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Dear Dr. Lundborg:

Thank you for asking me to review the draft North Coast RWQCB dissolved oxygen guidelines. When reviewing these guidelines I carefully read all of the material directly supplied as well as the Washington and Oregon State dissolved oxygen guidelines (ODEQ 1995, WDOE 2002). I placed less emphasis on the USEPA (1986) guidelines because these were more than 20 years old. I also read two journal articles on this topic (Greig et al. 2007, Jensen et al. 2009).

It is my general opinion that the current draft guidelines of the North Coast RWQCB dissolved oxygen standard still need some important revisions before they are complete. I would advise basing these guidelines on the strengths of the corresponding Oregon and Washington State guidelines. Presumably these two states have a larger staff and more resources at their disposal than does the North Coast RWQCB. I don't necessarily advocate directly adopting the standards of either of these states, but the arguments put forth in their guidelines were more thoroughly researched, vetted and explained than those put forth in this document. I see no reason why the RWQCB personnel in the North Coast region should not "cherry-pick" the best of these two reports to compile their own standards. Similarly, I will note that on page 53 of the material provided to me, the draft guidelines state *"one of the most simple and straightforward elements of the revision is to update the life cycle DO objectives based on the recommendations in USEPA (1986)"*. As I point out above, I think it would make more sense to model revisions after the ODEQ (1995) and WDOE (2002) guidelines.

Some aspects of the draft guidelines were over-explained and others required more detail. According to any environmental chemistry textbook, the oxygen concentrations when saturated can be described by Henry's Gas Law as a function of the solubility of O_2 in water and the partial pressure of oxygen in the atmosphere. In natural systems, the solubility of oxygen in water is strongly inversely related to temperature and the partial pressure of oxygen declines sharply as elevation increases. Oxygen concentrations in water can be reduced to well below saturated levels by bacterial decomposition of allochthonous organic material. Alternatively, this biochemical oxygen demand can be driven by excess plant production due to eutrophication, and subsequent bacterial degradation of autochthonous organic matter. Therefore, the external supply of both anthropogenic organic matter and nutrients can lead to oxygen stress in rivers and lakes. The health of nearly all aquatic animals is related to oxygen availability. The problem of acquiring sufficient oxygen is compounded by the fact that the physiological demands of aquatic fauna for oxygen increase dramatically as temperatures (and metabolic activity) increase. These points are of a "textbook" nature, and should for that reason be briefly summarized in the North Coast RWQCB dissolved oxygen guidelines.

The specific oxygen requirements of aquatic animals, and salmonids in particular, is the subject of a specialized mostly journal article literature. However, this literature as it relates to salmonid ecology is very thoroughly summarized in ODEQ (1995), WDOE (2002), Greig et al. (2007), and Jensen et al. (2009). For this reason, I do not think it is warranted to summarize the salmonid oxygen requirements literature *de novo*. This can be done much more succinctly by summarizing the key points of the four review studies indicated above.

In general, I am also concerned that most of the literature cited in support of the North Coast RWQCB dissolved oxygen guidelines is quite old. For example, the average paper on the DO requirements of salmonids cited in Carter (2005) was published more than 30 years ago (i.e 1974 ± 14 years). The salmonid requirements papers cited in the draft guidelines were just as old. Overall, nearly all of the archival studies cited on this topic were at least 20 years old. This would be fine if the aquatic ecology research community stopped studying this topic two decades ago, but this is not the case. I spent a short time searching in the Web of Science, and in addition to recent review papers previously mentioned, I found eleven studies published on the importance of intragravel DO for salmonids since the most recent paper cited in the North Coast RWQCB dissolved oxygen guidelines (i.e. Greig et al. 2007, Dumas et al. 2007, Heywood and Walling 2007, Malcolm et al. 2005, Merz and Setka 2004, Youngson et al. 2004, Meyer 2003, Soulsby et al. 2001, Geist 2000, Curry et al. 1995, Deverall et al. 1993). Perhaps the personnel who prepared the DO guidelines lack access to a modern research library system that subscribes to all of the relevant journals. But even if this is the case, this problem needs to be rectified. At the very least, the folks in the North Coast RWQCB could pay one of Peter Moyle's graduate students to spend 2-3 days compiling a relevant database of journal articles for them. As I noted above, I don't think it is necessary for these guidelines to have an exhaustive review of the salmonid DO requirement literature, but much has been learned about salmonid IGDO related issues during the last decade and this new literature should be reflected in the draft guidelines.

