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Review of the scientific conclusions and the proposed desalination amendment to the Water Quality Control Plan for Ocean Waters of California

Summary

The starting point for this review are the conclusions in the "Description of Scientific Conclusions to be Addressed by Peer Reviewers," which are:

> *1. A receiving water salinity limit of two parts per thousand (ppt) above natural background salinity is protective of marine communities and beneficial uses.*
>
> *2. A subsurface seawater intake will minimize impingement and entrainment of marine life.*
>
> *3. A 0.5 mm, 0.75 mm, 1.0 mm, or other slot sized screens installed on surface water intake pipes reduces entrainment.*
>
> *4. Multiport diffusers and commingling brine with other effluents can dilute brine discharge and provide protection to aquatic life.*
>
> *5. The Area Production Forgone (APF) method using an Empirical Transport Model (ETM) can effectively calculate the mitigation area for a facility's intakes.*

I have reviewed these as commensurate with my expertise. I have significant concerns over the validity of Conclusion 1 due to far field effects on dissolved oxygen with a negatively-buoyant plume. I believe Conclusion 1 needs to be reconsidered and its implementation in the WQCP requires significant revision. Conclusion 2 is true and does not engender any significant comments. Conclusion 3 is true, but it is not clear that specifying a mesh size is the best approach for regulation in an area that is still undergoing technological advances – particularly since the mesh has consequences for energy costs. It might be better to specify required maximum entrainment limits and a test system for new technologies. Conclusion 4 is well-founded, but its implementation in the WQCP raises some concerns for comingling systems that are not well balanced or when the comingling water is shut down. The concerns raised in Conclusion 1 apply to Conclusion 4 to the extent that a negatively-buoyant plume is developed. I do not have the expertise to make any comments on Conclusion 5. Specific details are provided in the sections below.

Comments on Conclusion 1 and its implementation in the WQCP

My opinion

Conclusion 1, as written – "two parts per thousand (ppt) above natural background salinity *is* protective" – is not supported by the state-of-the-science, which merely indicates 2 ppt *might* be adequate for *some* brine discharges. Comprehensive in situ experiments to analyze benthic ecosystem functioning under a weak far-field salinity plume have not been conducted. Because such a plume can cause reduction in dissolved oxygen (DO) levels, the present state-of-the-science cannot support a clear near-field salinity limit that is protective in any absolute sense. Furthermore, the proposed changes to the Water Quality Control Plan (WQCP) reflect the *assumption* that 2 ppt is protective, which could allow brine discharges to cause significant ecological harm. Finally, the monitoring required in the WQCP is inadequate to detect some forms of ecological harm in the far field.

Overview of problems

Conclusion 1 is too broadly stated, and as such is simply is not supported by the present state-of-the-science or by the Jenkins et al (2012) report of the Science Advisory Panel on Management of Brine Discharges to Coastal Waters. Indeed, Jenkins et al (2012) does not make the sweeping statement that such a limit "is protective," but instead provides a number of caveats as to the design and placement of discharges that is necessary for protection. Their conclusion would be better condensed as

> *A receiving water salinity limit of two parts per thousand (ppt) above natural background salinity should be protective of marine communities and beneficial uses for a well-designed and well-placed brine discharge.*

The differences between the statement "is protective" and the caveats above are important because: (1) California often plays the role of first regulator or as an exemplar for critical environmental issues, and a broad misstatement of what is protective could have long-term consequences throughout the nation and the world; (2) the proposed changes to the California WQCP should specifically address the caveats in the design and siting of the brine discharge rather than assuming that 2 ppt is protective for all cases.

Changing Conclusion 1 to reflect the caveats discussed in Jenkins et al (2012) will require rethinking the approach for approval and monitoring of negatively-buoyant brine discharges. Whether or not a brine plume can cause hypoxia at the sediment-water interface in the plume far field should be evaluated in brine disposal design, siting, and monitoring program.

Elaboration: Is 2 ppt proven protective? Why not?

