Review of the Draft Basin Plan Amendment to Establish a Policy for the Implementation of the Water Quality Objectives for Temperature

Sally Thompson

Executive Summary

This review focuses on the six conclusions and assumptions highlighted in the Request to External Peer Reviewers.

The main review findings are:

1. The conclusions and assumptions presented have substantial scientific validity. Minor comments relating to wording, caveats and exceptions are provided. Overall, the scientific basis presented is sound.
2. The suggested site-specific, case-by-case approach is valid and important.
3. There are several omissions in the policy and draft report that I recommend addressing explicitly.
    a. Spatial and temporal variations in stream temperature are not discussed with respect to the management objectives. Thus, local thermal refuges, diurnal temperature ranges, temperature pulses, and seasonal temperature variations are not considered. These factors have significant implications for habitat quality and fish lifecycles. They merit specific consideration from monitoring and management points of view.
    b. The differences in energy balance drivers occurring in different parts of a river network are not discussed, although these differences are likely to have significant implications on the efficacy of the proposed management actions.
    c. The spatial and temporal constraints on the proposed management actions (e.g. minimum buffer extents, timescales needed for recovery) are not discussed, although these factors are likely to have significant implications for the efficacy of the proposed management actions.
4. The intention of the policy with respect to the regulation of disturbance versus enforcing requirements for restoration or mitigation is unclear. This distinction is important. Current science strongly supports the value of preserving existing stream shading and riparian vegetation to prevent environmental degradation. Current science does not provide strong evidence that restoration activities will reverse environmental degradation in terms of thermal loads.
5. The temperature drivers that are likely to be most universally important for regulating stream temperatures are addressed by the plan. Some drivers that are likely to provide background changes or be important in specific instances were neglected (e.g. turbidity, urbanization, global warming).

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I have structured this review around the six core assumptions and conclusions that were to be addressed by the peer reviewers.

1. Increased solar radiation loads are the primary controllable driver of elevated water temperatures. Increasing solar radiation loads (decreased shade) result in increasing stream temperatures. Preserving shade is a legitimate means of preventing stream temperature increases.

1.1. Comments on the main conclusion

It is well established that increased levels of solar radiation often play an important role in elevating stream temperatures. Moore et al (2005) provided a comprehensive review of the problem and analysis of 18 studies which support an increase in stream temperature following removal of riparian vegetation. Bowler et al. (2012) conducted a meta-analysis which reviewed over 250 papers and quantitatively compared 20 studies, finding *universal* **support for the causal link between removal of riparian vegetation, increased solar loading on the channel, and increased stream temperature**. Numerous place-based studies indicate significant increases in stream temperature downstream of exposed reaches with limited shade and riparian vegetation (Nichols, Willis et al. 2013). It is therefore legitimate to consider regulation and manipulation of stream shading as a management tool for stream temperatures. This approach is supported by broad-based scientific evidence.

There are some nuances, however, which are worth reflecting on.

Firstly, it is clear from the review presented by the scientists here, as well as other research, that solar radiation is not *always* the primary driver of elevated water temperatures. Examples can be readily found where lowered groundwater tables (Loinaz, Davidsen et al. 2013), surface water diversions, point-scale discharges (Loinaz, Davidsen et al. 2013), agricultural return flows (Oremland, Steinberg et al. 1991; Fujimoto, Ouchi et al. 2008), and potentially anthropogenic climate change (Roth, Westhoff et al. 2010) contribute to stream temperature increases. While Conclusion 5 “Evaluation of these impacts is most appropriate on a site-specific, case-by-case basis” broadly covers these distinctions, it may be appropriate to consider rephrasing Conclusion 1:

“Increased solar radiation loads are **likely to be** the primary controllable driver of elevated water temperatures **in most waterways in the North Coast Region**.”

Secondly it is not clear that preserving shade will *always* be effective in preventing stream temperature increases. The value of riparian shading for temperature modification is contingent on channel width (Moore, Spittlehouse et al. 2005). In large streams where riparian canopies cannot effectively shade the entire water surface, riparian shading is unlikely to modify stream temperature on average (Lee, Huang et al. 2012). Similarly, the importance of riparian shading for temperature control appears to vary throughout the river network. A recent study suggests that **riparian buffers may have minimal influence on the temperature of headwater streams**. In a clear-cut experiments over 11 small headwater channels (1.9 – 8.5 ha watersheds) in Washington State, Janisch et al. (2012) found no significant differences in temperature between clear cut channels, continuously buffered channels, and patch-buffered channels. Tree cover provided little predictive insight into temperature changes, which were more strongly correlated to the total water surface area in the streams.