In your cover letter to me, you also asked me to specifically address several specific issues including: 1) the scientific basis for the 3 mg/L IGDO correction factor, 2) whether background DO conditions could be approximated by 90 or 85% saturation, 3) general procedures for estimating "natural temperatures", and 4) general procedures for determining if natural conditions prevent attainment of life cycle based DO objectives. I will address each of these points, and several others below.

1) InterGravel Dissolved Oxygen (IGDO)

I was asked to comment on "whether current science supports the use of a 3 mg/L correction factor to translate" the IGDO requirements to ambient DO objectives. I am concerned that a blanket 3 mg/L correction factor will be overly protective in many cases, and <u>under protective</u> in the more important cases where IGDO availability really is a problem (for example if fine sediment loading is excessive). This 3 mg/L safety factor is apparently based a 1965 Masters Thesis from Oregon State University via the 1986 USEPA DO guidelines. I find this rationale problematic since a great deal of research has been done on this topic in the intervening 44 years. For example, two excellent comprehensive review papers have been recently written on this topic (Greig et al. 2007, Jensen et al. 2009).

From the literature it is clear that a myriad of factors influence the difference between IGDO and water column DO concentrations, the most important being the presence of fine sediments (and the organic content of these sediments) in the interstitial spaces of the gravel. Based on these reviews I suggest that instead of selecting a fixed safety factor to protect IGDO concentrations, which might be overly protective in some cases and under-protective in others, that a safety factor be determined on the basis of the fine sediment content of the spawning habitat in a particular river. In particular, I think this safety factor should be determined as a function of anthropogenically derived fine sediments. An IGDO safety factor based on the presence and characteristics of anthropogenically derived sediments would be a much more scientifically based and protective approach to this particular problem. In general, North Coast RWQCB could adopt a 2 mg/L safety factor across the board, and much more stringent safety factors when anthropogenic fine sediments are a concern. By basing these guidelines primarily on fine sediments, it is will also make it much more likely that the root cause of large differences between water column DO and IGDO concentrations will be addressed. In general, I found the discussion of the IGDO issue had a weak scientific basis in the draft DO guidelines. In contrast, both the Oregon and Washington guidelines had more rigorous discussions of this topic. I think this aspect of the draft guidelines needs to be considerably updated and rethought in lieu of the modern literature (e.g., Greig et al. 2007, Jensen et al. 2009).

2) Background DO conditions ≈ 90 or 85% saturation?

On page 40 of the material supplied to me, the text states *"Figure 3 indicates staff's **rough estimate** of the minimum DO concentrations that occurs as a result of natural fluctuations in DO concentrations resulting from photosynthesis, respiration, turbulence, and biological and chemical oxidation"*. However, this figure is merely the theoretical DO concentration at 85% saturation for a range of temperatures and elevations, so the "evidence" that background DO conditions can be approximated by 85% saturation is tautological. In my opinion, the draft guidelines do not present scientifically based evidence that the background DO levels can be approximated by 85 or 90% saturation. This evidence should be derived from actual data showing the distribution of DO saturation values typically observed during unperturbed natural conditions. I suggest the 5^{th} or 10^{th} percentile of these natural percent DO saturation distributions be used to represent minimum background DO levels. If this is done, it should be acknowledged in the new guidelines that by definition these minimum background levels will be violated with some regularity even in natural systems. But the value in these "minimum standards" will manifest itself in cases where it is clear these minimal DO saturations levels are being missed significantly more often than expected based on "natural conditions". For example, if the minimum standard for percent DO saturation is set to the 5^{th} percentile for undisturbed systems, and this minimum standard is violated significantly more often than 5% of the time in a system that is suspected to be impaired there would be unequivocal evidence of actual impaired beneficial use.

