Appendix 1: Regional Water Board Staff Response to Peer Review Comments on the Peer Review Draft Staff Report Supporting the Policy for the Implementation of the Water Quality Objectives for Temperature

August 28, 2013

In accordance with Section 57004 of the California Health and Safety Code, the North Coast Regional Water Quality Control Board (Regional Water Board) is required to receive external scientific peer review of the scientific basis of any proposed amendment to the Water Quality Control Plan for the North Coast Region (Basin Plan).

This document is a compilation of comments provided by the scientific peer reviewers of the Peer Review Draft Staff Report Supporting the Policy for the Implementation of the Water Quality Objectives for Temperature, July 1 2013.

The following individuals provided scientific peer review of the Peer Review Draft Staff Report Supporting the Policy for the Implementation of the Water Quality Objectives for Temperature:

Mark T. Stacey, Ph.D.
Professor, Department of Civil and Environmental Engineering
University of California

John C. Stella, Ph.D.
Assistant Professor
Department of Forest and Natural Resources Management
State University of New York

Sally E. Thompson, Ph.D.
Assistant Professor
Department of Civil and Environmental Engineering
University of California

The reviewers were asked to evaluate 6 statements representing the assumptions, assertions, and conclusions that constitute the scientific basis of the proposed actions to determine whether the scientific portion of the proposed rule is based upon sound scientific knowledge, methods, and practices. Reviewers were also invited to address any other scientific issues that should be part of the scientific portion of the proposed rule that are not otherwise described. Finally, the reviewers were invited to comment on whether taken as a whole, the scientific portion of the proposed actions are based upon sound scientific knowledge, methods, and practices.

The reviewer's comments and Regional Water Board staff responses are presented below.

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.

Stacey 1:
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).

Regional Water Board response:
Additional discussion describing equilibrium temperature and the interaction of temperature drivers has been added to the report in response to the comment.

Thompson 1:
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**."

Regional Water Board response:
Regional Water Board staff acknowledge that the suggested qualifiers are appropriate. The conclusion referred to was written to direct the reviewers to the scientific issues in the Policy; however, the specific language is not contained in the Policy. The temperature impacts associated with surface water diversions, point source discharges, and agricultural return flows are addressed through this Policy. Staff have modified the staff report to reflect the qualified statement.

Thompson 2:
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."

Regional Water Board response:
Staff agrees that shade is not an effective means of preventing temperature increases in streams with great widths in relation to tree heights, on average. Staff also agrees with Dr. Thompson's comment (Thompson 12) that shade provided by vegetation may be ecologically significant in situations where it reduces solar loading to thermal refuges. Language acknowledging these concepts has been incorporated into the staff report.

Staff have reviewed the article by Janisch, et al (2012), and note the authors' reservations that confounding factors were not controlled in the experiment, such as the shade provided by slash debris, the composition of the streambed substrate, and the degree of interaction with wetlands. Both the interaction with wetlands and the substrate composition were shown to correlate with temperatures after the fact. Furthermore, the authors point out that while the results of the study generally show higher temperature increases in clear cut streams versus buffered streams, the results did not agree with other studies of headwater streams (Gomi et al 2006), that showed much higher temperature increases associated with loss of shade. The authors point out the extremely low flows that existed during the experiment, as well as the possibility that the temperatures were buffered by hyporheic exchange. The sum of this information indicates that in some cases thermal processes other than solar insolation may be the dominant process determining stream temperatures. Language acknowledging this concept has been incorporated into the staff report.

Thompson 3:
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.

Regional Water Board response:
The topic of when shade controls are not effective at controlling temperatures, such as wide stream channels relative to the height of vegetation, has been incorporated into the staff report.

Stella 1:
From the large number of studies conducted, it appears that riparian shade is the major driver of water temperature that can be controlled directly by human land management actions…

Regional Water Board response:
Comment noted.

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.

Stacey 2:
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.

Regional Water Board response:
Comment noted. The causal link between sediment loads and water temperature is discussed below.

Thompson 4:
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.

Regional Water Board response:
Comment noted.

Thompson 5:
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.

Regional Water Board response:
These issues are addressed in the response to the "big picture" comments, below.

Thompson 6:
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).