Again, the case-by-case approach suggested in Conclusion 5 is suitable for addressing many of these special cases. These observations do suggest, however, that a more cautious statement about the legitimacy of preserving shade to maintain low stream temperatures might be warranted.

“Where existing stream channel shading is extensive or can otherwise be shown to represent a significant control on stream temperatures, preserving shade is a legitimate means of preventing stream temperature increases.”

1.2. Comments on the supporting information

Site potential effective shade: The site-potential effective shade concept is appealing, but will present challenges in terms of evaluation over large scales, realism and consistency between different locations with different land use history, climate, geology etc. In highly disturbed systems where streams are already extensively managed, linking channels to local natural benchmarks may be unrealistic.
By setting TMDL levels on shade as a function of potential shading, problematic situations could arise where the shade could be considered highly impacted, even where full shading would do little to affect bulk stream temperatures (the lower reaches of large rivers again provide an example of this situation). These distinctions are addressed at the policy level based on the proposed site-specific approach. The TMDL development, however, does not seem to have adopted a fully site-specific approach by linking TMDLs to potential effective shading, rather than the temperature changes that could be achieved by potential effective shading.

1.3. Summary

Increased solar radiation is a significant driver of elevated water temperatures. It is probably the dominant driver of elevated water temperatures in watersheds in

Northern California. It is likely that some sites experience other significant forms of thermal modification. In some parts of the river network shading may be decoupled from mean channel water temperatures (e.g. in first order groundwater dominated reaches), while in other locations channel width may be too large for riparian shading to influence mean water temperature. The site-specific, case-by-case approach should therefore be extended to the temperature effects of the TMDLs applied to shading, and to the language surrounding this conclusion.

2. The establishment of riparian buffers for temperature protection is an effective and important management measure for the control of some types of sediment and discharges.

2.1. Comments on the main conclusion

It is uncontroversial that the presence of riparian vegetation will reduce rates of bank erosion and sediment mobilization in many circumstances (Liu, Zhang et al. 2008). Provided the spatial extent of riparian vegetation is large enough (both in terms of buffer width, buffer slope and buffer length along the channel), and the vegetation is sufficiently dense, it is feasible that riparian vegetation will provide an important management measure to prevent addition of sediment into streams.

Two things are unclear in this conclusion specifically, and in the policy overall. The first is the basis for defining a riparian buffer. The second is whether the “establishment of riparian buffers” is intended purely as a preventative measure (to preserve existing vegetation and prevent future impacts) or if it also is considered a technique for mitigation, offset or restoration. Assessing the likely value of restoration for both sediment and temperature management perspectives is considerably more problematic than assessing the value of prevention. I have expanded on these comments under the “Big Picture” section.

2.2. Comments on the supporting information

All the provided supporting information relates to in-channel geomorphology, which may be negatively impacted by increased sediment loading on streams. The additional role of sediment in increasing turbidity, which alters the absorption of light by the water column was not discussed (Henderson-Sellers 1986). It is unclear whether this factor has been overlooked or considered unimportant in this study. It may be more direct to develop conclusions about channel geomorphology, and the value of riparian vegetation for channel geomorphology (by stabilization of banks and regulation of sediment discharges).

2.3. Summary

The substance of the conclusion is valid, provided suitable buffer characteristics are applied. The lack of discussion of these characteristics, and whether buffers are a preventative or restoration measure needs to be clarified. The role of sediment as a driver of channel geomorphology is valid, but somewhat indirect (it would be clearer to focus on geomorphology with sediment reductions as one strategy to be employed). The role of sediment in modifying turbidity and the spectral properties of water could be also considered.

3. The diversion and storage of water has the potential to elevate water temperatures.

3.1. Comments on the main conclusion

Again, this conclusion is substantively sound, with minor caveats. Reductions in flow will reduce the thermal mass and the velocity within a stream. This can be readily observed from the energy balance equation for a reach:

$$\Delta T = \frac{\sum Q}{\rho C_p V D} L \tag{1}$$

Here ρ is the density of water, C_p the heat capacity of water, V the mean streamflow, D the mean depth, and Q is the net heat exchange. Clearly for lower depths and velocities, greater temperature increases will occur (Moore, Spittlehouse et al. 2005).

