculation methods. As a matter of policy, Poseidon used the Roberts-derived calculation method codified in the SED and, more specifically, followed the example calculation provided on page 85 of the SED.

Conclusions

The efficacy of the turbulence mortality mechanism put forth in Section 6 of Roberts (2016) is questionable, and the calculus presented for estimating turbulence mortality impacts is based on mutually exclusive assumptions compounded by several formulation errors and unsupported survival assumptions. Hence, there appears to be no foundation for substituting this methodology for the turbulence mortality assessment guidance in the SED document of the OPA.

The Roberts calculation method represents an unvetted, project-specific alternative calculation approach using the same information that was available during the development of the SED and OPA, but only to arrive at a different answer. It does not present the type of "additional data" contemplated in the SED as being necessary to justify an update of the Ocean Plan.

References

Foster, M.S., G.M. Cailliet, J. Callaway, K. Mead-Vetter, P. Raimondi, and P.J.W. Roberts. 2013. Desalination Plant Entrainment Impacts and Mitigation. Expert Review Panel III. **http://www.swrcb.ca.gov/water_issues/programs/ocean/desalination/docs/erp_final.pdf**

Grant, G.H., R.W. Stewart, and A. Moilliet. 1962. Turbulence Spectra from a Tidal Channel. *Journal of Fluid Mech*anics 12:241-268.

Heisenberg, W. 1948. *Proc. Roy. Soc*. A., vol.195, no 402.

Kolmogorov, A.N. 1941. *C.R. Acad. Sci., USSR*., vol 30, no. 301.

Kovasznay, L.S.G. 1948. *J. Aero. Soc*., vol.15, no. 745.

Neitzel, D.A., D.D. Dauble , G.F. Cada , M.C. Richmond, G.R. Guensch, R.P. Mueller, C.S. Abernethy, and B. Amidan. 2004. Survival Estimates for Juvenile Fish Subjected to a Laboratory-Generated Shear Environment. *Transactions of the American Fisheries Society* 133: 447-454. DOI: 10.1577/02-021.

Raimondi, P. 2017. Procedure for Calculating Discharge Entrainment Volume Having Turbulent Intensity Sufficient to Cause Planktonic Mortality. Prepared for CA State Lands Commission.

Roberts, P.J.W. and K. Mead-Vetter. 2013. The Effects of Turbulence and Turbidity Due to Brine Diffusers on Larval Mortality: A Review. Appendix 1 to Foster et al. 2013. Prepared for the State Water Resources Control Board, Sacramento, CA.

Roberts, P.J.W. 2016. Modeling Brine Disposal into Monterey Bay. Prepared for ESA Environmental Science Associates, San Francisco, CA. July 6, 2016. 62 pp.

SWRCB (State Water Resources Control Board). 2015. Final Staff Report Including the Final Substitute Environmental Documentation, Amendment to the Water Quality Control

Plan For Ocean Waters of California, Addressing Desalination Facility Intakes, Brine Discharges, and the Incorporation of other Non-Substantive Changes. May 6, 2015.

Walter, R.K., M.E. Squibb, C.B. Woodson, J.R. Koseff, and S.G. Monismith. 2014. Stratified Turbulence in the Nearshore Coastal Ocean: Dynamics and Evolution in the Presence of Internal Bores. *Journal of Geophysical Research: Oceans* 119(12): 8709-8730. 10.1002/2014jc010396