I will also point out that I suspect the "background DO objectives" presented in Table 2 (page 39) of the material provided to me, are also based on "rough estimates" and should be based on more rigorous data in cases where impairment might be a concern. Ideally, comprehensive datasets documenting "natural conditions" would be obtained prior to any signs of incipient impairment.

3) Procedures for estimating "natural temperatures"
The write up on pages 55-57 of the draft guidelines describing how "natural temperatures" might be estimated at a disturbed site were well thought out and scientifically based.

4) Non-Attainment Due to Natural Causes
The problem of non-attainment due to natural conditions needs to be strengthened considerably in the draft DO guidelines. As is extensively discussed in the Oregon and Washington DO guidelines and alluded in the North Coast region draft guidelines, in some cases it may be impossible to meet DO objectives for purely natural reasons. How will anthropogenic loading that negatively affects DO concentrations be managed in systems that are in non-attainment for natural reasons? This needs to be given careful consideration because in cases like this an absolute "no impact" standard will result in unreasonable outcomes. For example, if the standard is no impact, even recreational use (which could theoretically damage riparian vegetation or increase sediment and nutrient loading somewhat) would be excluded. The States of Oregon and Washington have dealt with this problem by setting the lowest allowable impact at 0.2 mg/L below saturation. In my opinion, this seems like a very reasonable approach and should be directly adopted by the North Coast RWQCB.

The personnel of the North Coast RWQCB should make a more concerted effort to define natural DO levels in the most important aquatic habitats of this region, in particular systems that are anthropogenically degraded or are naturally sensitive to DO stress. In several places in the draft guidelines, rationalizations were made for why this had not been done in the past. For example, an insufficient availability of DO sondes was alluded to several times. These explanations are not justifiable in the opinion of this reviewer. Surely considerable DO data has been archived during the last several decades and an effort should be made to extract the distribution of natural saturation levels from these data. In some cases, more DO data will be necessary to establish estimates of natural conditions for specific systems and this additional data should be collected when necessary. As previously noted, I am of the strong opinion that "natural conditions", as measured by typical percent DO saturation distributions for undisturbed waterbodies, should take precedence when establishing DO objectives for systems that are suspected to be impaired. Natural DO conditions should be established for a representative, but moderately small, number of field sites within the region that are known to be minimally impaired at presented. From these field studies of undisturbed systems, distributions of naturally occurring percent DO saturation levels could be established. These distributions could then be applied throughout the region.

Stream Classification System

I found the Washington State approach of classifying streams according to their "type of use" and level of protection for aquatic biota to be compelling model. Each waterbody in the North Coast region should be classified into one of the categories specified below and the DO in these systems managed accordingly. The RWQCB should be explicit as regards its intended beneficial uses for every major waterbody within the region, as well as all smaller waterbodies that support salmon and steelhead. In the current draft, it is unclear which types of waterbodies these standards are intended for, and as near as I could tell there was no mention of lakes whatsoever. This is problematic, as the types of DO standards that are most appropriate will depend greatly on the types of fish that are known or thought to naturally occur in these systems. The DO guidelines need to more clearly state which types of waterbodies will be held to what DO standards.

For example, I suggest these categories for the North Coast region:

Critical habitat: aquatic habitats containing endangered or threatened aquatic fauna with high DO requirements.

Salmon spawning habitat: important anadromous salmon spawning habitat.

Salmon rearing habitat: important anadromous salmon rearing habitat.

Cool water fish habitat: habitat for native non-salmonid fish that also require high oxygen conditions.

Warm water fish habitat: habitat for native and introduced warm water fish.

Lake habitat for salmonids: lakes that have anadromous or resident salmonid populations.

Lake habitat for warm water fish: lakes that do not naturally contain salmonids or native cool water fish.

Estuarine habitat: the lower reaches of salmon bearing streams and rivers, and other estuaries.

Based on what I have read I suggest the following long-term average DO standards:

General: all salmonid habitat will be considered in compliance if average DO exceeds 10 mg/L, and IGDO is not adversely impacted by anthropogenic factors (e.g. fine sediment loading).

Critical habitat: no more than 0.2 mg/L below saturation.