It is not always true, however, that storage will increase temperatures. The Klamath River study cited in the Staff Report suggests that thermal delays and reduced temperature extremes result from dam releases. While these delays and reduced temperature extremes may be problematic in unimpaired waterbodies, they may also offer opportunities to mitigate thermal effects in streams that are experiencing high temperature conditions.

Similarly, diversion of flow suggests that only surface water abstraction has the potential to alter stream temperatures. In groundwater-fed streams, it is clear that significant impacts may also result from groundwater pumping. For instance, in a modeling study, water table fluctuations leading to reduced groundwater input were shown to potentially increase stream temperatures by 0.3 to 1.5^{o}C (Loinaz, Davidsen et al. 2013). This is comparable to the changes associated with solar radiation. Groundwater abstraction has the same potential to influence stream flow and temperatures as surface diversions and should be explicitly identified as such.

Thus, a more appropriate conclusion might be:

Reductions in streamflow due to surface water diversion, groundwater abstraction or storage of water have the potential to elevate water temperatures **and alter the magnitude and temporal pattern of in-stream temperature variations.**

3.2. Comments on the supporting information

No additional comments

3.3. Summary

The substance of the conclusion is valid, although the statement should be expanded to specify surface and groundwater abstraction, and to clarify the potentially complex effects of storage on timing and magnitude of thermal pulses.

4. The Policy comprehensively identifies the temperature factors that must be addressed.

4.1. Comments on the main conclusion

The policy has identified the major factors that must be addressed, however there is scope to be more explicit and to add some further factors that are likely to be minor in most cases, but might be important in some specific instances:

1. As discussed above, turbidity alters stream energy budgets, and has not been explicitly addressed in this policy.
2. Groundwater abstraction should be more explicitly identified as a factor impacting temperature. Listing it as a "land use" factor is indirect.
3. Similarly, surface water abstraction should be explicitly identified as a factor, rather than considering it a function of land use.
4. Recent studies highlight a national trend of increasing stream temperatures. One potential reason for this may be global warming (Kaushal, Likens et al. 2010). While it is unlikely that this can be addressed at the local level, it may be important to consider stronger local mitigation targets to offset this background of regional temperature rise. For example, if 1°C temperature rises were expected due to background warming, it may be more appropriate to limit in-stream warming to 4°C rather than 5°C, as an uncontrollable factor would be likely to impose the additional 1°C rise.
5. Urbanization is strongly associated with increased stream temperatures, and urban stormwater may thus merit consideration as a point source of heat (Kaushal, Likens et al. 2010). While Northern California is not extensively impacted by urbanization, population growth in the region is likely to mean that urban land area will increase in the future. Since urban development is often planned and regulated, there are real opportunities to design urban water management to minimize thermal impacts on receiving water bodies.
6. Irrigation return flows have a real potential to provide a point heat source and may require more overt consideration (Oremland, Steinberg et al. 1991; Fujimoto, Ouchi et al. 2008).

4.2. Comments on the supporting information

No additional comments

4.3. Summary

The most significant factors are addressed, in specific cases other factors may be important, and some are identified here.

5. Evaluation of the risk of temperature impacts associated with a project is most appropriate on a site-specific, case-by-case basis.

5.1. Comments on the main conclusion

It is *highly appropriate* that temperature impacts should be evaluated on a site specific, case-by-case basis.

5.2. Comments on the supporting information

No additional comments

5.3. Summary

No additional comments

6. The types of actions necessary to recover a waterbody that is temperature impaired due to reductions in stream shade are the same types of actions that prevent a waterbody from becoming temperature impaired.

6.1. Comments on the main conclusion

This is scientifically justifiable. The only point of differentiation that requires clarification is how the policy relates to mitigation/offsets/restoration, in the context of impaired versus unimpaired water bodies. There is more confidence and a greater chance of success associated with preventing temperature impairment through the recommended strategies than there is in reversing temperature impairment through restoration, mitigation or offset creation. See big picture comments below.

6.2. Comments on the supporting information

No additional comments

6.3. Summary

No additional comments

7. Big Picture

7.1. Improved definition of stream temperature factors for habitat value:

One limitation of the existing policy is that the nuances of stream temperature as an indicator of habitat quality are not explored. For example, while bulk stream temperatures may not be affected by bank shading, local cool sites might be generated. These sites are significant aquatic refuges. Because only "stream temperature" was discussed, I have highlighted that riparian vegetation in wide channels may not be significant as a driver of in-channel temperatures. This of course ignores its potential significance in generating local thermal refuges, which can be ecologically significant (Nichols, Willis et al. 2013).