Regional Water Board response:
Staff has been unable to find support in the literature for the hypothesis that turbidity has a significant effect on stream temperatures. Staff are familiar with the literature on stream heating processes and note that the seminal works on the topic are silent on the topic of turbidity (e.g., Poole and Berman 2001, Sinokrot and Stefan 1993, Webb et al 2008). It may be that turbidity impacts the distribution of temperatures in the water column. The notion that turbidity leads to increased temperatures through altering the absorption of light doesn't comport with the known properties of water, where water bodies act as "black bodies" with high absorption properties. To some degree the issue is moot, because turbidity is most often present at times when temperatures are not a concern, and more significantly turbidity is a pollutant that is already regulated. The water quality objective for turbidity requires turbidity be increased no more than 20% above background, which is a relatively stringent standard.

Stella 2:
…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.

Regional Water Board response:
Comment noted.

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

Stacey 4:
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.

Regional Water Board response:
See response to Stacey 1.

Thompson 7:
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:

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

Here ρ is the density of water, Cp 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.

Regional Water Board response:
Staff agree that storage of water doesn't always increase temperatures, and that management of cold water from the bottom of reservoirs may provide opportunities to positively affect water temperatures. However, the stated assumption is that the storage of water has the potential to increase water temperatures; the implication is that the Regional Water Board should evaluate such conditions when considering the water quality impacts associated with onstream impoundments.

Thompson 8:
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.**

Regional Water Board response:
Staff agrees that groundwater withdrawals have potential to impact stream temperatures, depending on the situation. The topic is explicitly identified in section 4.3 (hydrodynamics) in relation to the Scott River TMDL. The Policy directs staff to address "…activities with the potential to reduce instream summer flows or reduce sources of cold water…", which includes reductions of cold water derived from groundwater.

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

Stacey 4:
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.

Regional Water Board response:

Additional discussion describing equilibrium temperature and the interaction of temperature drivers, as well as air temperatures and channel roughness (Manning's n) has been added to the report in response to this and other comments offered by Dr. Stacey.

Thompson 9:
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).

Regional Water Board response:
The following responses correspond to the numbered points above:
1: See response to comment "Thompson 6", above.
2 & 3: The intent is to address temperature concerns with water withdrawals, both surface and subsurface. The wording "land uses associated with" is meant to be broad to cover the range of activities that may reduce cold water flows. Often the reductions in flows are associated with active diversions, but other land use activities, such as those that limit or eliminate groundwater recharge resulting in

decreased groundwater inputs to a stream, for instance, are not associated with diversions. Text has been added to the report discussing this topic.
4. Additional text has been added discussing the issue of global warming and the associated regulatory implications.
5 & 6. The Policy explicitly directs the Regional Water Board to prevent, minimize, and mitigate temperature alterations associated with "(t)he quality, quantity, location and timing of effluent, storm water, and agricultural return flow discharges."

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

Stacey 5:
I believe this balance is handled, and justified, well.

Regional Water Board response:
Comment noted.

Thompson 10:
It is *highly appropriate* that temperature impacts should be evaluated on a site specific, case-by-case basis.

Regional Water Board response:
Comment noted.

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.

Stacey 6:
I commend the authors on the clarity with which they addressed this issue.

Regional Water Board response:
Comment noted.

Thompson 11:
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.

Regional Water Board response:
Comment noted. The issue of prevention vs restoration is addressed below.

7. "Big Picture" Comments:

