Peer Review of the North Coast Regional Water Quality Control Board:
"Scientific Basis of the Proposed Basin Plan Amendment to Establish a Policy for the Implementation of the Water Quality Objective for Temperature"

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Overview

The purpose of this peer review is to evaluate the scientific basis for a proposed amendment to the Water Quality Control Plan for the North Coast Region (Basin Plan). As specified in the request for external peer reviewers (Bryan McFadin letter, revised 30 June 2013), I have focused my review on the NCRWQCB Staff Report and on the assumptions and conclusions described in Attachment 2 of the request letter. My area of expertise is riparian forest ecology, including vegetation dynamics, response to disturbance, and interactions between riparian vegetation and fluvial processes. Therefore this review pays special attention to these processes while considering the entire scope of issues and implications of the proposed policy changes.

General Comments

In general, the scientific basis for the proposed amendment to the Basin Plan appears sound. The proposed actions to achieve and maintain water quality described in Section 7 of the Staff Report are based on a large number of existing scientific studies, temperature models, and monitoring programs for stream networks and their basins in the North Coast region. In particular, the large number of TMDL assessments completed to date in the North Coast region which specifically consider temperature (as listed in Table 1 of the Staff Report) indicate a relatively mature level of science focuses on this issue in the region. I also appreciated the inclusion of a clear conceptual model for the drivers of elevated water temperature (Figure 5), a diagram of the physical model scheme (Figure 3), and the example of sensitivity analyses of model variables (Figures 2 and 4, but see my comments below regarding this).

With regard to the focus topics posed in Attachment 2 of the peer review request letter, the nature of the water quality problem and potential solution seems fairly clear. From the large number of studies conducted, it appears that riparian shade is the most influential driver of water temperature that can be controlled directly by human land management actions (topic #1), and that maintaining some form of riparian buffer protection throughout a network, particularly in low-order stream reaches, should result in the preservation of more riparian shade and consequently lower levels of solar heating to the water surface (topic #2). Other human-influenced factors such as sediment load and flow alterations appear to affect water temperature as well, but to a lesser degree than riparian shade.

Though these general assumptions appear sound, there are nevertheless several issues that could be better addressed in the Staff Report. These fall into several general areas, which are outlined more in detail below:

1. *Parameter and system uncertainty, and resulting error propagation in the models.*
2. *Differences in riparian/upland vegetation communities (species composition, canopy structure, riparian zone width) among reaches based on topography, network position, geomorphic setting, and disturbance history.*
3. *Potential unintended consequences with regard to desired geomorphic processes.*
4. *Non-stationarity of regional climate warming, and resulting complications in setting temperature targets.*

1. Parameter and system uncertainty, and resulting error propagation in the models.

1.1 There is a general lack of quantification of uncertainty in either the natural system or in temperature models presented as the scientific basis for the proposed policy change. Quantifying uncertainty is critical for assessing how well models can predict system behavior, and management prescriptions and recommendations that are based on modeling results need to be considered in light of uncertainty in the models. There are at least three types of uncertainty analysis which are relevant here: (a) accuracy assessment of modeled temperature compared to observed instream temperature (i.e., model validation); (b) sensitivity analysis of model parameters on predicted temperatures; and (c) propagation of parameter error through the temperature models.

1.2 In a brief review of several original reports (e.g., Navarro, Scott and Klamath River TMDL studies), I have not seen many examples of rigorous model validation or uncertainty analysis presented. The Navarro River temperature TMDL study provides one good example of a parameter sensitivity analysis (Figure 4 of the Staff Report, and Figure 5-2 of NCRWQCB 2000), and the prominence of riparian shade as a driver is supported by strong correlations between water temperature and measured shade (Figures 5-3 and 5-4 in NCRWQCB 2000). However, the degree to which the temperature models were quantitatively validated, and how uncertainty in model parameters may qualify model predictions are not apparent. I recognize that these studies operated under time and budget constraints, and in some cases the complexity of the water quality/temperature models made uncertainty analysis difficult. Consistent with TMDL guidelines, the studies typically include sections on Margins of Safety, and assume a conservative approach to recommendations. Nevertheless, some numerical estimates as to model uncertainty should be included in the Staff Report, to the degree that these analyses were completed for individual projects with specific consideration of modeling shade and its influence on water temperature.