Significant temporal variability in stream temperatures also often occurs, even within a day. Lags due to travel time between upstream and downstream areas may mean that “pulses” of hot water arrive in different locations at different times. This generates challenges for monitoring, but also variation that can be important for habitat diversity (Nichols, Willis et al. 2013). It is unclear whether or how this policy could account for spatial and temporal variability. There are several anecdotal accounts of misinterpretation of local stream temperatures based on a fixed monitoring time missing the arrival of thermal pulses from upstream. High frequency monitoring methods can circumvent this problem. Explicitly considering the role of localized cool refuges might also provide greater flexibility in identifying site-specific strategies.

7.2. Value of restoration of riparian vegetation for temperature control

Although there is significant literature describing the effect of removing shade and riparian vegetation on stream temperatures, peer reviewed studies describing the effects of restoration of riparian vegetation are less widely published, and unclear in their results. For instance, in a paired study along four streams in New Zealand, some of which had experienced restoration of riparian habitat 20 years previously, no significant differences in stream temperature between treatment and control sites could be found (Collins, Doscher et al. 2013). A review of multiple riparian buffer plantings in New Zealand found that in only one site (where complete canopy closure had occurred) were stream temperatures reduced in the reach where restoration occurred (Parkyn, Davies-Colley et al. 2003). There is therefore an asymmetry, in that **it is very clear that removal of vegetation and increases in solar exposure are likely to increase temperatures; but it is not clear that restoration of riparian vegetation will lower stream temperatures**. It is likely that this discrepancy results from the need to consider the specific characteristics of riparian buffers. Since these considerations are relevant to the design of buffers, whether for restoration or protection, I have elaborated on some issues below.

7.2.1. Buffers must be long enough relative to the stream reach for their impacts on temperature to be significant.

Ignoring groundwater, hyporheic and tributary inputs, the change in temperature ΔT within a stream over any reach length L:

$$\Delta T = \frac{\sum Q}{\rho C_p V D} L$$

Here ρ is the density of water, C_p the heat capacity of water, V the mean streamflow, D the mean depth, and Q is the net heat exchange. The length of the reach L over which solar inputs are reduced needs to be large enough to meet a target value of ΔT for that reach; the greater the flow rate (VD) the longer L will have to be (Moore, Spittlehouse et al. 2005). Thus, short buffer lengths may be ineffective in modifying temperatures.

7.2.2. Buffers need to be at least as wide as they are tall to realize full benefits of microclimatic modification.

While a narrow buffer can reduce stream-shading, wider buffers are needed to allow a distinct microclimate (e.g. with cooler air temperatures and greater humidity) to be generated relative to open surroundings (Moore, Spittlehouse et al. 2005). Wider buffers also have a greater potential to become self-sustaining from an ecological point of view, rather than becoming colonized by weedy vegetation (Collins, Doscher et al. 2013).

7.2.3. Buffers must capture and contain significant channel sediment sources if they are to impact stream geomorphology

Detailed analyses of sediment sources in stream networks usually identify particular locations (subwatersheds, point sources etc) that dominate the input of sediment into watersheds. Buffers should include these areas to have a significant impact on sediment loading.

7.2.4. Timescales for recovery are long

As intimated in the examples from New Zealand, it may require decades for restoration of riparian vegetation to meaningfully alter physical characteristics of the local thermal regime. Similarly, even if buffers are successful in reducing sediment inputs into channels, the long residence time of sediment within channels may mean that few if any changes to the in-stream geomorphology and thus vulnerability to thermal loading occur on observable timescales.

7.3. Space and timescales

As alluded to in several points above, the policy is silent on space and timescales. While perhaps “site-specific” and “case-by-case” analysis encapsulates this, it is worth reiterating that there are specific lengthscales (related to flow and channel morphology) and timescales (related to processes of plant growth, riparian recovery and sediment residence times) that will impact the efficacy of any given intervention. A broader discussion of these issues would be beneficial.

7.4. Tradeoffs

Protection of riparian buffers leads to broader questions of riparian management, weed control, ecological value etc. While this policy is clearly targeted at in-channel conditions, a holistic approach that acknowledges the interface with riparian ecology more broadly would be valuable. I also note that although the policy has focused on riparian vegetation, emergent, in-channel vegetation has also been shown to help control stream temperatures, and often leads to improvements on faster timescales than are needed to develop a closed-canopy riparian buffer (Roth, Westhoff et al. 2010).

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