Salmon spawning habitat: no more than 0.5 mg/L below saturation.

Salmon rearing habitat: no more than 1.0 mg/L below saturation.

Cool water fish habitat: no more than 2.0 mg/L below saturation.

Warm water fish habitat: no more than 4.0 mg/L below saturation.

Lake habitat for salmonids: not less than 7 mg/L on average in the hypolimnion.

Lake habitat for warm water fish: not less than 4 mg/L on average in the hypolimnion.

Estuarine habitat: not more than 1 mg/L below naturally occurring levels.

The seven day minimum standard shall be no less than 8 mg/L in any anadromous salmon bearing streams or rivers.

The standards above have the advantage of being simple so determining compliance is easy to monitor. Most of the standards above are relative to saturation, but in cases where the system is naturally below saturated oxygen levels, the standards should apply to the expected natural DO concentration. For example, along the west coast of the US, many estuaries are naturally below saturation because density stratification (due to freshwater inputs) and nutrient rich conditions along the entire coast naturally lead to moderately (and in some cases severely) hypoxic conditions.

Seasonal Impacts on DO Criteria

Dissolved Oxygen standards within a system should vary seasonally depending on the predominant use during that period of the year, e.g. a salmonid rearing standard during the summer months and a salmonid spawning standard during the fall and winter. The State of Washington compared data documenting the timing of salmon/steelhead spawning to water DO data to derive their salmonid spawning standards for specific systems. This is an important consideration because many systems will always be within compliance during the colder months of the year, but might be out of compliance as spawning habitat during warm periods in the fall. These out of compliance periods need to be considered within the context of the proclivity of anadromous salmon to delay their spawning until water temperatures are favorable. For example, some salmon runs migrate into rivers before temperatures are favorable for spawning and wait until suitable conditions arise. If the DO standard is based on a particular DO concentration during for example late September this could be difficult to achieve certain years solely for climatic reasons. However, if the standard is relative to saturation as recommended above this would be much less of a regulatory problem. The literature which assesses the capacity of salmonids to delay spawning until favorable temperature conditions prevail should be reviewed and considered within the context of this particular issue. Failing the salmonid spawning DO objectives early in the spawning season when only a small portion of the population has spawned is far less problematic than failing these objectives latter in the season after most fish have spawned.

Temperature, Oxygen Demand and Fine Sediments

When considering potential anthropogenic impacts on DO, equal consideration should be given to factors that might affect water temperatures (as this affects the concentration at which oxygen will be saturated), direct or indirect (via eutrophication) biochemical oxygen demand (as this affects whether DO saturation will be meet), and fine sediment loading (as this affects IGDO exchange with the overlying water). For example, agricultural practices could impair riparian vegetation, as well as load warmer water, nutrients and sediments with return flows. If the temperature in a stream or river is increased due to damaged riparian habitat such that the concentration at which DO would be saturated declined by 1.5 mg/L, this system would be out of compliance even if it was saturated with DO. Similarly, if excessive erosion caused fine sediments to reduce IGDO 1.5 mg/L more than it would otherwise be, the system would also be out of compliance even if the overlaying water was in compliance. It is essential that the DO guidelines are designed to focus management attention of those factors that have the most direct impact on the DO limitations that will have the greatest impact in any particular system.

Long-term climate impacts on life cycle based DO objectives

One important detail that is never mentioned in the draft DO guidelines is the issue of climate change and how that might affect DO concentrations in some systems. Northern California is towards the southern end of the natural range for anadromous salmonids, especially inland of the fog-belt where summer air temperatures can be quite high (> 30 °C). This is particularly the case for inland areas of the the Klamath/Trinity River system. It is well documented that the mean average temperature in the Pacific Northwest region has increased by 1.0-1.5 °C during the last 50 years, and there is every reason to expect this rate of temperature increase will continue through the remainder of this century (Service 2004). How will warming of stream/river water solely due to this mechanism be treated vis-à-vis the DO standard? It is conceivable that a further warming of 1.5 °C could tip a number of systems in the North Coast region past the point of no return as it regards being viable salmonid habitat.

If you have any questions about my comments, please don't hesitate to contact me.

Sincerely,

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