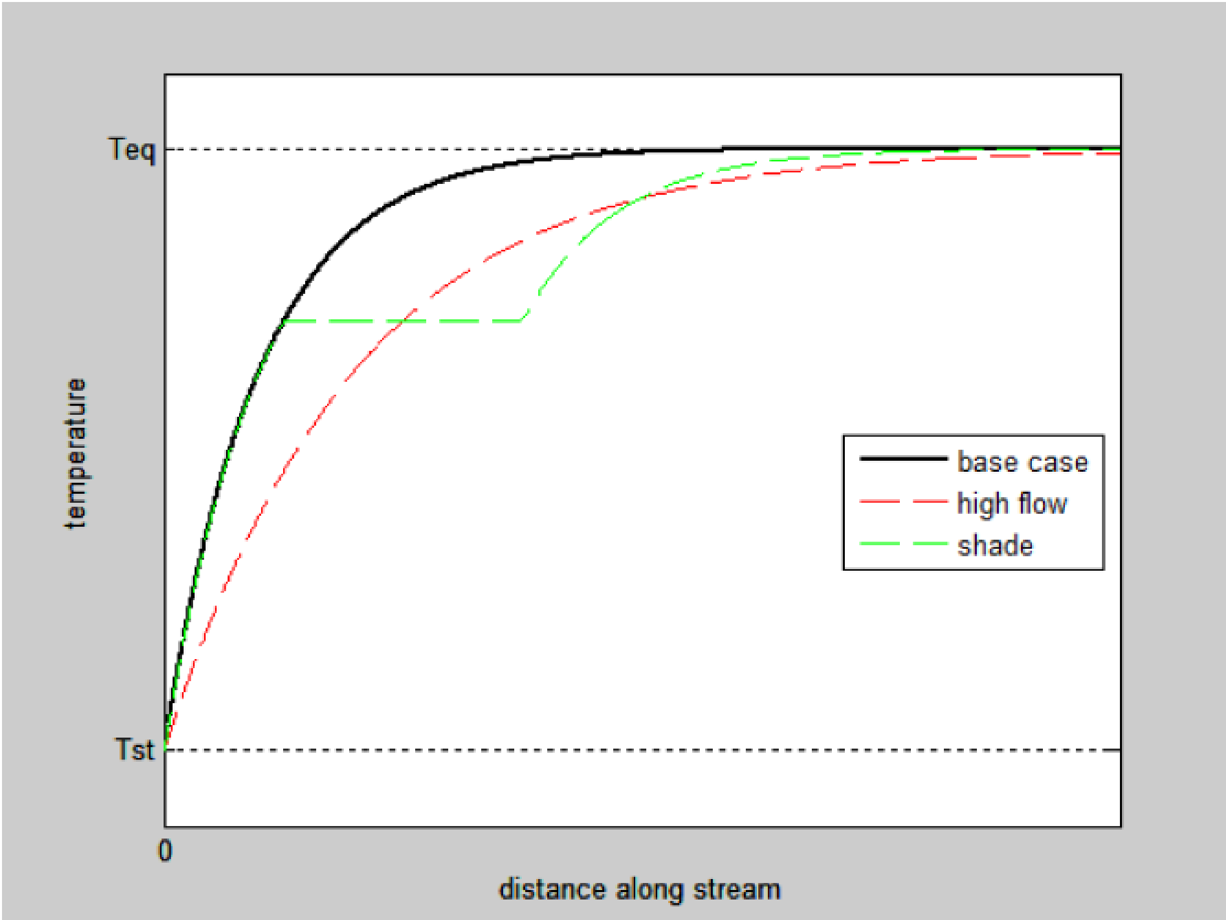
Stacey 7:
Discussion of Conceptual model. The authors make it clear that multiple factors are simultaneously acting to alter stream temperatures, but the description they provide seems to convey a conceptual model that does not address the interactions between the various factors.

Regional Water Board response:
See response to Stacey 1.

Stacey 8:
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.

Regional Water Board response:
See responses to Stacey 1, Stacey 4, and Thompson 9.

Stacey 9:
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.

Regional Water Board response:
Staff agree with the Dr. Stacey's description of these processes. The concepts discussed above have been incorporated into the staff report.

Stacey 10:
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.

Regional Water Board response:
This Policy attempts to achieve natural temperatures by restoring and maintaining the conditions that drive temperature consistent with their unaltered states. Dr. Stacey is correct in pointing out that this is to some degree a losing battle in the face of global climate change. Additional language discussing these topics and their regulatory implications has been incorporated into the staff report.

Stacey 11:
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.

Regional Water Board response:
Dr. Stacey is correct 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." This has been clarified in the text of the staff report.

Stacey 12:
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).

Regional Water Board response:
The water quality objective for temperature states "at no time or place" shall temperatures be increased 5^{o}F. This language is unequivocal, thus the consideration of thermal refugia is appropriate. The question of how small of a pool would be negligible relates back to beneficial uses. Water quality objectives are established to maintain beneficial uses, therefore the scale that is relevant is the scale that is significant in the context of the beneficial uses in question. Language describing this concept has been incorporated into the staff report.

Stacey 13:
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.

Regional Water Board response:
Staff also identified the loss of riparian vegetation associated with channel widening and the loss of thermal refugia associated with stratified pools as possible temperature impacts associated with increased sediment loads. However this discussion was not included in the section titled "Land use activities with the potential to increase sediment delivery." The report includes discussion of a study of Deer Creek in northern California, where Tompkins (2006) found that reduced daily maximum water temperatures in hyporheic seeps on the order of 3.5 ^{o}C (6.3

^{o}F) created thermal refugia for salmonids. The report also discusses a study similar to Tompkins', in which Loheide and Gorelick (2006) documented daily maximum temperature reductions on the order of 2 ^{o}C (3.8 ^{o}F) in a study of a 1.7 km (1.1. mi) stream reach of Cottonwood Creek in Plumas County, California.

Stacey 14:
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 may be 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.