From an engineering standpoint, the 2 ppt threshold seems both reasonable and achievable. From a laboratory standpoint, the 2 ppt threshold appears to prevent sever toxic effects of salinity. However, convincing field monitoring of existing brine discharges to prove a 2 ppt threshold "is protective" simply do not exist. Jenkins et al (2012) *recommends* the use of 5% of natural salinity variation – or about 1.7 ppt for coastal water – based on a thorough review of the state-of-the-science. However, they note that the state-of-the-science is actually rather sketchy and incomplete. The best that can be said is that *a 2 ppt threshold appears satisfactory from a toxicity viewpoint, but that cannot be taken to imply a threshold that is protective of an ecosystem*. The underlying problem is that salinity, unlike low-concentration dissolved toxics (such as metals), affects the local flow field by stratification, which reduces mixing and can lead to reduced dissolved oxygen (DO) levels in the benthic layer, with the follow on effect of stressing the ecosystem. Thus, the regulatory methods that are typically used to evaluate effects of dissolved toxics must be supplemented by approaches that consider the physical salinity effects on the local flow field and stratification, as well as how stratification and sediment oxygen demand (SOD) affect the dissolved oxygen (DO) levels in the plume. A simple salinity standard without an additional DO or mixing rate standard for negatively buoyant plumes cannot be considered protective. It should be noted that DO problems have not been observed in existing brine discharges, but this appears to be because DO has not been routinely monitored in the far field plume where problems might occur. That is, DO will not likely be a problem in the near field or regulatory mixing zone where monitoring is typically undertaken. Furthermore, unlike positively buoyant wastewater discharges, negatively buoyant brine discharges have not been well studied, and the State of California should carefully consider the relative paucity of existing research in revising the WQCP so that approvals do not move ahead of the state-of-the-science.

What happens to dense plumes beyond the regulatory mixing zone?

Negatively buoyant brine plumes outside the regulatory-defined mixing zone cannot be assumed to simply disappear without consequences. The assumption that the regulatory mixing zone approach is adequate appears to be a hold-over from prior regulation of positively-buoyant plumes. Note that Jenkins et al (2012) goes to some length to explain the effects of negatively buoyant plumes and considerations that should be included in the regulatory scheme. It does not appear that their concerns were adequately implemented in the WQCP.

The key difference between a positively buoyant plume at the surface and a negatively buoyant plume at the bottom is that the former is subject to strong mixing energetics from wind and breaking waves, where the latter only mixes due to its own movement down the slope. These differences are reflected in concept of "entrainment." Active turbulence within the plume itself will entrain ambient water, hence diluting the difference between the plume and ambient. With this dilution, DO from the ambient water is mixed with the plume water. For buoyant surface plumes, the active turbulence from wind and waves ensures rapid entrainment of the ambient and DO replenishment. In contrast, a dense brine plume has only its bottom-generated (shear) turbulence to entrain ambient water, so its dilution rate and DO resupply rate are much smaller. Furthermore, to the extent that the plume does have entrainment and mixing, this slows the plume and weakens the entrainment rate. Note that turbulence from the ambient acts as detrainment – reducing the plume thickness – but has minor impact on entrainment into a plume. That is, detrainment to the ambient slowly makes the plume thinner, but does not dilute the plume and hence does not resupply DO through the plume to the sediments.

An example might make this issue clearer. For a dense brine plume, the entrainment rate is a function of the slope and the salinity difference (e.g. Dallimore et al 2001, Bo Pedersen 1986). For slopes on the order of 10^{-3} to 10^{-4} with small salinity differences the entrainment rate can expected to be on the order of 10^{-4} to 10^{-5}. Using the Dallimore et al (2001) approach, 1000 m downstream from the 2 ppt threshold point in a plume of 1 m thickness the salinity for a steeper slope (10^{-3}) would be expected to be near ambient – i.e. complete mixing (the plume has fully entrained the ambient); but the less steep slope

(10^{-4}) would only see the salinity increment reduced by about 10% (0.2 ppt). It follows that the length scale for full mixing of the plume on a 10^{-4} slope is on the order of 10 km. For plume velocities on the order 0.01 to 0.1 m/s, the implied transit time from the 2 ppt threshold to the edge of the plume is 1 to 10 days. During that transit time, if the sediment oxygen demand (SOD) is greater than the DO replenishment rate due to entrainment, the plume will slowly lose DO, which can result in hypoxia in the far field of the plume. Jenkins et al (2012) discusses these effects and refers the reader to Hodges et al (2011) for further details. Note that close to the regulatory mixing point, with the strongest stratification of the plume, there will actually be higher DO levels than where the plume stratification is weaker but the transit time is longer. Thus, modeling and monitoring to the regulatory mixing point is insufficient. Some combination of modeling and monitoring of far field conditions is necessary to predict and ensure that far field hypoxia is not an issue for negatively buoyant plumes.

