Review of Draft Staff Report Supporting the Policy for the Implementation of the Water Quality Objective for Temperature

By: Mark Stacey, Professor in Civil & Environmental Engineering Department, UC-Berkeley
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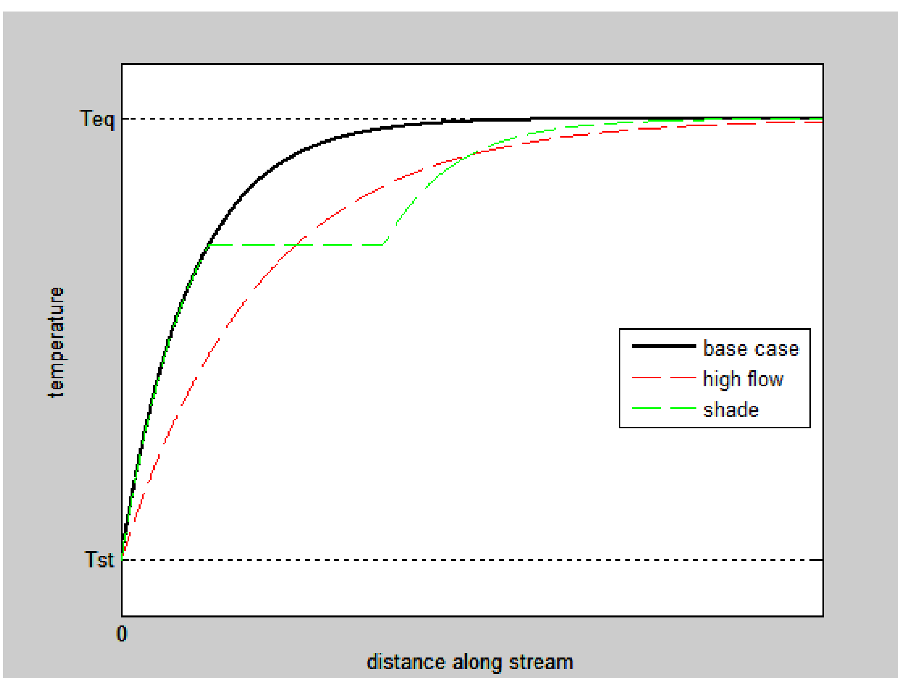
<u>"Big Picture" Comments</u>

I have completed my review of the Draft Staff Report Supporting the Policy for the Implementation of the Water Quality Objective for Temperature. I would like to commend the authors on the clarity of the report and I am supportive of their conclusions in general terms, particularly the focus on multiple factors. I also appreciate the approach of managing shade as a leading factor. At the same time, I feel that there are couple of scientific issues that should be a part of the presented development, and I will discuss them at more length in the following sections. Briefly, the first is that the interplay between the various factors was not well developed, and the role of long-term climate change and/or variability is insufficiently addressed. Secondly, the role of spatial variations, and what scale of variability the policy aims to address, are not clearly delineated.

Discussion of Conceptual model. The authors make it clear that multiple factors are simultaneously acting to alter stream temperatures, but the description they provide seems to convey a conceptual model that does not address the interactions between the various factors. Further, the role of long-term atmospheric warming must be better integrated into the discussion, as shade, flow and other factors must all be considered in that context. Briefly, air temperature, which will increase by several degrees under most climate projections, establishes the equilibrium temperature for a waterbody. The other factors described in this report, including shade, flow, and ratio of depth to width, affect the *rate* (in space or time) at which the water temperature approaches that equilibrium. As a result, if air temperatures increase, the demands on shade, flow and other factors will increase if water temperatures are to be preserved. I try to illustrate these interactions with the following, conceptual figure showing the evolution of water temperature along an arbitrary channel reach:



In this case, we start at a cool temperature ('Tst') at the upstream end of the reach, and then the waters approach the equilibrium temperature ('Teq') with distance along the reach. Here I show the temperatures actually reaching the equilibrium temperature, but of course that may or may not happen within a given reach. The key point here is that the base case trajectory will be determined by the equilibrium temperature, which is itself strongly dependent on air temperature and will increase over time with climate forcing. The second case shown in the figure illustrates the effects of increased flow (dashed red line), which decreases the effective spatial rate of approach to the equilibrium temperature (note that the temporal rate of increase remains the same, but the whole temperature distribution is pushed downstream). The final case illustrates how a region of complete shading modifies the temperature trajectory (dashed green line). Here I show the extreme case where in a portion of the reach (the part with the flat part of the green curve) the water temperature does not increase at all in order to illustrate the spatial interactions between these three driving forces. Note that downstream of the shaded section, the water temperature again begins to increase towards the equilibrium temperature; this rate of increase is determined by the flow rate. As such, both shade and flow have similar buffering effects on water temperature – they extent the cool water signature from upstream further down into the reach – but neither addresses the equilibrium temperature that would be reached at the end of a long reach. I think the report would benefit from a clearer, and more complete, presentation of these factors and how they interact to determine the distribution of water temperature along a stream reach.