1.3 One particularly important case of the uncertainty issues described above is in the calculation of shade potential for any given project. Knowing what the potential shade for a reach is, relative to its current condition, is critical for 'regulation of shade as a controllable factor' (Section 3.4 of the Staff Report). Though temperature models differ somewhat in approach, all the studies I reviewed appear to include a spatially-explicit (e.g., GIS-based) submodel that calculates the potential shade for each site or reach. As reported in the methods sections of these studies, potential shade is calculated based on the stream channel morphology and orientation, surrounding topography, vegetation communities present in the riparian zone, tree density, and the maximum height growth potential of tree species in those communities. The calculation of potential tree height and density can vary considerably among sites and reaches, especially within environmentally heterogeneous environments such as riparian zones (Friedman and Lee, 2002; Balian and Naiman, 2005; Fierke and Kauffman, 2005). If the approach taken in the Navarro River study is typical, potential shade is predicted using predictions of tree height based on diameter at breast height (dbh), with a single curve determined for each species[1]. However, there is considerable variation in both the dbh-height curve and maximum tree height at maturity for key species such as redwood and Douglas-fir. When implementing the proposed policy changes for reaches of interest, it would be helpful at a minimum to propagate the error associated with the dbh-height relationship, as well as riparian stand density, through the calculations of potential shade, in order to understand the likely variation potential shade values. Some range of these values should be used as goals for restoration and as inputs to the stream temperature models. The data on modeled versus observed shade presented in Figure 5-17 of the Navarro River study (NCRWQCB 2000) is a good start in this direction. This study also used a range of 5% to 70% shade in the model sensitivity analysis, and found differences in predicted temperature of >3 degrees C. For any given project that falls within the proposed Water Quality Control Plan amendment, how great is the uncertainty in potential shade estimates, and how great the resulting temperature uncertainty?

2. Differences in riparian/upland vegetation communities (species composition, canopy structure, riparian zone width) among reaches based on topography, network position, geomorphic setting, and disturbance history.

2.1 The Staff Report includes a section on "Site-specific implementation" (Section 3.2), which identifies some of the local factors that may influence the effect of riparian shade on instream temperature. In addition to the factors listed, I suggest several more to consider in reference to their effect on potential shade for a site. These are described below. Overall, it is unclear how these considerations—both

[1] Though out of the scope of the current review, it should be noted that recent advances in remote sensing, especially in acquisition and processing of LiDAR data, have the potential to greatly increase the accuracy of riparian canopy height estimation and structure (e.g., Seavy et al., 2009), and consequently estimates of riparian shade potential.

those described in the existing document and others that reviewers identify—will be implemented in a consistent way within the policy amendment. Perhaps further development of quantitative or qualitative guidelines will be necessary, either as ranges of parameter inputs into models or some rubric to scale their outputs in light of site-specific factors.

2.2 One important consideration influencing shade potential is that species composition and canopy structure of riparian vegetation varies greatly depending on network position and geomorphic controls on the reach (e.g., unconfined vs. confined, alluvial versus bedrock). Particularly in the North Coast region, low-order streams tend to be dominated by tall conifers that grow close to the stream channel, whereas high-order streams may have a mixture of conifers and much shorter hardwoods, particularly along wider alluvial reaches. Vegetation community maps used to calculate potential shade typically do not take into account this level of detail, yet this can be very important in terms of estimating maximum potential height of the streamside vegetation. The variation in riparian vegetation composition within a network can amplify the difference in shade potential between narrow, confined, conifer-dominated headwater streams and downstream reaches with wider active channels, less topographic shading from unconfined valleys, and more varied vegetation with significant amounts of hardwood and shrub species of shorter stature. The descriptions of shade models that I reviewed take into account the topography and active channel width, but not the near-stream vegetation communities as separate from the landscape level vegetation maps. Looking to the applicability of this temperature TMDL approach beyond the North Coast region, the variation in riparian community structure and composition within a network can be even more pronounced in other regions (e.g., Central Valley and/or desert streams). Therefore in both the North Coast region and more generally, there should be some thought as to how to quantify the effects of vegetation composition gradients within stream networks as inputs to shade-based temperature models.