Regional Water Board response:
Staff have included language to the staff report acknowledging other factors under management control that determine width-to-depth ratios.

Thompson 12:
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).

Regional Water Board response:
Staff have added language to the staff report that discusses these concepts. Also, see response to Stacey 12.

Thompson 13:
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.

Regional Water Board response:
This Policy attempts to achieve natural temperatures by restoring and maintaining the conditions that drive temperature consistent with their unaltered states. This approach addresses spatial and temporal variability through the recognition of the spatial and temporal variability of the drivers of temperature. Regional Water Board staff have found temperature data collected from grab samples to have little utility. Staff monitors temperature using temperature recorders that measure at least every hour, deployed for multiple days and often many weeks.

Thompson 14:
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.

Regional Water Board response:
Staff have reviewed the papers cited, and note that the buffers evaluated in them were intended to address sediment and nutrient concerns. Staff agree that adding shade to a stream that is at equilibrium with high air temperatures will not have a great effect. This appears to be the case in the reaches studied. Still, others have demonstrated that reductions in temperature associated with restored riparian areas, and even restored emergent vegetation, can be achieved in relatively short time scales. The report provides examples of this from the Pacific Northwest. This issue is also relevant to the topic of equilibrium temperature. Staff have added language to the staff report discussing the concepts of equilibrium, preservation, and restoration.

Thompson 15:
Ignoring groundwater, hyporheic and tributary inputs, the change in temperature ΔT within a stream over any reach length L:

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

Here ρ is the density of water, Cp 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.

Regional Water Board response:
The Regional Water Board most often relies on the implementation of pre-defined operating rules, performance standards, best management practices, or restrictions on certain activities to address potential water quality impacts associated with nonpoint source land uses, in lieu of prescribed buffer requirements for individual projects, often in the context of adaptive management. This approach addresses multiple water quality concerns associated with near-stream activities, as well as the cumulative impacts associated with multiple projects across the landscape. Language describing this approach has been incorporated into the Staff Report.

Thompson 16:
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).

Regional Water Board response:
See response to Thompson 15. Also, the information describing the magnitude of effects of human activities on microclimates indicates changes are relatively small and difficult to quantify (Bartholow 2000, Brosofske 1997, Chen et al. 1993, Chen et al. 1999, Dong et al. 1998, Ledwith 1996). The Regional Water Board's approach of addressing site potential effective shade through riparian buffers addresses solar radiation, which has been demonstrated to result in heat fluxes an order of magnitude higher than those associated with air temperature and wind speed (i.e., convection and evaporation) (Johnson 2004). Nonetheless, riparian management practices that address site potential effective also provide a level of protection of microclimates.

Thompson 17:
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.

Regional Water Board response:
While it is true that buffers must functionally capture and contain significant volumes of sediment in order for them to affect geomorphology, this is not the only purpose buffers serve. Buffers prevent disturbances that often generate sediment delivered to stream channels, they filter sediments eroded from activities outside of buffers, they provide root strength in streambanks and unstable areas, and they provide vegetative cover to prevent surface erosion. Sediment load reductions associated with these benefits may not be large enough to affect geomorphology, but they do contribute to other water quality issues associated with biology, such as spawning gravel composition, that the Regional Water Board has an interest in controlling. The point of assumption number 2 is that riparian buffers for temperature protection are an effective and important measure for other water quality concerns besides temperature, not that they provide the sediment controls necessary to prevent changes in geomorphology by themselves. The Regional Water Board addresses sediment discharges directly through the implementation of the Sediment TMDL Implementation Policy, which requires the Regional Water Board address sediment sources through both regulatory and nonregulatory activities, similar to this Policy.

Thompson 18:
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.

Regional Water Board response:
Regional Water Board staff concur with Dr. Thompson's statement regarding long recovery timescales following vegetation removal and sediment inputs. These timescales of recovery support the need to prevent, minimize, and mitigate impact associated with nonpoint sources of pollution.

Thompson 19:
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.

Regional Water Board response:
Staff have added new text that addresses the issues Dr. Thompson raises above.

Thompson 20:
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).

Regional Water Board response:
The Regional Water Board recognizes that efforts to protect the functions of riparian areas should not lead to riparian areas becoming "no management zones", and that doing so can create other issues such as those identified by Dr. Thompson. The Regional Water Board embraces an approach of prevention, minimization, and mitigation of impacts associated with activities that have potential to cause or contribute to elevated water temperatures. At the same time, the Regional Water Board acknowledges that management activities in riparian zones are often necessary. Text has been added to the staff report that acknowledges these ideas. Staff are also keenly aware of the incredible temperature reductions that have accompanied the growth of emergent vegetation following cattle exclusion in areas of the Shasta River watershed and recognize the need to consider these benefits as well as benefits associated with riparian vegetation. Staff has added language clarifying the site potential effective shade concept also applies to emergent vegetation.