This also leads to a related question as to ***how the "natural state" should be defined***. If "natural state" is based on historical temperatures, then under warming air temperatures, *more* shade or flow would be required than during historical conditions. Alternatively, if "natural state" is based on historical distributions of shade and flow, then preserving the natural state will lead to increases in water temperature due to changes in air temperature (and equilibrium water temperature). In essence, my conceptual picture of the goals of the policy is to do our best to fight a losing battle against increasing air and water temperatures, by making use of shade and flows to mitigate the effects of elevated equilibrium temperatures. Even though air temperatures and, by extension, equilibrium water temperatures are beyond management control, they need to be discussed in order to clearly establish the goals and approaches of the policy.

Spatial Scales of Interest and Level of Detail in the Report. It was very difficult to determine the approach used to reach the qualitative results, for example in Figure 2 in the report. Even going to the supplementary materials (NCRWQB 2000), I was left with uncertainty as to exactly how these sensitivity calculations were done. Of particular concern in this case is the spatial structure of the calculations and where the analyzed temperatures were relative to the shade. It appears that the analysis was for a single reach with a single-valued fractional shading and the output temperature was at the downstream end of that reach. The sensitivity of water temperature to shading will decrease with distance downstream of the shaded region (as illustrated in the figure above), and it isn't clear what spatial scale should be resolved or considered to meet the policy goals.

This leads to a related concern about how ***thermal refugia*** are to be considered, both in the analysis of water temperature and in the application of the policy. Does the removal of a small pool that locally leads to an increase in water temperature of more than 5 degrees violate the standard? How small of a pool would be negligible? I think the report would benefit from a clear statement as to how the authors are thinking about spatial scales of interest, even if it is just to give a context to the report and the results presented (particularly in Figure 2).

The Roles of Sediment and Manning's n in Water Temperatures. Finally, I would note that the link between sediment load and water temperature is not well developed. The report does make the effective argument that many of the management options available for controlling water temperature will also help control sediment loading. But, the authors also go on to state that sediment load is one of the factors that causes changes in water temperatures. The reasoning goes that sediment load can (a) change the width-to-depth ratio of the stream; and (b) alter (reduce) hyporheic exchanges, which are sources of cool water at various locations along the streams. While I agree that the effects of fine sediments on hyporheic exchange would likely increase stream temperatures, the scale of the effect, both in terms of the spatial scale and the magnitude of the temperature change, is not analyzed or presented. The report would be more persuasive if these effects were quantified.

With regards to the influence of sediment load on width-to-depth ratio, I would note that this is an indirect effect on water temperature. Further, there are other factors besides sediment load that have strong influence on width-to-depth ratio, ***most notably Manning's n***. I would suggest that the report acknowledge these related influences: that width-to-depth ratio maybe the factor that directly influences water temperature (or rather, the rate of change of water temperature as discussed above), but that other factors (such as Manning's n) that are under management control will work to determine the width-to-depth ratio.

<u>Comments on "Assumptions and Conclusions"</u>

In the review instructions, a set of specific directions were given for the reviewers. Most of my concerns were included in the sections above, but in order to be clear and complete, I will briefly address each of the requests here.

Reviewers are asked to critique the approach of preserving shade for the control of elevated water temperature. The approach of preserving shade is well argued and presented, but the conceptual model for how shade interacts with other factors should be further developed, in particular the role of air temperature, equilibrium temperature and the interaction of shade and flow in defining the spatial structure of water temperature must be considered both in the discussion of the factors that govern water temperature and in defining the "natural state" for the system (discussed above in "Big Picture" comments).

Reviewers are asked to critique the approach of addressing sediment discharges and temperature concerns associates with riparian vegetation concurrently through the establishment of riparian buffers. I found the report convincing that many management actions would act to control sediment discharge and water temperature simultaneously. However, the causal link between sediment loads and water temperature is less well established, but in my opinion it doesn't need to be.

Reviewers are asked to assess the need to address flow related factors as part of the proposed Policy. As described in the "Big Picture" comments above, the interplay between shade, flow and air temperature (even though it is external to management control) should be more clearly developed in the report. Flow has a similar effect on water temperature to shade: both reduce the rate at which the water temperature approaches its equilibrium. As such, changes in flow can mitigate or accentuate the effectiveness of shade in pursuing the policy objectives.

Reviewers are asked to consider whether the Policy comprehensively identifies the actions and features subject to human control that influence the most significant drivers of stream temperature. I think the report does a good job of identifying the important controllable factors, but their interaction is not well-developed, and I think it is a mistake to leave out factors that are not under (immediate) human control (specifically air temperature). Further, although Manning's n is identified as a factor, it is discounted quickly and its effect on both depth and flow, and hence water temperature, are not developed.

Reviewers are asked to critique the validity of using a case-by-case approach to addressing impacts of projects, as opposed to the establishment of prescriptive rules that apply region wide. I believe this balance is handled, and justified, well.

Reviewers are asked to assess the rational (sic) for the approach to regulating activities in impaired vs. unimpaired waterbodies. I commend the authors on the clarity with which they addressed this issue.