2.3 A related issue is that the natural and human disturbance history of a reach needs to be considered when setting potential shade targets. Riparian zones are highly dynamic ecosystems, with physical drivers such as flooding, fire and drought exerting strong influences on the vegetation community trajectory. The structure of riparian vegetation will be highly dependent on the time since a large disturbance, particularly in steep, semi-arid systems such as the North Coast region where extreme events (e.g., the 1964 and 1997 floods) cause channel-setting disturbances over large spatial scales (e.g., networks to regions) and subsequent riparian community recovery can last decades until maximum vegetation height and density are achieved. The Staff Report alludes to this process directly affecting instream temperatures, in its citation of Klamath River water temperature rising following the clearing of riparian vegetation in the 1997 flood event (de la Fuente and Elder 1998, as cited on p. 22 of the Staff Report). That peak flow event, which was classified at a 19.5 year recurrence interval, resulted in acute alteration—bank erosion, deposition or removal of vegetation—of 16% to 19% of all stream channels within the Klamath River basin (de la Fuente and Elder 1998). Presumably events of this magnitude will occur at least several times a century, well within the life span of the dominant shade tree species in the region. Therefore disturbance is a major control on the shade potential of the riparian ecosystem in the North Coast region, can affect large areas of the stream network synoptically, and can limit the spatial extent of older riparian stands dominated by tall trees. This process must be considered when using reference reaches to set potential shade targets and in predicting the long-term effect of management actions.

3. Potential unintended consequences with regard to desired geomorphic processes.

3.1 The discussion of sediment processes in conjunction with stream temperature is a useful feature of the Staff Report and reflects complex interactions among multiple water quality components. As noted in the report, excess sediment loading can affect instream temperature through alteration of the channel morphology and interations with riparian vegetation dynamics. In addition, many of the riparian buffer prescriptions to mitigate high instream temperatures through increased shade will have the positive benefit of mitigating sediment delivery to the channel, and vice versa. In a similar vein, it is important to consider potential *negative* interactions between riparian vegetation management and geomorphic process goals, particularly along regulated streams in the North Coast region. Along the Trinity River, for example, severe alteration of the river's hydrology led to riparian encroachment within the former active channel (Trush et al., 2000). Presumably, this created increased riparian shade as the active channel decreased and vegetation increased in density and height, and the increased shade was presumably a benefit to maintaining low instream temperature, particularly in a reach with greatly reduced discharge and thus less capacity to buffer high heat loads. However, the vegetation encroachment and subsequent formation of high, immobile riparian berms severely altered the channel morphodynamics, sediment delivery processes, and large woody debris recruitment, and greatly reduced the overall habitat for native salmonids and other aquatic organisms. In the case of the Trinity River, the interests of maintaining riparian shade and of maintaining a natural, dynamic stream channel were at odds, and contemporary river restoration efforts are focused on removing the riparian berms and rescaling the active channel (TRRP 2013). The Trinity River is a fairly extreme case of river manipulation, but it highlights the importance of considering potential tradeoffs between competing management concerns, in this case shade potential and sediment processes.

4. Non-stationarity of regional climate warming, and resulting complications in setting temperature targets.

4.1 The issue of climatic warming poses challenges to stream and riparian management worldwide, in particular in sensitive areas such as California and other Mediterranean-climate regions (Underwood et al., 2009; Stella et al., 2012). Because of the strong link between air temperature and instream temperatures, ongoing regional warming in California will make freshwater streams less habitable for salmonids and other cold water organisms at the southern edge of their ranges. It is unclear to me how this non-stationarity of the system will be considered within the proposed TMDL policy amendment. How will temperature models incorporate the 'new normal' into predictions and land management prescriptions? Is it possible that meterological and hydrologic changes may increase the relative strength of these drivers on instream water temperature, with potentially less influence from riparian shade? I recommend that the Staff Report provide some acknowledgement of this issue, and potential implications for policy.

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