Stella 3:
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.

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.

Regional Water Board response:
Regional Water Board staff agree that model validation and accuracy assessment are important components of water quality modeling analyses. The Regional Water Board, the USEPA, and their contractors have attempted to address this step in the process in each instance. For instance, the Scott River temperature model development process for the temperature TMDL analysis follows the standard approach of calibrating the model using data from one period and evaluating the performance of the model based on the model's predictions for another, independent time period. A suite of accuracy statistics are provided in a table and discussed in the text, and comparisons between predicted and observed temperatures traces are provided in an appendix. A separate appendix contains an assessment of the RIPTOPO shade model's performance compared to measured data. The modeling exercise conducted explicitly evaluated the sensitivity of the model parameters on predicted temperatures. Similarly, the Klamath River TMDL report includes an appendix that discusses the model testing process in great detail. Other analyses also contain discussions of model validation, and sensitivity, albeit not through a consistent approach.

It is important to understand the utility of the modeling exercises, which is the identification of temperature factors that are affected by human activities and most important for the control of temperature. The results of the modeling exercises are not integrated into permits and have only been integrated in water quality goals in a few select cases. The results of the shade and temperature models developed for the temperature TMDLs are not intended to be used in place of a site-specific approach to implementing temperature protection. The shade and temperature models have been used to identify the most important factors to consider in source reduction efforts, estimate loading at a watershed scale, and elucidate important physical processes and interactions, such as the temperature effects of the interaction of groundwater and surface water.

Stella 4:
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[33]. 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?

Regional Water Board response:
The results of the shade and temperature models developed for the temperature TMDLs are not intended to be used in place of a site-specific approach to implementing temperature protection. The greatest utility of the model exercises conducted in support of temperature TMDL development is in identifying which factors that drive temperature dynamics are important, as well as when temperature drivers have a negligible effect on temperatures. An example of this is the analysis conducted for the Lower Eel River temperature TMDL. The results of

[33] 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.

that analysis were used to demonstrate that: 1) the shading of the mainstem Eel River (and corresponding temperature differences) was negligible under any vegetation scenario. The same analysis showed that temperatures of tributary streams are quite sensitive to riparian vegetation conditions. The results were not used to define what levels of shade, or height of vegetation, or water temperatures are necessary for achievement of the TMDL and water quality objectives. Rather, the results are used to illustrate that riparian vegetation needs to be managed in a manner that does not elevate temperatures in these areas. In this way the policy implications and implementation strategies are not sensitive to the model calibration. However, Regional Water Board staff acknowledges that developing a better understanding of the relationship of effective shade to buffer depth and density is a good goal and intend to pursue the goal through effectiveness monitoring.

Stella 5:
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 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.

Regional Water Board response:
Regional Water Board staff has expanded the section on site-specific implementation and added a section discussing the use of management measures and adaptive management in the context of nonpoint source permitting.

Stella 6:
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.

Regional Water Board Response:
These issues are important considerations in the development of shade models. However, these considerations are made at the site-specific level for individual projects. In these situations the types of vegetation present are known. The assumptions of the shade models do not come into play at the project level permitting scale. This policy directs staff to address elevated water temperature concerns at the project-level, taking into account the site-specific factors, as they relate to the consistent conclusions of north coast TMDLs: that shade, sediment, and flow concerns need to be evaluated and addressed, if necessary, for the protection of water temperature.

Stella 7:
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.

Regional Water Board response:
Staff agrees that the issues presented in the comment above are relevant and must be considered in any analysis of a site's history, trajectory, and potential. The site-specific approach this policy directs allows for those types of considerations in the implementation of the permitting and grant programs. The general approach that this policy and the intrastate temperature objective calls for is the regulation of activities in a manner that ensures that natural recovery processes that disturb, rearrange, and recover stream channels and riparian zones continue. Additional text discussing these issues has been added to the Staff Report.

Stella 8:
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 interactions 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 <u>*negative*</u> 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.

Regional Water Board response:
Staff agrees with the point Dr. Stella makes and has added new text describing how the site-specific approach is intended to allow for these kinds of situations to be acknowledged and addressed.

Stella 9:
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.

Regional Water Board response:
Staff have added new text to the staff report discussing the topic of climate change and its ramifications.