Because of the general characteristics of flow along the California coastline, it is likely the most desalination plants will not have any trouble preventing development of hypoxia in the far field plume. However, there are likely to be locations where a poorly sited or poorly designed discharge could result in an extensive hypoxic far field. Because the science on this issue is relatively new, it is recommended that California take the lead on developing regulatory modeling and monitoring strategies that address this issue.

Implementation of discharge standards in 2014 Ocean WQCP

The Jenkins et al (2012) report outlined a 3-pronged approach to regulation (see their Chapter 7) that separately addresses the surf zone, inner shelf, and deep water disposal. These distinctions were not implemented in the WQCP. Recommend the State reconsider this issue and revise the WQCP to implement the strategies of Jenkins et al (2012). In particular, deposition in the surf zone might have less stringent considerations for negatively buoyant plumes due to the strong mixing action of breaking waves that can influence bottom mixing in shallow water. Specific rules for modeling and monitoring in the WQCP should take into account the differences between these zones.

Comments on the WQCP by section

II.A.3. – Compliance requires only sampling within the initial dilution field, which neglects far field effects of salinity stratification on DO.

II.C and II.D. – Chemical characteristics for DO (II.D.1) are focused only on oxygen demand within the waste (which is negligible for brine), and there is no consideration of the reduction of DO due to combination of physics of stratification and mixing (arguably part of II.C) and the interaction with SOD (arguably part of II.D).

II.D.7. b. – Table 1. There is no water quality objective for minimum DO (or maximum DO deficit) in the far field plume.

III.A.2.– Recommend a general provision that "Waste discharged to the ocean must not result in sustained low dissolved oxygen conditions" with additional definitions for the maximum allowable time interval for low DO and the minimum allowable low DO limit. Benthic ecologists should be consulted to set these values. To preserve the meaning of "above a water quality limit" elsewhere in the plan, it may be necessary to write a regulatory limit for a DO deficit (i.e. the excursion below a natural level that cannot be exceeded).

III.L.2.a.(2) and elsewhere – The phrase “to minimize intake and mortality,” which is used in a number of places, is troublesome and potentially limiting when considering the potential stressor effects of chronic low DO on the benthos, which can result from a negatively buoyant brine discharge. Such effects may not be directly attributable to increased mortality, but can have a significant impact on the overall health, sustainability, and habitat suitability of an ecosystem. Recommend consulting a benthic ecologist on an improved way to write a general statement of the regulatory purpose.

III.L.2.c.(4) – This section appears to require a positively-buoyant plume, however this requirement is at odds with allowing a 2 ppt increase in salinity. A 2 ppt increase in salinity will result in a dense negatively-buoyant plume. Recommend rewriting this section with something like “Design the outfall such that negatively buoyant plumes do not result in DO deficit levels below the Table 1 standard in the plume far field.” There will be a need to define a regulatory far field condition and provide a DO deficit standard as noted for comments on II.D.7.b and III.A.2 above.

III.L.2.c.(4) – Using anoxia (zero oxygen) as a limiting condition is not protective of the marine ecosystem. Sustained hypoxia (low oxygen) is known to be detrimental and can be consequence of only a weak negatively buoyant plume.

III.L.2.d.(2) – Recommend a subparagraph specifically addressing far-field DO considerations for brine discharge technology

III.L.2.d.(2)(b) – The requirement that multiport diffusers “be engineered to maximize dilution and minimize the brine mixing zone” are inherently at odds. The diffusers cannot significantly change the overall flux rate associated with the ocean water moving through the brine mixing zone, therefore maximizing dilution inherently requires maximizing the size of the brine mixing zone for a given throughput of ambient water. Recommend that this requirement simply be stated that multiport diffusers be designed to maximize the near-field dilution.

III.L.2.e.(1) – The Marine Life Mortality Report does not require a report on far-field effects of salinities, which may be less than 2 ppt but still cause stratification, reduced mixing, low benthic DO, and habitat loss. The areas impacted, and the time scales/conditions under which such impacts occur during operation should be reported. This issue is critical because subparagraph III.L.2.e(3)(b).iii only requires mitigation for mortality that is reported in the Marine Life Mortality Report. It is possible that the impact area of low DO is much larger than the regulatory mixing zone.

III.L.3.b. – Recommend that the receiving water limitation for salinity should be rewritten as the lower of 2 ppt or a salinity increment that maintains the far field DO deficit above the regulatory criteria of Table 1 (see comments on on II.D.7.b and III.A.2 and III.L.2.c.(4) above).

III.L.3.c – The alternative salinity receiving water limitation needs to be rewritten to include far field DO considerations. The present wording is focused only on the toxicity of salinity and not on its impact on stratification and benthic DO.

III.L.4 – Monitoring programs should be modified to specifically include far field monitoring for salinity, temperature, and DO.

Comments on Conclusion 2 and its implementation in the WQCP

I have reviewed the standards and scientific justifications for the subsurface seawater intakes. Although this is not my specific research area, I have a general expertise in environmental fluid mechanics that allows me to judge the physical basis of the conclusions (albeit not the marine life aspects).

To be pedantic, the statement in Conclusion 2 that “subsurface seawater intakes will minimize impingement and entrainment of marine life,” is not precisely correct. It would be better to state that such methods will *reduce* impingement and entrainment relative to surface intakes. It is not clear that science supports these as the “minimum.”

I cannot find any problems with either the scientific basis for requiring subsurface seawater intakes or the implementation program in the proposed regulations.

Comments on Conclusion 3 and its implementation in the WQCP

I have reviewed the standards and scientific justifications for the specification of screen sizes. Although this is not my specific research area, I have a general expertise in environmental fluid mechanics that allows me to judge the physical basis of the conclusions (albeit not the marine life aspects).

Although Conclusion 3 is well-founded, there is an open question as to whether 0.5 mm, 0.75 mm, 1.0 mm, or other slot sized should be specified for surface water intake pipes to reduce entrainment of marine life. I have not been able to reach a clear conclusion myself from reading the background literature. However, it is not clear to me that specifying a fixed mesh is necessarily the best regulatory approach. The mesh size affects energy use, and hence costs, and there are clearly a wide variety of different methods that are both feasible and effective. I support the regulations, III.L.2.d.(1)(c)iii, that allow the owner/operator to select equivalent alternative technologies that have the same benefit. It would likely be beneficial to develop a specific set of standards for entrainment that are not linked to a mesh size; that is, rather than comparing an alternative to the performance of a given mesh, all system should be compared to a desired set of entrainment limits. By setting regulations based on clear limits rather than mesh size, the state will remove the difficulty of determining what is “equivalent” to the specified mesh.

Comments on Conclusion 4 and its implementation in the WQCP

I have reviewed the standards and scientific justifications for the conclusion that multiport diffusers and comingling are effective at diluting the brine discharge and hence provide protection for aquatic life. This conclusion is correct, with the caveats discussed associated with Conclusion 1 – i.e. residual density anomalies resulting in a negatively buoyant plume may still cause harm in the far field, even though immediate toxic effects in the near field are ameliorated.

The implementation of these ideas in III.L.2.d.(2)(a) could be made clearer. The assumption inherent in the comingling strategy is that the wastewater (low salinity) mixing with the brine (high salinity) results in a positively-buoyant discharge; i.e. the resulting salinity is *always* less than ambient. However, this result will actually depend on the volume flow rates of brine and the comingled source. Where comingling does not always produce a positively buoyant plume, then multiport diffusers will necessarily be required. Recommend this section of the regulations be rewritten so that the preferred technology is comingling with a sufficient flow rate to provide a positively-buoyant plume under all desalination plant operating conditions. This regulation would imply that a shut down of the comingled water source requires shut down of the desalination plant.

Comments on Conclusion 5

I do not have the expertise to provide any comments on the effectiveness of ETM/APF models